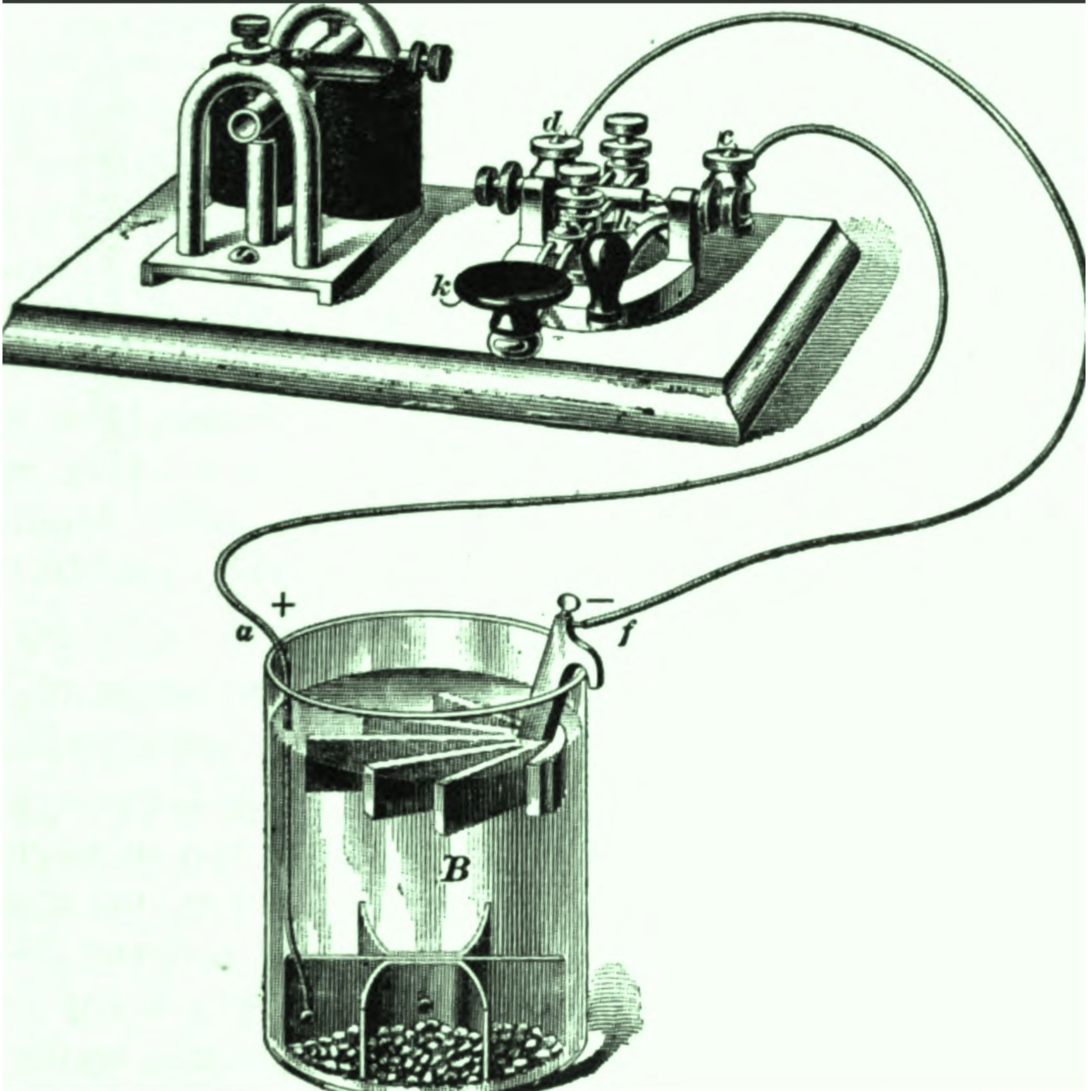

A Treatise on Telegraphy, Prepared for Students of the ...

International Correspondence Schools

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59 S—15509-2-17-02-2m

A TREATISE

ON

TELEGRAPHY

PREPARED FOR STUDENTS OF

THE INTERNATIONAL CORRESPONDENCE SCHOOLS

SCRANTON, PA.

Volume II

ELEMENTS OF TELEGRAPH OPERATING

TELEGRAPHY

WITH PRACTICAL QUESTIONS AND EXAMPLES

First Edition

SCRANTON

INTERNATIONAL TEXTBOOK COMPANY

1901

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BURR PRINTING HOUSE,
FRANKFORT AND JACOB STREETS,
NEW YORK.

CONTENTS.

ELEMENTS OF TELEGRAPH OPERATING.

INTRODUCTION.

1. The operation of telegraphic apparatus is not, as many people suppose, a very complicated and difficult matter to understand; but to become a first-class operator requires *constant practice and the acquisition of information on every practical point connected with the apparatus and the operation of the instruments.*

A person can usually become fitted, in four or five months of steady practice, to take a position in a small telegraph office; while, if proper diligence is exercised, one to two years of experience should enable one to become a first-rate operator. It is always much easier for a skilled operator to secure steady employment at first-class wages than it is for a third- or fourth-rate operator to obtain employment, even at the lowest rates.

In order to become an expert operator, the best time to learn is between the ages of fifteen and twenty-five.

2. The systematic and continual practice that the student should pursue may be divided, broadly, into three classes:

1. Morse writing with the key, and without a companion.

2. Combined Morse writing and reading with a companion student in the same room.

3. Practice in Morse writing and reading of messages, social conversation, and printed matter, the two students being in different rooms or houses.

The first step is to memorize the Morse alphabet and to practice making the characters with the key. This can be done alone, without a companion student.

The student should become so familiar with the Morse signals that no more effort will be required to make a Morse letter on the key than to speak a word in his native tongue.

3. The second step consists in key writing or sending by one student, while another tries to read the words that are sent, and, as far as possible, to copy them. Considerable training at this work is necessary, in order that the student may become perfectly familiar with the *sound* of the Morse letters. The students should alternately send and receive. This practice serves to correct inaccuracies in sending the signals, for each one must make the signals correctly, or they cannot be read by the other.

4. As soon as the students have become able, by pursuing the above system of practice, to hold a conversation of short sentences in "Morse" with each other, they should begin the separated practice, that is, with the instruments set up in separate rooms or houses. Connect the instruments as explained in Arts. **33** to **42,** inclusive, and practice sending and receiving, copying everything as it is received. The two or more persons practicing should be entirely dependent on the telegraphic apparatus for their communication.

Whenever it is possible, the student should secure an opportunity to finish his practice in a telegraph office. A few weeks of such work will familiarize the student with office routine, and will give, besides, an excellent opportunity to practice reading by sound and copying the constantly passing messages.

TELEGRAPH CODES.

5. Following are given in a convenient form the characters in the Morse code representing the letters in the English alphabet, and the characters in the Phillips code representing punctuation and other marks. These are the characters in common use in the United States and Canada, except for submarine telegraphy.

THE MORSE ALPHABET.

A	B	C	D	E	F	G
· —	— · · ·	· · ·	— · ·	·	· — ·	— — ·
H	**I**	**J**	**K**	**L**	**M**	**N**
· · · ·	· ·	— · — ·	— · —	——	— —	— ·
O	**P**	**Q**	**R**	**S**	**T**	**U**
· ·	· · · · ·	· · — ·	· · ·	· · ·	—	· · —
V	**W**	**X**	**Y**	**Z**	**&**	
· · · —	· — —	· — · ·	· · · ·	· · · ·	· · · ·	

NUMERALS.

1	2	3	4	5
· — — ·	· · — · ·	· · · — ·	· · · · —	— — —
6	**7**	**8**	**9**	**0**
· · · · · ·	— — · ·	— · · · ·	— · · —	——

The decimal point is often transmitted by spelling out the word *dot*. For instance, 67.895⅔ may be transmitted *67 dot 895 2 e 3*; thus,

6	7	d	o	t	8
· · · · · ·	— — · ·	— · ·	· ·	—	— · · · ·
9	**5**	**2**	**e**	**3**	
— · · —	— — —	· · — · ·	·	· · · — ·	

THE PHILLIPS PUNCTUATION CODE.

. Period	· · — — · ·
, Comma	· — · —
: Colon (*KO*)	*K* — · — *O* · ·
:— Colon dash (*KX*)	*K* — · — *X* · — · ·
; Semicolon (*SI*)	*S* · · · *I* · ·
? Interrogation	— · · — ·
! Exclamation	— — — ·
- Fraction line (*E*)	·
— Dash (*DX*)	*D* — · · *X* · — · ·
- Hyphen (*HX*)	*H* · · · · *X* · — · ·
' Apostrophe (*QX*)	*Q* · · — · *X* · — · ·
$ Dollars (*SX*)	*S* · · · *X* · — · ·
c Cents (*C*)	*C* · · · (with a space before the last dot)
£ Pound sterling (*PX*)	*P* · · · · · *X* · — · ·
/ Shilling mark	· · — —
d Pence (*D*)	*D* — · ·
. Decimal point	— · — —
Capitalized letter (*CX*)	*C* · · · *X* · — · ·
¶ Paragraph	— — — —
:" Colon followed by quotation (*KQ*)	*K* — · — *Q* · · — ·
( ) Parenthesis (*PN*)	*P* · · · · · *N* — · *P* · · · · · *N* — ·
or	
(at beginning (*PN*)	*P* · · · · · *N* — ·
) at end (*PY*)	*P* · · · · · *Y* · · · ·

“ ”	Quotation (*QN*)	*Q* ..–. *N* –. *Q* ..–. *N* –.
or		
“	at beginning (*QN*)	*Q* ..–. *N* –.
”	at end (*QJ*)	*Q* ..–. *J* –.–.
“ ‘ ’ ”	Quotation within a quotation (*QX*)	*Q* ..–. *X* .–.. *Q* ..–. *X* .–..
	Underline or italics (*UX*)	*U* ..– *X* .–..
or		
	at beginning (*UX*)	*U* ..– *X* .–..
	at end (*UJ*)	*U* ..– *J* –.–.
[ ]	Brackets (*BX*)	*B* –... *X* .–.. *B* –... *X* .–..

DOTS, DASHES, AND SPACES.

6. The dot is taken as the unit by which the lengths of the dashes and spaces are measured. The following table gives the relative lengths of the different dashes and spaces:

Signal.		Duration of Signal.
Dot	· (1)	1 unit
The dash	— (3)	3 units
The long dash (*L*)	—— (5)	5 units
The extra-long dash (cipher)	——— (7)	7 units
Space between parts of a letter	— 1 —	1 unit
Space in spaced letters	— 2 —	2 units
Space between letters	— 3 —	3 units
Space between words	— 6 —	6 units

It will be noticed that there are four lengths of spaces and three of dashes, or four including the dot.

7. The dot (*e*) is made by a firm downward stroke of the key followed immediately by a quick upward motion. On the sounder a dot is indicated by a down stroke, immediately followed by an up stroke.

A dash (*t*) is made by holding the key down as long as it takes to make 3 dots. On the sounder the short dash is indicated by a down stroke followed, after an interval of 3 dots, by an up stroke.

A long dash (*l*) is made by holding the key down as long as is required to make 5 dots. Theoretically the long dash (*l*) should be twice the length of a dash, or 6 units in length when the dash is made 3 units.

The extra-long dash (*0*, cipher) is prolonged so as to occupy the time required for 7 dots. Theoretically, the extra-long dash (*0*, cipher) should be one-half longer than the long dash (*l*), that is, 9 units in length when the long dash (*l*) is made 6 units. However, in practice, the *l* and the *0* are generally made the same; occurring alone, the long dash would be read as *l*, but when found among figures it would be translated as *0* (cipher). This has not been found to cause any inconvenience. The theoretical values for the long and extra-long dashes will hereafter be given in this Course in order that they may readily be distinguished, but the student should shorten them at least to 5 and 7 units, respectively.

NOTE.—When the student has thoroughly mastered the art of sending and receiving, the length of the dash, long dash, and extra-long dash may be shortened as follows: Dash to 2 units; long dash to 4 units; and extra-long dash to 5 units. This will be done unconsciously in rapid sending. By thus shortening the dashes, a material gain in rapidity of transmission is effected without any great disadvantage. Where recording instruments are used for receiving, this shortening of the dash is not advisable, for it is then very easy to mistake a dash for a dot.

8. The intervals between dots or dashes in the same letter are called *breaks*, and in letters that do not contain spaces, the dots and dashes should follow one another as closely as possible. But in the spaced letters *o* (· ·) *c* (·· ·) *r* (· ··) *y* (·· ··) *z* (··· ·) *&* (· ···) the space should occupy the time

required for 2 dots, just about double that ordinarily used between the elements of a letter. Such a space is indicated on the sounder by an interval of the duration of 2 dots, or 2 units between the instant of breaking and the next make. The up-and-down motions occupy about 1 unit of time.

9. The space between letters should occupy the time required for 3 dots or 3 units. The space between words should occupy the time required for 6 units; that is, the key remains against the upper contact for 5 units, the up-and-down motion occupying 1 unit of time.

MEMORIZING THE MORSE CODE.

10. In the first place, it is necessary to memorize the Morse alphabet—not in alphabetical order, but in such a way that any character can be called to mind at will. It is sometimes a help and advisable in memorizing the letters to try making them with the telegraph key. The period, comma, and interrogation are the only punctuation marks in frequent use, and are the only ones with which the student need now concern himself. The student should learn the Phillips punctuation code, and not the Morse; for the latter is not in general use in this country, and for this reason is not given here.

In memorizing the alphabet, it is not advisable to learn the letters alphabetically. By grouping the letters in the following manner, they can be learned much more readily and with less labor:

DOT CHARACTERS.

E	*I*	*S*	*H*	*P*	*6*
.	..	...	....	.....	......

SPACED CHARACTERS.

O	*C*	*R*	*Y*	*Z*	*&*
. .	.. .	. ..	.. ..	... .	. ...

DASH CHARACTERS.

T	*L*	*M*	*5*	*0*
—	━━	— —	— — —	━━━

DOT-AND-DASH CHARACTERS.

A	*U*	*V*	*4*
· —	· · —	· · · —	· · · · —

DASH-AND-DOT CHARACTERS.

N	*D*	*B*	*8*
— ·	— · ·	— · · ·	— · · · ·

After the student has thoroughly memorized the preceding characters, he should write down and memorize the characters representing *F*, *W*, *G*, *K*, *Q*, *3*, *J*, *X*, *2*, *1*, *7*, *?*, *9*, *Period*, and *Comma* in the order given.

11. Fractions.—Fractions are made by substituting a dot, that is, the letter *e*, for a hyphen between the figures.

½
·——· · ··—··

¼
·——· · ····—

⅔
··—·· · ···—·

⅗
···—· · — — —

⅞
——·· · —····

$\frac{9}{10}$
—··— · ·——· ━━━

$\frac{11}{12}$
·——· ·——· · ·——· ··—··

12. Numbers.—In large numbers, a larger space than usual is made between every three figures; for example,

1,000
·——· ━━━ ━━━ ━━━

1,600
·——· ······ ━━━ ━━━

21,708
··—·· ·——· ——·· ━━━ —····

43,956
····— ···—· —··— — — — ······

TELEGRAPH APPARATUS.

INSTRUMENTS.

13. The student that desires to learn the art of telegraphing will need, for practicing, a telegraph key, sounder, and battery. There are several grades of instruments, varying in quality and price. A legless key and sounder separate—that is, not mounted upon the same base—and one or two Gordon cells, would make an excellent combination. But the learner's set, which consists of a key and sounder mounted upon one base and a gravity cell, is convenient for the beginner. The separately mounted instruments are preferable, because they can be placed in the most suitable and convenient positions on the table, independently of each other, or the key may be placed in one room and the sounder in another room, if two students have only one set between them.

DESCRIPTION OF SIMPLE TELEGRAPHIC APPARATUS.

14. Telegraph Key.—The telegraph key is an instrument for opening and closing the electric telegraph circuit. A good key with all the necessary adjustments is shown in Fig. 1. It consists of a nickel-plated steel lever r pivoted in trunnion screws x, z, which are mounted in standards projecting upwards from the brass base piece. The locknuts x', z' serve to bind the trunnion screws in any position to which they have been adjusted. A coil spring b serves to press upwards the forward end of the lever r. The up-and-down movement of the lever, or the *play* of the lever, as it is called, is regulated by the screw g, which is secured in its proper position by the locknut g'. The upward pressure of the spring b on the lever r may be regulated to suit the sending operator by means of the screw a, which is secured in the desired position by the locknut a'. A screw p, which passes through the steel lever r, has on the under side of it

a small piece of platinum. When the handle or button *k*, which is made of insulating material, such as hard rubber, is pressed down, the platinum piece on the under side of the screw *p* makes contact with a similar piece of platinum projecting upwards from a metal button-like piece of brass. To this brass button is connected a small, flat, projecting piece of metal *e*. A thin strip of metal connects *e* with the binding post *c*. Now, the binding post *c*, the thin metal connecting strip, the piece *e*, the brass button to which *e* is joined, and the platinum tip of the button are all insulated from the base and from all other parts of the key; but the lever *r* is in metallic connection, through the spring *b* or through the trunnion and its screws *z*, *x*, with the base and the binding

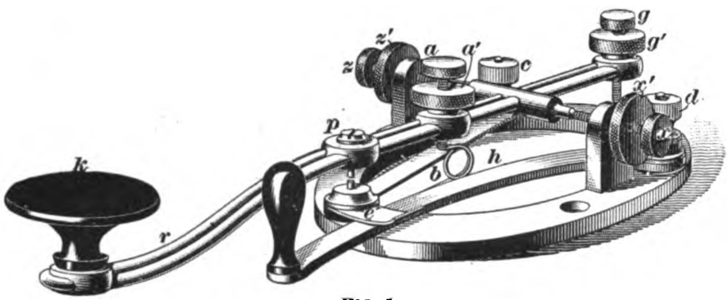


FIG. 1.

post *d*. The piece *h* is called the *circuit-closer*. The rear end of it is pivoted by a screw to the base of the key, so that it makes contact with the binding post *d*. When *h* is turned so as to touch the metal piece *e*, the electric circuit between the two binding posts *d* and *c* is closed, even though the lever *r* is up so as to keep the two platinum points apart. If *h* is open, that is, if it does not touch the piece *e*, then the circuit between the two binding posts *d* and *c* is closed only so long as the two platinum points are kept in contact by depressing the knob *k*. The key shown in the figure is made by the Western Electric Company. The keys on some learners' sets do not have any screws for adjusting the upward pressure of the spring on the lever of the key. The spring on such keys is shaped differently from the one shown

in this figure and is carefully adjusted before the instrument is sent out.

15. Telegraph Sounder.—The telegraph sounder is an electromagnet so constructed that it gives forth sounds that correspond to the up-and-down motions imparted to a key that is connected in the same electric circuit with it. A sounder is shown in Fig. 2. The various parts are mounted upon a hollow brass plate, which in turn is fastened to a highly polished wooden base. There are two coils *m*, *m* (one being almost hidden by the other in this figure), made of fine insulated copper wire surrounding two soft-iron

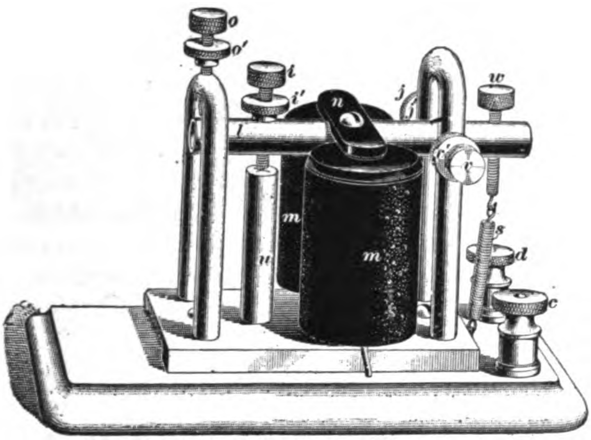


FIG. 2.

cylindrical rods or cores as they are called. A piece of soft iron *n*, called the *armature*, is fastened to a metal lever *l*, the two together being called the *armature lever*. This lever is pivoted between two screws *v*, *j*, called *trunnion screws*, which when once adjusted are locked in place by the lock-nuts *v'*, *j'*. The armature is normally held in its upper position by means of the tensile spring *s*, which pulls down on the short end of the lever *l*. The pull of this spring is regulated by the screw *w*. The down stroke of the lever is limited by the lower end of the screw *i*, which strikes against the piece *u*, called the *anvil*, while the up stroke is limited by the lever

striking against the lower end of the screw *o*. The play—that is, the up-and-down movement of the armature lever—can be adjusted by means of these screws *i* and *o*, and after the proper adjustment is obtained, it can be made secure by the locknuts *i'*, *o'*. The two ends of the wire forming the two coils are permanently fastened, one to the binding post *c*, and the other to the binding post *d*.

16. Resistance of Sounders. — Sounders used for short lines have an electrical resistance of 4 or 5 ohms, and are called *local sounders*. For lines over 1 mile and under 10 miles in length, sounders should be used having their magnets wound with more turns of finer wire, and therefore offering a higher resistance to the electric current than those employed on circuits under 1 mile. Such high-resistance sounders are called *main-line sounders*, and are usually wound with so much fine wire that their electrical resistance amounts to 20 ohms. It may be well to add here that all sounders, and, in fact, all telegraph instruments that are connected in the same line circuit, should always have about the same electrical resistance. More complete descriptions of such sounders and keys as are extensively used by large telegraph and railroad companies will be given later.

17. Combined Sounder and Key. — In Fig. 3 is shown a sounder and key mounted upon the same wooden

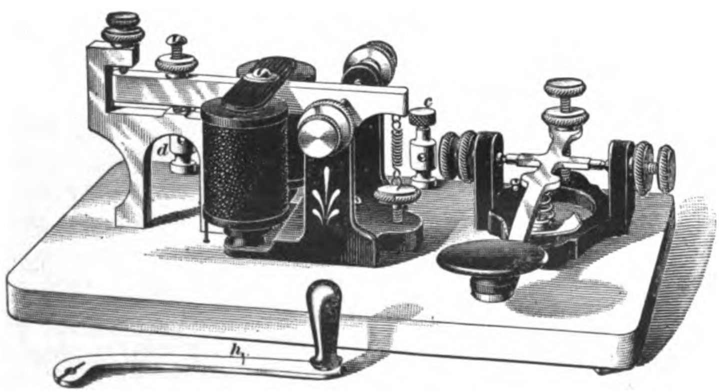


FIG. 3.

base. Such a combination is known as a *learner's telegraph set*. The sounder occupies the left-hand and the key the right-hand portion. This key and sounder, although differing slightly in some details from the key and sounder already described, are exactly the same in action. The key and sounder are properly connected by wires under the base. Upon the rear of the wooden base are two binding screws *d*, *c*, to which the wires from the battery are connected. The circuit-closer *h* is here shown detached from the key, as it would be only when a dry cell is used to operate the sounder. When a gravity or other closed-circuit cell (see Arts. **19** to **22**, inclusive, for explanations concerning the various kinds of cells) is used, the circuit-closer should be secured in place upon the key, as is *h* in Fig. 1 and Fig. 4.

BATTERIES.

18. The Battery.—A cell is an apparatus for generating an electromotive force by means of chemical action. If the two elements or poles of the battery are joined by a continuous metallic wire or circuit, an electric current will continue to flow in one direction through the metallic circuit so long as the circuit remains complete or closed, provided the electromotive force is maintained by the chemical action. A battery, in the strict sense of the word, is a combination of two or more cells, although the two terms are used somewhat indiscriminately.

19. Cells may be roughly divided into two classes: those suitable for furnishing an electric current continuously, and those suitable for supplying current intermittently. The former are called closed-circuit cells, and the latter open-circuit cells. Closed-circuit cells may be used to supply intermittent currents—that is, they may be used on circuits that are normally open—but open-circuit cells should never be used where a continuous current is required—that is, on circuits that are normally closed. Gravity, Gordon, Edison-Lalande, and bichromate cells are samples of the

closed-circuit type; the dry and Leclanché are open-circuit cells. There are many modifications of the Leclanché cell.

20. A gravity cell can be maintained in excellent condition by keeping it on a closed circuit about half the time; that is, by keeping the circuit-closer *h* on the key in Fig. 4 closed during half the time that the key is not being used. For a beginner, who uses the set mostly for practice, this can generally be done without any inconvenience, even if there is another distant set on the same line, in which case the circuit-closer can usually be left open at night. A Gordon battery may be kept on open or closed circuit, but the more it is kept on open circuit the longer the charging solution and materials will last. This is a clean cell, and requires very little attention. However, the gravity cell is much less expensive, and has proved, all things considered, so satisfactory that it is practically the only primary cell used by the large telegraph companies in this country. For fire-alarm, police, and railroad-signal systems, the Gordon batteries are extensively used.

21. The dry cell is the smallest, cleanest, and cheapest of all cells, but is not very satisfactory, except when but little used, and that intermittently. The student must, therefore, if this cell is used, keep the circuit open at the key at all times, except when actually working with the key. To make sure that the cell is not left on a closed circuit, a key should be used from which the circuit-closer (*h* in Fig. 3) can be removed; for, if the circuit-closer were left attached to the key, and were closed accidentally or otherwise for any length of time, the dry cell would very soon become exhausted and rendered useless. With the circuit-closer removed, the dry cell should last for several months' practice.

22. The circuit may be kept closed all the time when gravity or Gordon cells are used. The manner of connecting up the apparatus will be the same, no matter what kind of cell is used. For use with one sounder and key, a single cell is generally sufficient; but in case two cells are used, join

the wire running from one of the binding posts of the sounder or combination set to the zinc of the first cell, joining the copper of this cell to the zinc of the second cell. The copper of the second cell is joined to one binding post of the key or combination set, as the case may be. Two cells so joined are said to be connected in series, and will make the sounder operate about twice as vigorously as one cell.

23. The Setting Up and Care of Cells.—Directions for setting up and caring for a cell are usually sent with it, but for the gravity cell they will be given here.

After unpacking the cell, wash the copper and the zinc, and the glass jar. Unfold the copper strip so as to form a sort of cross, and place it in the bottom of the jar. Suspend the zinc in the jar by hooking the catch on the side of the jar. The zinc has a binding post with a hole in which to fasten a connecting wire. Put the blue crystals (called *bluestone* or *copper sulphate*) which come with the cell in the bottom of the jar, distribute them equally between the leaves of the copper, and pour enough water into the jar to cover the zinc. A gravity cell properly set up is shown in Fig. 4.

24. Immediately after setting up, as described above, the battery is not in condition for use, but may be brought into condition by carefully pouring into the top of the jar a solution of sulphate of zinc. For this purpose, dissolve 4 or 5 ounces of sulphate of zinc in a little water, and pour into the jar gently, so as to mix the two solutions as little as possible. It is a good plan, if there is no great hurry to use the cell, not to put in the zinc until the solutions have had time to settle into their normal condition. This prevents or reduces the formation of a black deposit on the zinc. When there is much of this black deposit, remove the zinc and brush or scrape it off.

Bluestone should be dropped into the jar as it is consumed, care being taken that it goes to the bottom and that none of it lodges upon the zinc. The need of bluestone is shown by the fading of the blue color, which should be kept at least as high as the top of the copper, but should never reach the

zinc. There should always be some bluestone crystals in the bottom of the jar.

If no zinc sulphate is added in setting up the cell, it will be necessary to short-circuit the cell, that is, to connect the zinc and copper terminals of the cell with a short piece of copper wire. The cell must be left connected in this manner for some time before it will be in good working condition—24 hours will not be too long, although a shorter time may be sufficient.

25. After the battery has been started, no further attention is required except to keep it supplied with bluestone and water until the quantity of sulphate of zinc in solution has become excessive. During use, the chemical action in the cell causes sulphate of zinc to be formed, and consequently this substance accumulates in solution, the copper sulphate being consumed at the same time. The specific gravity of the zinc sulphate being less than that of the copper sulphate, the former solution will remain on top. When the zinc sulphate becomes too dense, it will be necessary to draw off a portion of the top of the liquid with a cup or battery syringe, and replace the solution removed with clean water. The condition of a cell may be judged from its appearance. When the cell is in good condition the solution in the bottom is a bright-blue color, the blue fading to a water color before reaching the zinc. A very pale or dirty brown-colored solution indicates a deteriorated condition of the cell. When the zinc becomes coated, it should be taken out, scraped clean, and washed.

26. Cleaning the Cell. — The cell will need to be thoroughly cleaned out occasionally, depending on how much it is used. To do this, remove the zinc, clean it by scraping with a knife or some other edged tool, and wash it with plenty of water. If in a hurry to use the cell again, pour the clear liquid into a separate jar, leaving behind the oxide and dirt that have gathered in the bottom of the jar. If the cell will not be needed for 24 hours—the time required for short-circuiting the cell in order to bring it into working

condition—it is very much better to throw all the old solution away. Throw away the sediment, and clean the copper and the jar, and set up the cell again as already described. In case the cell is required at once and the clear liquid was saved, use this first, adding enough clear water to cover the zinc. The cell in this case will soon be ready for use, and

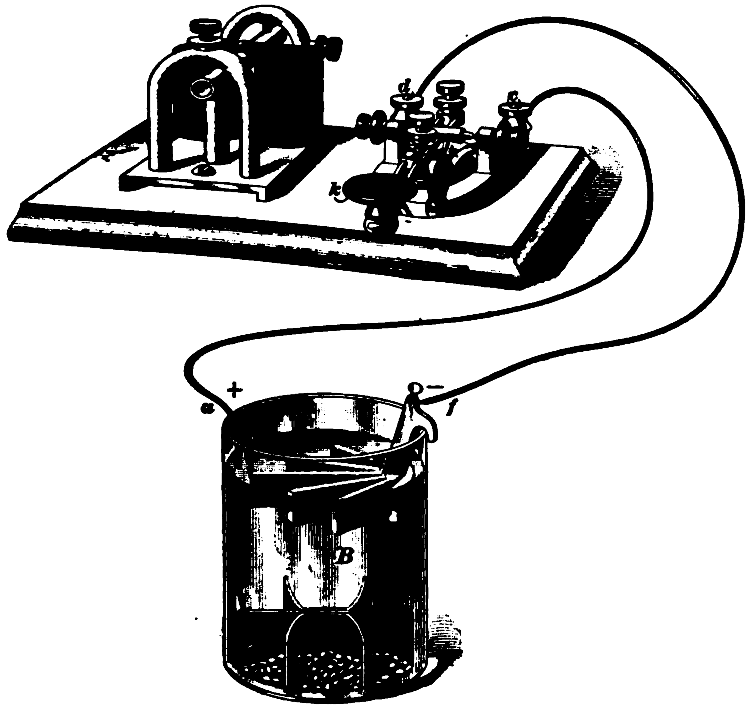


FIG. 4.

short-circuiting it should bring it into working condition very rapidly.

The connections at the cell terminals should be kept free from dirt and corrosion. The cell will work more vigorously when warm, that is, above 65° or 70° Fahrenheit; and under no circumstances should it be allowed to freeze, for then the current will be much impaired, if not entirely stopped.

27. Combined Learner's Set.—The combination of a key and a sounder mounted together upon one base is shown in Fig. 4, properly connected to a gravity cell *B*. The set should be firmly fastened upon a table far enough back to allow the whole forearm and elbow to rest upon the table. The battery should be placed upon the floor under or near the table.

To connect this set as shown in the figure, proceed as follows: Take a piece of copper wire and remove the insulating material for about an inch at one end; connect this end to the copper terminal *a* (called the *positive pole*) of the battery *B*; run the wire to the telegraph set upon the table, in order to get the proper length, and cut it off; bare the end for about ½ inch and fasten it in the binding post *c*. Then cut off another piece of wire long enough to reach from the telegraph set to the battery; remove the insulating material for ½ inch at each end; fasten one end in the binding post *d* and the other end to the zinc terminal *f* (called the *negative pole*) of the battery *B*.

28. Separate Sounder and Key.—A sounder and key not mounted on the same base are set up and connected as shown in Fig. 5. The key should be firmly screwed down on a table in a convenient position, and in such a manner that the forearm, including the elbow, may rest upon the table. The sounder should also be screwed down to the table in a convenient position to the left of the key. The battery may be placed upon the floor, either under or near the table.

29. To connect this set, proceed as follows: Remove the insulating covering for an inch at the end of the copper wire. Fasten this bared end to the copper terminal *a* (the positive pole) of the battery *B*, and, taking a piece of the wire long enough to reach to the sounder, cut it off, and bare this end for about ½ inch. Then fasten this bared end in the binding post *c*, upon the base of the sounder. To the other binding post *b*, upon the base of the sounder, fasten the bared end of another piece of wire, and, after

cutting off a piece long enough to reach to the key, fasten the bared end in one of the binding posts upon the base of

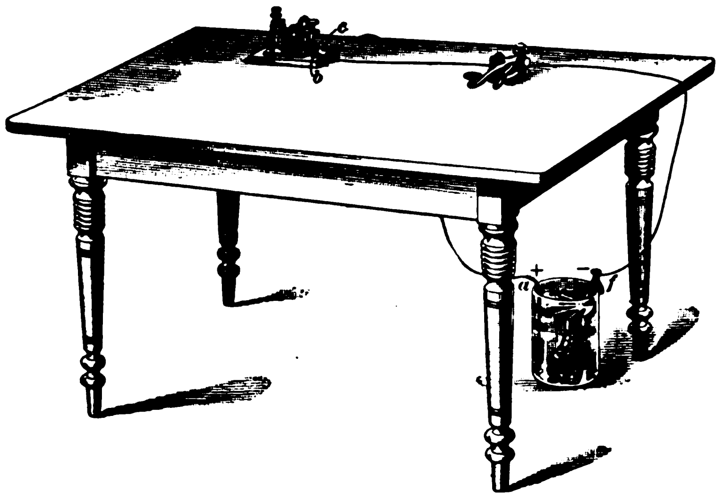


FIG. 5.

the key. In a similar manner, connect the other binding post upon the base of the key with the zinc terminal *f* (the negative pole) of the battery.

30. Trying the Apparatus.—After setting up and connecting the telegraph apparatus, as described above, it should be tried to see that it is all right. As a rule, the instruments will be shipped properly adjusted. If a gravity cell is used, it will not work properly as soon as it is set up; so do not readjust the sounder or key to suit such a condition, but short-circuit the battery (by closing the circuit-closer *h*, Fig. 4) for from 12 to 24 hours. With a Gordon cell this is not necessary, and under no circumstances should it be done with a dry cell. First open the circuit-closer *h* by moving it to the right. Now, if the battery is in good working condition, and the instruments are properly adjusted, pressing down the front knob or handle *k* of the key as far as it will go should cause the electromagnet of the sounder to draw down the armature lever, producing a clear click; and on releasing the key the armature lever of the

sounder should be drawn upwards by the spring, producing another clear click. The first movement, caused by the closing of the electric circuit by depressing the key, is called the *down*, or *forward*, *stroke*, and the latter, caused by the opening of the electric circuit by releasing the key, is called the *up*, or *back*, *stroke* of the sounder.

31. If the operation of the key does not produce this result after the gravity cell (if this cell is used) has been given time enough to get in good condition, then examine all the connections made, see that all are tight and firm, with none of the insulating covering of the wire intervening between two joined wires or between a wire and a binding post, and also see that all binding-post screws are tight. It will also be well to trace out the connecting wires, to be sure that you have connected the proper binding posts together. The apparatus will probably work all right after the above has been done.

32. The armature lever of the sounder should move freely, having a play between the top and the bottom stops of about $\frac{1}{16}$ inch. In its lowest position, the iron armature should never touch the iron cores of the electromagnet. There should always be at least room enough between the armature and the iron cores to pass through one thickness of ordinary writing paper. The spring that draws the armature lever upwards should be set with sufficient tension to raise the lever promptly when no current is flowing through the magnets. To prevent imperfect electrical contact, the points of the key should be kept clean. All binding posts and screws should be kept tight.

CIRCUITS.

33. To Connect Two Sets.—In order to learn how to receive, the sender and the receiver should be located in different rooms or houses, and they should not communicate with each other except by means of the telegraph. If desirable, more than two telegraph sets may be connected in the

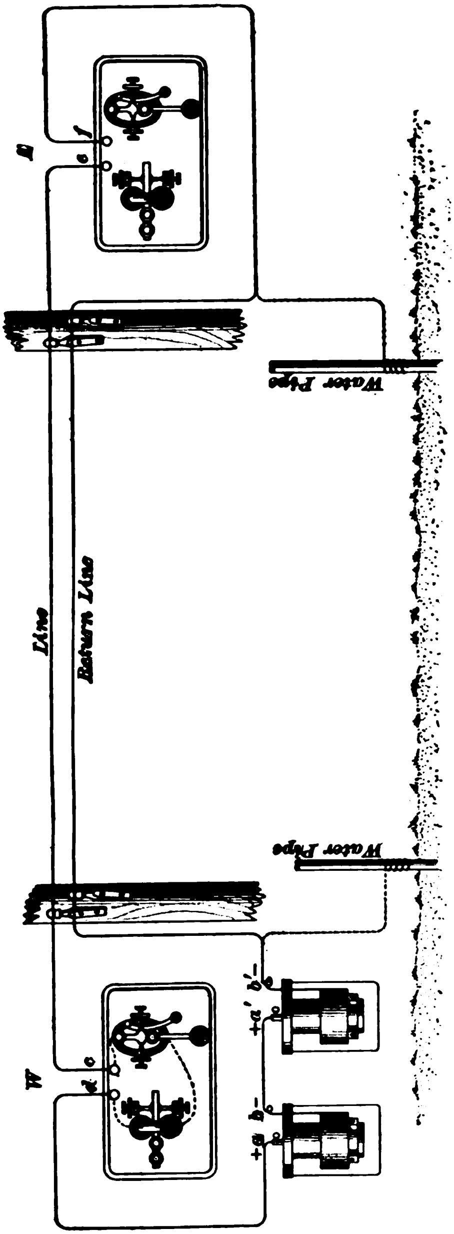


FIG. 6.

same circuit, in which case a person at any one instrument can send, and those at all the other instruments can receive.

Fig. 6 shows two learners' sets connected together. For two instruments that are connected in one circuit and do not require more than about 100 feet of No. 14 iron wire to reach from one set to the other, counting one way only, at least three cells are needed. For a short line it is convenient to place the cells at one end, and not some at one end and the rest at the other end. The cells shown in this figure represent Gordon cells. Where two cells are used for this purpose they should be connected exactly as shown in this figure. That is, the zinc, or negative pole, *b* of one cell should be connected to the copper, or positive

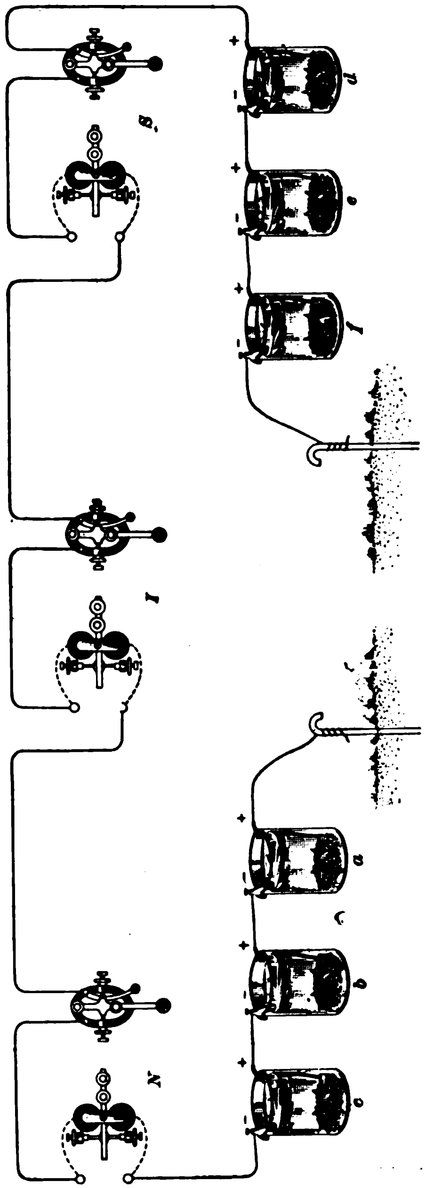


Fig. 7.

pole, a' of the other cell, connecting the free positive and negative poles a and b', respectively, as though they were the terminals of one and the same cell. Thus, one of these two free poles a should be connected to the binding post d, and the other pole b' to the return line, which should be connected to the binding post f at office E. The line wire connects together the binding posts c and e.

In case only one wire is used, the earth being utilized as a return circuit, then the return line shown in the figure would not be necessary; and, instead of connecting b' and f to it, they would be connected to the water or gas pipes, as shown by the dotted lines.

34. Three Sets in One Circuit.—In Fig. 7, three offices are shown connected to one line circuit. A sounder and a key are

placed at every office and three gravity cells at each terminal office. The earth is utilized as a return circuit, and, consequently, only one line wire is necessary. Where more than two instruments are used on the same line, at least one more cell will be required for each additional sounder. For an outdoor line, at least one additional cell will be required for each quarter mile of No. 12 B. W. G. (Birmingham wire gauge) galvanized-iron wire used. Beyond one mile it will be necessary to add at least three cells for each additional mile.

Notice how the cells are connected in Fig. 7. At the office *N* the copper pole of cell *a* is grounded to a water pipe, the zinc pole of this cell being connected to the copper pole of cell *b*. The zinc of cell *b* is connected to the copper of cell *c*, and the zinc of cell *c* to one of the binding posts on the sounder. At the *S* office, one of the binding posts on the key is joined to the copper of cell *d*, the zinc of cell *d* to the copper of cell *e*, the zinc of cell *e* to the copper of cell *f*, and the zinc of cell *f* is connected to the water pipe. The other connections are clear enough to need no further description.

35. When two or more instruments in the same house are to be connected, use insulated copper wire, called "annunciator," or "office," wire. A No. 18 B. & S. gauge copper wire will be about the right size. Insulated wire may be fastened in place by small staples or double-pointed tacks, care being taken not to cut or injure the insulated covering, and never to fasten two wires under the same tack. The wire must be kept out of contact with water or gas pipes, and all metal work.

36. Joints in an Electric Circuit.—In this country wires are usually connected by the American telegraph joint, as shown in Fig. 8. The ends of the two wires should be thoroughly cleaned and scraped; and in the case of wires with an insulating covering, the insulation must be carefully removed for about 1¼ inches at each end, without cutting

or nicking the wire with the knife used. If nicked, the wire may break very easily.

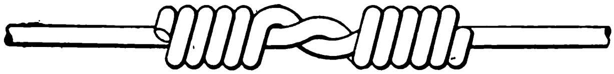


FIG. 8.

To make the joint, place the bare wires side by side, and then wind each end tightly around the other. It is best to solder the joint to insure perfect electrical contact.

37. To prepare it for soldering, the joint may be cleaned with a solution of muriatic acid, in which about as much zinc as possible has been dissolved. This solution is commonly known simply as "acid." If the joint is to be covered in any way—with insulating tape, for instance—it should not be soldered with acid, but with resin or some other non-corroding flux.

It may here be remarked that it is not so easy to make a resin joint as one on which acid is used, which explains the disfavor in which the former is usually held by poor workers. Acid removes grease from the wire, such as a careless workman may have smeared on from his fingers, but when the wire is not handled after cleaning, resin will make a good joint. An alternative method is to tin both wires before twisting them together, using acid as a flux; then wipe carefully, cleaning thoroughly to remove all trace of acid, and twist them together as in Fig. 8, using pliers to bend the wire, if necessary. The joint can then be soldered very easily with resin as a flux.

38. When joining the wire to a binding post, the end of the wire should first be made clean and bright, then placed in the hole in the binding post, and firmly fastened there by the screw. Do not allow the bare end of a wire to touch anything except the binding post or another wire to which it is intentionally joined. By wrapping 8 or 10 inches at the end of a wire in a close spiral around a lead pencil, and then sliding out the pencil, a neat springy spiral, sometimes called a pigtail, can be made, by means of which no slack

need be left in the wiring, and it will give a neat appearance to the connections.

39. The Earth as a Return Circuit.—It has been known for a long time that, when one pole of a battery is connected with the earth, and a wire from the other pole is carried to some distant place and there connected with the earth, a current will flow through the circuit about as readily as though it had been completed by a large wire. That is, the earth is practically one huge conductor. This is easily understood when we remember that moisture is present, more or less, everywhere beneath the surface of the earth, and that water is a very fair conductor. All telegraph companies use the earth as a return path for the electric current, thus saving the expense of constructing and maintaining separate return wires for each circuit. But, on very short lines, especially indoor lines, it is generally more convenient and better to run two wires than to make earth connections.

Water and gas pipes, on account of their extensive ramifications through the ground, make excellent contact with it, and for this reason make good terminals to which the wire running to ground may be fastened.

40. In case the earth is used as a return circuit, the wires to be grounded should preferably be connected to the same system of pipes (water pipes are best); that is, if it can be avoided, do not connect at one end to a gas pipe and at the other end to a water pipe. If the wires are grounded by means of a gas pipe, make the connections, if possible, to the pipe on the street side of the meter. For, if this is not done and the meter is not in place or is later removed, the return line will be open. Moreover, the white or red lead used in iron-pipe joints often makes the joints offer considerable resistance to the current before it can reach the ground.

An earth-return circuit may be obtained by connecting the return wires at each end to pieces of sheet copper that contain about 5 square feet. These copper plates should be

placed in a well (never in a cistern) or in a stream of water, or should be buried in soil that is always moist. The joint between the wire and the plate should be a good metallic connection, preferably soldered, and covered well with a moisture or waterproof paint.

41. Outdoor Lines.—For short outdoor lines, the least expensive but very suitable wire to use is No. 12 B. W. G. (Birmingham wire gauge) galvanized-iron or steel wire. This bare iron wire must be supported on what are called *insulators*, in such a manner that the bare wire cannot touch any buildings, trees, posts, or any other object except the insulators. If this is not done, more or less of the electric current originating at one end will escape to the earth and return through the earth to the grounded pole of the battery at the originating end, without having passed through the telegraph apparatus at the distant office.

NOTE.—The iron wire just mentioned weighs 176 pounds, and measures about 30 ohms to the mile.

42. Insulators are made of glass, porcelain, or hard rubber, and the kind to be employed will depend on the position and locality in which they are to be used. What is known as the single petticoat glass insulator will be the kind needed for a short private line. Wooden-pin brackets can be bought, upon which the glass insulators are screwed, the brackets being nailed to supporting poles, trees, or houses, as the case may be. In Fig. 6, the line wires are shown supported on glass insulators and wooden brackets. No more can be said here on this subject, but later, the construction of outdoor lines will be fully treated.

OPERATING.

SENDING.

43. Method of Holding the Key.—The proper position for holding the key is shown in Fig. 9, and is the one adopted by the majority of the most speedy and perfect operators.

Rest the first finger on the top and near the edge of the key button, with the thumb and the second finger against the opposite edges, as shown. Curve the first and the second finger so as to form the quarter section of a circle. Avoid straightness or rigidity of these fingers and thumb. Partly close the third and the fourth finger. Rest the elbow easily upon the table, allowing the wrist to be perfectly limber. When the proper "swing" is acquired, the forearm moves

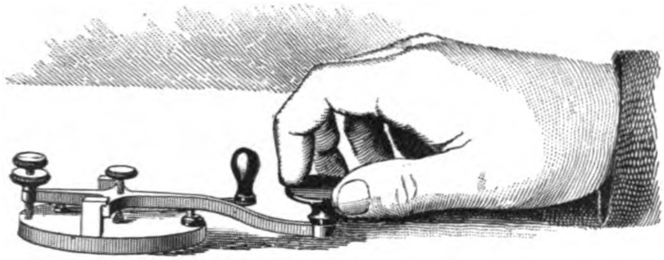


FIG. 9.

freely in conjunction with the wrist and fingers. The fingers and thumb should act as the end of a lever, the wrist and forearm doing the work. Let the grasp on the key be moderately firm, but not rigid. Grasping the knob tightly will quickly tire the hand and destroy control of the key, causing what is termed "telegraphers' cramp," or the "glass hand."

44. Avoid too much force or too light a touch, and strive for a medium firm closing of the key. It is not the heavy pressure of the key but the evenness of the stroke that constitutes good sending. Telegraph repeaters can be adjusted for both light and heavy senders, but not for an uneven sender. A telegraph repeater adjusted for either a light or a heavy sender might be out of adjustment for a perfect sender. The motion should be directly up and down, avoiding all side pressure. Never, of course, allow the fingers or thumb to leave the key; that is, do not tap or strike the key with the fingers, or allow the elbow to leave

the table. The correct method of sending is an easy one, and, when it is properly done, an operator should be able to send for 12 hours continuously without tiring.

45. Adjustment of the Spring of the Key.—In the matter of adjusting the spring of the key, there is considerable difference of opinion. Two of the very fastest senders use very stiff springs, but many other fast senders use springs that are barely strong enough to keep the weight of the key from closing it, and some even use a spring that will not open the key itself, in which case the thumb and second finger must be used to raise the key. A moderate amount of play and a medium tension of the spring should be used by the beginner, unless he has good reason for believing another adjustment more suitable. The spring on the key of the learner's combination set has the right stiffness for the average beginner.

46. Practice in Sending.—Begin the use of the key by making dashes in succession, first at the rate of about one a second, and then gradually increasing to two or three. Care should be taken to make the break between the dashes as short as possible, for there is always a tendency to make too large a space between dashes, and this should be guarded against.

The dots should be made as regularly as possible, and at the rate of about five a second, and the speed increased with practice; but, no matter how fast the dots are made, they should be regular, definite, and uniform.

Next attempt the long dash at the rate of one a second, increasing to ninety a minute. Then practice on the following exercises (Arts. **47** to **57**, inclusive) in the order given. In each exercise, after learning to make each character correctly without hesitating, write them in succession, both forwards and backwards, until able to do so without having to repeat a single character before proceeding to the next. *Do not leave an exercise until it has been thoroughly mastered.*

DASH CHARACTERS.

t	*l*	*m*	*5*	*0*
—	——	— —	— — —	———

47. The tendency that beginners have, in making a letter, to prolong the final dash or dot, can be overcome by making it with a movement apparently a little quicker than that used for the preceding dash or dot. In making characters containing a succession of dashes, see that they follow one another as closely as possible, for too much space is very apt to be put between dashes.

DOT CHARACTERS.

e	*i*	*s*	*h*	*p*	*6*
·	· ·	· · ·	· · · ·	· · · · ·	· · · · · ·

48. Practice each one of these characters until the right number of dots can be made for each one almost unconsciously, being careful at the same time to make all dots of equal duration and not to prolong the last dot into a dash. Do not give up practicing characters containing a number of dots in succession until you can make the correct number every time without failing; for, to make 5 dots when you should make 6 or vice versa is a very bad habit.

DASH-AND-DOT CHARACTERS.

n	*d*	*b*	*8*
— ·	— · ·	— · · ·	— · · · ·

49. There is a great tendency to make the break between the dash and the dot too long; and, should this be done, for instance, in making the letter *n*, then *te* is made instead of *n*.

DOT-AND-DASH CHARACTERS.

a	*u*	*v*	*4*
· —	· · —	· · · —	· · · · —

50. In each of the above, let the dots and the dash follow one another closely, and avoid making the dash too short or too long.

SPACED CHARACTERS.

o	*r*	*&*	*c*	*y*	*z*
· ·	· · ·	· · · ·	· · ·	· · · ·	· · · ·

51. In making these letters, the space should be made just double that ordinarily allowed between the elements of a letter. Avoid making this space too long, as there is more likelihood that it will be made too long rather than too short. Hold the key down for the duration of one dot only; the down-and-up motion of the key is equivalent to another dot; so that the total space is equivalent to 2 dots or 2 units.

SOME MISCELLANEOUS CHARACTERS.

i	*a*	*n*	*s*	*u*	*d*
· ·	· —	— ·	· · ·	· · —	— · ·

h	*v*	*b*	*p*	*4*	*8*
· · · ·	· · · —	— · · ·	· · · · ·	· · · · —	— · · · ·

52. This exercise shows that, if the last dot in *i*, *s*, *h*, or *p* is carelessly prolonged into a dash, the character following it will be made instead of the one intended. It will be noticed that *a* is the opposite of *n*, *u* the opposite of *d*, *v* the opposite of *h*, and *4* the opposite of *8*. If *a* and *n* are run too closely together, you will have *1*; similarly, too little space between *t* and *h* will produce *8*.

OTHER MISCELLANEOUS CHARACTERS.

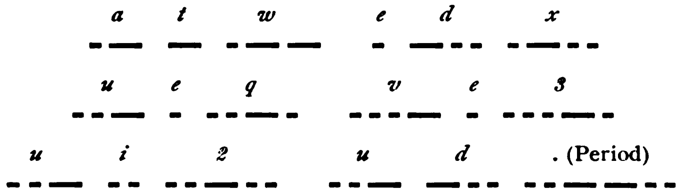
d	*k*	*j*	*g*	*7*
— · ·	— · —	— · — ·	— — ·	— — · ·

53. Two of the most difficult characters to make correctly are *k* and *j*. If the final dash in *k* is made too short, it will be *d*, and if too much space is made before the final dash, it will form *nt*. Similarly, too much space before the second dash in *j* will transform it into *nn*.

RESULTS OF IMPROPERLY MADE CHARACTERS.

54. In the following lines, the first two characters, improperly connected by too short an interval, will make the third character. Thus, if *a* and *t* are connected by too short

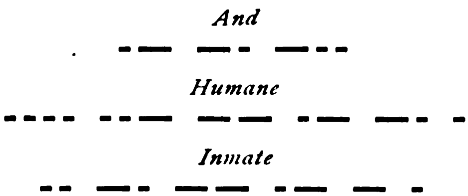
an interval, *w* will be made; and if *e* and *d* are made with too short an interval between them, an *x* will be made, and so on.



Repeat each of the preceding groups until each character in them can be made at will. The beginner should be careful to form each character correctly, for this will lead to a perfect style in sending. There are almost as many styles of sending among operators as there are styles of penmanship.

The preceding groups having been mastered, the transmission of words may next be taken up, followed by the transmission of short sentences, care always being taken to write one correctly before beginning another. The student at first will need to make the length of the spaces between letters and words greater than 3 and 6 units, respectively, as given in Art. **9.** However, as he progresses and becomes more familiar with the combination of dots, dashes, and spaces that represent the various characters and consequently is able to recognize them quicker, he can shorten the spaces to 3 and 6 units. But he should never get into the habit of running the letters or words together.

55. Words Not Containing Spaced Letters.—The following words contain no spaced letters, and for that reason are easier to practice upon at the start:



Judgment

Limited

Maintain

Xenium

56. Words Containing Spaced Letters.—In words containing spaced letters, care must be taken to make the various spaces in the correct proportion to one another; that is, the space between letters should be three times, and the space in spaced letters two times, the usual space between the parts of a letter. Some words containing spaced letters are here given:

Barn

Chair

Desire

Exchange

Family

German

Opinion

Practice

Terminate

Umbrage

Vacant

Warrant

57. The following are good words on which to practice: *Let*, *little*, *take*, *train*, *jaw*, *knoll*, *knot*, *need*, *nod*, *ice*, *rice*, *person*, *poison*, *Mississippi*. Be careful to make *an*, *h*, *i*, *j*, *k*, *p*, *s*, and *th* correctly, in order to avoid their being taken for other characters, as previously indicated.

58. Accurate Sending More Desirable Than High Speed.—The student should cultivate a firm, even, smooth style of sending, and strive for accuracy rather than for speed. The custom of timing for ascertaining the speed of sending should be very sparingly indulged in by the beginner, for it is likely to produce careless habits. The speed of sending should be graduated to suit the capacity of the receiver; the latter should never be crowded.

Strictly first-class work may not be required in your first position as an operator, but you *must be reliable*. High speed is not necessary, and above all things do not be afraid to break, for it is expected of a beginner. Do not imagine that the manager is listening for every break you may make, for, even if he did, he would forget it much sooner than an error that may be caused by your failure to break. Breaks are soon forgotten, but errors are recorded, and are evidence of carelessness that will appear against the operator when an advance in position or salary is expected.

59. It is well to remember that an operator is no judge of his own Morse, and therefore should not try to see how fast he can send until he has had considerable experience. Fast sending is seldom indulged in by strictly first-class operators, but fast time is made by them on account of their steady, even gait, their perfect characters, and few repetitions or mistakes. Accept the average receiver's opinion in regard to your sending before you decide for yourself that your sending is all right, for the poorest operators often think that their sending is good. If the receiver tells you that you do not space properly, or calls your attention to some particular fault, do not get angry, but take the hint, and try to remedy your weak points.

RECEIVING.

60. To learn to receive, it is necessary for the beginner to have another person send to him or to use an automatic sending device of some kind, for one cannot read by sound from his own writing. It is very desirable that the sender should be able to make the signals distinctly and correctly, otherwise it will be very difficult, if not impossible, for the learner to understand the signals. However, two beginners can get good practice by taking turns at sending and receiving, each correcting the faults of the other. If you are around a commercial or railroad telegraph office, practice reading the messages to yourself as they pass over the lines. Do this, however, in your spare time, without neglecting your regular work.

A letter is determined by the time or times the lever of the sounder strikes the bottom or top stops, and by the duration of time between these clicks. The back, or up, stroke is as necessary in order to read by sound as the forward, or down, stroke, and these should be distinguished from each other, for the length of time during which the armature remains down could not otherwise be determined.

61. The student should begin to read by sound by receiving letters and copying them; he should continue this exercise until each letter is instantly recognized, and should then practice receiving words and then sentences. The speed of receiving and copying should be gradually increased until he is capable of doing both rapidly.

Open the key whenever a word is not understood and repeat the last word received. A receiver, and especially a beginner, should not hesitate or be ashamed to ask for a repetition by breaking and telegraphing back the letters *rr* or *rcpt* (meaning "repeat"), for it is better to make a large number of breaks with requests to repeat, or for information, than to make one mistake.

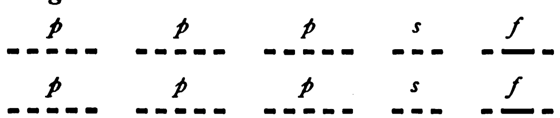
62. The student should try to copy that which is sent him *as far behind transmission as possible*. Although this will be hard to do, especially at the beginning, because it

divides the attention and requires the exercise of memory, it must be accomplished before one can become a good receiver of rapid sending. The beginner will find it difficult at first to keep one or two words behind, but by continual practice this can be improved on very much. Expert operators are able to put off writing the first part of a message until receiving the latter part.

When the student can receive and copy legibly at the rate of about twenty words a minute, he should try to practice on regular lines in some office, which will give him the necessary experience with office work and forms that he can scarcely acquire in any other way. When he is able to receive and copy at the rate of thirty words a minute, he may look for a position as a regular operator. The student should also learn to use the typewriter for copying the messages directly as received from the sounder. The skilful use of the typewriter in receiving is necessary to secure employment as an operator with some companies, especially with the press associations.

GENERAL INFORMATION.

63. Office Calls.—Every telegraph office has a call or name, which consists usually of one or two letters; thus, the call for New York is *n y*; Chicago, *ch*; Baltimore, *b*; San Francisco, *s f*. If San Francisco desires to communicate with Philadelphia, he repeats the latter's call on the line until answered. It is proper to sign one's home office every three or five calls, in order that others on the line may know who is using the wire. The call would be made as follows:



When the Philadelphia operator hears the call, he opens his key and replies by repeating "*i*" several times and signing his own call; thus:

TABLE 1.

COMMON ABBREVIATIONS.

Word or Phrase.	Symbol.	Word or Phrase.	Symbol.
From	*fm*	Correct, or all right	*o k*
Signature	*sig*	Quick	*qk*
Check	*ck*	Repeat	*rr*
Go ahead	*g a*	Street	*st*
Paid	*pd*	Avenue	*ave*
Collect	*col*	Through	*tru*
Free, or Deadhead	*dh*	Address	*ads*
Answer	*ans*	Guaranteed	*gtd*
Hear, or here	*hr*	Business	*biz*
Another	*ahr*	Tariff	*tff*
Charges	*chgs*	Telegraph	*tel*
Message	*msg*	Amount	*amt*
Messenger	*msgr*	Break	*bk*
Operator	*opr*	Express	*ex*
Office	*ofs*	Freight	*frt*
Battery	*bat*	Passenger	*pasgr*
Good morning	*g m*	Before	*b4*
Good night	*g n*	Mistake	*msk*
Immediately	*immy*	Number	*no*
Important	*impt*	No more	*n m*
Minute	*min*	Nothing	*ntg*
Give better address	*g b a*	Instrument	*inst*
Give some address	*g s a*	Morning	*mng*
Ground wire	*g w*	Train	*trn*
Please	*pls*	Manager	*mgr*
Superintendent	*supt*	Way bill	*w b*
Conductor	*condr*	Circuit	*ckt*
Engineer	*engr*	Do you understand ?	*13*
Wait a minute	*1*	The end, or finis	*30*
Where shall I go ahead ?	*4*	Are you ready ?	*77*
What is the matter ?	*18*	Who is at the key ?	*134*
Accept my compliments	*73*	Deliver	*92*
See former service	*s f s*	Delivered	*92 d or deld*
No such number	*n s n*	Special delivery	*spl dely*

When answered as above, San Francisco proceeds with his business. The same is followed between any other two offices.

64. Common Abbreviations.—To increase the speed of sending telegraph messages, many abbreviations are used. In Table 1 are given a few of the more common abbreviations, not in alphabetical order, but those most used being given first. Many other abbreviations will be readily acquired in actual business.

65. Abbreviations Adopted by Postal Telegraph Company.—The Postal Telegraph Company has adopted a system of abbreviations, or a so-called code, for office or service messages. The code is very simple, and the contractions already in common use have been retained. By its use, service messages will not only be much more quickly prepared and transmitted, but clerks and operators will be relieved of the work of constantly rewriting phrases of considerable length. The abbreviations employed are those in common use, initials, and combinations of letters designed to assist in memorizing them. This service code is given in Table 2.

MESSAGES.

66. Commercial Messages.—A commercial message may be divided into eight parts, as follows: The number of the message, the office call, the operator's personal signal, the check, date, address, body, and signature. In messages, the following plan will be followed: All parts of a message that are both transmitted and copied will appear in *italic;* all parts transmitted but not copied will be enclosed in parenthesis ( ); all parts that are written by the receiving operator but not transmitted will be enclosed in brackets [ ]; and finally all parts appearing on the original and final message but not transmitted will be in SMALL CAPITALS.

TABLE 2.

POSTAL TELEGRAPH COMPANY'S SERVICE CODE.

Code Word.	Meaning.	Example.
CANCEL	Cancel and file.	Our H 41 New York, Henry Briggs, signed Hooper, CANCEL.
COLLECT	Collect there. Payment refused.	Your A 216 Chicago, Weld & Son, signed Paterson, COLLECT.
COLUNK	Collect there. Addressee unknown.	Your A 219 Buffalo, Henry W. Gerrish, 21 Monmouth St., East Boston, signed Gerrish & Co., COLUNK.
DELD	Delivered O. K.	Your A 117 of 31st, John C. Wilson, DELD.
D F S	Disregard former service.	
DUP	Duplicate quickly from original, word not understood.	Your G 91 Armour & Co., tenth Abhor, DUP.
G B A	Give better address. Unknown at address given. Not in directory.	Your A 94 N. Y., Wm. Newcomb, 31 Broad St., signed G. J. Foss, G B A.
H A	Hurry answer	Our A 83 Price, McCormick, signed Jones & Co., H A.
H C	Hurry press check.	Transcript 30th, H C.
MISSING	Missing number. Describe.	Your C 16, MISSING.
NOFTRAF	No office this line. We transfer and turn in tolls as uncollectable.	Your F 32 John Peters, Austin, N. Y., signed Fleming, NOFTRAF.
ORNORD	Original not received. Have delivered duplicate with explanation. Please trace.	Your C 90 Chicago, Swift & Co., Boston, signed Swift, ORNORD.
LOCKED	Place closed. Will deliver soon as open.	Your A 94 Hartford, Horace Conkling, signed F. H. French, LOCKED. (*This message to be sent only when the place is closed for some unusual cause.*)
R F O	Repeat from original. Message not understood.	Your 204 Boston, G. F. Smith, signed Henry, R F O.
S O S	See our service.	
S Y S	See your service.	
TRANSFER	Transfer there and instruct us to cancel.	Your 46 Elmira, John G. Fitch, San Antonio, signed Reynolds, TRANSFER.
UNDELD	Undelivered. Addressee has left.	Your B 38 St. Louis, F. H. Webster, signed James, UNDELD.

67. The Check.—Preceding the check come the following parts in the order given: The abbreviation *hr* (hear), *city* or *tru* (through), the abbreviation *No* followed by the number of the message for that day, the sending-office call, the sending operator's personal signal or sign, the receiving operator's personal sign (the latter appears only on the received message blank). Then comes the check itself, including the abbreviation *ck* (check), the number of words charged for, and finally the word *paid*, *collect*, or *free*. Sometimes *ahr* (another) is used in place of *hr*, and if the message is free, the reason is generally given. Stating the number of words charged for aids in preventing errors and omissions. In messages sent collect, the word *collect* is counted but not charged for. The check should read *11 collect*, for a collect message containing 10 words in the body of the message.

The first line in an ordinary 10-word paid message, sent from Scranton direct to some office without requiring to be relayed (that is, retransmitted), would be as follows:

(Hr city No) *35 scr sn* [hs] (ck) *10 paid*

If the message is for some place other than that to which it is sent, and hence has to be relayed, and if collect instead of paid, it would be as follows:

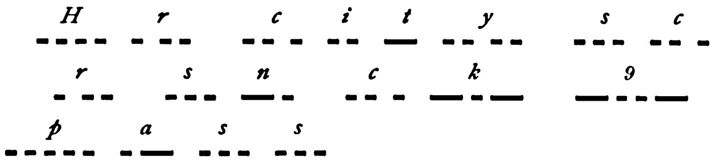
(Hr tru No) *35 scr sn* [hs] (ck) *11 collect*

The symbol *hr* is the signal that precedes each message; *city* means that the message is for some one in the city or town to which it is sent; *tru* means that the message has to be sent through to some other office; *scr* is the sending-office call; *sn*, the sending operator's personal sign; and *hs*, the receiving operator's personal sign. The symbol *hs* is not transmitted, but is written on the telegram by the receiving operator.

When a message is sent free on account of a pass, the number of the pass is not sent; but, if free on an operator's account, *opr* is sent, preceded by the abbreviation *dh* for

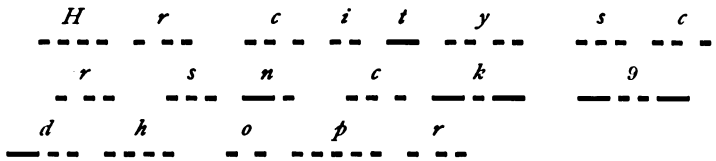
deadhead. The first line for such a message containing 9 words would be as follows:

(Hr city) *scr sn* [hs] (ck) *9 pass* No 225



But, if sent on an operator's account, it would be sent thus:

(Hr city) *scr sn* [hs] (ck) *9 dh opr*



68. The Date.—The date consists of the name of the place where the message originates, the month, the day of the month, and year. The month and year are always omitted in actual transmission. Sometimes on the same wire the office call is given instead of the name of the place; but when the message goes beyond the line on which it originates, and in all commercial business, the name of the place must be sent. The name is often abbreviated, but it is better to spell it out in full, especially if the abbreviation is not well known and can be mistaken for another place. The sending operator always prefixes the word *from*, abbreviated to *fm*, or *fr*, before the date, but the receiving operator never copies this down. No periods are transmitted after abbreviations.

69. The Address.—The address should consist of the full name and address of the person to whom the message is sent. The number of the street, as Third street, should be written in words. When the office at which a message terminates is on the same line, the name of the place is not sent, but only the office call; when, however, the message goes through, the destination is spelled out in full. The

address is always preceded by the word *to*, and a *period follows the address*, thus separating it from the body of the message. The receiving operator never copies down this word *to* before the address. Except at the end of the address, that is, before the body of a message or train order, the period is seldom used. The comma is used in place of the period at the end of sentences, and the comma as ordinarily used is not transmitted.

70. Body of Message.—The body of the message is embraced between the period and the signature. No abbreviations are permitted, or, if inserted, each abbreviation is considered a word. Numbers should be spelled out in full, and if the figures also are inserted, they too are counted. The body of some messages is composed of combinations of figures, letters, and disjointed words—words often not to be found in any dictionary. Such messages have no meaning or sense until interpreted by means of a key in the possession of the sender and receiver, and are either code or cipher messages. Code and cipher messages are considered elsewhere.

71. Signature.—The signature of the sender is preceded by the abbreviation *sig* without a period; in fact, periods are seldom if ever sent after abbreviations or initials in any part of an ordinary message. When there are several signatures, only the last one goes free. The receiving operator never copies down the abbreviation *sig*. The time the message is received should be placed under the signature in a typewritten message, or on the same line with the check or immediately above it in a message written with a pen.

72. Complete Message.—A complete message is given on the next page, exactly as it would be transmitted by the sending operator. The part in SMALL CAPITALS appears on both the original and the final copy of the message, but is not sent. The words or abbreviations in ordinary type in parenthesis, thus (ck), are sent but not copied. The part in ordinary type in brackets, thus [hs], is written

on the telegram but is not transmitted. The part of the message both transmitted and copied is in *italic*.

(Hr city No) *35 scr sn* [hs] (ck) *9 paid*

(Fm) *Scranton* SEPT *12* 1899

(To) *W S Henry*

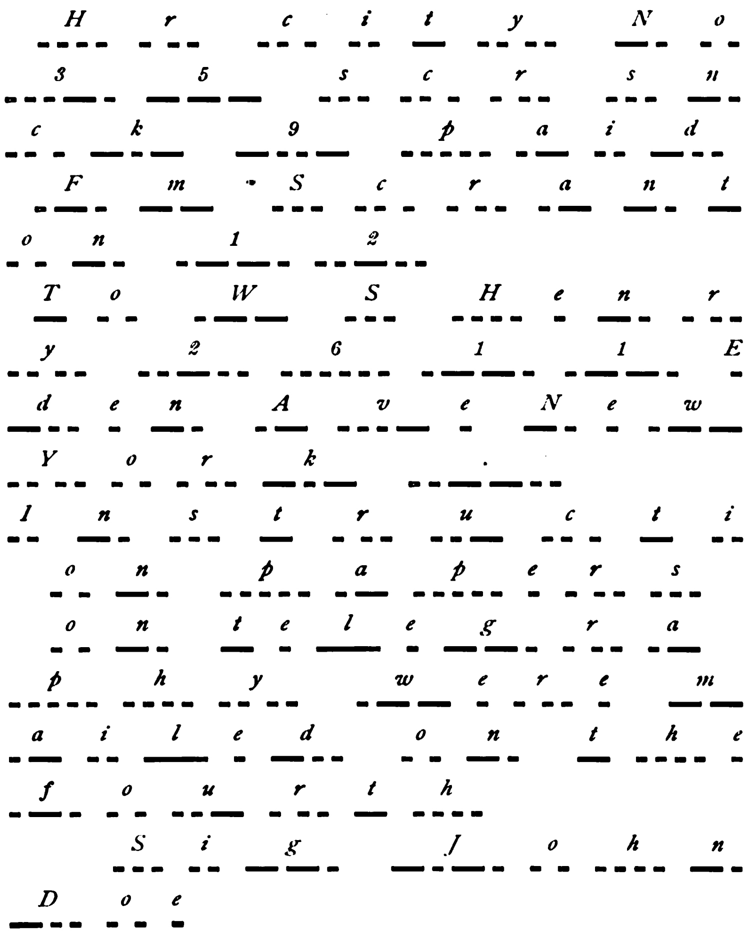
2611 Eden Ave

New York.

Instruction papers on telegraphy were mailed on the fourth

(Sig) *John Doe*

[6:45 P. M.]



Form No. 1.

THE UNITED STATES TELEGRAPH COMPANY.

This Company **TRANSMITS** and **DELIVERS** messages only on conditions limiting its liability, which have been assented to by the sender of the following message.

Errors can be guarded against only by repeating a message back to the sending station for comparison, and the Company will not hold itself liable for errors or delays in transmission or delivery of **Unrepeated Messages**, beyond the amount of tolls paid thereon, nor in any case where the claim is not presented in writing within sixty days after the message is filed with the Company for transmission.

This is an **UNREPEATED MESSAGE**, and is delivered by request of the sender, under the conditions named above.

JOHN DOE, President and General Manager.

NUMBER	SENT BY	REC'D BY	CHECK

RECEIVED at 632 WYOMING AVE., SCRANTON, PA. ____________ **190**

Dated ____________

To ____________

The ordinary blank form of the "unrepeated" message of the Western Union Telegraph Company is the same as that given on the preceding page. The forms of all telegraph companies vary, yet the difference between them is so slight that the one given may practically be said to be typical of them all.

A message sent from Scranton to Columbus, requiring to be relayed, say at Buffalo, would be as follows. Buffalo's received copy would be:

(Hr tru No) *37 scr sn* [hs] (ck) *15 paid Dely chgs gtd 3 ex w*
(Fm) *Scranton* SEPT *12* 1899
(To) *W S Henry*
2611 Eden Ave
Columbus.
Instruction papers on telegraphy were mailed on the fourth as you requested (Sig) *John Doe*
[6:55 P. M.]

Dely chgs gtd stands for "delivery charges guaranteed." These are the three extra words. They are included in the check and are charged for.

The copy received at Columbus would be:

(Hr city No) *37 scr sn* [px] (ck) *15 paid 3 ex w Dely chgs gtd*
(Fm) *Scranton* SEPT *12* 1899
(To) *W S Henry*
2611 Eden Ave
Columbus.
Instruction papers on telegraphy were mailed on the fourth as you requested (Sig) *John Doe*
[7:10 P. M.]

73. Suppose that W. S. Henry, 2611 Eden Ave., New York, to whom the following telegram was sent by John Doe, from Scranton, had left New York before the message was delivered, but had left orders for his telegrams to be forwarded to him to Youngs Hotel, Boston, and also that this message was collect, the rate to New York being 25 cents and from New York to Boston 33 cents. The message, beginning with the (ck), as forwarded from New York to Boston, would be as follows:

(ck) *15 collect 33 c & 25 c 4 ex w*

(Fm) *Scranton Pa* SEPT *12 via New York Sept 12*

(To) *W S Henry*

Youngs Hotel

Boston.

Have all instruction papers on telegraphy reached you wire answer (Sig) *John Doe*

[7:45 P. M.]

The four extra words (4 ex w) are Scranton Pa SEPT 12 and, of course, the word "collect" is included in the check, making 15 words, only 14 to be charged for, however. Experience in an office is almost indispensable before all rules for checks and message forms can be thoroughly understood.

74. Address Incomplete or Incorrect.—If the address of the message from Scranton to W. S. Henry, New York, were received in such a shape that the party could not be located, New York would telegraph back the following:

(To) *Scranton*

g b a [give better address] *your No 35 of twelfth Henry sig Doe*

(Sig) *New York*

Scranton might reply to this message:

(To) *New York*

Cant [cannot] *g b a our No 35 of twelfth Henry sig Doe*

(Sig) *Scranton*

75. Through Receiving. — An operator should always say *O K* and sign his own personal letters or signal, as shown below, when he is through receiving a message or a number of messages.

O *K* *S* *n*

- - —- - — - - - — -

If no *O K* is received, it will be known that the message has not been properly received, and must be repeated.

76. Repeated Messages.—In order to avoid mistakes or delays, the sender of a message may have it *repeated*, that is, telegraphed back to the originating office for comparison. There is an extra charge of one-half the regular rate for repeating a message, and the words *repeat back*,

which must be inserted in the check, are also charged for. Extreme care must be taken by all operators in receiving, and especially in sending, repeated messages.

When a notice of the delivery of a message is requested by a customer, the words *report delivery* should be inserted in the check and charged for. Such a *report delivery* message should be answered by a collect message addressed to the sender of the original message. The answer should state the time of delivery, or if not delivered, the reason why.

77. Mistakes in Receiving and in Sending.—An operator, after receiving a message, should be careful that he has the correct number of words called for by the check sent with the message. If they do not agree, the error should be found by comparing with the sending operator. To do this, it is customary to begin at the period, and to write the first letter in each word until the missing portion is found. If the sending operator perceives that he has made a letter incorrectly, he stops, makes seven or more dots, says *msk* (mistake), and begins again with the last word he made correctly.

78. Suppose, in sending the first message given, that either the sending operator at Scranton failed to send the word "mailed," or else that the receiving operator at New York neglected to copy it. The New York operator would have only 8 words, while his check called for 9. New York would signal back *8 w*, signifying that he had only 8 words instead of 9. The Scranton operator would count the words again, and if he found there were 9 as before, he would signal *9 paid*, and immediately signal the first letter of each word in the body of the message. This is termed *lettering* the message. He would transmit .(period) *i p o t w m o t f*. The New York operator would signal back *g a* (go ahead) *fifth*, which would be the word immediately preceding the missing one. The Scranton operator would then signal the words *were mailed*, and the missing word *mailed* would be discovered.

Supposing a 12-word message from Scranton, similar to the one given in Art. **72,** but omitting in the check the words *Dely chgs gtd 3 ex w*, passed through Buffalo and reached Columbus with only 10 instead of 12 words in the body of the message. The Columbus operator who discovered the error would signal back to Buffalo *10 w no exa.* The Buffalo operator would look over his message, and, finding in his copy but 10 words, would signal to Columbus *bk hold it, I will get fixed.* The Buffalo operator would then signal to Scranton to get his No. "37." When the Scranton operator had found his No. 37, Buffalo would signal *10 w no exa.* The Scranton operator would locate the error and send the missing words to Buffalo. The Buffalo operator, after correcting his own copy, would proceed to help the Columbus operator to correct his copy.

79. Do not begin to transmit a word until you know what it is. A receiver dislikes very much to spoil his "copy" by having to alter or erase a word. A clue to an obscure word will usually be given by the sense of the message, which can be obtained by reading the whole message through. Do not hold the wire any longer than is really necessary, nor bother the chief operator until you have first done your very best to decipher the doubtful word.

When the receiving operator finds that he is not getting a message correctly, he breaks, that is, opens the circuit, and telegraphs back *ga*, followed by the last word correctly received; the sender should immediately resume his message, beginning with the word indicated by the receiver. If the receiver wants the entire message repeated he should signal *rr* or *rept* (repeat).

80. Counting Words in an Ordinary Message. On regular full-paid business, the charge for any number of words up to 10, inclusive, is the same, but for all over 10 words, an additional rate per word is charged. The *words to be counted* include all those in the *body of the message*, all signatures—except the last one, if several are signed

83. Night and Reduced-Rate Messages.—Night messages, which are sent at reduced rates, may be handed in at any time. They are usually transmitted during the evening or during any slack time, but must never be delivered until the next morning. These messages are copied on blanks printed in red ink, and the sending operator sends the word *red* before the number, and the words *night rate* immediately after the check.

Government messages have priority over other business, and are sent at reduced rates. Press messages are also sent at reduced rates. Such messages as government and press despatches, which require especially quick service, are called "pink" messages, because such messages are copied upon pink blanks and the word *pink* is written before the abbreviation No on the message blank and is transmitted before the number of the message. *Govt* is transmitted and copied after the check on a government message.

84. Business for the Company.—Between employes and on company business, no checks are sent with the message, and much less formality is necessary than with commercial business. Those messages that are used to assist in the prompt transaction of business and the correction of errors are called *service*, or *office*, *messages*.

85. Privacy of Messages.—No information of any kind respecting messages should be given to any one other than the party to whom the message is addressed. A person that wilfully divulges the contents or the nature of such contents may be punished, if convicted, by a fine of not more than one thousand dollars, or by imprisonment for not more than six months, or by both such fine and imprisonment.

The Western Union Telegraph Company has the following rule on this subject: "Any officer, clerk, operator, or other employe handling messages, who shall report or divulge the contents of such messages to any officer of the company, or other person, shall be promptly dismissed from the service of the company, and prosecuted under the law making it a

81. Counting Words in Code and Cipher Messages.—In code and cipher messages consisting of combinations or groups of letters, figures, punctuation marks, and words, each letter, figure, punctuation mark, and word must be transmitted exactly as written by the sender. Each word to be found in a dictionary or code book is to be counted 1, as usual. For groups of letters not contained in a dictionary or code book, and for groups of figures, count 1 for each 3 letters or figures and fractions of 3. For instance, in the following cipher message, the number to be charged for would be 9. If intended for transmission, punctuation marks are included in the count as if they were figures or letters.

(No) *35 scr sn* [hs] (ck) *9 paid cipher*

(Fm) *Scranton* SEPT *12* 1899

(To) *W S Henry*
2611 Eden Ave
New York.

Turtle *14643* *cbrbm;* *particulars* *1734*
(1) + (2) + (2) + (1) + (1) + (2) = 9

(Sig) *General Manager John Doe*
[7:30 P. M.]

It will be noticed in the message that the word *cipher* is sent immediately after the full check, and before the abbreviation *fm.*

82. Charge for Messages.—In addition to what has already been said on this subject, the following remarks may be added. In case several copies of the same message are made and delivered to different persons, each copy must be paid for.

To calculate the full charge for a message that goes to an office on the line of another telegraph company, determine the rate to the transfer office, and to this add the rate between the transfer office and the place of destination. A message must be all prepaid or all collect when it is transmitted over two or more lines. Pay in advance is generally required from transient customers for both a message and an answer.

uniformity in the forms that are used on the various roads, no general forms that will apply to all roads can be given. Each road usually gives positive directions regarding the use of every train-order form. These directions are usually embodied in a set of rules, which the men may study and learn at their leisure, thus avoiding the necessity of repeating such direction in the body of each order.

ABBREVIATED AND CIPHER SYSTEMS.

88. Phillips's Code of Abbreviations.—Mr. W. P. Phillips's code is a system of abbreviations, or is a sort of shorthand applied to telegraphy. It consists of single letters and combinations of two or more letters, which arbitrarily represent figures, words, and whole phrases. The Morse code is used for all letters and figures, but not for all the punctuations. Words and phrases that occur most frequently in newspaper reporting are represented by single letters and short combinations of letters; for example,

Cj means *coroner's jury*
Abmn means *abomination*
Cqas means *closed quiet and steady*

This code contains several thousand characters or abbreviations, and to be able to use it to the best advantage, the press operator must memorize as much of it as possible.

Since so many abbreviations are used, it is often impossible for the receiver to copy the matter in full as fast as it comes over the wire, and in that case some sort of an ink register is necessary with which to receive the message. Several operators can be kept at work transcribing the despatches from the record on the paper ribbon as fast as it comes in, at the same time making, by some manifold process, a copy for each newspaper interested.

If the student desires to engage in press work or cares to look further into this subject, which is sometimes called *stenotelegraphy*, he should obtain the complete Phillips code, which is published in book form.

TYPEWRITING.

89. The typewriter is so rapidly coming into general use for writing down the telegraph messages as the operator receives them from the sounder, and also for transcribing the messages from the receiving ribbon in certain automatic systems, that a few words regarding the use and operation of the typewriter may be very useful to the inexperienced operator.

The operators of the regular telegraph companies use the typewriter quite extensively even now, and the expert manipulation of the typewriter by the receiver is a necessity in order to secure employment with the press associations.

A good typewriter can write from 60 to 70 words a minute, but an expert telegraph operator cannot send steadily over 40 to 45 words a minute; consequently a receiver has plenty of time, in addition to writing the message, to insert the "time received," the operator's "personal sign," etc., even when receiving at the fast rate mentioned. Every young operator should learn to operate the typewriter rapidly and accurately.

90. Typewriting Machines.—The typewriting machines of today are well nigh perfect, and the telegraph operator should not be careless, slovenly, or slow in his work with the typewriter any more than when manipulating the telegraph key.

Typewriting machines may be divided into two distinct classes, called *double-case machines* and *shift-key machines.* Those that have a key for each character that the machine will print are the **double-case machines,** and those that, while printing as many characters as the others, have but one key for each two characters, and in some machines but one key for each three characters, are called the **shift-key machines.** Those machines that print more characters than they have keys are provided with a key by which either the roll on which the printing is done or the keyboard may be so moved as to allow the different characters to come in contact with the paper at the proper place. This

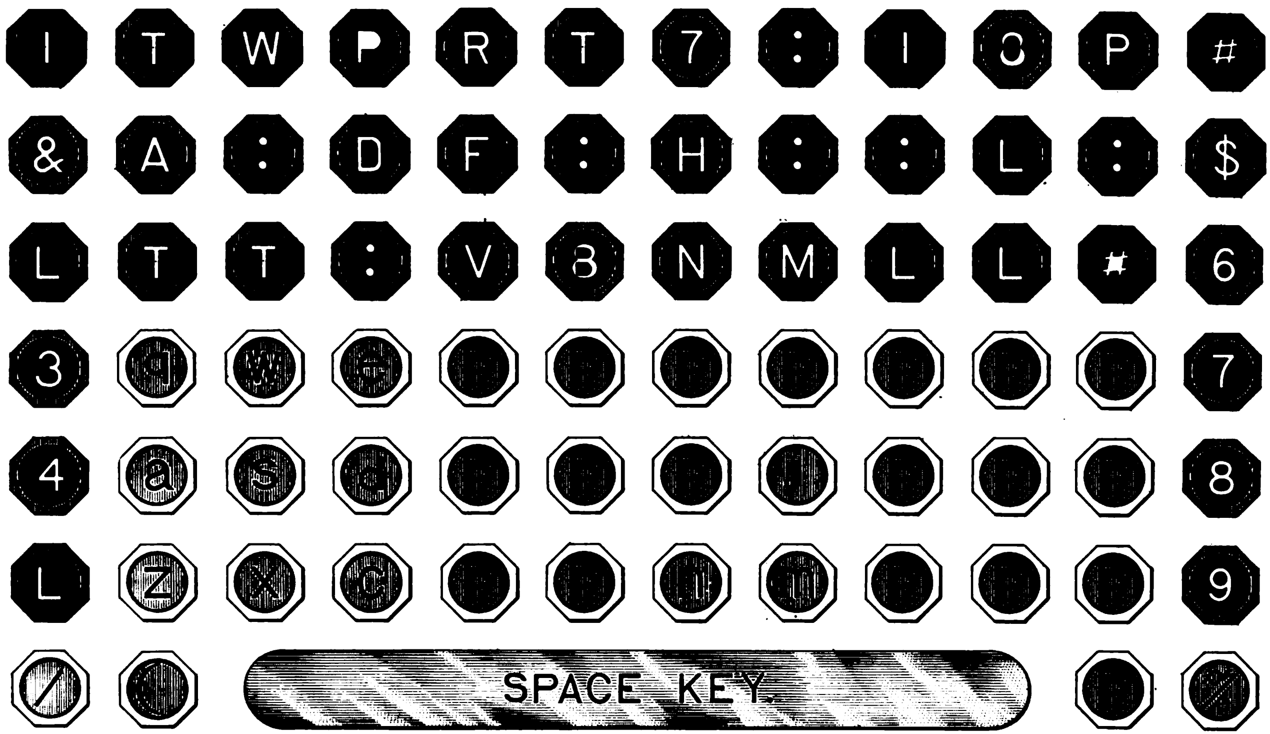


FIG. 10.

FIG. 11.

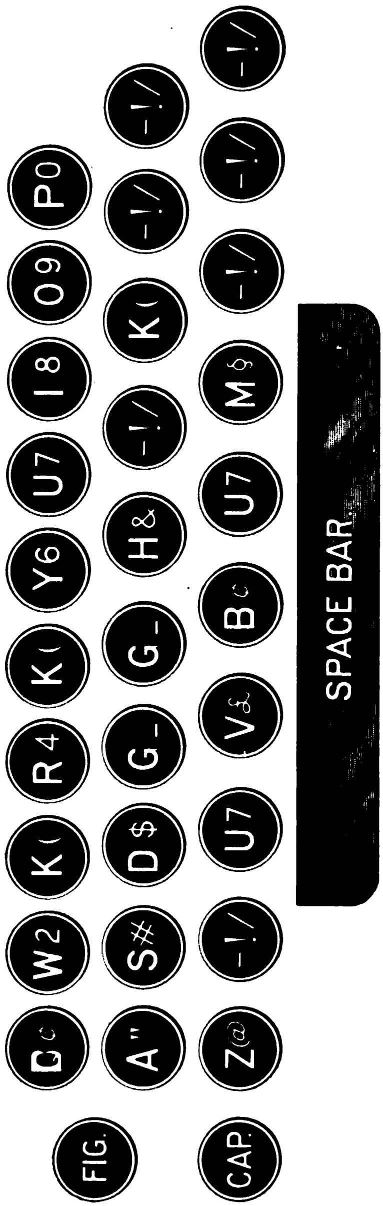


FIG. 12.

key is called the **shift key,** and from it the machine takes its name. Machines having three characters to a key have two shift keys, one for capitals and one for figures and characters. Of the double-case machines, the Smith Premier, Fig. 10, is perhaps the best example, and of the single shift-key machines, the Remington, Fig. 11, while the Universal Hammond, Fig. 12, may be named as a representative of the double shift-key machines. While there are a number of plans on which the letters of the alphabet are arranged in typewriter keyboards, there is one arrangement, called the *universal keyboard*, that is more generally used than the others. The diagrams show the plan of this keyboard as used in the above machines.

91. In operating a typewriter, the old-time method of picking out the keys with one finger of each hand has been done away with, and the

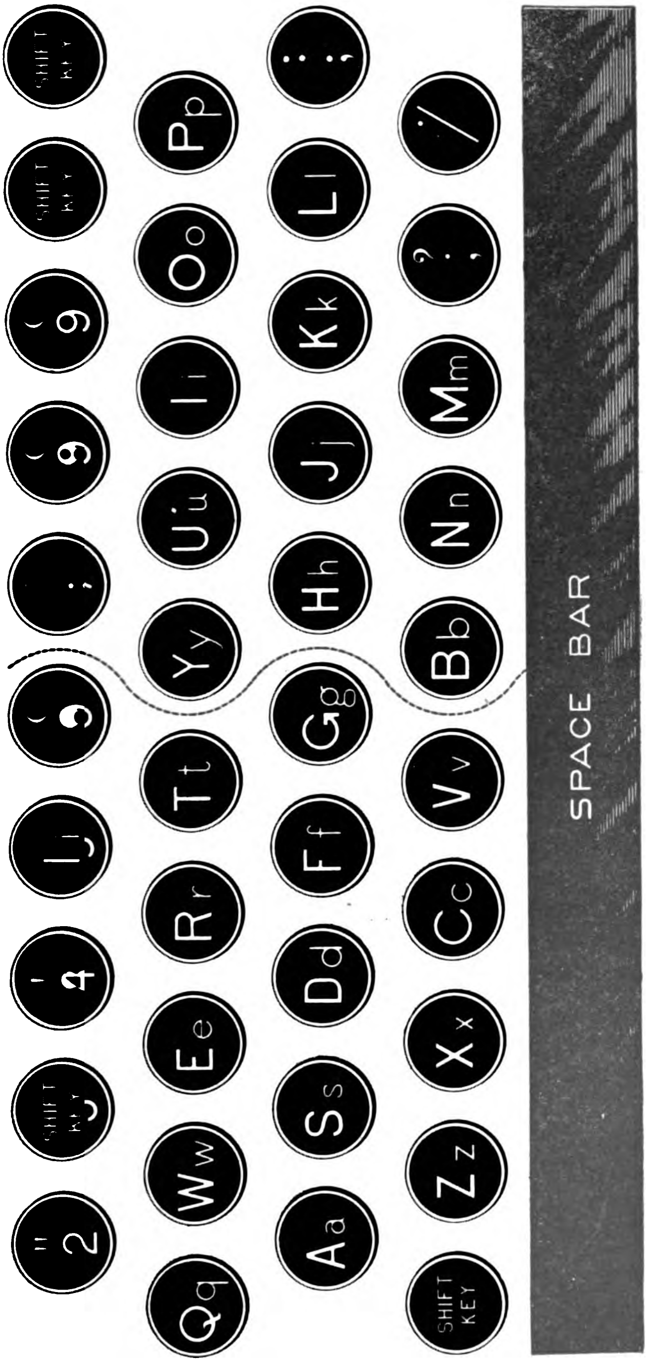


FIG. 13.

T. G. Vol. II.—5.

modern operator uses all the fingers of each hand in writing, scarcely looking at the keyboard. To do this, although requiring much diligent practice, is not so difficult as may at first be imagined. It is accomplished by allotting certain keys to certain fingers and taking care that each finger does its allotted work. On the Remington, the keyboard may be divided as shown by the dotted line in Fig. 13.

All the keys at the left of the dotted line in Fig. 13 are for the left hand, and all those at the right of this line, and including the space bar, are for the right hand. The work on the right-hand side of the keyboard may be divided among the fingers of the right hand, as follows: Operate the space bar with the right thumb, the first two rows of keys at the right of the dividing line with the first finger, the next row with the second finger, the next row with the third finger, and the last row with the little finger. The work for the left hand may be assigned as follows: The first two rows of keys at the left of the dividing line are for the first finger, the third row for the second finger, the fourth row for the third finger, and the fifth row, including the shift key, for the little finger. While there are a number of plans for dividing the work among the fingers, the above is a plan that can be used on all the universal machines with the least possible change, and the operator that will become familiar with this method of fingering will be able to write at greater speed, and will find typewriting much less a task than if other methods are used. To acquire speed in typewriting, no better plan can be followed than that of writing words of frequent occurrence, phrases, parenthetical clauses, addresses, and short letters, over and over again, always being careful to use the correct fingering and never trying to write so fast that the work will not be done accurately. In both sending and typewriting, always work first for accuracy and then for speed. Each typewriter is accompanied with a book of directions for its operation and care; we simply advise that all directions issued by the manufacturers be explicitly followed, especially those on cleaning and oiling the machines.

OBTAINING EMPLOYMENT.

92. Applying for a Position.—Do not expect to get a position simply because you want it; if you get one, it will be because you deserve it; therefore, you should honestly feel that you can acceptably fill a certain position before applying for it.

The candidate who, when calling for an interview, presents a neat, businesslike appearance, who introduces himself in a pleasant style of address, who can show that he knows how to respect himself and at the same time be respectful to a possible employer, who is straightforward, frank, and unhesitating in answering all questions put to him, is sooner or later sure to obtain the position for which he is seeking.

93. Entering a Position.—Having secured a situation, do not consider the battle entirely won. You are but just begun, and much hard work and study must yet be done. On taking up the duties of a new position, one must begin at once to adapt himself to the new surroundings and to fit himself to the place. One of the first considerations will be to find out those peculiarities of the business, either in technical language, figures, or routine, that are likely to prove troublesome in the work.

In a new position, one cannot be too careful, for his own sake, to start, and continue, on good terms with his fellow-workers. He should do nothing that will prejudice himself or his position in the estimation of his associates, for he will often be in need of some friendly assistance, which their experience will enable them to give him. Civility and cheerfulness cost nothing, and are very effective aids to one in any position of life—especially to one that is taking up new work. A pleasant manner and address, together with a good temper, help to smooth over the rough places and to ease the wear and tear of business life. Though cheerfulness and good temper are in a great measure governed by natural disposition, yet those that are not thus fortunately gifted may do much to neutralize the defects of an

opposite character, and may, to a degree, cultivate the art of making friends. Care must be taken, however, that in your desire to be on good terms with all, you do not overdo the matter. There is more in the quotation "Familiarity breeds contempt" than appears on the surface. While it is very natural for each one to think his own method of doing a thing the best, it must also be borne in mind that it is not so much your duty to convert the company to your methods as to serve them by observing theirs.

TELEGRAPHY.

(PART 1.)

ELECTRIC TELEGRAPHY.

1. Electric telegraphy is the art, science, or process of transmitting intelligible signals or signs between distant points by means of electric impulses moving between those points. Messages may be transmitted in this manner by visible or audible signals, both methods being largely used. The essential parts of electric telegraph systems are the transmitting and receiving apparatus, and, also, except in wireless telegraphy, the line wire connecting the two distant points.

SHORT HISTORY OF TELEGRAPHY.

2. Before going into the details of the various electric telegraph systems of the present day, it will be well to take a hasty glance over such discoveries and inventions as have made the present systems possible. Before the discovery and use of the voltaic pile or battery, about 1800 A. D., several attempts were made to transmit signals to a distance by using electricity generated by friction. The first idea was to use a separate wire for each letter or character. In 1774, Le Sage, of Geneva, constructed an electric telegraph with twenty-four wires, one for each letter in the French alphabet, using frictional electricity as his agent of transmission. Lomond later simplified this method, using but

one wire and a system of signals. Methods in which electric sparks and discharges from Leyden jars were used for signaling were devised about 1800, but nothing of practical importance resulted from these methods.

3. In 1809, Sömmering, of Munich, devised an electric telegraph depending on the fact that an electric current will decompose acidulated water and give off bubbles of gas. He used a separate wire and key for each letter and a voltaic pile as his source of electricity. The ends of the wires projected in a row into the bottom of a long, narrow vessel under a series of inverted tubes, and, by closing keys at the sending station, bubbles of gas were produced and collected in the tubes at the ends of the corresponding wires at the receiving station. The letters of the alphabet could therefore be transmitted in any order desired. About the same time, Dr. J. R. Coxe, of Philadelphia, proposed, independently, a system very similar to that invented by Sömmering.

4. Importance of the Electromagnet.—After the important discovery of electromagnetism by Romagnési, of Trente, in 1805, and again, independently, by Oersted, of Copenhagen, in 1819, and the production of an electromagnet by Sturgeon, of England, in 1825, a fresh impetus was given to electric telegraphy. In 1828, Professor Henry, of Albany, New York, independently discovered that, by wrapping around a plain iron core many turns of insulated wire through which an electric current was passed, he could, at pleasure, magnetize and demagnetize the iron core. Thus, both Sturgeon and Henry produced the electromagnet, which is absolutely essential to nearly every method of electric telegraphy now in use.

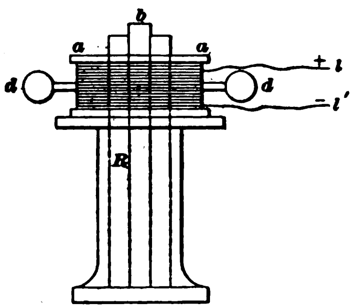


FIG. 1.

5. Gauss and Weber's Telegraph. — The telegraphic apparatus invented by

Gauss and Weber, of Göttingen, in 1833, was one of the earliest forms depending on the discovery of Oersted. Fig. 1 shows the transmitter, and Fig. 2 the receiving instrument. The transmitter consisted of a standard *R*, in the center of which there were three large, straight, permanent magnets *b*, weighing 25 pounds each. The similar poles of these magnets were placed together and a coil *a a* of insulated wire surrounded their upper ends. This coil contained 7,000 turns of insulated copper wire and was wound on a wooden spool that had two handles *d*, *d* by which it could be moved up and down. The wires *l*, *l'* from this coil were connected at the receiving station, shown in Fig. 2, to the two wires *l*, *l'*

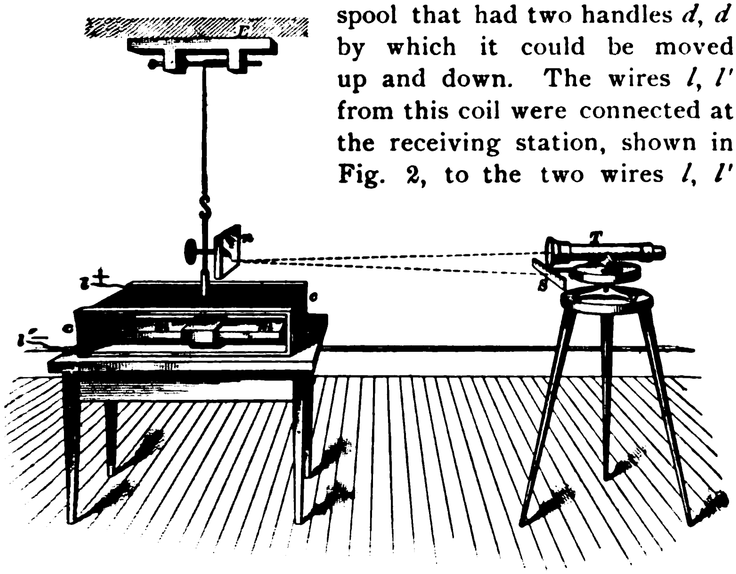


FIG. 2.

of the flat rectangular coil *c c*. To the ceiling was fastened the support *E*, from which was suspended, by a number of silk fibers, the mirror *n* and a flat permanent magnet *m m*. This magnet was 18 inches long, and was free to vibrate inside the coil *c c*. At a distance of about 12 feet was placed the telescope *T* and the scale *S*, by which means a very small deflection of the magnet *m m*, to which the mirror *n* was rigidly fixed, could be observed.

By raising the spool of wire *a a* at the transmitting or

sending office, an electromotive force was induced in the coil *a a*, and a current of electricity would flow through the circuit in one direction. This current, passing through the coil *c c*, would cause the magnet *m m* to rotate and thus produce a deflection of the mirror in a direction that could be observed by looking through the telescope. By lowering the coil, the induced current would flow through the circuit in the opposite direction and produce a deflection of the mirror in the opposite direction. By the combinations of right and left deflections, an alphabet was arranged.

6. Professor Steinheil, of Munich, developed this invention of Gauss and Weber, finally producing a transmitter and an ink-recording receiver capable of transmitting and receiving messages at the rate of 6 words per minute. He was anticipated, however, in the idea and construction of a self-recording receiver by Morse, whose work will be mentioned presently. But Steinheil's apparatus was too complicated to exist alongside the newer and simpler systems that were brought forward. Professor Steinheil was the first to discover that the earth could be used as one conductor, thus requiring only one line wire, the earth being used as the return circuit. He made this discovery in 1837, while attempting to use the rails of a railway as telegraphic conductors.

MORSE'S INVENTION OF THE TELEGRAPH.

7. The possibility of utilizing Professor Henry's electromagnet for an electric telegraph system was conceived by an American portrait painter, Samuel F. B. Morse, in 1832. Although he worked diligently on his system, still he was unable, for the lack of money, to apply for a patent until 1837.

Morse's first ideas on telegraphy included the following apparatus and method: A voltaic cell as a source of electricity; outgoing- and return-wire conductors; a system of signals consisting of dots and spaces to represent numbers;

a method of sending electric impulses representing these dots, and the use of an electromagnet at the receiving end that caused a pencil to draw, nearly at right angles across a moving paper, one V-shaped mark for each electric impulse. By counting the number of marks across the paper between two spaces, the spaces being indicated by long, straight lines lengthwise

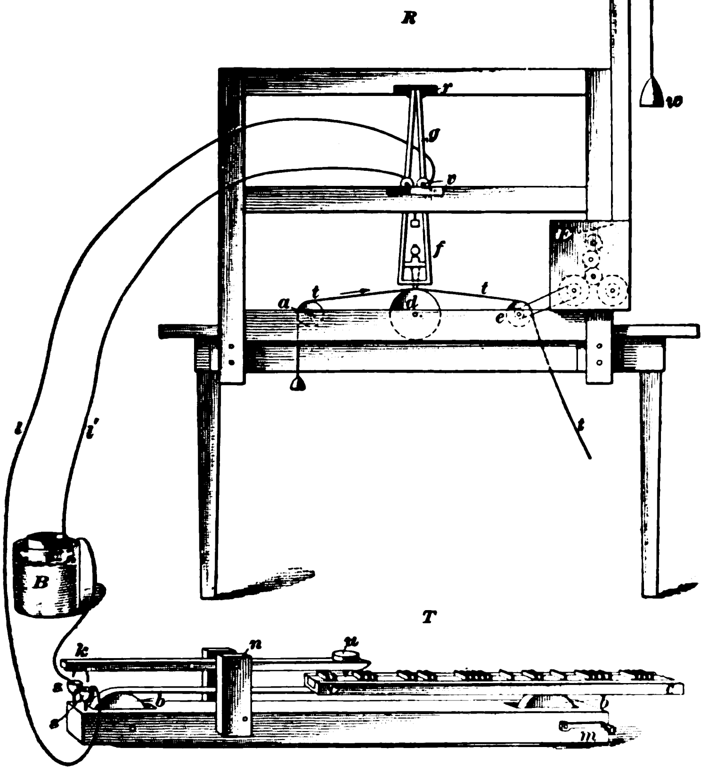


FIG. 3.

of the paper, and by looking up the number in a telegraphic dictionary, the corresponding word could be found.

8. Morse's First Apparatus.—The first model constructed by Morse, in 1835, is shown in Fig. 3. *T* is the transmitting, and *R* the receiving, apparatus; *B*, the voltaic cell; and *l*, *l'*, the two line wires. It was not then known that the earth could be used as a return circuit, so two wires were employed. The transmitter consisted of a stout piece of wood on which were fixed two rollers *b*, *b*, and over these ran an endless belt to which was attached the composing stick *c c*. On this composing stick the symbols or types, shown in Fig. 4, could be arranged in any order desirable. At *n* (Fig. 3) was pivoted a lever, on the front end of which

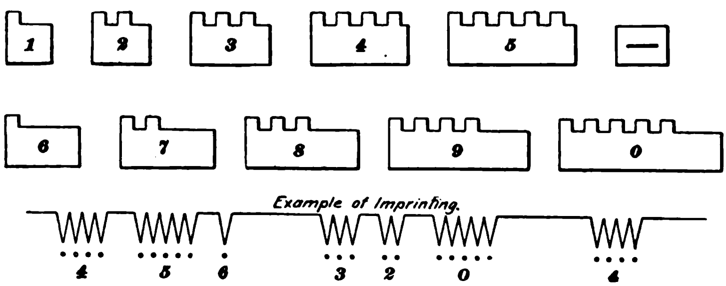


FIG. 4.

was a weight *u* to keep that end depressed. By turning the handle *m*, the composing stick with its type was moved along, and every time one of the projecting pegs of the type came against the wedge under *u*, that end of the lever was lifted up, causing the two ends of a bent piece of wire at *k* to dip into two mercury cups *s*, *s* and close the circuit of the battery *B*. Thus, every time a peg passed under *u*, an electric impulse was sent over the line to the receiving apparatus *R*. The important part of the receiving apparatus was an electromagnet *v* secured to an artist's wooden stretching frame, the iron armature of the magnet being fastened opposite to it on a sort of pendulum *g* hanging from an axis *r*. At the bottom of the pendulum was a tube to hold a lead pencil on which rested a weight to press the pencil against a ribbon of paper *t t t*. This paper was kept moving steadily over the

drums *a*, *d*, *e* by means of the clockwork *E* and the weight *w*. The pendulum *g* in its normal or at rest position, where a weight and, later, a spring tended to keep it, caused the pencil to make a straight line in the direction of the motion of the paper.

Whenever a current was sent over the line and through the electromagnet *v*, by closing the circuit between the mercury cups *s*, *s*, the armature was attracted, pulling the pendulum with it and causing the pencil to draw two lines nearly at right angles to the direction of the motion of the paper, one line as the pendulum moved toward the magnet due to the attraction, and another as it returned to its original position after the current had ceased to flow. One **V** thus made would represent a single impulse.

The type used in the transmitting apparatus at one end of the line and the record made by the receiver at the other end are shown in Fig. 4. Both the sending and receiving apparatus were automatic in action after the type characters were set. It will be noticed that the meaning of one type character depends not only on the number of pegs projecting upwards, but also on the length of the space following the last peg on the type. Morse exhibited his apparatus at various times before the faculty of New York University, the Franklin Institute at Philadelphia, and, finally, before President Van Buren.

9. In 1843, a bill was finally passed through Congress appropriating $30,000 for the purpose of erecting an experimental line between Washington and Baltimore. Morse kept improving his system so that, by 1844, the apparatus consisted of an electromagnetic circuit-closing device called a *relay*, an embossing register, and a simple circuit-closing *key* at each end of the line.

10. In Fig. 5 is shown his recording apparatus, or embossing register as it is called, and a key mounted on the same baseboard. To one end of the lever *a*, which is pivoted at *c*, is fastened the armature *b*, and to the other end

are secured three steel points that indented or embossed the paper ribbon as it was drawn along by the clockwork and weight *w*. There seems to be no good reason for using three steel points, for one record has since proved to be sufficient. When the armature was attracted by the electromagnet *m m*,

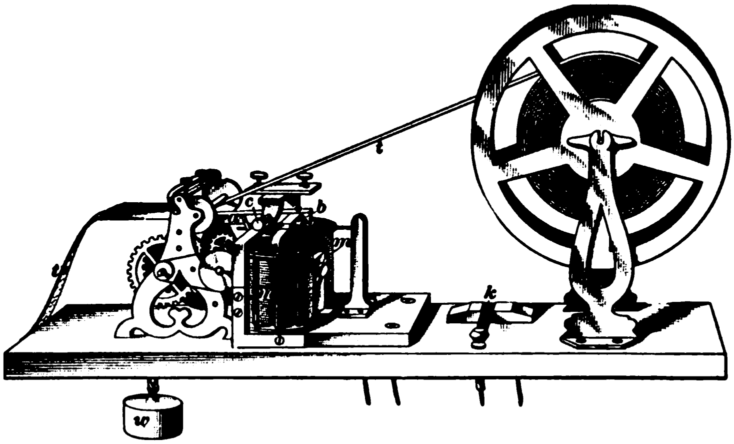


FIG. 5.

the steel points pressed the paper upwards into three corresponding grooves in a roller, against which the paper *t* was pressed as it was drawn along. A depression, or indentation, in the paper stood for a dot or a dash, depending on its length. Thus, indentations representing dots and dashes, and separated by intervening unindented portions representing spaces, formed permanently embossed characters on the paper.

The key *k* mounted on the same base was a very simple affair. When not in actual use by the operator, a metallic plug was placed between the contact points, to keep the circuit closed.

11. On the Baltimore-Washington line, Morse used an electromagnetic relay, connecting the coils of his embossing register in a separate circuit, the opening and closing of which was controlled by the armature of the relay, as shown in Fig. 6. This figure shows the complete diagram

of connections used at both ends. *R* and *R'* represent the relays; *S* and *S'*, the coils of the embossing registers; *K* and *K'*, the keys; *B*, the battery; and *G* and *G'*, the connections with the ground. The relays *R* and *R'* are connected in series with the line, the battery *B*, and the two keys *K* and *K'*. The relays control the opening and

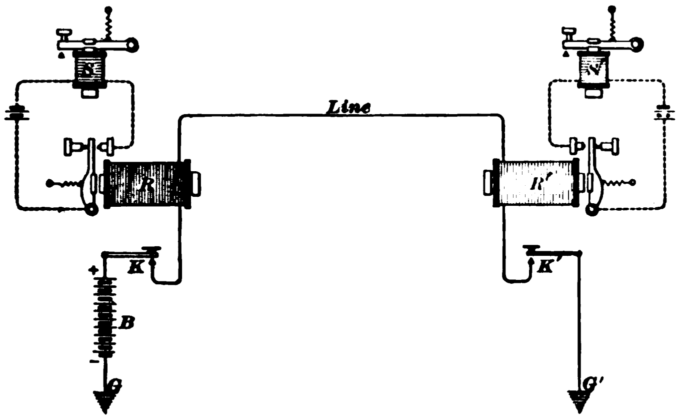


FIG. 6.

closing of the local circuits of the two registers *S* and *S'*. When both keys *K* and *K'* are closed, the armatures of the two relays will be attracted and thus close the two local circuits, one at each end of the line, in which are connected the registers *S* and *S'*. If either *K* or *K'* is opened, then both local circuits will be opened. When the local circuits are closed, the styles of the registers make indented marks on the paper corresponding to dots and dashes, and when the local circuits are open, the styles are withdrawn from the paper and no indentations are made, thus separating the dots and dashes by spaces.

12. The telegraphic alphabet, called the *Morse alphabet*, as arranged and used for telegraphing between Baltimore and Washington, is still employed all over the United States and Canada, except for submarine-cable work. About the

first public news to be sent over the Baltimore-Washington line was the report of a national political convention in session at Baltimore in 1844. The relay used by Morse over this line was an exceedingly large and clumsy affair, weighing 150 pounds, while the relay of today weighs only 3½ pounds.

13. By an accident to the insulation of the line circuit, it was discovered that only one wire was necessary and that the earth could be used as one path for the current. This was also discovered, as stated in Art. **6**, by Professor Steinheil in 1837. The insulation between the two line conductors that Morse at first used becoming defective, the system of connections shown in Fig. 6 was tried; that is, instead of employing a second wire as a return path, the circuit was connected to the ground *G*, *G'* at each end and the earth used as a return path. The system of connections shown in this figure is used today all over the United States, Canada, and Mexico where relays and registers, or sounders, are employed.

14. Alfred Vail is usually given the credit for the discovery of the fact that the characters could be read by the sound made by the recording lever, as well as by the marks made on the paper. This led to the use of a sounder, on account of its simplicity, and the recording apparatus was dispensed with.

The method of communication originated by Morse and developed by Morse and Vail, including both the alphabet and the arrangements of the line and local circuits and apparatus, has been continued in general use ever since in this country, with the addition of such practical improvements as experience has from time to time suggested.

15. To Alfred Vail, a skilful mechanic and inventor, who became a partner of Morse in 1837, considerable credit is due for the success of Morse's system. He entirely reconstructed the apparatus and embodied in it many practical features, and prevailed upon his father, Stephen Vail, to

supply the money whereby the development and introduction of the electric telegraph became possible. His efforts in overcoming many of the practical difficulties that arose in connection with the first telegraph line between Baltimore and Washington, in 1844, and his genius and untiring diligence during the development of the telegraph deserve a great deal of praise. It is claimed that he put the Morse telegraph code into its present practical and satisfactory form, and the register that he made in 1844 has been improved but little since that time.

INVENTION OF COOK AND WHEATSTONE.

16. Cook and Wheatstone took out their first joint patent in England in 1837, and their first actual working telegraph circuit was erected in 1838. For this system, six wires and five magnetized needles, enclosed in wire coils, were used, combinations of deflections of the needles forming a system of signals.

The modern single-needle apparatus, of which there are over three thousand in use in Great Britain, was first employed on a public line running out of London in 1845. This apparatus was a combination of the ideas of both Cook and Wheatstone. The combination of right and left deflections of a single vertical pointer in front of a dial furnished a system of signals representing the letters of the alphabet. The pointer was attached to the axis of a vertical, thin iron bar permanently magnetized, and it was deflected to the right or left, depending on the direction of the electric current that was sent through the coil of wire surrounding the thin iron bar.

AUTOMATIC AND CHEMICAL RECORDING SYSTEMS.

17. About 1854, two competing systems of telegraphy were introduced in this country. One was the House printing telegraph, by which the message was delivered on a

ribbon of paper, plainly printed in Roman letters. The other was a system devised by Professor Alexander Bain. It recorded dots and dashes by the chemical discoloration of the recording paper. Both were operated with reasonable success, but neither of them seemed able to compete with the relay and sounder, probably on account of the simplicity and efficiency of the latter.

18. Chemical Recorder.—The extreme sensitiveness of the Bain recorder to feeble currents will warrant a brief description of it here, but the description of printing and chemical telegraph systems will be more fully given later.

In Fig. 7 is shown Bain's chemical telegraph, or *electro-motograph*, as it is called. The lever *l* is pivoted on a universal joint at *H*. The spring *t* pulls the lever *l* to the left,

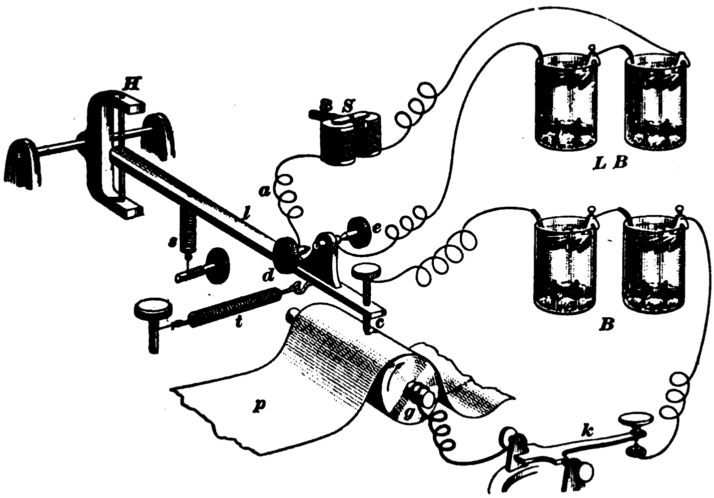


FIG. 7.

and the spring *s* causes the platinum-tipped screw *c* to be pressed against the paper *p*. The metal drum *g* is revolved continuously by clockwork in the direction shown by the arrow. If this is to be used as a relay to control the opening and closing of a local circuit, the *zinc pole* of the battery *B must* be connected to the screw *c*, although the

reverse is shown in the figure, and the copper pole through the key *k* to the shaft of the drum *g*. A local circuit containing an electromagnet *S* and a local battery *L B* may be connected, as shown, to the lever *l* and the stop *d*.

When the key is closed, a current flows from the battery *B* through the key *k*, the metal drum *g*, and the moistened paper *p* to the platinum-tipped screw *c*, and back to the battery *B*. The paper is moistened with a solution of common salt and pyrogallic acid. When no current is passing through the paper, on account of the key *k* being open, the friction between the paper and the platinum-tipped screw *c* is sufficient, with the springs *t* and *s* properly adjusted, to keep the lever *l* pressing against the stop *e*. But when the key is closed, the current decomposes the chemicals, rendering the paper so slippery to the platinum tip *c* that the spring *t* easily pulls the lever against the stop *d*, thus closing the circuit containing the electromagnet *S* and the local battery *L B*.

If the paper is moistened with a solution of iodide of potassium and starch in water, and the *positive, or copper, pole of B connected to c*, as in the figure, a permanent blue line will be made on the paper whenever the current is flowing, thus giving a permanent record of the message, and no sounder would be necessary. By its use, messages may be transmitted and received by currents so weak that the ordinary electromagnetic relay would fail to operate or even give an indication of the passage of the current. Two cells, it is said, will operate it over a line 200 miles in length.

THE MORSE SYSTEM.

19. The only instruments really necessary at each station on the simplest form of the Morse telegraph circuit, where the line does not exceed 20 or 30 miles in length, are a *telegraph key* and a *telegraph register*, or *sounder*.

20. The Key.—This is an instrument for opening and closing the circuit. By this operation, various combinations

of long and short current impulses are sent over the circuit. A typical key is shown later on, in Fig. 12.

21. The Sounder.—This instrument consists of an electromagnet and a pivoted armature, adapted to give forth a sound whenever an electric current starts or stops flowing through the coils on the instrument. A typical sounder is illustrated later on, in Fig. 22. When the current starts to flow through the coils on the sounder, the iron armature is attracted, and a lever, to which the armature is fastened, strikes a stop and produces a loud click. When the current stops flowing through the coils, the armature is no longer attracted, and a spring quickly pulls it back to its first position, causing the lever to strike another stop and so produce another loud click. The interval of time that elapses between two such clicks determines whether the signal is a dot or a dash. Telegraph codes and sounders will be fully described further on.

MORSE CLOSED-CIRCUIT SYSTEM

22. The simplest form of a telegraph circuit is shown in Fig. 8. *L* represents the line wire connecting the two stations *W* and *E*. *K* and *K'* are keys; *B* is a battery; *S* and *S'* are sounders for receiving messages; *G* and *G'* are metallic plates by means of which the wire is connected with the earth, or *grounded*, as it is usually termed. The circuit is traced as follows: When both keys *K* and *K'* are closed, the current starts from the positive, or plus, pole of the battery *B* and passes through the key *K* and the sounder *S* to the line, and thence through the sounder *S'*, the key *K'*, and the plate *G'* at station *E*, and finally back through the earth to *G* and the negative, or minus, pole of battery *B*. The earth is generally used instead of a return wire, and may, for all practical purposes, be considered as a conductor of very small resistance, for, although it is comparatively a *poor conductor, its practically unlimited area renders its resistance negligible in comparison with that of a long line wire.*

When both keys are closed, a continuous current will flow around the circuit, so that the electromagnets of the sounders will attract their armatures. If, now, one key is opened, the current will be interrupted, and both electromagnets will release their armatures and allow them to be drawn upwards by the springs *s* and *s'*. If the key is closed again, both

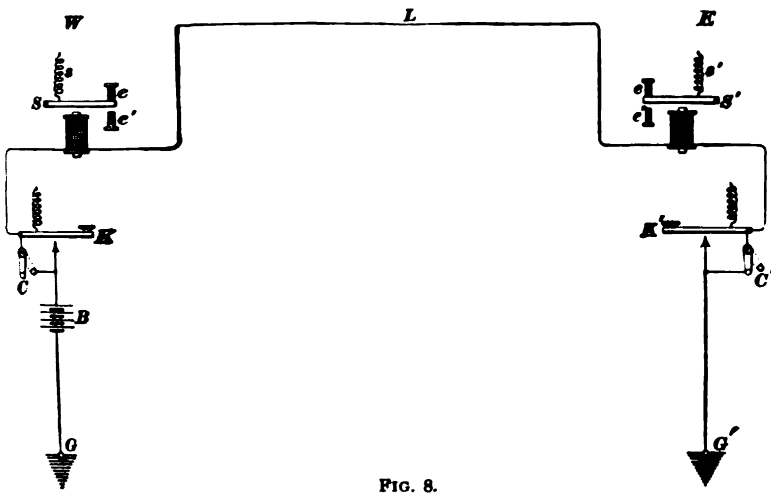


Fig. 8.

armatures will be drawn down as before. The motion of the armature is limited by the stops *e* and *e'*. The downward movement of the armature causes a sound distinguishable from that made by the upward movement, and these movements are called the *down* and *up* strokes, and by certain combinations of these strokes, messages are received by sound.

23. When the line is not in use, the circuit is left closed, and for this purpose small switches *C* and *C'* are provided for every key. Closing one of these switches accomplishes exactly the same result as depressing the key. It saves the operator the inconvenience of having to hold down his key when he wishes to leave the circuit at his station closed for some time. In Fig. 8, the switches *C* and *C'* are in the proper positions to enable the operator at station *W* to *send* to

station *E*. When telegraphing, the switch *C* or *C'* at the receiving station must be closed, and that at the sending station open. When the line is idle, both switches must be closed. The necessity for these rules concerning the use of the switches will be appreciated by supposing that the operator at *E* has left his switch open. It will then be impossible for the operator at *W* to control the sounder at *E*, for, no matter whether the circuit is open or closed at *W*, it is open at *E*, and therefore no current can pass over the line.

RELAY CIRCUIT.

24. The Relay.—When a telegraph line is more than about 30 miles in length, it becomes difficult and impracticable to render the current in the line circuit strong enough to operate the somewhat heavy armature of a sounder with sufficient vigor to produce a loud enough sound. The sounder is then replaced by an electromagnetic device called a **relay.** A relay is a telegraphic receiving instrument having an armature that moves in accordance with impulses of currents that pass through the coils on the magnet cores of the instrument, and, in so moving, opens and closes a second circuit, called a *local* circuit, in which may be included a sounder and as powerful a battery as desirable, while the relay, on the other hand, may be so delicate as to work with a very weak current. A typical relay, shown later on, in Fig. 16, includes an electromagnet, the two coils of which are generally wound with many turns of fine wire, and a small, light armature. When a current passes through the coils of the relay, the armature is attracted toward the magnet, and its upper end touches a contact screw and so closes the local circuit. When the current ceases to flow through the coils of the relay, the armature is no longer attracted, and a spring promptly pulls it away from the magnet and the contact screw and causes it to rest against a second screw with an insulated point. Thus the local circuit is opened as the armature leaves the first-named screw.

25. The arrangement in which relays are employed at two telegraph offices *W* and *E* is illustrated in Fig. 9. In this figure, *R* and *R'* are the relays; *K* and *K'*, the keys; *B* and *B'*, the main-line batteries; *L B* and *L' B'*, the local batteries; *S* and *S'*, the sounders; and *G* and *G'*, the ground connecting plates. *B* and *B'* are called the *main-line batteries* because they are connected directly in the main or line circuit, while *L B* and *L' B'* are connected with the sounders in circuits that do not go outside of the office and, hence, are called *local batteries*, and the circuits containing them are called *local circuits*. A current starting from the

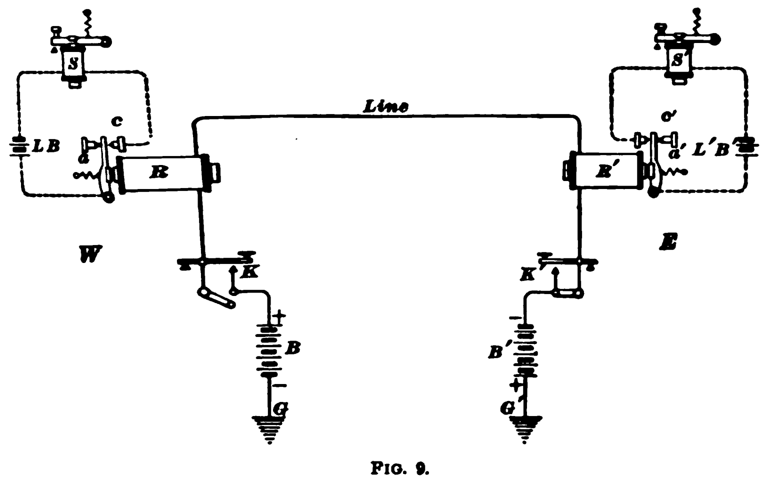


FIG. 9.

battery *B* passes through the key *K*, relay *R*, the line, relay *R'*, key *K'*, battery *B'* to the earth through the ground plate *G'*, and returns through the earth and the ground plate *G* to the battery *B*. It should be noticed that the batteries *B* and *B'* are *in series with each other*, *B* having its negative pole to earth and positive pole to the line, while *B'* has its positive pole to earth and its negative pole to the line. When the circuit is closed, both relays are energized and attract their armatures *a* and *a'*; and when the circuit is opened, both relays lose their magnetism and release their armatures. The armatures *a* and *a'* therefore make and

break the two local circuits at contacts *c* and *c'*, and thus act as keys in the local circuits, each of which contains a register, or sounder, and a battery.

26. When the telegraph operator at one office desires to send a message to the other, he interrupts the flow of the current by opening the switch of his key. This causes the relays to lose their magnetism, release their armatures, open both the local sounder circuits, and causes the sounders to click. Now, if he operates his key by closing and opening the circuit so as to form the characters representing the letters of the alphabet in the order in which they occur in a message, the armatures of his own and the distant relays, as well as those of the sounders controlled by them, will respond to every make and break in the circuit caused by operating the key, and, consequently, the message may be read by ear from the clicks made by the sounders; and the receiving operator writes it down as fast as it comes to him. Since the sending operator's sounder also responds and gives out the message, the receiving operator may evidently interrupt him at any time by opening the line circuit at his key and thus stop the flow of current through the relays. This causes the sending operator to realize that the circuit has been broken, because his own sounder no longer corresponds to the movements of his own key. He then closes his switch to give the original receiving operator an opportunity to communicate with him.

27. As many cells of battery as are necessary may be used in the local circuit at *L B*, and thus the sounder may be made to produce a loud sound even though the current in the line wire is exceedingly feeble. One cell is often sufficient, but it is customary to use two cells in the local-sounder circuit. Except in large offices, where dynamos or storage batteries are used, all current for both main-line and local circuits is usually obtained from gravity or crowfoot cells. Batteries and dynamos adapted for use in telegraphy will be considered later.

INTERMEDIATE OFFICES.

28. Almost any number of intermediate telegraph offices may be connected in the same circuit with the two terminal offices. Fig. 10 (*a*) shows one intermediate office *I* connected in the line between the two terminal offices *W* and *E*, with one-third of the whole number of main-line cells at each office. Fig. 10 (*b*) shows two intermediate offices *A* and *B* and two terminal offices *W* and *E* on the same circuit with one-half the whole number of main-line cells at each terminal office and none at the intermediate offices. All keys, relays, terminal and intermediate main-line batteries are connected in series in the same line circuit.

All the cells may be located at one terminal or end station, as in Fig. 6, or one-half the number may be at each end station, as in Fig. 10 (*b*), or the cells may be distributed, some being placed at each station, as shown in Fig. 10 (*a*). Where several sets of cells are used, the cells in each set must not only be connected in series with one another, but the various sets must all be connected in series in the circuit and not opposing one another. To connect the line batteries properly, when there is a battery at each office, as shown in Fig. 10 (*a*), start at station *E*, for instance, and there connect the zinc, or negative, pole of the battery *B'* to the ground plate *G'*, and the copper, or positive, pole through the key *K'* and relay *R'* to the line; at the intermediate station, connect the east line to the negative pole of the battery *B"*, the positive pole of *B"* through the key *K"* and relay *R"* to the west line, and at the west station connect the line through the relay *R* and key *K* to the negative pole of the battery *B*, the positive pole being connected to the ground plate *G*.

29. Intermediate Batteries.—It is not very often necessary to connect batteries in the line at small intermediate stations. The best arrangement is to have an equal number of cells at each terminal station. When one terminal station is large and well equipped with dynamos,

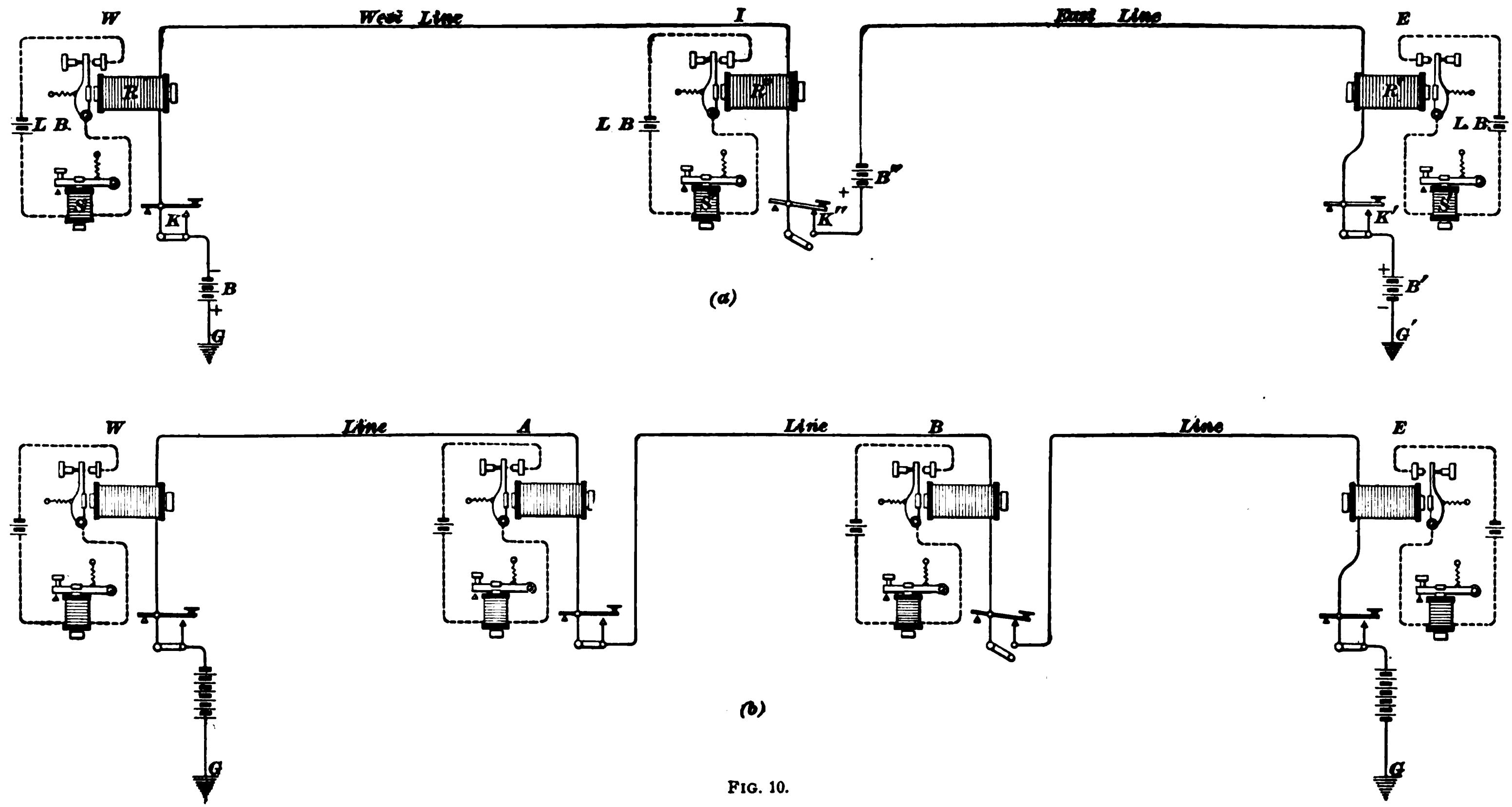

W
West Line
I
East Line
E
R
R''
R'
L B.
L B
L B
S
K
K''
K'
B
B'''
B'
G
G'
(a)
W
Line
A
Line
B
Line
E
G
G
(b)

FIG. 10.

which are now rapidly coming into use for supplying the current for telegraph lines, and the other station is not so well equipped, it may be advantageous to let the former station supply all the current. Furthermore, where the intermediate office is a large one, well equipped with dynamos for use as intermediate batteries, and the terminal offices, on the other hand, are small ones, then the whole current may be advantageously supplied from the intermediate-office dynamo, and no batteries need be used on such a line at the small terminal offices.

30. Intermediate Offices on One Line.—As many as thirty or forty intermediate offices are sometimes connected on a single circuit, but twenty instruments are probably as many as should be placed in a single circuit to work advantageously. Of course, only one of the operators can be sending at one time, but all the others may receive the message. The message may be of interest to only one or two offices out of the thirty or forty on the line, but all the other offices have to remain idle until the one sending is through, or else interrupt him if the other business is so much more important that it is allowable to do so.

31. The foregoing arrangement of line and apparatus is known as the **Morse closed-circuit system,** because, in the normal condition, that is, when no messages are being sent, all the keys are closed and the battery is connected to the line, causing current to be normally flowing through the whole circuit. This system is used all over the United States, Mexico, and Canada, except for submarine-cable telegraphy.

MORSE OPEN-CIRCUIT SYSTEM.

32. In Europe, what is known as the **Morse open-circuit system** is used. This system, with two terminal offices and one intermediate office on one line, is shown in Fig. 11. When all the keys are at rest in their normal position, that is, when no message is being sent, all the keys

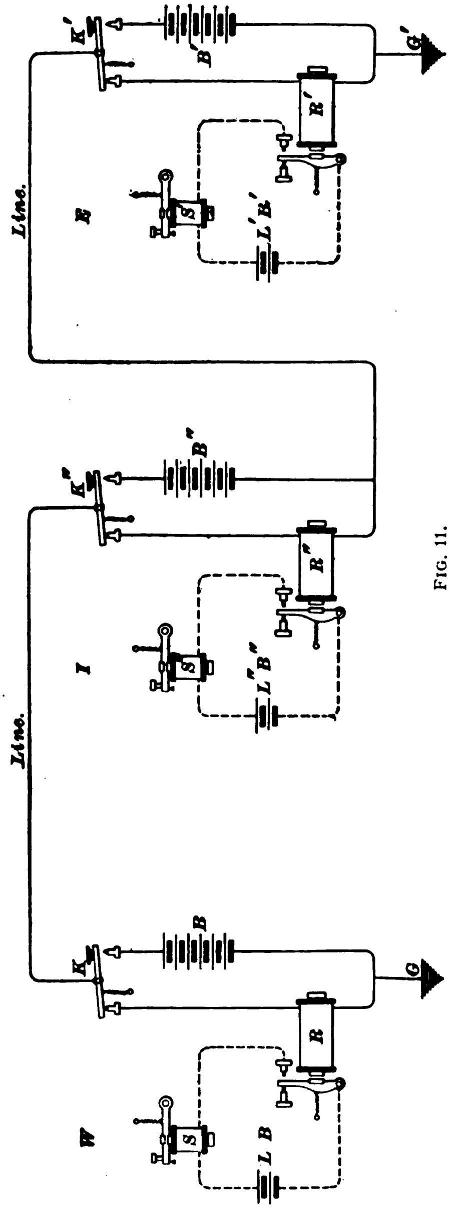


FIG. 11.

and batteries are so arranged that all batteries are on open circuit, although all the relays are connected in series in the circuit. Thus, normally, no current flows through the line or through the local-sounder circuits, and the batteries are all on open circuit, from which fact it derives its name. When a message is to be sent, the sending operator closes his key, the battery at his station is introduced into the line circuit, and his relay is cut out. Thus, current is sent over the line operating all but the home, or sender's, relay. It is a simple matter, however, to so connect the relays that the home relay will be operated by the home key.

In Fig. 11, *R*, *R'*, and *R"* are the relays; *S*, *S'*, and *S"*, the sounders; *B*, *B'*, and *B"*, the main-line batteries; *K*, *K'*, and *K"*, the keys; and *L B*, *L' B'*, and *L" B"*, the

local batteries for operating the local sounders at the *W*, *E*, and *I* offices, respectively. It should be noted that the like poles of all the batteries *B*, *B'*, and *B"* are connected to the front contacts of the keys, for the sake of uniformity. This is not at all necessary, however.

RELATIVE ADVANTAGES OF THE OPEN- AND CLOSED-CIRCUIT SYSTEMS.

33. Advantages of the Closed-Circuit System.—The whole battery may be located at any one station or divided up among any number of stations. *This gives the closed-circuit system a decided advantage over the open-circuit system where there are a large number of offices on one line.*

Since the current is flowing even when not sending, the system may be easily kept in adjustment, ready for sending and receiving messages at short notice. The cells, being normally on closed circuit, maintain a more constant electromotive force and do not run down when the line is being used, and, as a result, the current is apt to be more even and steady than on the open-circuit system.

34. Disadvantages of the Closed-Circuit System. Since the current is flowing constantly, the battery material is being steadily consumed whether the line is in use or not. A continuous current seems to increase flaws in cables, and for this reason this system is not used for submarine telegraphy.

If all the cells are at one end, the current due to leakage between the line and the ground will be strongest at the office nearest to, and weakest at the office farthest from, the battery. If serious enough, this can sometimes be partially reduced by distributing the cells among the various offices.

35. Advantage of the Open-Circuit System.—Consumption of battery materials takes place only when the line is being used. It is suitable for submarine-cable work. The resistance of one relay is cut out of the circuit when a key is closed.

36. Disadvantages of the Open-Circuit System. It is necessary to have the same number of cells at each office, and a sufficient number to operate the whole system. Since it is not likely that the batteries at all stations will be in the same condition, all the relays may need readjusting whenever a different office starts to send. The current is not apt to be as steady as in the closed-circuit system. If there is leakage on the line, causing the current to be stronger at the sending office, there is no means to avoid it except by improving the insulation of the whole line.

TELEGRAPH CODES.

37. Telegraph codes consist of combinations of dots, dashes, and spaces, which represent letters, numerals, and punctuation marks. The dot is taken as the unit by which the lengths of the dashes and spaces are measured. The following table gives the relative lengths of the different dashes and spaces:

Signal.		Duration of Signal.
Dot	1 ▬	1 unit
Dash	3 ▬▬	3 units
Long dash (*L*)	5 ▬▬▬	5 units
Extra-long dash (*cipher*)	7 ▬▬▬▬	7 units
Space between parts of a letter	▬ 1 ▬	1 unit
Space in spaced letters	▬ 2 ▬	2 units
Space between letters	▬ 3 ▬	3 units
Space between words	▬ 6 ▬	6 units

It will be noticed that there are four lengths of spaces and three of dashes, or four including the dot. Theoretically, the long dash (*l*) should be twice as long as the dash and the extra-long dash (*0*, cipher) should be one-half longer

than the **long dash** (*l*), that is, 9 units in length when *l* is made 6 units. However, the long dash (*l*) is seldom made longer than 5 units and the cipher seldom longer than 7 units. Furthermore, in practice, the *l* and *0* (cipher) are frequently made the same; occurring alone or in words, the long dash would be read as *l*, but when found among figures, it would be translated as *0* (cipher).

38. A material gain in the rapidity of transmission may be effected, and without any great disadvantage, by shortening the dash to 2 units, the long dash to 4 units, and the extra-long dash to 5 units. Where recording instruments are used, this shortening of the dash is not so advisable, for it is then very easy to mistake a dash for a dot.

39. Telegraph Codes.—There are several different telegraph codes: the *Morse*, the *Continental*, the *Bain*, and the *Phillips punctuation* codes. The Bain code is seldom, if ever, used. The various codes are given on accompanying pages.

40. It will be noticed, in such characters as parenthesis ( ), brackets [ ], quotation marks " ", *italics*, etc., which are composed of two parts separated by one or more words, that the characters representing them must be sent before and after the intervening word or words. The following modifications are included in the Phillips code:

‒ ‒ ‒ ‒ ‒   ‒ ‒ ‒ ‒ *PY* for the second parenthesis mark in place of *PN*, which stands for the first parenthesis mark, as formerly.

‒ ‒ — ‒   — ‒ — ‒ *QJ* for the second quotation mark in place of *QN*, which still stands for the first mark, as formerly.

‒ ‒ —   — ‒ — ‒ *UJ* for the second underline signal in place of *UX*, which stands for the first underline signal, as formerly.

The paragraph means that the receiving operator should commence a new line.

41. The Australasian colonies (except West Australia and New Zealand, where the Continental code is used)

ALPHABETS.

LETTERS.	MORSE.	CONTINENTAL.	BAIN.
A	·—	·—	·—
B	—···	—···	·—·
C	·· ·	—·—·	···
D	—··	—··	··—
E	·	·	·
F	·—·	··—·	·———
G	——·	——·	·—··
H	····	····	·——
I	··	··	··
J	—·—·	·———	···—
K	—·—	—·—	·——·
L	——	·—··	····
M	——	——	·—·—
N	—·	—·	··——
O	· ·	———	——
P	·····	·——·	—·—
Q	··—·	——·—	—·—·
R	· ··	·—·	——·
S	···	···	—··
T	—	—	—···
U	··—	··—	—·
V	···—	···—	———·
W	·——	·——	——··
X	·—··	—··—	—··—
Y	·· ··	—·——	——
Z	··· ·	——··	———
&	· ···		————

NUMERALS.

FIGURES.	MORSE.	CONTINENTAL.	BAIN.
1	·——·	·————	·————
2	··—··	··———	··———
3	···—·	···——	···——
4	····—	····—	····——
5	———	·····	·····
6	······	—····	————·
7	——··	——···	———··
8	—····	———··	——···
9	—··—	————·	—····
0	——	————— or —	——·——

PUNCTUATIONS, ETC.

	Morse.	Continental.		Phillips.
. Period	··——··	·· ·· ··		··——··
: Colon	—·— · ·	———···	*KO*	—·— · ·
:— Colon dash			*KX*	—·— ·—··
; Semicolon	·—·—·	—·—·—·	*SI*	··· ··
, Comma	·—·—	·—·—·—		·—·—
? Interrogation	—··—·	··——··		—··—·
! Exclamation	———·	——··——		———·
- Fraction line	·	——		·
— Dash			*DX*	—·· ·—··
- Hyphen		—····—	*HX*	···· ·—··
' Apostrophe		·————·	*QX*	··—· ·—··
$ Dollars			*SX*	··· ·—··
c Cents			*C*	·· ·
£ Pound sterling		·— ·—··—	*PX*	····· ·—··
/ Shilling mark		···		··— —
d Pence			*D*	—··
Capitalized letter			*CX*	·· · ·—··
: " Colon followed by quotation			*KQ*	—·— ·· —·
. Decimal point		·——		— ·——
¶ Paragraph	————	·—·—··		————
Italics or underline		·—·· ·—··	*UX*	··— ·—··
( ) Parenthesis	·—··—	—·— —·—	*PN*	····· —· ····· —·
[ ] Brackets			*BX*	—··· ·—·· —··· ·—·
" " Quotation marks		·—· ·—·	*QN*	··—· —· ··—· —·
" ' ' " Quotation within a quotation			*QX*	··—· ·—·· ··—· ·—··

employ a code that is a modification of the Morse. The characters that differ from the Morse are the following: *C* -— — - - for -- -; *O* - — - — for - -; *R* - - — - — for - --; and *Z* — — — — for --- -; *underline*, or *italics* —- - - — —- - - —; *bracket*, or *parenthesis* -— - - - -— - - -; *quotation*, -— - — -— - — -— - — -— - —, altered generally to -- -- -- --; quotation within a quotation, "''", -- --. The period, interrogation, and exclamation marks, which are the only other punctuation marks in general use in those colonies, are exactly the same as the Morse. With them, the exclamation mark is generally used to express mirth or laughter.

MORSE CODE.

42. The system of combining dots, dashes, and spaces to represent the letters, numerals, and punctuation marks, as arranged by Vail or Morse or both, is known as the *American Morse*, or more often, simply as the **Morse code.**

THE PHILLIPS PUNCTUATION CODE.

43. The Phillips punctuation code has superseded the Morse for punctuations, and is much more complete and systematic. Except for submarine telegraphy, the Morse code for letters and numerals and the Phillips code for punctuations are used throughout the United States and Canada.

CONTINENTAL CODE.

44. A modification of the Morse code, called the **Continental,** is used all over the world for submarine telegraphy, and for land telegraphy in almost every country except the United States, Canada, and parts of Australia. On account of its extensive use, it is coming to be known

as the *universal* code. The Continental is much superior for signaling through long submarine cables, and, owing to the fact that it has no spaced letters that are apt to be taken for double letters, it is freer from errors of transmission. For instance, with the Morse code, it is very easy for *ee* to be taken for an *o*. On a siphon submarine-cable recorder, it would be practically impossible to avoid such errors. The American, or Morse code, owing to the fact that there are fewer dashes in it, is about 5 per cent. more rapid than the Continental. However, the Continental is preferable for several reasons, and would doubtless have been adopted in this country if the Morse alphabet had not already obtained such a strong foothold among operators. So far, it has been found impossible to get the operators to learn a new code.

By comparing the Morse and the Continental codes, it will be seen that the figure *4* and the following fifteen letters *a*, *b*, *d*, *e*, *g*, *h*, *i*, *k*, *m*, *n*, *s*, *t*, *u*, *v*, and *w* are the same in both; but the numerals, except the figure *4*, the punctuation marks, and the following eleven letters *c*, *f*, *j*, *l*, *o*, *p*, *q*, *r*, *x*, *y*, and *z* are different.

ABBREVIATED AND CIPHER SYSTEMS.

45. Phillips Code of Abbreviations.—Mr. W. P. Phillips's code is a system of abbreviations, or a sort of shorthand applied to telegraphy. It consists of single letters and combinations of two or more letters, which arbitrarily represent figures, words, and whole phrases. Words and phrases that occur most frequently in newspaper reporting are represented by single letters and short combinations of letters; for example

Q means *on the.*
Cj means *coroner's jury.*
Abmn means *abomination.*
C q a s means *closed quiet and steady.*
S c o t u s means *Supreme Court of the United States.*

This code contains several thousand characters or abbreviations, and, to be able to use it to the best advantage, the press operator must memorize as much of it as possible.

Since so many abbreviations are used, it is impossible for the receiver to copy the matter in full as fast as it comes over the wire, and, for this reason, some sort of an ink register is necessary with which to receive the message. Several operators can be kept at work transcribing the despatches from the record on the paper ribbon as fast as it comes in, at the same time making, by some manifold process, a copy for each newspaper interested.

If the student desires to engage in press work, or cares to look further into this subject, which is sometimes called *stenotelegraphy*, he should obtain the complete Phillips code, which is published in book form.

46. A B C Code.—This is a very extensive and complete code, arranged for the use of the public, especially for sending submarine cablegrams. By its use, a long message can be transmitted by means of a few words, and the cost of a cable message, which might otherwise be very expensive, can be made quite reasonable. It is published in book form, and both the sender and receiver must have a copy of the code book, for the telegraph and cable companies will not form or translate the message. By its use, a secret or private code can be very easily arranged, as will be shown presently. Each page in the book is divided into three columns. In the first column are figures from 1 to 99,999, inclusive, in the second column are words or combinations of letters arranged alphabetically, and in the third column are placed the words, phrases, or sentences that the numbers or words in the first or second column represent.

This will be understood better if we take an example. Suppose the body of a message to be cabled is as follows:

Tugs now assisting; we write you full particulars.

In the code book, look up the important words "tugs" and "write." These two words will be found in their

proper places, and the two complete lines containing them, one in each line, are as follows:

14,643	*Turtle*	*Tug (s) now assisting*
15,419	*Worthily*	*I (we) write you full particulars*

The body of the message would then be written by the customer ready for transmission as follows:

Turtle Worthily

The operator would send these two words, and the one to whom the cablegram was addressed would find the meaning by looking up in his code book the two words "turtle" and "worthily." Thus, instead of eight words, only two had to be transmitted and paid for.

47. Cipher A B C Code.—As stated before, any one can, by using this code, arrange a secret and private cipher. To do this, take ten different letters, or, preferably, a *ten-letter word in which the same letter does not occur more than once.* The word "Cumberland" satisfies the two conditions. Number each letter as follows:

c	*u*	*m*	*b*	*e*	*r*	*l*	*a*	*n*	*d*
1	2	3	4	5	6	7	8	9	0

In the first column of the code book, opposite the two phrases "Tug (s) now assisting" and "I (we) write you full particulars," are the two numbers 14,643 and 15,419, respectively. In the word "Cumberland," *c* represents the numeral 1, *u* the numeral 2, *m* the numeral 3, and so on. Thus, the number 14,643 is represented by the group of letters *cbrbm*, and the number 15,419 by *cebcn*. On the message blank, the sender using this cipher code would write, as the body of the message, the two following combinations of letters, for they are not apt to be words:

cbrbm cebcn

These letters would be transmitted by the operator, in groups exactly as written, and the person to whom the message was addressed would first translate it into the two numbers 14,643 and 15,419 by means of the private code word "Cumberland" and the numerals corresponding to each letter in this word. Then, by looking up these numbers in the code book, the correct meaning would be obtained. It is evident that only the parties knowing what numeral corresponded to each letter in the code word could interpret the message.

48. If the code runs up to 99,999, that is, to five figures, each combination of letters transmitted should contain five letters, and, therefore, if the number contains less than five figures, ciphers must be prefixed to make five figures. This is necessary, to avoid the risk of a wrong grouping of the letters by either the sending or receiving operator. For instance, suppose the word "best" were to be sent. In the code book would be found:

1,734	*Becalming*	*Best*

Now, 1,734 has only four figures in it, but five must be used by prefixing a cipher; thus, 01,734 and the corresponding combination of letters to be sent would be *dclmb.*

49. Speed of Telegraphing.—In a telegraph tournament held in New York in May, 1898, the winner in the championship 5-minute sending contest sent 254 words with only one error, and his Morse was said by the judges to be perfect. The highest recorded speed of legible telegraphy, in which the Morse code was used, was made in a previous contest in which 265 words were sent in 5 minutes. An expert operator can send from 35 to 40 words per minute, but a steady working rate of 25 to 30 words per minute is regarded as good.

50. Typewriters.—The typewriter is rapidly coming into general use for writing down the telegraph messages as

the operator receives them from the sounder, and also for transcribing the messages from the receiving ribbon in the Wheatstone automatic system. The operators of the large telegraph companies use it quite extensively, and the expert manipulation of the typewriter by the receiver is almost a necessity in order to secure employment with the press associations.

A good typewriter can easily write from 60 to 70 words per minute; an expert telegraph operator cannot send steadily over about 40 to 45 words per minute; consequently, the receiver has plenty of time, in addition to writing the message, to insert also the "time received," the "operator's sign," etc., even when receiving at the above fast rate. By means of the Phillips abbreviated code system, the speed of transmission may be raised to 65 or 70 words. The receiving operator must also be an expert typewriter, and such operators are frequently called *typotelegraphers*.

51. In the telegraph tournament mentioned in Art. **49**, typewriters were used in a message-receiving contest. The receiving and recording of messages on typewriters under the great speed used in the contest was quite difficult, owing to the rapid shifting of the machine, combined with the necessarily prompt and proper adjustment of the blanks in the typewriter. An operator, who had in another contest shown himself capable of sending 253½ words in 5 minutes, sent 50 messages in 32 minutes 37 seconds. The winner finished first with 20 imperfections. He filled in the month and year in every case and punctuated completely, and his typewriting was of a very superior character.

52. As many as 413 words have been written with a typewriter in 4½ minutes, from dictation. Hence, from what has been stated, it may be seen that to transmit 254 words in 5 minutes by the present method of sending, is a more remarkable feat than to typewrite 413 words in the same time. The telegraph sender is confined to the use of one hand and has to make many strokes to form one complete

letter, while the typewriter receiver has the free use of eight fingers, each one of which makes a complete character or letter with a single stroke. This comparison illustrates the necessity of improving the present method of sending if a further increase of speed for manual transmission is to be obtained.

TELEGRAPH INSTRUMENTS.

TELEGRAPH KEYS.

53. The **key,** as already defined, is an instrument for making and breaking the circuit. It may be well to state that the *down* stroke is often called the *make*, and the *up* stroke, the *break*, referring of course to the making and breaking of the circuit.

54. Bunnell Legless Key.—A form of key very extensively used is shown in Fig. 12. It consists of a steel lever *l* and trunnion, all in one piece, and pivoted in trunnion screws *c*, *c*, which are mounted in standards projecting upwards from the brass plate *m*. Locknuts *c'*, *c'* serve to bind the trunnion screws in any position to which they have

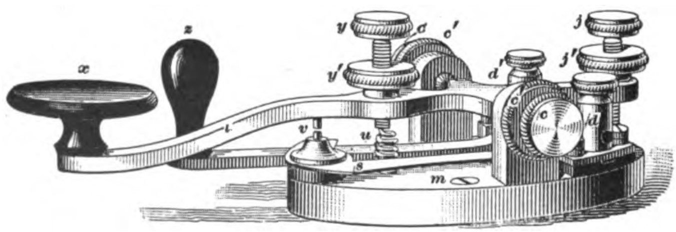


FIG. 12.

been adjusted. A coiled spring *u*, which may be adjusted by the screw *y* and secured by the locknut *y'*, serves to press the forward end of the lever upwards. The upward movement of the forward end of the lever is limited by the screw *j*, and the latter is held securely in position by the locknut *j'*. As the handle, or button *x*, made of insulating

material, is pressed down, a platinum contact point *v*, carried on the under side of the lever, makes contact with a point of similar material carried on, but insulated from, the base *m*. This lower contact point, or anvil, as it is sometimes called, is in metallic connection, by means of a flat strip of metal *s*, with the binding post *d*, which is also insulated from the base plate *m*. The other binding post *d'* is connected directly to the base plate. These binding posts *d* and *d'* form the terminals of the key.

The path through the instrument may be traced as follows: From the binding post *d*, by means of the strip *s*, to the lower contact point; then, when the key is depressed, to the upper contact point *v*, thence by the trunnion, trunnion screws, and spring *u* to the base plate *m*, and to the other binding post *d'*. The switch handle *z* is connected with a metallic arm called the *circuit-closer*, pivoted directly on the base *m*, and, when pressed toward the key lever *l*,

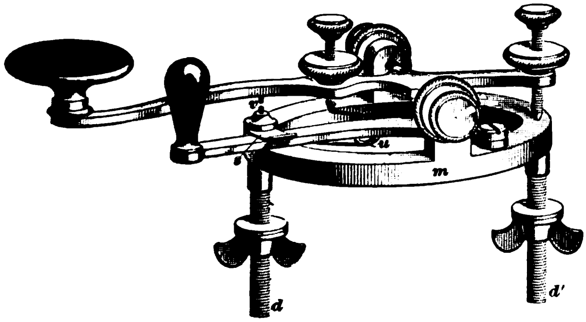


FIG. 13.

makes contact with an extension of the strip *s*, thus short-circuiting the key. This is shown more clearly on the key illustrated in Fig. 13. This circuit-closer will be easily recognized as performing the same functions as the switch *C* in Fig. 8. This key (Fig. 12) is fastened to the table by ordinary screws passing downwards through holes in the base *m* into the table. The key in this figure has a solid base, but this key is now being made with a skeleton base similar to the leg key shown in Fig. 13.

55. Bunnell Leg Key.—This key, shown in Fig. 13, is very similar to the legless key just described. It is fastened to the table by means of two legs, washers, and thumb-screws, in place of ordinary screws. Furthermore, these legs *d* and *d'*, taking the place of the binding posts *d* and *d'* in Fig. 12, form the two terminals of the key. The wires terminating at the key are clamped between the under side of the table and the thumbscrews. The leg *d'* is connected directly to the base, but *d* passes through the base *m*, being insulated from it by hard-rubber bushings, and connects with the projecting strip *s* and the anvil *v*.

56. Victor Key.—The construction of the **Victor key,** shown in Fig. 14, is quite different from any other key. Instead of the trunnion screws used in most keys, there are two relatively long knife-edge bearings at the junction of the light steel lever *l* and the projections *a*, *a'* from the base plate *m*. The spring *u* is adjusted by the screw *y*. The amount of play, that is, the amount of the up-and-down

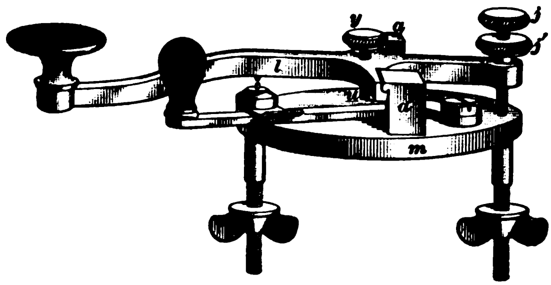


FIG. 14.

motion of the lever, is adjusted by the screw *j* and locked by the nut *j'*. The motion is easy and directly up and down, without any side play. The wear on the knife-edge bearings is quite small, and what little wear there may be is automatically taken up by the spring *u*. It is claimed that this key will work as true after being used for years as when new. The Western Electric Company now owns the patents on Victor telegraph instruments.

57. Western Electric Key.—This key is shown in Fig. 15. In this key, the upper platinum point is fastened to the end of the screw *p*, which passes through the lever *r*,

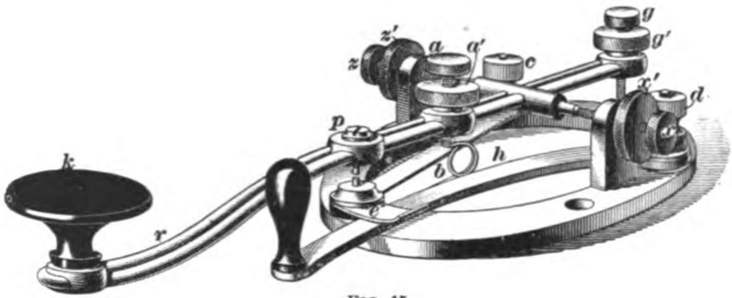


FIG. 15.

so that, if ever necessary, this screw with the platinum contact can be removed and replaced without disturbing the key.

58. Remarks Concerning Keys.—The tendency in this country has been towards a light but strong key. An operator should use a key suited to his style of operating, because by so doing he may be able to increase his speed considerably. The contacts on most good keys are made of platinum, because of the ability of that metal to resist, better than most other metals, the corroding and fusing action of the electric arc that is always formed at the break. When a key, on rising, does not break the circuit, it is said to "stick." The sticking of a key may be due to one of several causes. The principal cause is the fusing action of the electric spark at the contact points, but it may be caused by metallic dust collecting on and bridging over the contact points, or by an improper adjustment that causes the points to come together improperly and bind. The contact points should be kept clean by drawing between them a piece of hard clean paper or fine emery cloth, or they may even be rubbed very gently with a very fine file and then wiped clean. Frequent use of the file should, however, be avoided. Other troubles are often mistaken by an inexperienced operator for a sticking

key. Dirty relay points, for instance, would act in exactly the same manner as far as the effect on the sounder or register is concerned. In such a case, the relay contacts should be cleaned with fine emery paper. Pivot screws often cause trouble from being loose, and, to prevent this trouble, they should be kept as tight as is consistent with a free and easy movement of the key. The legs on leg keys should be 2 inches long, having 40 well-cut threads to the inch, with a thumbscrew and two washers for each leg.

TELEGRAPH RELAYS.

59. The **relay** consists of an electromagnet that, by its action on an armature, opens and closes the circuit of a local battery powerful enough to operate a sounder or register. The magnet is generally wound with a large number of turns of insulated copper wire in order to enable the feeble line current usually employed to produce in the cores a magnetization sufficient to attract the armature. But, in order to get the large number of turns necessary in the space allowed, fine wire must be used, and hence the relay will usually have a resistance high in comparison with that of a local sounder.

60. Bunnell Relay.—The main-line relay manufactured by Bunnell & Company is shown in Fig. 16. The electromagnet consists of two soft-iron cores on which are the coils p, p', the cores being connected together at the rear by a soft-iron yoke piece. To this yoke piece is attached one end of the screw b, by means of which the electromagnet can be moved backwards or forwards. This screw b is supported by the pillar k. The cores of the electromagnet are arranged to slide easily through the coils and the supporting frame f, which is securely fastened to the wooden base. This piece f also carries the adjusting stop-screws e and d and their locking nuts e' and d'. The armature and lever is made out of one piece of soft iron. It is pivoted between trunnion screws supported by the brass piece g, which is

fastened to the wooden base, but insulated by the wooden base from the piece *f*. The trunnion screws are provided with locknuts, so that, after being once adjusted, they can be securely locked in place. To the armature *a* is attached one end of the retracting spring *s*, to the other end of which is fastened one end of a piece of silk cord, the other end of the cord being fastened and wrapped around the adjusting screw *h*. This screw *h* passes through one end of the rod *r*, which slides easily through the pillar *o*, but is secured in any position by the setscrew *c*. By turning the screw *h*, the thread is wound or unwound, increasing or decreasing, respectively, the pull of the spring *s* on the armature.

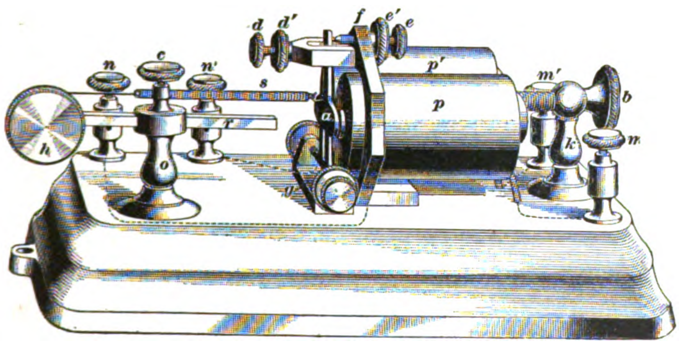


FIG. 16.

When the thread is all wound up and the end of the spring reaches the screw, the screw and rod *r* should be moved out away from the armature. The spring must never be wound up around the screw. Many springs are spoiled by doing this. The front stop-screw *e* should be so fixed that, when the armature is against it, there is at least the thickness of a piece of ordinary writing paper between the iron armature and iron cores. The back stop-screw *d* should be adjusted so that the armature shall not have over $\frac{1}{32}$ inch play. The tip of the back stop-screw contains a piece of hard rubber or other insulating material, so that the armature cannot close the local circuit through the screw *d* to the frame *f*.

a one-piece iron armature and lever, adjustable front and back stop-screws with locknuts, an arrangement for adjusting the armature retracting spring, and a mahogany-wood base with a metal rim. This relay is 6½ inches long by 3½ inches wide. The rear stop-screw *c* has an insulating end made of hard rubber, the front stop-screw *b* is tipped with platinum, as is also that side of the armature which makes and breaks contact with the front stop.

Although it has not so many adjustments as the regular main-line relay, still those it has are usually sufficient. These relays are used for private telegraph lines, and may be obtained wound as high as 100 ohms, but they are more generally wound to have resistances of 20, 40, and 75 ohms. A 100-ohm pony relay is suitable for a line 50 to 75 miles long

63. Remarks on Relays.—The contact points, between which the circuit is made and broken, should be made of platinum, in order to resist the corroding and fusing action of the electric arc that is always formed when the contact points separate and break the current. The contact screw next to the coils at which the circuit is opened and closed is called the *front stop;* the other screw, against which the armature is pulled by the retracting spring when no current flows through the relay coils, is called the *back stop.* The point of the rear, or back, stop-screw is made of insulating material, or else the whole screw must be insulated from the supporting frame.

The armature and lever, that is, the entire moving part of a relay, should be made as light in weight as is consistent with the rigidity required, in order to make its inertia as small as possible. The less inertia possessed by the moving parts, the more promptly will the circuit be opened and closed, causing the signals to be made more distinctly and with less danger of their running together when the current is feeble or the speed of transmission especially rapid. Some armature levers are made light in weight by making both the lever and the armature out of one piece of iron, using a

good quality of soft iron, and no more of it than is absolutely necessary. On account of its extreme light weight, aluminum is replacing brass for the levers of relays that are made with an iron armature fastened to a lever of other metal.

64. Adjustment of Relays. — The front and back stops must be adjusted so that the armature of the relay shall not move more than $\frac{1}{32}$ inch; and, when the movement of the lever is very feeble, the distance should be made as small as possible. Under ordinary circumstances, this adjustment scarcely ever needs alteration after it has once been made correctly. The armature should never touch the iron cores; otherwise, it will stick against them when the current is broken, on account of the residual magnetism remaining in the cores. There should always be room enough between the iron armature and the cores to insert one thickness of ordinary writing paper.

To adjust a new relay, screw the magnet cores almost as far forward as they will go; adjust the front contact screw so that when the armature is against it there shall be the thickness of an ordinary piece of writing paper between the armature and the cores; adjust the back stop-screw to allow the armature a play not to exceed $\frac{1}{32}$ inch; and, finally, adjust the spring so that the normal current, when sent through the coils, will promptly pull the armature against the front stop, and so that the spring will as promptly pull the armature away when the current ceases. It will be necessary to readjust the position of the iron cores and the tension of the spring from time to time as the current strength varies.

65. Effect of Leakage on the Adjustment.—During wet weather, on badly working wires, a relay often remains still when a distant office is sending, and it is necessary in such cases to adjust high, that is, to move the cores farther back or to make the tension of the spring high or strong, or both, in order to get signals from such stations.

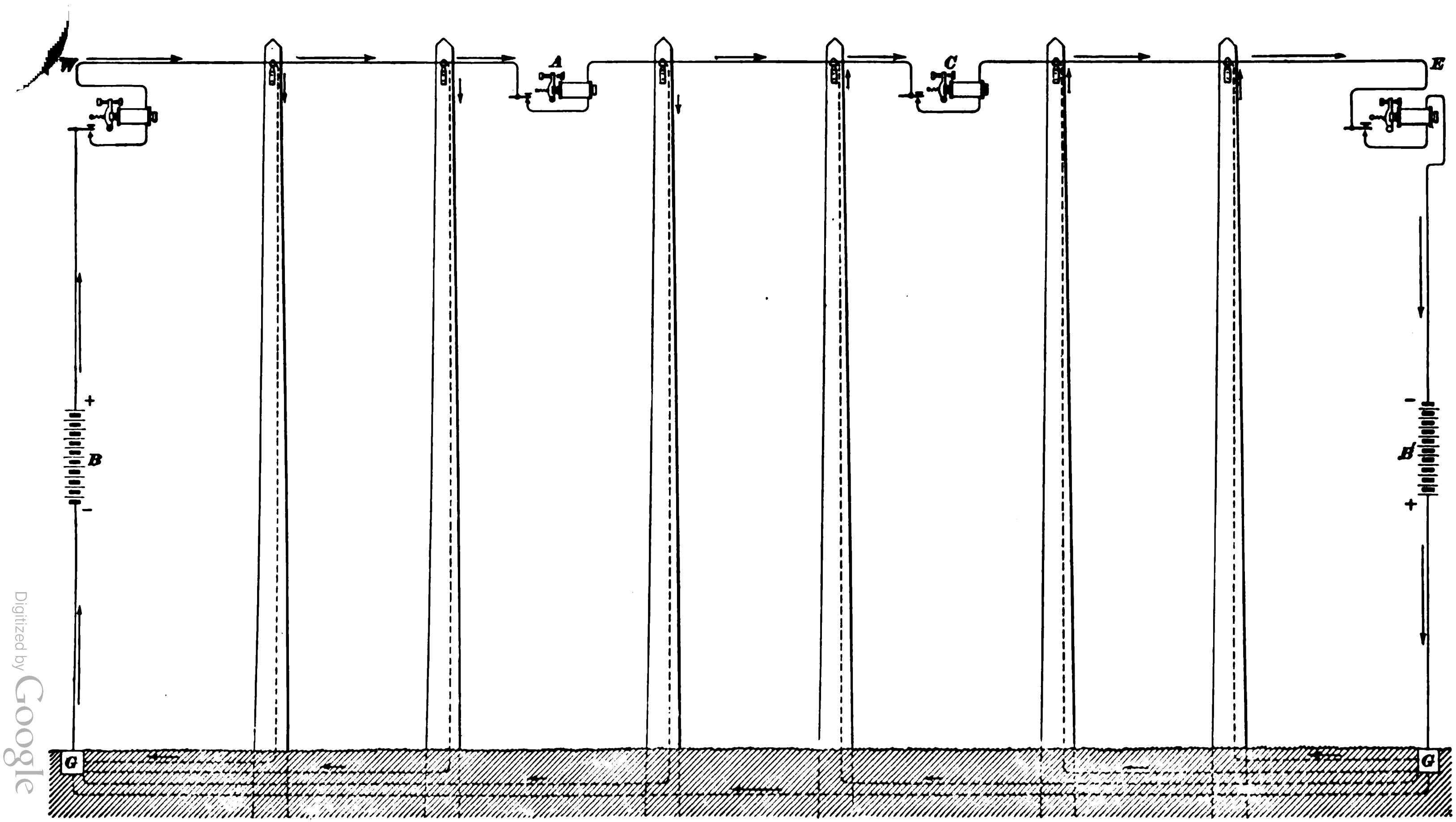


FIG. 19.

Especially is this so on lines on which the battery is divided, part of it being at each end. As most long lines are so arranged, it may occur quite frequently on them. It is caused by the leaking or escaping of current from the wire through the insulators and poles that are between the sending office and the office where the relay fails to respond. In rainy weather, this leakage may be considerable, and it may act the same as if some intermediate office had grounded the wire. In Fig. 19, let *W* and *E* represent terminal offices, and *A* and *C* intermediate offices on a long line having half the total number of cells at each end. The dotted lines represent the paths down the poles to the ground and back to the batteries along which the leakage currents flow, and the arrows indicate the direction in which the current flows. Now, if the leakage is very bad, very little of the total current from the battery *B* will reach *C*, and less still will reach station *E*. Similarly, very little current from *B'* will reach *A*, and still less will reach *W*. However, the current flowing from both the batteries *B* and *B'* through the relays at *W* and *E* will be stronger than if there were less or no leakage. The current through *A* and *C* will be smaller, and perhaps much smaller than the current at either *W* or *E*. The relative values of the currents along the various paths, when all the keys are closed, are shown approximately by the lengths of the arrows.

Under the conditions represented in the figure, the operation of the key at *E* will cause the relay at *E* to work vigorously, the relay at *C* less vigorously, that at *A* still less vigorously, and the relay at *W* even less vigorously than the one at *A*. The same thing will happen in the reverse direction when the key at *W* is operated. When an intermediate key is operated, only a part of the current that flows through one end relay is interrupted, and the relay at one end, as *W*, will respond less and less vigorously the farther off the sending office is from the end *W*. When a key far distant from *W* is open, the current at *W* may still be sufficient to make the relay hold its armature if the adjusting spring is at its usual tension.

This effect on a relay can evidently occur in either direction when a battery is placed at both ends, but only in one direction when the battery is all at one end. If there is a battery at one end only, then opening a key at any office will cut off all the current, whether it is large or small, from the entire line on the side of the key away from the battery, and the armatures of all relays beyond will be released. Sometimes, therefore, on hard-working lines, where there is much escape on account of a rain storm, it is advantageous to take the battery off at one end, ground that end, and work with a battery at one end only.

66. To Determine in Wet Weather if the Line Is in Use.—The key should never be opened, in order to call an office on an apparently idle circuit during wet weather, until it has been ascertained whether another office is using the wire. The relay may be out of adjustment and, therefore, may fail to indicate that the line is in use. The best way to determine whether some one is using the wire, is to place your finger lightly on the armature lever of the relay and gently move it away from the contact point. that is, away from the cores of the magnet. If some one is sending, the signals will be at once heard or felt by the finger.

67. To Adjust the Relay in Wet Weather.—If it is evident from the method given in the preceding article that some one on the line is sending, and you wish to receive the message, then screw the magnet cores away from the armature until the relay stands open. Now, turn down or weaken the retractile spring until the signals can be easily read. Care should be taken not to weaken the spring too much, for the signals may be shut out entirely. In rainy weather, it is much better to move the magnet away from the armature than to make the retractile spring too stiff. A weak spring is more sensitive than a stiff one. Whenever possible, the relay should be adjusted for the most distant office on the circuit, because, as a rule, it will then be adjusted for all intervening stations.

TELEGRAPH SOUNDERS.

68. A **sounder** must produce a clear, loud click, and, in order to accomplish this, a strong electromagnet is necessary. The moving armature and lever are usually quite massive compared with the similar parts of a relay. The object of using a sounder is to obtain a louder and clearer click than can be obtained with a relay. Sounders are made in a variety of forms, but all are the same in principle. The one to be employed in any particular instance will depend on circumstances. Some operators can more readily distinguish a light sound than a heavier one, and *vice versa*.

69. Bunnell Sounder.—The Bunnell sounder is shown in Fig. 20. It consists of an electromagnet, over the two iron cores of which are wound the coils *m* and *m'*, and an armature *a* of soft iron, the latter mounted on a brass or aluminum lever *l*, which is pivoted between the trunnion

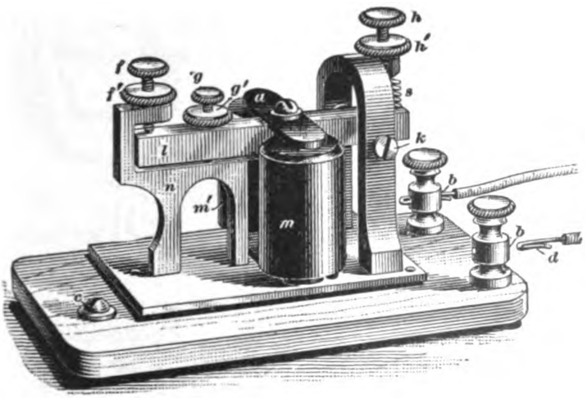


FIG. 20.

screws *k*. The armature is normally held in its upper position by means of the compression spring *s*, which bears down on the short end of the lever *l*, the compression of the spring being regulated by the thumbscrew *h* and locked, after adjustment, by the locknut *h'*. The down stroke of the lever is limited by the lower end of the screw *g* striking against the anvil *n*, and the up stroke by the lever striking

against the lower end of the screw *f*. The play of the armature can therefore be adjusted by means of the screws *f* and *g*, and, after the proper adjustment is obtained, it can be made permanent by the locknuts *f'* and *g'*. The binding posts *b*, *b* form the terminals of the circuit through the coils, the current passing through them in series so as to make the upper pole of one iron core have north polarity and the upper pole of the other core have south polarity. The sounds given out by the sounder may be augmented by mounting the instrument on a sounding board. The metal plate and the wooden base are usually constructed with this idea in view, and, for this reason, are slightly separated. The coils are covered and protected by a polished hard-rubber casing.

70. Improved Bunnell Sounder.—This sounder, shown in Fig. 21, is in many respects exactly like that shown in Fig. 20. In this improved sounder, the usual metallic resonator plate *c* is supported at three points, only two of which can be seen in the figure, on a second resonator

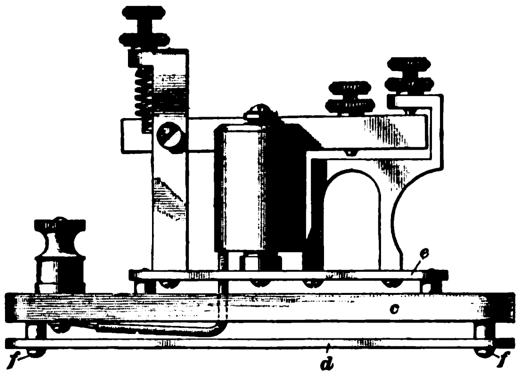


FIG. 21.

plate *c* made of thin wood, not over $\frac{3}{8}$ inch thick. This wooden plate, which is very thin and sonorous, is supported and protected by a second base plate *d* of metal, preferably of aluminum, because the latter is light. This aluminum plate, which carries the weight of the entire instrument, is

supported on three points, but only two *f*, *f* can be seen in the figure. The object of this construction is to increase the sonorous effect and to protect the thin wooden base.

71. Western Electric Sounder. — This sounder, shown in Fig. 22, is made by the Western Electric Company and is extensively used by the Western Union and other telegraph companies. It has a retractile spring instead of a compression spring as used in the Bunnell sounders. The

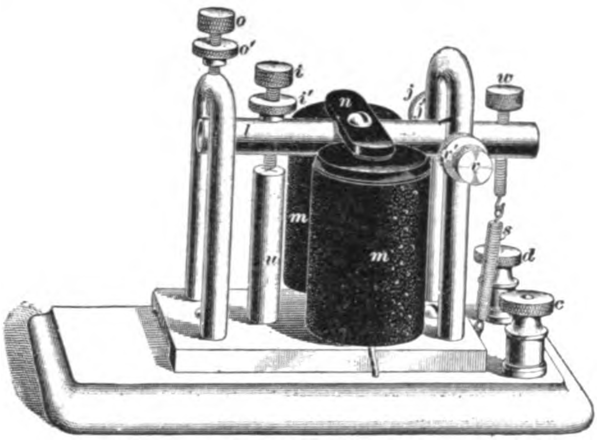


FIG. 22.

tension of this spring *s* is adjusted by the screw *w*. The lever *l* and the upright pieces are made of brass tubing, and the coils *m*, *m* are covered and protected, as is usual in all well-made telegraph instruments, by a polished hard-rubber casing.

72. A sounder much used on railway lines is shown in Fig. 23. It gives a loud sound that makes it suitable for railway stations and other places where external disturbing noises are apt to interfere with the sound of the instrument. The armature lever is quite massive, and, in its downward motion, strikes upon the hollow bridge-shaped piece *b*, and the original sound thus produced is reenforced, owing to the fact that the metal base *a* is mounted on the wooden base

so as to leave a small air space between the two, the combination acting as a sounding box. The retractile spring and the screws for adjusting it are shown in the figure.

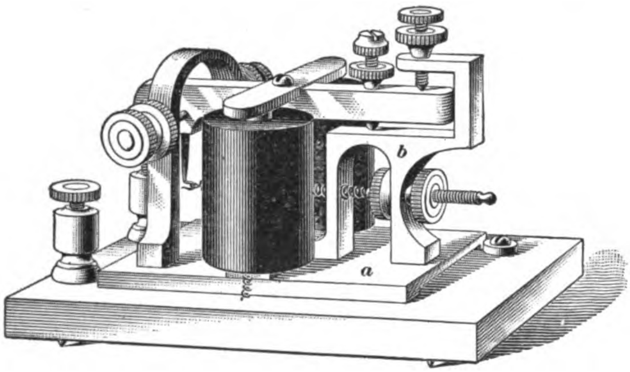


FIG. 23.

73. Resonators for Sounders.—A **resonator** is a hollow box or case that greatly increases and *concentrates in one direction* the sound made by a sounder placed within it, so that an operator at one desk is not disturbed by sounders at other desks, and can hear his own sounder in spite of the noise made by the typewriters all around him. Resonators of various forms are quite extensively employed, especially in large telegraph offices.

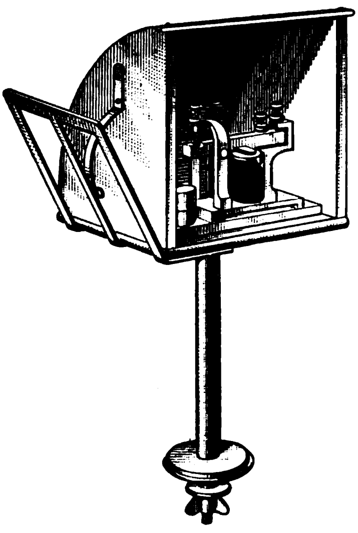


FIG. 24.

The adjustable resonator called the *Jones*, which is illustrated in Fig. 24, is the kind used by the Postal Telegraph Company. The shape of the resonator is clearly shown in the figure. The tops, or hoods, of the

resonators of this type that are installed in the New York office of the Postal Telegraph Company are removable and have a play of half a circle. The top is made of a hard fiber, the frame being of hardwood. They are fastened to the table by means of a wing nut or thumbscrew underneath the table. The metal being separated from the table by soft-rubber washers on each side of the hole and a soft-rubber bushing in the hole, no vibration passes from the sounder to the table. The resonator with the sounder encased in it may be turned, after being secured to the table, to the right or left, to suit the convenience of the receiving operator. The wires connecting with the sounder pass through the hollow supporting stem. On one side of the resonator is a clip for holding the blanks upon which the messages are written.

74. Remarks Concerning Sounders. — Sounders should be firmly screwed down to the table. Aluminum is coming more and more into use for various parts of sounders, relays, and other telegraph instruments, especially for the moving portions of the levers that do not have to be made of iron. When the sounder is used with gravity cells, in a local circuit controlled by a relay, it is generally wound to have a resistance of 4 ohms, and to 20 or 40 ohms when it is put directly in series with the main-line circuit, in which case it is called a *main-line sounder*. The size of wire and strength of current used for various sounders will be found in Arts. **114** and **115**.

75. Adjusting Sounders.—The sounder has three adjustments: one by which the distance of the armature from the magnet cores is regulated, one by which the play of the armature lever is regulated, and one that determines the degree of tension of the retractile spring. To adjust a sounder, the armature lever should be made to work easily and yet snugly on its pivots, which are then locked by their locknuts. Then, the screw limiting the downward movement should be adjusted and locked by its setscrew so that

there is room enough between the armature and the cores to pass one thickness of ordinary writing paper. The armature must never touch the cores, for, if it does, it is liable to stick on account of the residual magnetism left in the cores when the current is broken. The screw limiting the up stroke is then adjusted and locked by its setscrew, so as to give the proper length of stroke, which is about $\frac{1}{16}$ inch. Finally, the spring is adjusted so that when the current is interrupted the lever is pulled promptly back against its back stop-screw.

If the action of the magnet is very strong and the armature does not move away promptly when released, the tension of the spring must be increased. It may be necessary to screw up the front, or downward, limiting screw a little, in order to prevent the armature from coming so near the cores when attracted.

76. When the sounder is once properly adjusted and gives a satisfactory sound, it should be let alone. If it has worked well for a long time, but at length, in consequence of residual magnetism in the cores, the armature is not properly released when the current is interrupted, the wires coming to its binding posts should be reversed, thus reversing the magnetism. When the signals on the sounder are confused, evidence is given that the relay needs adjustment. In this case, the cores of the relay magnets should be moved nearer the armature when the current through the relay is feeble, and farther away when it is strong.

77. In a case where the sounder does not act, while the relay responds to a current in the line, there is some fault in the local circuit. The relay points should be closed with the fingers; if the sounder still does not respond, the condition of the relay points and the connections should be carefully looked after, and the electromotive force of the local batteries tested with a millivoltmeter, or it should be otherwise ascertained if they come up to the standard requirements. If the batteries and relay points are all right and

the sounder cannot now be made to respond by closing the relay points, the trouble is in the magnets of the sounder, in a bad joint, broken wire, or loose binding post. The binding posts of all instruments should be gone over frequently and regularly to insure that none of them are loose.

COMBINATION SETS.

78. Pocket Relay.—This instrument, shown in Fig. 25, is really a main-line sounding relay and key, made in a very compact and convenient form for carrying in the pocket. It generally has a case for enclosing the whole instrument when not in use. It is about 6 inches long, 3 inches wide, and 2½ inches deep. It has all the adjustments of a relay, and gives a sufficiently loud sound

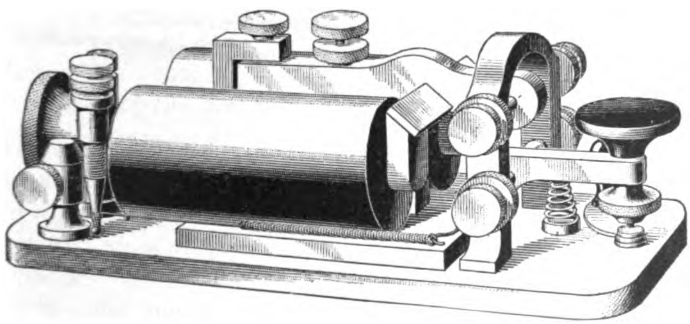


FIG. 25.

for the temporary use for which it is intended. It has two binding posts by which it can be connected directly in series with the line wire. The construction is sufficiently well shown in the figure to need no further description. It is used for testing out on the road when repairing breaks and crosses, and also by the railroad companies in establishing a temporary office at a point where an accident has blocked the track.

79. Box Relay.—In Fig. 26 is shown a so-called **sounding-box relay.** A regular main-line relay magnet

is enclosed in a rectangular box made of thin wood; the box, acting as a resonator, causes the relay to give forth sounds clear and loud enough to be read without requiring the use of a local sounder. However, contacts, connections, and binding posts are provided so that a local sounder can be connected in and used with it. The ends of the iron cores project slightly and slide easily through holes in the left-hand end of the box cover, and their position may be adjusted, forwards and backwards, as in a main-line

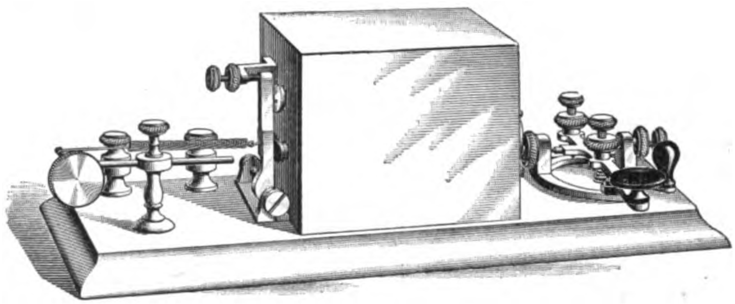


FIG. 26.

relay, by a thumbscrew projecting through the right-hand end of the box. This screw cannot be seen in the figure. The relay has all the adjustments of a regular main-line instrument. There is a key mounted on the same base with the relay. The key and relay are permanently connected together by wires in grooves on the under side of the wooden base. This combination set is used by linemen when making repairs and tests on the road where local batteries for operating a regular sounder cannot always be obtained, and for much the same purposes as the pocket relay.

80. Army Field Telegraph Set.—In Fig. 27 is shown a main-line sounding relay and a key mounted on one base, in a very compact manner, making the set very suitable for field telegraph work. This form has been used by the United States Army Telegraph Service since May, 1898. The magnets are full size, and the coils may

be wound to have any resistance, even as high as 300 ohms. The sounder has the wooden and aluminum resonator base that was described in connection with Fig. 21, and a nickel-plated carrying case. The outside dimensions (with the

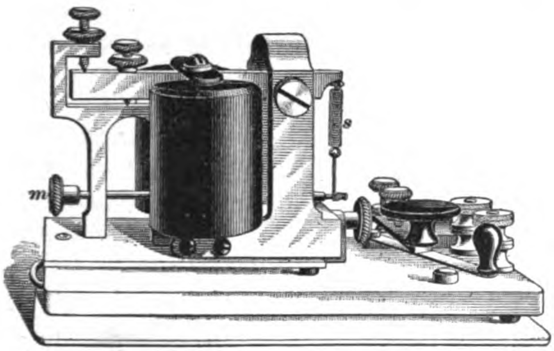


FIG. 27.

case on) are 6 inches long, 3⅛ inches wide, and 4 inches deep. The tension on the retractile spring *s* is regulated by means of the thumbscrew *m* in a manner clearly shown in the figure.

81. Embossing Register.—This is an instrument for automatically recording the signals by impressions produced on a paper ribbon. The principal parts of an

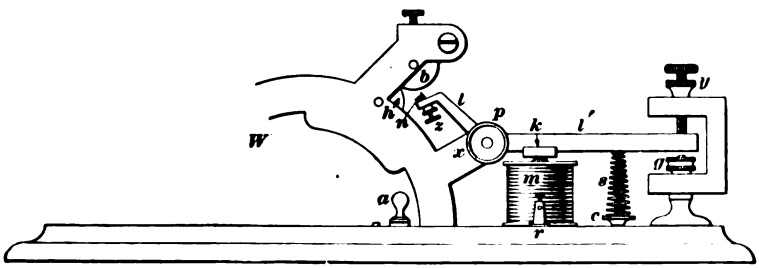


FIG. 28.

embossing register are shown in Fig. 28. Its action is similar to the sounder, as will be seen. A current passing through the magnet coils *m*, only one of which can be seen

in the figure, causes the armature *k*, which is fastened to the lever *l'*, to be attracted. The travel of the lever *l'* is limited by the adjustable screws *g* and *y*. When no current passes through the magnet coils, the compression spring *s* forces up the lever *l'* and the armature *k*. The lever *l'* is pivoted by an arbor at *p*, and carries at the end of *l* a steel point or style *n*. The arbor and style may be adjusted by screws *x* and *z*, respectively. The style *n* presses against the roller *b* when a current is flowing through the coils of the magnet. A strip of paper passes between the rollers *h* and *b* and covers a slight groove cut around the roller *b*. The style *n* is adjusted just over this groove. One end of the line wire is connected to a binding post *r*, while the other end is connected to a binding post hidden from view back of *m*. The current passes through the two coils as in a sounder. When a key is closed at a distant station, a current flows through *m*, the armature *k* is attracted, and the style *n* makes a raised impression on the paper. These impressions form dots and dashes, depending on the length of time that the key is depressed. When the circuit is open, the style is forced away from the paper by the action of spring *s*, which is adjusted by screw *c*. The rollers *b* and *h* are moved by clockwork at *W*, which is started and stopped by a brake controlled at *a*. In the figure, the clockwork used to draw the paper between the rollers *b* and *h* is omitted. The old-style registers had the clockwork operated by a weight.

82. Modern Embossing Register.—This register is now made with both single- and double-registering devices. A modern single-pen embossing register is shown in Fig. 29. As much of the apparatus as possible is protected from dust and dirt by being placed in a case of brass and glass. Even the pivots in the sides of the brass case are covered, to keep out the dust. *h* is the handle for winding up the clockwork, which is driven by a coiled spring. The clockwork, by means of rollers that are not all shown in the figure, draws the paper along past the embossing style, or pen. There is

a slight groove in the roller immediately opposite the steel-pointed style, causing the style, when the armature is attracted, to press the paper into the groove, thus forming embossed characters on the paper as it is being drawn along between the style and the roller. When the armature *a* is attracted by the magnet, the bell-crank lever *l*, to which the armature *a* is fastened, communicates the motion to the

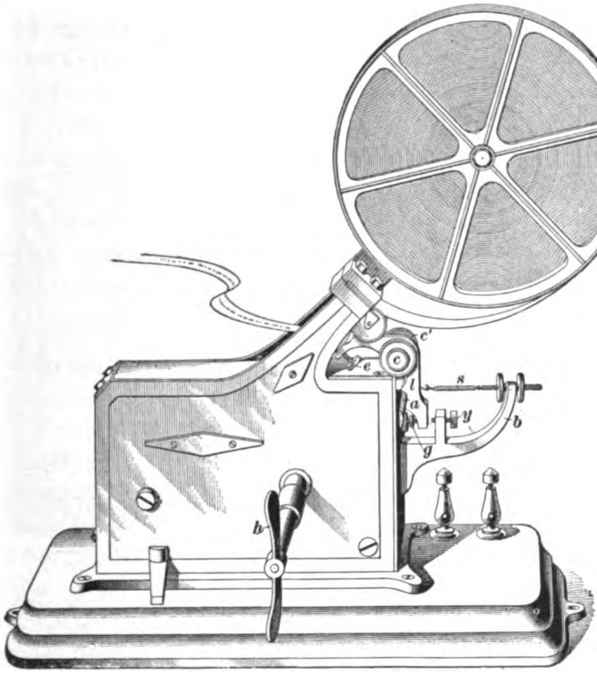


FIG. 29.

style. The armature lever *l* is pivoted by means of the trunnion screws *c*, *c'*. The tension of the retracting spring *s* is adjusted by the screws at the end of the projecting arm *b*. The range of motion of the armature lever is adjusted by the front and back stop-screws *g* and *y*, respectively. The steel-pointed style is adjusted by the screw *e*. This register is so similar in principle to the one already described that it is unnecessary to say more about it.

Registers are usually connected in a local circuit and controlled by a relay in the same way as a sounder. In this case, it is wound to have a resistance of 4 ohms, with a wire .027 inch in diameter, which is between a No. 21 and No. 22 B. & S. gauge.

83. The **double-embossing register** is exactly the same as the single register, except that there are two electromagnets, two armature levers, two styles, etc. alongside one another, but only one clockwork, one case, one paper ribbon, and reel, all being mounted on one base. It is really two independent and separate instruments, but the cost of one clock, case, and reel is saved. These registers are now provided with self-starting and self-stopping devices, which will be described in connection with the ink register. The embossing register is used in the district-telegraph-messenger and fire-alarm systems, and somewhat in district and small offices, but is being superseded by the ink register.

84. Ink-Recording Register.—The **ink-recording register** is preferable to the embossing register because its record is much more easily read. It is used quite extensively in small offices and wherever a permanent record is desirable. One is shown in Fig. 30. As much of the apparatus as possible, including the clockwork, is placed inside a case made of brass and glass, the whole being mounted substantially on a wood-and-iron-rimmed base.

When a current flowing through the magnet coils causes the armature to be attracted, the armature lever, carrying the paper with it, moves up against the disk *e*, which is kept moistened with ink by an ink roller *n*. When the current ceases, the spring *s* draws the armature lever and paper away from the disk or printing wheel *e*, as it is called. The ink roller *n* is lightly pressed against the disk *e* by the spring *c*. The paper *p p* passes through a guide on the armature lever just under the ink disk *e* and then between two rollers *a* and *r*, the rotation of which pulls the paper along. The rollers *a*, *r*, *n*, and the disk *e* are kept rotating by the clockwork as long as signals are coming in over the

line. Whenever necessary, the clock spring is wound up by the handle *H*. While receiving a message, the armature lever causes the paper to be alternately pressed up against and withdrawn from the disk *e*. By this operation, a long

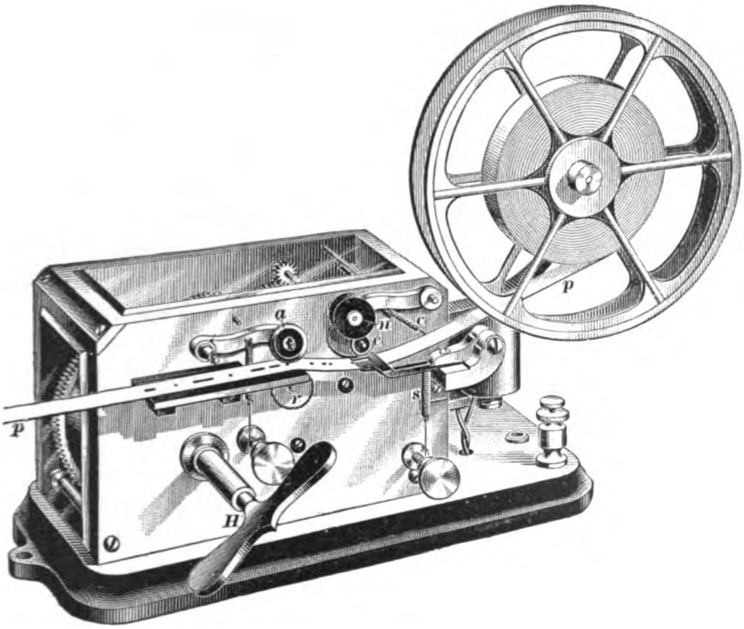


FIG. 30.

or short mark is made on the paper, according to the duration of the contact between the disk and the paper.

When used in a local circuit, the magnet coils of an ink register are wound, like the embossing register mentioned in Art. **82**, to have a resistance of about 4 ohms.

85. Self-Starting Device for Registers.—Embossing and ink registers now have automatic self-starting and self-stopping devices. Fig. 31 shows only the escapement and the self-starting and stopping mechanism of a register controlled by the Western Electric Company. *g* is a pallet rod fastened to the same axis *p* as the pallet *n*. The clockwork tends to revolve the escapement wheel *e* and to

make the pallet *n* and the pallet rod *g* vibrate. *m* is a stop-arm, pivoted on the frame at *d*. It prevents the vibrating of the pallet rod *g* whenever it comes in line with the latter, and consequently stops the clockwork. On the wheel *e* is a worm *h*, into the thread of which the forward end of the arm *c* normally rests. The rear end of *c* is fastened rigidly to the piece *o*, from which projects the pin *b*. A spring *l* tends to push the piece *o* and with it the arm *c* over to the left whenever the forward end of *c* is lifted out of the worm *h*, thus tending to move the stop-arm *m* out of the path of the pallet rod *g*. When the armature *a* is attracted, the arm *k* strikes the pin *b* and lifts the piece *o*, thus raising the forward end of *c* out of the worm-thread. The spring *l* immediately forces the arm *c* and the piece *o* over toward the left, thus moving the stop-arm *m* out of the path of the pallet rod *g*. The forward end of *c* then drops into the extreme left-hand end of the worm *h*, leaving *g* and *n* free to vibrate until the worm has revolved sufficiently to again bring *m* into line with *g*. When a message is being received, the arm *k* keeps continually striking the pin *b* before the stop-arm *m* can get back in the way of the pallet rod *g*. The clockwork feeds out the paper while a message is being received, but stops when the signals have ceased long enough to allow *m* to get in the way of *g*. Thus, little or no paper is wasted.

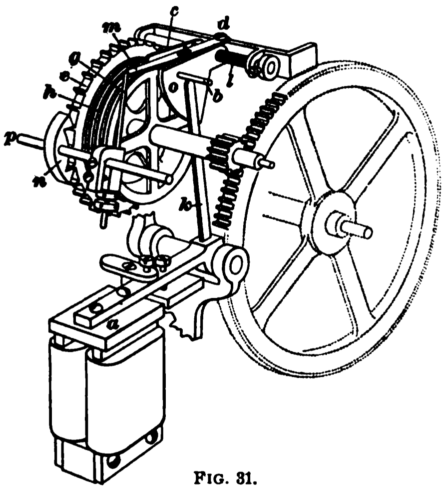


FIG. 31.

86. Adjusting Registers.—All adjustments required for a sounder are also necessary for a register, and, in

addition, there is the regulation of the rollers that draw the paper along and the adjustment of the style or ink roller. The length of stroke, the distance of the armature from the cores, and the spring are adjusted exactly in the same manner as for a sounder.

After making these adjustments, locate the pen point of the embossing register in the following manner: Close the local circuit and let the register run; at the same time, screw up the style until it makes a good, clear impression on the paper; then secure it in this position by tightening up the locknut. When the circuit is open, the limit screw must be so adjusted as to allow the style to just clear the paper. A paper running crooked indicates that the rollers on one side press together more tightly than on the other, and the side that carries the paper the faster should be loosened a little. Loose pivots will cause irregular dashes, sometimes too deep and again not deep enough; consequently, the pivots should be kept reasonably tight.

As in the case of a sounder, there is a fault in the local circuit when the register does not respond to the movements of the relay armature. It is very likely due to dirty relay points, a loose connection, or a weak local battery. While a register should be kept clean, it should never be taken apart out of curiosity. This remark applies to all instruments. Most of the troubles of young operators are the result of unnecessary tinkering with the instruments.

TELEGRAPH ELECTROMAGNETS.

87. Fig. 32 is a representation of an electromagnet, showing the relative size of the various parts of a type of magnet largely employed in the most successful American telegraph instruments. This electromagnet consists of the following parts: The cores *C*, *C*, cylindrical in form, and around which the coils of insulated copper wire are wound; a rectangular yoke piece *E*, which unites the two cores; and

the rectangular armature A, which is movable and forms a

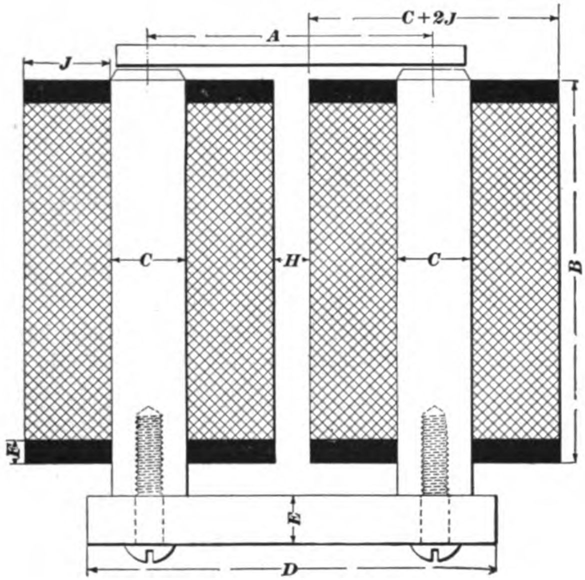


FIG. 32.

very important part of the magnetic circuit. The magnetism shows its presence by attracting this armature.

MAGNETIC CIRCUIT OF TELEGRAPH INSTRUMENTS.

88. With a given number of ampere-turns, the strength of an electromagnet can be increased by decreasing the magnetic reluctance of the magnetic circuit. This reluctance can be decreased by decreasing the length of the magnetic circuit and by increasing the cross-section of both the iron and the air gap, and by using iron having a higher permeability. It is better to make the path of the lines of force short rather than to increase the cross-section of the iron, because the shorter a magnet of given strength, the quicker it will magnetize and demagnetize, and this is very desirable indeed in electromagnets for telegraph instruments.

To aid in reducing the reluctance, the cores and the yoke piece should fit together nicely and as tight as possible, and the air gap between the cores and the moving armature should be as short as the use for which the magnet is designed will allow. The reluctance of the air gaps between the two cores and the armature, especially when the armature is at its greatest distance from the cores, is much greater than that of all the rest of the circuit, so that the length of the cores will have, in telegraph magnets, little effect on the total reluctance of the circuit. The cores are made as short and as small in diameter as practicable, almost regardless of the effect on the reluctance, in order to make the magnet quick-acting. The cores must be long enough, of course, to hold the necessary number of turns; and the cross-section of the cores must be great enough to allow the given number of ampere-turns to set up enough lines of force to attract the armature, and without bringing the iron anywhere near its magnetic saturation point.

89. Residual Magnetism.—When a mass of soft iron in a coil of wire is magnetized by passing a current through the coil, an appreciable time elapses after the circuit is first closed before the iron reaches the maximum state of magnetization that the current in the surrounding coil is capable of producing. And, when the current is stopped, the iron does not lose its magnetism instantly. Furthermore, the iron will retain some of its magnetism for a more or less indefinite length of time, depending on the magnetic quality of the iron. This is termed **remanent,** or, more properly, **residual, magnetism.** This residual magnetism is a result of magnetic hysteresis. The larger the magnetic hysteresis in iron, the more persistently does it hold on to its residual magnetism. An iron that has a large hysteresis factor may retain but very little magnetism, but it holds on to whatever amount it does have with a great deal of force, and may require severe treatment to remove it. The tenacity with which it holds on to its residual magnetism is called its **coercive force.** Coercive force may also be defined as the

amount of negative, or opposing, magnetizing force that is required to reduce the residual magnetism to zero.

On the other hand, soft irons, in which the hysteresis is very small, may, if very carefully and properly handled, be made to retain considerable magnetism, but the slightest jar or touch will remove it entirely, so that not even the slightest trace is left. Its coercive force is very small. To secure quickness of action and freedom from residual magnetism, the very best quality of soft iron, i. e., with the highest permeability and lowest coercive force, should be used. Under ordinary usage in a telegraph instrument, very good soft iron loses all its magnetism almost instantly when the magnetizing force is removed.

90. There are some brands of cold-blast charcoal iron, such as Norwegian, Swedish, and a Lowmoor iron, that, when carefully annealed, show scarcely a trace of residual magnetism, and these brands are therefore preferred in the manufacture of magnet cores. After annealing, it is very important that the iron be left black and that no attempt be made to brighten it up. If it is filed, or touched ever so lightly with a tool of any kind, it will be slightly hardened, and will certainly show traces of residual magnetism. For the same reason, the armature of an electromagnet should never be permitted to hammer on its cores.

A magnet with cores and yoke made of the best magnetically soft-iron wire of small size would be an efficient one, and, even with the cores only made of iron wire, it should be more efficient than one with solid cores, if the joints between the cores and yokes were properly made. It is rather difficult, however, to do this.

91. Time-Constant.—When current is first turned into a circuit possessing considerable self-induction, it is resisted rather by the inductance than by the resistance. The increase in the strength of the current is governed by the ratio of $\frac{L}{R}$, in which L equals the inductance and R equals the resistance; and this ratio represents the time that it

takes for the current to reach a definite fraction of its final strength. This fraction is .63, or nearly $\frac{2}{3}$. Thus, if in any circuit we divide the inductance in henrys by the resistance in ohms, the ratio gives the **time-constant** of the circuit, or it expresses the time that it will take for the current to reach about two-thirds of its final value.

Anything that will increase R without increasing L will diminish the ratio $\frac{L}{R}$, and, hence, render the conditions more favorable for rapid working. Let us see how the ratio $\frac{L}{R}$ will be affected by rewinding a magnet with more turns of a finer wire. This would increase the resistance, but in order to keep the ampere-turns the same, the current required would of course be less. If the magnet were rewound to have twice the number of turns with a wire of *one-half the cross-section*, $\frac{L}{R}$ would not be affected. For L is proportional to the square of the number of turns, and, hence, it is four times as great as before, and, there being twice as many turns of a wire of one-half the cross-section, the resistance R is also four times as great as before. Consequently, the ratio $\frac{L}{R}$ has the same value as before. In order, however, to get *twice as many turns of wire in exactly the same space* it will be necessary to use a wire of somewhat less than one-half the cross-section, because the smaller the wire, the larger is the percentage of space that is occupied by the insulating covering of the wire; hence, the resistance will increase faster than the square of the number of turns, and, consequently, $\frac{L}{R}$ will diminish. With a No. 24 B. & S. double silk-covered wire, the copper occupies 62 per cent., but with a No. 26 B. & S. wire the copper occupies only 55 per cent. of the volume of the coil, or a loss of 7 per cent., on account of the larger proportion that the thickness of the insulating covering now bears to the diameter of the bare wire.

Although not stated, it has been assumed in the foregoing remarks on the time-constant that the circuit possesses no electrostatic capacity, or, at least, a perfectly negligible amount of it. If it also possesses electrostatic capacity in addition to resistance and inductance, it becomes a more complicated matter, and it will not be advisable to take it up here.

92. The average value of the inductance and the time-constant of a few instruments are added here to give the student some idea of the value of such quantities. A Morse 148-ohm relay in ordinary adjustment: $L =$ about 5 henrys, and $\frac{L}{R} =$ about .034 second. A polarized 417-ohm relay with the armature .004 inch from the poles and a testing current of 6.3 milliamperes: $L = 1.72$ henrys. A 20-ohm sounder with the armature .004 inch from the poles and a testing current of 125 milliamperes: $L = 191$ millihenrys, and $\frac{L}{R} = .0095$ second. A 14-ohm sounder: $L = 265$ millihenrys.

93. The less iron used in an electromagnet, the shorter the cores; and the less complete the iron circuit is made, the quicker the magnet acts. Some relays used in repeater and quadruplex sets have exceptionally short cores, which makes them act very promptly, and a polarized relay now used by the Western Union Telegraph Company in some of its quadruplex sets has no yoke piece. The absence of the yoke piece doubtless makes the magnet less efficient, requiring on it more ampere-turns to give the same pull on the armature; but in this case it is more important to have a quick-acting relay than one of the highest efficiency.

The speed of a solid-core magnet may be increased by slotting the core parallel to its axis to about one-quarter of its diameter, and by drilling a hole along the axis nearly the entire length of the core, starting from the pole face next to the armature. The solid cores act as though it required time for the magnetism to soak in.

94. Proper Proportions of a Telegraph Magnet. The best theoretical proportions to secure the maximum magnetic effect from a given number of ampere-turns have been found to be as follows: Make the yoke, cores, and armature of equal length, the yoke being of somewhat greater cross-section than the cores, and the armature of equal cross-section, but broader and thinner than the yoke. In order to make a quick-acting magnet—a very important consideration in telegraph apparatus—experience has shown that the above theoretical proportions may sometimes be modified with practical advantage.

The most important quality essential to an electromagnet for telegraphic apparatus is the quickness with which it responds when the circuit is closed or opened, and then comes its efficiency, that is, its maximum attractive force with a given number of ampere-turns. These two properties oppose each other, and, hence, it is necessary in practice to sacrifice, to a certain extent, the efficiency in order to more completely obtain the first. The results of investigations have shown that the outer diameter of the coils should be three times the diameter of the cores, and that the length of each coil should be equal to its own diameter, although, as a matter of fact, the coils are usually a little longer than their diameter. Fig. 32 shows the relative size of the magnet of a Western Union relay. It has also been determined that the best results are obtained by making the area of the poles of the magnet practically the same size as the cores, that is, neither enlarging nor reducing the area of the pole faces, and the pole faces should be perfectly plane. It is best (before annealing, however) to file off the sharp edge, thus reducing the pole area a trifle, but this also reduces the magnetic leakage, and the one counterbalances the other.

95. The coils in all telegraph instruments are usually covered with a polished vulcanized-rubber casing, to protect them from dust and mechanical injury and to add to their appearance. In all electromagnets used in telegraph

instruments, the iron armature should be so adjusted, as already stated under sounders, relays, and registers, that it can never come so near the iron cores or pole pieces but that one thickness of ordinary writing paper may be drawn between them. This is to prevent the armature from sticking to the cores and also to keep the armature from striking the cores. The continual striking of an armature against the cores is sufficient to harden them and cause them to retain their residual magnetism more tenaciously, as already explained.

WINDING FOR SOUNDERS AND RELAYS.

96. The resistance of a line increases directly as its length. With a given line circuit, the only way to increase the current is to increase the difference of potential at the terminals of the circuit. But it is neither advisable nor practicable in telegraph circuits to use so very high an electromotive force, and, hence, it is usually impossible to get a current through a long and, therefore, high resistance line that is strong enough to operate an ordinary sounder properly. The student may ask, Why not decrease the resistance? To decrease the line resistance sufficiently would require such a large wire that its cost would prohibit its use entirely. But, by putting the sounder, with a separate battery, in a local circuit that is opened and closed by the armature of a relay, the desired results can be obtained, because only sufficient pull need be exerted on the relay armature to bring two contact points together; and, with the sounder in a local circuit of low resistance, there is no difficulty whatever in securing a current large enough, even with only a few cells of battery. By having sufficient turns of wire on the relay, a very small current will be sufficient to cause the magnet to attract the armature and so close the local circuit containing the sounder and local battery.

97. Coils Designated by Their Resistance.—The resistance of a wire varies directly as its length and

inversely as its sectional area, or inversely as the square of its diameter. From this it is evident that the number of turns in a coil, since this varies as the length of the wire, has a definite relation to its resistance, and, therefore, the resistance of a coil may be taken as a measure of the number of turns of wire it contains. Now, it is easy to measure the resistance of a finished coil, but it is not an easy matter to determine the number of turns or the length of wire used. On account, therefore, of this practical convenience, and not because the resistance itself is a desirable quantity, it is customary to speak of an electromagnet as having a certain resistance instead of a certain number of turns, and, therefore, to designate it by its resistance. Thus, we speak of a 150-ohm relay and not of a relay of 8,640 turns, although this latter would be a more direct way of indicating the value of the relay, because the more turns there are, the smaller need be the magnetizing current for a given magnetization.

98. We will now explain why the winding of a relay for a long-line circuit should be different from the winding of a sounder for a short or local circuit. The same principle will explain the reason for winding relays, some with low-resistance coils of relatively few turns for short lines, and others with high-resistance coils of a relatively large number of turns for long lines.

With a magnetic core of given length and cross-section, the force with which the armature is drawn toward the cores is approximately proportional to the square of the product of the current and the number of turns in the coil. This product is called the **ampere-turns.** There are two limiting conditions, however: one is that the depth of winding for short-core electromagnets, such as are used in telegraph instruments, shall not exceed the diameter of the core, making the outside diameter over the coil about three times that of the core; the other is that the cores shall never even approach magnetic saturation. In regard to the latter point, it is sufficient to state that, in telegraph magnets, the dimensions of the iron parts, the number of turns of wire in

the coils, and the strength of current are such that magnetic saturation is never closely approached.

99. It has been determined that a sounder wound with about 940 turns of wire works well when a current of $\frac{1}{4}$ ampere is flowing through the coils. This gives $.25 \times 940 = 235$ ampere-turns as the most favorable condition for its operation. In order to keep this product constant, the number of turns should vary inversely as the current strength. That is, with a given battery, the larger the resistance of the circuit, and, therefore, the smaller the current, the larger should be the number of turns in the coils of the electromagnet. But the winding space is limited, and it is not practical to use a wire smaller than No. 40 B. & S. gauge, so that there is a limit to the number of turns that can be wound on the iron core. Consequently, if the product of the maximum number of turns that can be put in the given space by using the smallest wire and the largest current obtainable over a line circuit with an electromotive force as high as it is practical to use, is less than 235, the sounder cannot be successfully used on that line circuit. For lines over 20 miles in length, it is found more economical and successful to use a relay and a lower electromotive force, with the sounder in a local circuit, than to attempt to get a current large enough to work the sounder in the main line by using the high electromotive force that would be required. A relay that is not designed to give a loud sound, and requiring much less energy to operate its small, light armature, can be used to better advantage to control the opening and closing of a local circuit containing a sounder and a separate battery.

100. If a sounder of 4 ohms resistance is put in a local circuit with two gravity cells, the current may be calculated as follows:

The resistance of one sounder............	4 ohms.
The internal resistance of two cells.......	4 ohms.
Total resistance......................	8 ohms.

The resistance of the connecting wires, being very small, may be neglected. The electromotive force of two gravity cells is about 2 volts. Therefore, the current will be $\frac{2}{8} = \frac{1}{4}$ ampere. $\frac{1}{4} \times 940 = 235$ ampere-turns. This is the most favorable condition for the successful working of a sounder, as already mentioned.

101. Now, as an example, merely, take a line of No. 14 B. & S. gauge copper wire 10 miles in length, with five stations on it.

The line resistance will be about........	80 ohms.
The resistance of five 4-ohm sounders...	20 ohms.
The internal resistance of thirty cells...	60 ohms.
Total resistance..................	160 ohms.

The current $= \frac{30}{160} = .1875$ ampere. Ampere-turns $= .1875 \times 940 = 176$. This number of ampere-turns is too small to operate the sounder satisfactorily. By using 50 cells, the current would be equal to $\frac{50}{80 + 20 + 100} = .25$ ampere. Thus, the 10-mile circuit would require 50 cells, if 4-ohm sounders were used, in order to operate them under the most favorable conditions.

102. Let us see what can be done by using relays with the sounders in local circuits. A 150-ohm relay has 8,640 turns of wire in the coils, and requires .02 ampere to work it. This makes no allowance for line leakage. Hence, the minimum ampere-turns required to work an ordinary relay are $8,640 \times .02 = 173$. The line under consideration is a short one, and a 37.5-ohm relay will be tried.

Line resistance......................	80 ohms.
Five 37.5-ohm relays.................	187.5 ohms.
Internal resistance of twelve cells.....	24 ohms.
Total resistance.................	291.5 ohms.

The current $= \frac{12}{291.5} = .041$ ampere. The 37.5-ohm relay, made by connecting the two coils of a 150-ohm relay in parallel instead of in series, would have one-half of .041 ampere in each coil, giving $8,640 \times \frac{.041}{2} = 177$ ampere-turns. This relay would then work all right, since 177 is greater than 173.

The system is now working with 12 cells of battery in place of 50 where 4-ohm sounders were tried. Two cells in each local circuit will only bring the total number of cells up to 22. Thus, 28 cells are saved, and, even if the main-line current does vary somewhat, the sounders will work more uniformly, which would not be the case if the sounders were in the main-line circuit. When the signals are read by sound, it is essential that the sounders work the same at all times.

103. Resistance of Magnets in the Same Circuit.—All telegraph electromagnets, such as relays, main-line sounders, etc., that are connected in series in the same line circuit, should have the same resistances. This will cause all the electromagnets so connected to work equally well.

MAGNET-WINDING CALCULATIONS.

104. If a given space is filled with a winding of insulated wire, the resistance of the whole coil will be approximately proportional to the square of the number of turns of wire. Furthermore, the number of turns of insulated wire that can be put in a given space will be approximately inversely proportional to the square of the diameter over the wire and its insulation. For, if a given spool, wound full of wire, is rewound with another wire of one-half the cross-section, the spool will contain twice the number of turns, and, therefore, twice the length of wire. But the resistance per unit length of the second wire is twice that of

the first. Therefore, since the spool contains twice the length of wire, each unit length of which has twice the resistance of the first, the total resistance of the spool rewound with the smaller wire will be four times as great as it was originally. That is, doubling the number of turns and using a wire of one-half the cross-section quadruples the resistance. Hence, the resistance varies as the square of the number of turns. If exactly the same space is occupied in each case, this is only approximately true.

105. We may now summarize this as follows: Let R be the resistance, n the number of turns, and d the diameter of the wire with which a given spool is filled. If this same spool is refilled with a wire whose diameter is d', then the resistance R' and the number of turns n' will have such values that the following formulas will be approximately satisfied:

$$\frac{R}{R'} = \frac{(n)^2}{(n')^2}. \qquad \textbf{(1.)}$$

That is, the resistance is directly proportional to the square of the number of turns.

$$\frac{n}{n'} = \frac{(d')^2}{(d)^2}. \qquad \textbf{(2.)}$$

That is, the number of turns is inversely proportional to the square of the diameter of the wire.

From the two formulas above, it is evident that

$$\frac{R}{R'} = \frac{(d')^4}{(d)^4}. \qquad \textbf{(3.)}$$

That is, the resistance is inversely proportional to the fourth power of the diameter of the wire.

If the ampere-turns are kept constant, then

$$\frac{C'}{C} = \frac{n}{n'}. \qquad \textbf{(4.)}$$

in which C and C' are the currents necessary with n and

n' turns, respectively. From formulas **2** and **4,** it is evident that

$$\frac{C'}{C} = \frac{(d')^2}{(d)^2}, \qquad (5.)$$

and from formulas **1** and **4,** that

$$\frac{(C')^2}{(C)^2} = \frac{R}{R'}. \qquad (6.)$$

That is, the current varies inversely (formula **4**) as the number of turns, directly (formula **5**) as the square of the diameter of the wire, and inversely (formula **6**) as the square root of the resistance. The above formulas are hardly approximately correct, except between wires of very nearly the same size, because the smaller the wire, the larger will be the percentage of the total space occupied by the insulating material on the wire.

106. The diameter of a copper wire, in inches, that will fill a bobbin, or spool, of given dimensions and offer a given resistance can be found approximately by the following formula:

$$d_w = .0288\sqrt[4]{\frac{l(d_0^2 - d_1^2)}{r}}, \qquad (7.)$$

in which

d_w = diameter of the bare copper wire;
l = length of the winding space on the spool;
d_0 = outside diameter of the coil;
d_1 = inside diameter of the coil and, generally in telegraph magnets, practically the same as the diameter of the iron core; (The above must all be expressed in inches.)
r = resistance of the coil in ohms. In telegraph electromagnets having two coils, r is the resistance of one coil only.

NOTE.—The total number of turns in a coil is equal to the cross-section of the coil, normal to the direction of the wires, in square inches, multiplied by the number of wires that can cross a square inch. This may be written as follows: No. turns = No. square inches × wires per

square inch. The total length of wire is evidently the total number of turns multiplied by the mean length of one turn. The mean length of one turn $= \frac{\pi}{2} \times (d_0 + d_1)$. Hence, the total length of wire in the coil = No. square inches × wires per square inch $\times \frac{\pi}{2} \times (d_0 + d_1)$. The cross-section of the coil in square inches $= \frac{l \times (d_0 - d_1)}{2}$, in which l is the length of the coil; and the number of wires per square inch $= \frac{1}{d_x^2}$ approximately, in which d_x is the diameter in inches of the wire over its insulating cover. Then the total length of wire in the coil $= \frac{l \times (d_0 - d_1) \times \pi \times (d_0 + d_1)}{2 \times 2 \times d_x^2}$. Now a copper wire $\frac{1}{1,000}$ inch in diameter and 1 foot long has a resistance of 10.5 ohms (international ohms at 75° F., or 24° C.); hence, a copper wire 1 inch in diameter and 1 inch long will have a resistance of $\frac{10.5}{12 \times (1,000)^2}$ ohms, and a copper wire having a diameter of d_w inches will have a resistance of $\frac{10.5}{12 \times (1,000)^2 \times d_w^2}$ ohms per inch of length. Then for the total resistance r of the wire in the coil, we get $r = \frac{l(d_0 - d_1)\pi(d_0 + d_1) \times 10.5}{4 \times d_x^2 \times 12 \times (1,000)^2 \times d_w^2}$. In order to reduce this to a convenient form, it is necessary to make the approximation that $d_x = d_w$. This is not a very serious error, especially in this case, where some of the other quantities may not be very exact, and the error reduces as the wire increases in size. Making this approximation, simplifying, and solving for d_w, we get $d_w = \sqrt[4]{\frac{10.5 \times \pi \times l(d_0^2 - d_1^2)}{4 \times 12 \times (1,000)^2 \times r}}$, or $d_w = .0288 \sqrt[4]{\frac{l(d_0^2 - d_1^2)}{r}}$ inches.

After calculating d_w, the size of the wire that has this diameter may be obtained from a wire table. In order to allow for irregularities in winding, insulation, etc., the next smaller gauge wire should be used, because a length of the smaller wire having the required resistance will not quite fill the space, while, for the next larger size of wire, the spool would not hold enough of the wire to produce the desired resistance, or, strictly speaking, there would not be enough turns.

107. The following table, giving the outside diameter of insulated wire, may prove useful in winding coils. In the table, S. C. C., D. C. C., and T. C. C. stand for single, double, and triple cotton-covered wire, and S. S. C. and D. S. C. stand for single and double silk-covered wire, respectively.

TABLE 1.

INSULATED COPPER WIRE.

Number B. & S. Gauge.	Diameter in Inches.						Square of Diameter. Bare (d^2).
	Bare (d).	S. C. C.	D. C. C.	T. C. C.	S. S. C.	D. S. C.	
1	.28900		.303	.307			.083690000
2	.25800		.272	.276			.066370000
3	.22900		.243	.247			.052630000
4	.20400		.216	.220			.041740000
5	.18200		.194	.198			.033100000
6	.16200		.174	.178			.026250000
7	.14400		.156	.160			.020820000
8	.12800		.140	.144			.016520000
9	.11400		.126	.130			.013090000
10	.10200	.1080	.112	.116			.010380000
11	.09070	.0970	.101	.105			.008234000
12	.08080	.0870	.091	.095			.006530000
13	.07200	.0780	.082	.086			.005178000
14	.06410	.0700	.074	.079			.004107000
15	.05710	.0630	.067	.071			.003257000
16	.05080	.0550	.059	.063	.05280	.05480	.002583000
17	.04530	.0490	.053	.057	.04730	.04930	.002048000
18	.04030	.0440	.048	.052	.04230	.04430	.001624000
19	.03590	.0400	.044	.047	.03790	.03990	.001288000
20	.03200	.0360	.040	.044	.03400	.03600	.001022000
21	.02850	.0320	.036	.040	.03050	.03250	.000810100
22	.02530	.0290	.033	.037	.02730	.02930	.000642400
23	.02260	.0270	.031	.035	.02460	.02660	.000509500
24	.02010	.0240	.028	.032	.02210	.02410	.000404000
25	.01790	.0220	.026	.030	.01990	.02190	.000320400
26	.01590	.0200	.024		.01790	.01990	.000254100
27	.01420	.0180	.022		.01620	.01820	.000201500
28	.01260	.0170	.021		.01460	.01660	.000159800
29	.01130	.0150	.019		.01380	.01580	.000126700
30	.01000	.0140	.018		.01200	.01400	.000100500
31	.00893	.0124			.01090	01290	.000079700
32	.00795	.0115			.00995	.01200	.000063210
33	.00708	.0105			.00908	.01110	.000050130
34	.00631	.0098			.00831	.01031	.000039750
35	.00562	.0086			.00762	.00962	.000031520
36	.00500	.0080			.00700	.00900	.000025000
37	.00445	.0075			.00645	.00845	.000019830
38	.00397				.00597	.00797	.000015720
39	.00353				.00553	.00753	.000012470
40	.00315				.00515	.00715	.000009888

108. The figures given in the foregoing table for the single and double silk-covered wire are for insulated wire made by the American Electrical Works. This company, which is a large manufacturer of all kinds of insulated wire, gives the following directions for determining the diameter of their cotton-covered magnet wire:

Add to the diameter of the bare wire

.006	inch for single	cotton-covered for Nos.	0000 to 7	B. & S.
.012	inch for double	cotton-covered for Nos.	0000 to 7	B. & S.
.005	inch for single	cotton-covered for Nos.	8 to 19	B. & S.
.01	inch for double	cotton-covered for Nos.	8 to 19	B. & S.
.0045	inch for single	cotton-covered for Nos.	20 to 40	B. & S.
.009	inch for double	cotton-covered for Nos.	20 to 40	B. & S.

A table constructed from these figures would differ but little from Table 1.

109. An expression that is often useful for magnet-winding calculations will now be given.

Let v be the volume in cubic inches of the space to be occupied by the coil, r the ohms per foot, d the diameter over the insulation of the size wire to be used, and R the total resistance of the whole coil. Then,

$$R = \frac{v \times r}{12 \times d^2}. \qquad \textbf{(8.)}$$

NOTE.—Derivation of formula **8.** Evidently $\frac{r}{12}$ is the resistance per inch. Now, the volume occupied by a given length of wire is equal to its cross-section multiplied by its length, and, hence, the volume v divided by the cross-section of the wire gives the length of wire. If the wire is wound on a spool, the area occupied by each wire will be approximately equal to the square of the diameter and not to $\frac{\pi d^2}{4}$, because, when the wires are piled over and alongside one another, each wire occupies nearly a square, each side of which is equal to the diameter of the wire, and the intervening spaces in each corner of each square are almost unoccupied and lost. Hence, the volume divided by the square of the diameter gives the approximate total length of wire. Therefore, the total length $\frac{v}{d^2}$ in inches multiplied by $\frac{r}{12}$, the resistance of the wire per inch, gives the total resistance of all the wire on the spool, that is, the resistance of the coil.

For any size wire, r and d can be obtained from tables; then, if either R or v is known, the other can be determined.

110. The following table, taken from the "Physical Laboratory Notes" of the Massachusetts Institute of Technology, gives the ohms (o) per cubic inch for some sizes of double silk-covered copper wire. By **ohms per cubic inch** is meant the number of ohms of a given insulated wire that can be put in a space of 1 cubic inch. It is not calculated from any formula, but is based on data obtained in winding

TABLE 2.

Data on Double Silk-Covered Copper Wire.

B. & S. Gauge Number.	o = Ohms Per Cubic Inch.	u	Pounds Per Cubic Inch.
20	.76	.79	.24
22	2	.69	.23
24	5	.62	.21
26	12	.55	.19
28	25	.49	.17
30	54	.43	.14
32	105	.37	.12
34	195	.31	.08
36	355	.25	.075
38	630	.19	.06
40	1,050	.13	.05

a few actual coils. The column headed u gives the ratio of the volume of the copper to the total volume of the coils as actually wound, and the last column enables one to determine the weight of wire necessary for a coil when the volume is known. As the wire becomes smaller, the insulation on it occupies a larger proportion of the total volume. For instance, a spool filled with No. 40 has only 13 per cent. of its volume occupied with copper.

111. Means to Reduce Sparking.—It has long been recognized that the sparking at the contacts of a local telegraph circuit can be reduced by winding the magnet with two wires connected in parallel with each other. That is to say, if the coil of a magnet, instead of being wound with one wire of the proper cross-section, is wound with two wires of half that cross-section and the same number of turns, these two windings being connected in parallel and giving the same magnetizing effect with a given current as does the single winding, then the sparking will be less.

In 1899 it was discovered and patented that a magnet wound with two wires lying side by side throughout their length and connected in series gives less sparking than the same magnet wound in the ordinary way with the same size

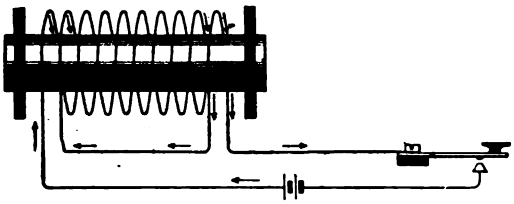


FIG. 33.

wire and the same number of turns. In fact, it is even claimed in the patent that the spark at the points of rupture may be almost wholly eliminated, thus protecting the contacts against destructive sparking. A coil wound in this manner is shown in Fig. 33. The reduced sparking is due to a condenser action between adjacent turns, which, in this method of winding, have considerably more difference of potential between them than would be the case in the ordinary method of winding. This creates electrostatic charges that balance to a certain extent the self-induction. Since there is, in this method, a greater potential difference between adjacent turns, better insulation might be required on the wire in some cases, and, furthermore, it is more difficult to wind the wire in this manner.

Another method by which sparking may be avoided, or at least much reduced, consists in permanently joining together

the two contact pieces by a non-inductive resistance so large that the current passing through it, when the contact is broken, is small enough not to be injurious or very wasteful. The same object is accomplished by connecting a condenser across the contact points.

112. Varley Coils.—An innovation in the art of coil winding has lately been introduced by the Varley Duplex Magnet Company. Their method is, wherever possible, to wind with bare wire. In order to prevent the short-circuiting between the various convolutions, a silk thread is wound parallel with the bare wire throughout its length, so that the adjacent convolutions are always held a slight distance apart. Between the several layers of the winding are introduced thin layers of oiled paper. This winding is accomplished entirely by automatic machinery, and the coils produced are very perfect. The machines are run at a high speed, and, at the proper intervals, the layers of paper are introduced without stopping the machinery or without the volition of the operator. This method, while being cheaper than the ordinary method in which the insulated wire is used, has also the additional advantage of making possible a given number of turns of a certain size of wire in a smaller space than can be obtained by the old method. Again, the convolutions are arranged with practically perfect uniformity, in decidedly sharp contrast to the results produced by the usual method, in which the wire is fed to the machine by hand.

DIMENSIONS OF TELEGRAPH INSTRUMENTS.

113. The following table of dimensions, in connection with Fig. 32, showing the form of electromagnets employed in telegraph and signal work, will be a useful guide in designing others for a similar purpose, for they are the result of considerable experimenting and practical experience.

No. 1 gives the dimensions of a Western Union relay. When this relay is wound with No. 30 B. & S. gauge

silk-covered copper wire, it will have a resistance of 150 ohms at 60° F. No. 2 is a Western Union sounder. Its resistance will be 1.9 ohms when wound with No. 22 B. & S. gauge silk-covered copper wire. No. 3 is the electromagnet used in a stock printer, and has a resistance of .7 ohm when wound with No. 17 B. & S. gauge double cotton-covered wire. It is a very quick-acting magnet. No. 4 is an ordinary bell magnet, having a resistance of about 25 ohms when wound with No. 30 B. & S. gauge single cotton-covered copper wire. No. 5 is a magnet used for operating semaphores in railroad signaling systems. It has a resistance of

TABLE 3.

	A	*B*	*C*	*D*	*E*	*F*	*H*	*J*	*C* + 2*J*
1	1.3750	2.0000	.3750	2.1250	.2500	.1250	.1875	.4375	1.2500
2	1.6250	1.5000	.4687	2.1250	.2187	.1250	.7175	2187	.9062
3	1.7500	1.4375	.5000	2.3750	.2500	.1562	.1250	.5937	1.6875
4	1.0937	1.0625	.3750	1.6250	.1875	.1250	.1875	.2812	.9375
5	1.8125	3.3225	.6250	2.7500	.2500	.1875	.4375	.3750	1.3750
6	1.3750	2.1250	.4375	2.1250	.2500	.1250	.1875	.4375	1.1250

1.2 ohms when wound with No. 17 B. & S. gauge single cotton-covered copper wire. It is slow-working, but for the use to which it is put this is no objection. No. 6 is a 150-ohm relay specified by some telegraph companies. It differs from No. 1 only in the dimensions *B* and *C*. The specifications for this particular relay further state that the core shall be 2¼ inches long, length of armature lever 2½ inches, conductivity of copper wire at least 97 per cent. that of pure copper, and an iron rim around the edge of an oiled wooden base.

COILS ON STANDARD INSTRUMENTS.

114. Standard telegraph magnets are wound with silk-covered wire as follows:

4-ohm sounder: 10 layers of 47 turns each; total number of turns, 940; size wire, No. 24 B. & S.

Sometimes this size sounder is wound with No. 23 B. & S. wire.

20-ohm sounder: 14 layers of 67 turns each; total number of turns, 1,876; size wire, No. 25 B. & S.

150-ohm relay: 30 layers of 144 turns each; total number of turns, 8,640; size wire, No. 30 B. & S.

4-ohm ink and embossing registers are wound with about No. 22 B. W. G. wire.

Main-line sounders and registers, for use on line circuits not over 20 miles long, are often wound with No. 30 B. & S. wire.

CURRENT STRENGTH REQUIRED BY TELEGRAPH INSTRUMENTS.

115. The following are the current strengths best adapted and used in practice for the telegraph instruments named:

4-ohm sounder	.25 ampere.
20-ohm sounder (depending upon the size)	.098 to .18 ampere.
40-ohm main-line sounder	.04 to .07 ampere.
200-ohm sounder	.026 ampere.
30-ohm pony relay about	.1 ampere.
150-ohm relay	.018 to .02 ampere.
300-ohm relay	.01 to .015 ampere.
Postal Telegraph quadruplex relay	.02 ampere.
200-ohm Wheatstone relay (used with a condenser)	.008 to .012 ampere.

In the case of instruments connected in a line wire from which there is more or less leakage, the figures given here represent effective currents. By *effective current* is meant the difference between the maximum current, which flows when all the keys are closed, and the minimum current, which flows when a distant key is opened.

NOTE.—The formulas given in Art. **105** will not hold between the instruments given above for the reason given in that article, and furthermore because the spools are not similar in size.

PRIMARY CELLS.

GRAVITY CELL.

116. The standard **primary cell** in the United States for telegraphic purposes is the **gravity**, one form of which is shown in Fig. 34. Another form, called the Callaud cell, is also used. In large telegraph offices, dynamos and storage cells are rapidly replacing the primary cell. The crowfoot is the form of gravity cell adopted by the Western Union Telegraph Company, and, for this reason, is frequently called the *Western Union*. It furnishes a working electromotive force of 1 volt. For continuous working, the most economical current output is about $\frac{1}{4}$ ampere. Its internal resistance varies considerably, depending on its condition, but 3 ohms may be taken as an average value. For convenience in calculation, 2 ohms will be used in examples in this section. Gravity cells are described in the section on *Batteries*.

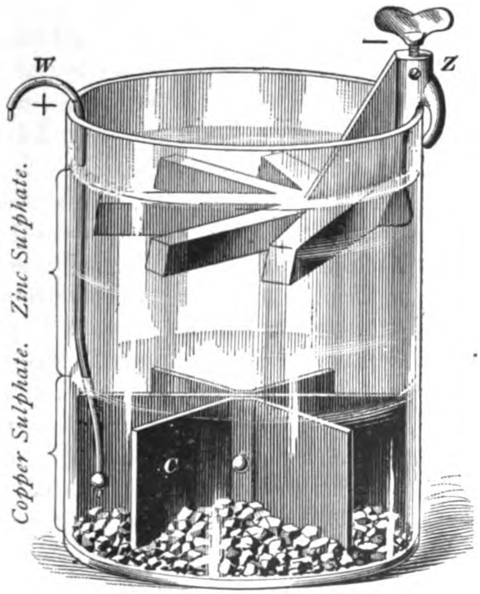


FIG. 34.

117. Directions for Setting Up.—Directions for setting up the gravity cell are as follows: Unfold the copper strip so as to form a cross and place it in the bottom of the jar. It is best to have the point where the copper connecting wire is riveted to the copper electrode near the

bottom of the cell, and the insulated covering on the wire should come close to the riveted joint. Suspend the zinc about 4 inches above the copper by placing the hook over the side of the jar. The zinc, or tripod, has a hole in it to receive the wire. Pour sufficient clean water into the jar to cover the zinc and drop in blue vitriol, or copper sulphate (also called *bluestone*), in small lumps. About 3 pounds is the proper amount to put in a cell to be used for heavy continuous work, for instance, for the local-circuit batteries that run the sounders. For main-line batteries, a smaller charge will be sufficient, and, in quadruplex circuits, the so-called "long" end of the battery will need less bluestone than the "short" end, because the former is not worked so continuously as the latter. The internal resistance may be reduced and the battery made immediately available by drawing about half a pint of solution of sulphate of zinc from a battery already in use, and pouring it gently into the jar; or, when this cannot be done, by putting into the jar 4 or 5 ounces of pulverized sulphate of zinc previously dissolved in a cup of water. If there is no hurry for the cells, do not put in the zincs until the solutions have had time to settle to their normal conditions, which will require about 48 hours. This prevents or reduces the formation of a black deposit on the zinc. When there is much of this black deposit, remove the zinc and brush or scrape it off. If no zinc sulphate is added in setting up the cell, it will be necessary to short-circuit the cell for some time (24 hours will not be too long) before it will be in good condition.

118. Caring for Cells.—Blue vitriol should be dropped into the jar as it is consumed, care being taken that it goes to the bottom and not on the zinc. The need of the blue vitriol is shown by the fading of the blue color, which should be kept at least as high as the top of the copper, but it should never reach the zinc. There should always be some bluestone crystals in the bottom of the jar.

After the battery has been started, no further attention is required, except to keep it supplied with bluestone and

water, until the quantity of sulphate of zinc in solution has become too great. As long as the battery continues in action, there is an increase of the quantity of sulphate of zinc in solution in the upper part of the jar. When this becomes too dense, it will be necessary to draw out a portion of the top of the liquid with a battery syringe or a cup and replace it with clear water. A hydrometer is convenient for the purpose of testing the strength of this solution. A hydrometer usually consists of a small glass tube, the lower end of which is enlarged and partially filled with fine shot or mercury. The tube, when placed in a solution, floats in a vertical position. When graduated according to the scale known as the *Baumé*, the hydrometer is floated in water, and the point on the stem on a level with the surface of the water is marked 1°; then it is floated in strong undiluted sulphuric acid, and the corresponding point marked 65°. The intervening space is divided into 64 equal divisions, called *degrees*. Hydrometers will be more fully described and illustrated in connection with storage batteries.

When the specific gravity of the solution in the gravity cell is less than 15° on the hydrometer scale, there is too little sulphate of zinc; when it is 30° or over, there is too much in solution, and it must be diluted. When the zincs become coated so as to interfere with the proper action of the battery, they must be taken out, scraped clean, and washed.

119. Cleaning Cells.—The cells should be cleaned out about once every three months. To do this, carefully remove the zinc, clean it by scraping with a knife, and wash it with plenty of water. Pour the clear liquid into a separate jar, leaving behind the oxide and dirt that may have gathered in the bottom of the jar. Now take out the copper, clean it and the jar, throwing away the sediment. Replace the copper, put around it some bluestone crystals, pour the clean liquid back into the jar, replace the zinc, and, without disturbing the liquid any more than is

necessary, add enough water to cover the zinc. The battery will soon be ready for use, and short-circuiting the cell or battery should bring it into condition very rapidly. Some question the advisability of using any of the old solution over again, preferring to use only fresh solution, but this requires short-circuiting the battery for at least 24 hours in order to bring it into working order, consuming both time and battery material. Entire fresh solution will give the best results, without doubt, where time or expense is not so important.

120. Condition of a Cell Judged From Appearance.—The condition of a gravity cell may be judged from its appearance. When the cell is in good order, the solution is a bright-blue color, the blue fading to a water color before reaching the zinc. A very pale or dirty brown-colored solution indicates a deteriorated condition of the cell. A local battery, being used harder than the main-line and quadruplex batteries, will need replenishing and cleaning oftener than the others, probably as often as once in six weeks, a main-line battery supplying three or more lines, about once in eight weeks, while a quadruplex battery will last from five to eight months.

The batteries should not be allowed to freeze, for, while frozen, the current is very much impaired or altogether suspended. Below 65° or 70° F., the internal resistance of the battery increases very rapidly. A battery works more vigorously while warm, for heat is a promotor of the chemical action. The connections should be kept free from dirt and corrosion, in order to allow the current a low-resistance path through them.

121. Oil on Gravity Cells.—Oil over the top of the solution will not only prevent the creeping of the salts, provided the oil is poured on before the creeping commences, but it will also prevent the evaporation of the solution. The oil makes it more difficult to clean the jar and the zinc and copper elements, but on the other hand

it saves the time that would otherwise be required for replenishing the cells with water. The oil may be readily removed by the use of sand and a wet cloth. The advisability of using oil is a disputed question and depends on circumstances. Only a good quality of a petroleum lubricating oil or a heavy paraffin oil should be used for this purpose. Common oil softens and rots the insulating covering of the wire running through it to the copper element, unless this insulation is made of a compound of paraffin and gutta percha (not india rubber). The creeping of the salts over the side of the glass jar may also be prevented by coating the upper part of the jar with paraffin. To do this, dip the inverted jar to a depth of about $\frac{1}{4}$ inch in a shallow dish of melted paraffin. The white zinc sulphate that creeps over the jars is a very fair conductor of electricity, and, if it extends from cell to cell, may cause considerable leakage and consequent waste of current and battery material.

122. Cost of Gravity Cells.—A 6″ × 8″ gravity cell complete costs about 55 cents, and the estimated average cost of maintenance of one cell is about $1.15 per year. This includes zinc, bluestone, labor, rent, breakage, and supervision. Another party estimates from his experience that the cost of material for one year is about as follows: Zincs, 50 cents; copper, 20 cents; bluestone, 30 cents; making altogether $1.00. This allows nothing for breakage of the glass jars, which is sometimes considerable when the jars are not made of well-annealed glass, and when there is considerable change in the temperature of the battery room.

GORDON CELL.

123. A Gordon cell is shown in Fig. 35. It is an improved modification of the Lalande-Chaperon type that is described in the section on *Batteries*. These cells are made with enameled-steel, porcelain, or glass jars, and a cover of

tin, porcelain, compressed fiber, or glass, fitting the jar nearly water-tight. Inside the jar is a perforated tin cylinder suspended by a rod of iron from the middle of the cover and held in place by insulating washers, in case a tin cover is used, and a brass connector. Within the perforated cylinder is deposited chemically pure cupric oxide (2¾ pounds for the large No. 1 cell). Special care is taken in the manufacture of this material that the copper is thoroughly oxidized. About 1½ inches from the bottom of the perforated cylinder are attached three lugs, made of porcelain and held to the perforated cylinder by means of iron stove bolts. These lugs sustain the weight of the zinc element, and, at the same time, keep the latter thoroughly insulated. The zinc is practically pure, and has its surface thoroughly amalgamated. Attached to the zinc by means of a copper rivet is a No. 12 copper wire running to the top of the jar and forming the negative terminal of the cell. The zinc element and the copper wire are pressed closely together, and the exposed copper is covered with a rubber insulation.

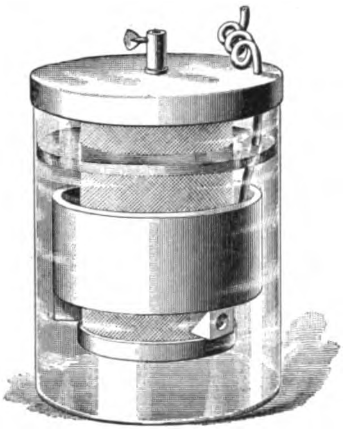


FIG. 85.

The solution consists of 1½ pounds of caustic soda, or hydrate of soda, dissolved in 6 pints of pure cold water. The water used should be free from lime or carbonaceous material. A heavy paraffin oil, floating on the surface of the caustic-soda solution, seals the cell and prevents the atmosphere, with the carbonic-acid gas that it contains, from reaching the solution. The carbonic-acid gas will change the hydrate of soda to carbonate of soda, and this latter is useless in the cell, if not injurious. Such useless consumption of the hydrate of soda would shorten the life of the cell and decrease its efficiency.

124. Life and Capacity.—These cells are now made in various sizes. Size No. 1 is 6 in. × 8 in., and size No. 2 is 4½ in. × 6 in., the guaranteed life of the two sizes being 250 and 100 ampere-hours, respectively. It is further stated that, under ordinary conditions, the life will be 25 per cent. longer than that given above. Furthermore, at a discharge rate of .08 ampere, as required for the average railway-signal service, cell No. 1 is warranted by the manufacturer to last six months without any attention whatever, and much longer where less current is required. These cells have been known to work in the main telegraph circuit of a railway company for six and seven months without any care, after which time the cells needed replenishing. To replenish the cell, new cupric oxide, zinc, and caustic soda are required.

A steady current of from 1 to 6 amperes from the No. 1, and from ¼ to 1 ampere from the No. 2, at an available electromotive force of from .65 to .75 volt can be obtained. The internal resistance is very small—about .04 ohm. They have been known to work without interruption at a temperature considerably below zero, at which temperature a gravity cell would be practically useless. The Gordon cell requires no attention until replenishment is necessary, and is much cleaner than the gravity cell; but care must be taken not to splash or spill the solution around, for it is injurious to both the hands and the clothes.

125. At present, the Gordon cell is used for many purposes and very extensively for railway-signal, fire, and police systems. One railroad company alone employs over 1,500 of these cells on its automatic railway-signal system. For use with telephone transmitters, its low internal resistance and freedom from polarization should make the cell quite suitable, although its low electromotive force is somewhat of an objection. For this purpose, the No. 2 cell would ordinarily be large enough. While the initial cost per cell may be high, it is claimed that, owing to the long life, small cost of maintenance, and the little attention required, compared with other good cells, the cost of

electrical energy produced by the Gordon cell is not over 80 per cent. as great.

126. Directions for Setting Up.—Remove the top cover by unscrewing the brass connector, and empty into the perforated cylinder the copper element contained in the pasteboard box. Fill the jar with pure cold water (No. 1, 6″ × 8″ cell, 6 pints, or within 2 inches of the top of the jar; No. 2, 4½″ × 6″ cell, 2¼ pints, or within 1⅛ inches of the top of the jar); then add and dissolve the electrosodium, being careful, by adding the sodium to the water slowly, and not all at once, to avoid creating too much heat. Proper care should be taken to see that the glass jar does not stand on a cold surface while dissolving the sodium. Stir the solution until the sodium is completely dissolved before putting the cell together. After the lid with the elements suspended from it has been put in place, pour the oil into the jar by inserting the neck of the bottle under the cover of the cell. This procedure is to be followed in order to prevent the oil from getting all over the zinc and cupric oxide, as would be the case if the oil were poured in first and then the electrodes inserted through the layer of oil. The oil is absolutely necessary for the efficient working of the cell, as the solution must not be exposed to the air, for the reason already given. The liquid should then stand 1 inch in the No. 1 and ⅞ inch in the No. 2 from the top of the jar, when the battery is ready for use.

127. Recharging.—Throw away the old zinc, copper element, and solution, and see that the jar and the perforated cylinder are thoroughly clean before setting up again. The usual precautions in handling battery solutions must be taken. No kind of animal or vegetable oil must be used in this type of cell.

EDISON-LALANDE CELL.

128. Although the **Edison-Lalande cell** has a comparatively low electromotive force (.7 volt), its internal resistance is so low that quite a large current can be obtained

from it when the external resistance is small enough, and without polarizing or injuring the cell in the least. It is very suitable where a large continuous current is required. It is fully described in the section on *Batteries*, and is similar, except in mechanical construction and arrangement of parts, to the Gordon cell.

FULLER CELL.

129. The **Fuller cell,** which is extensively used in England on the open-circuit Morse telegraph system, has been described in the section on *Batteries*. When not overworked, this cell is said to last four or five months without attention; otherwise it may need looking after as often as once a month. There is very little local action in this cell when on open circuit, and it does not polarize when in use. It is not used much in this country on regular telegraph lines, but has been extensively used in telephone systems.

This cell has the disadvantage of being very unpleasant to handle, on account of the nature of its solutions, and the further disadvantage of producing very serious damage to whatever it happens to be spilled on. It has the advantage, however, of being able to produce a high and constant electromotive force (2.1 volts), and of being able to maintain this voltage for a considerable period, even when acting through a small resistance. The cell used by the American Bell Telephone Company is termed the *standard Fuller cell*, and is the same as that shown in Fig. 1040, *Batteries*. In setting up this cell, the solution is made as follows:

Sodium bichromate...........	6 ounces.
Sulphuric acid................	17 ounces.
Salt water....................	56 ounces.

If bichromate of sodium is not obtainable, bichromate of potassium may be substituted for it in equal quantities. The former, however, is preferable, although there is very little difference in their action.

130. Mixing the Solution.—In mixing this solution, great care should be taken to pour the sulphuric acid into

the water very slowly. If the operation is reversed, the sudden formation of steam, due to the heat generated by the union between the acid and the water, is very likely to cause an explosion, throwing acid in all directions and frequently doing much damage. It is well, also, to mix the solution in an earthenware jar, or, if it is mixed in the glass battery jar, the latter should be previously placed in a vessel containing cold water, in order to prevent the great heat produced from cracking the jar. After having mixed the solution, the jar should be a little less than half filled with it, and the porous cup put in place. In the bottom of the porous cup should be placed about a teaspoonful of mercury, after which the zinc electrode is put in place and the porous cup filled with water. A tablespoonful of common salt added to the water in the porous cup will hasten the action of the cell.

LECLANCHÉ CELL.

131. The **Leclanché cell** is only suitable for use on circuits that are normally open and for work of an intermittent character. Leclanché cells are extensively used in the district-messenger service, for bells, burglar alarms, annunciators, and telephones, but they are not employed for ordinary telegraph work. This type of cell is described in the section on *Batteries*. Many varieties of the Leclanché cell are now made, and, for the purpose intended, they have proved quite satisfactory. The electromotive force is about 1.4 volts, while the internal resistance will vary from less than 1 ohm to 5 ohms or more, depending on the variety and condition of the cell.

HAYDEN CELL.

132. A very good form of the Leclanché cell is what is known as the **Hayden No. 2**, shown in Fig. 36. In this cell, the depolarizer, instead of being contained in a porous cup, as in the disque Leclanché cell, is contained within a

carbon cylinder, which forms the negative electrode of the battery. The zinc is substantially cylindrical in outline and surrounds the carbon cylinder, thus, by virtue of its large surface and the short distance between the two electrodes, producing a very low internal resistance. In Fig. 36, the carbon cylinder *C* is corrugated on its exterior surface, so as to present as large a surface as possible to the electrolyte, and contains the depolarizer *D*, composed of a mixture of manganese dioxide and crushed carbon in about equal portions, each being broken up into particles somewhat smaller than peas. The carbon cylinder *C* engages the cover-plate *B*, also of carbon, by means of a screw thread, as shown. The positive terminal *T* of the cell is composed of the threaded stud *t*, the washer *t'*, and the locking nut *t''*. The stud is secured in place by means of molten tin, which is poured into the hole in the cover-plate, the plate itself being previously heated to a high degree. After this, the entire cover-plate is boiled in paraffin, so as to prevent corrosion between the metallic terminal *T* and the carbon. Unless this or similar means is taken, this corrosion is sure to set in, due to the absorption of the chemicals in the solution by the porous carbon.

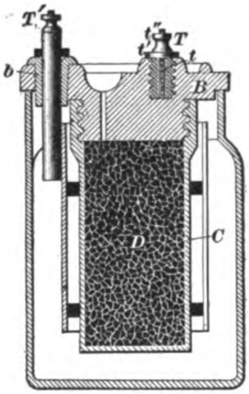


FIG. 36.

Around the carbon cylinder are stretched two heavy rubber bands, the purpose of which is to maintain the zinc cylinder at a proper distance from the carbon. A zinc rod carrying the negative terminal *T'* of the cell, passes through a porcelain bushing *b* in the cover-plate, it being soldered at its lower end to the zinc cylinder. Much trouble has been experienced in these cells, due to the rapid eating away of the zinc at the point where this rod joined it. This was undoubtedly due, in a large measure, to the presence of some foreign substance introduced by the solder, and also, to a less extent, to the fact that the action

was more violent at that point. This trouble has, however, been entirely overcome by painting the plate and the rod in the vicinity of the joint with some material such as a mixture of pitch and tallow, which adheres strongly to the surface and prevents the action of the electrolyte at this place.

DRY CELL.

133. The **dry cell** is described in the section on *Batteries*. It is suitable for so-called open-circuit work only. For intermittent use in the local circuit of a portable telegraph set, and in similar cases where it is desired to have a very light, small battery, these cells may answer the purpose temporarily, but they will not last any length of time in a closed circuit; their internal resistance is apt to increase enormously as they dry out; they have not the recuperative power, nor the constancy, nor are they so reliable as a good Leclanché cell. They have, however, the frequently desirable qualities of being small, portable, and cheap, but, except for temporary use, as mentioned before, they are not used in telegraph work. They have an electromotive force of about 1.4 volts, but their internal resistance depends so much on their construction and condition that no figure for this can be given.

ARRANGEMENT OF PRIMARY CELLS.

134. When a battery constitutes part of a circuit, the battery is not only acting as a source of E. M. F., but constitutes, also, a part of the total resistance of the circuit. We shall see that this internal resistance of the battery is, under certain conditions, very effective, and, in some cases, determines the most suitable arrangement of the cells for the production of the proper current strength. That part of a circuit which is external to the cell, or source of electrical energy, is called the **external circuit,** while the remaining part of the circuit, included within the cell or source of electrical energy, is called the **internal circuit.**

135. When joining together a number of cells *in series*, the positive pole of the first cell should be connected with the negative pole of the second, the positive of the second with the negative of the third, and so on throughout the whole series. It matters not which pole you commence with, provided you are careful not to connect like poles together. This must be as strictly observed in joining batteries hundreds of miles apart as if they stood side by side. How to join cells in series, parallel, or parallel-series, is explained in the section on *Principles of Electricity and Magnetism.*

136. In the formulas to follow, let

C = current in the circuit;
b = internal resistance of one cell;
B = total internal resistance of the battery;
R = external resistance of the circuit;
l = resistance of the line wire;
r = resistance of all relays in the same circuit;
e = E. M. F. of one cell;
E = E. M. F. of the whole battery;
N = total number of cells;
s = number of cells in series in one row;
p = number of rows or cells in parallel.

It is evident that $N = p\,s$, **(9.)**

and that $R = l + r.$

The total E. M. F. of a battery depends on the number of cells in series, and, therefore,

$$E = s\,e.$$

The total internal resistance depends on whether the cells are in series, in parallel, or in a combination of both

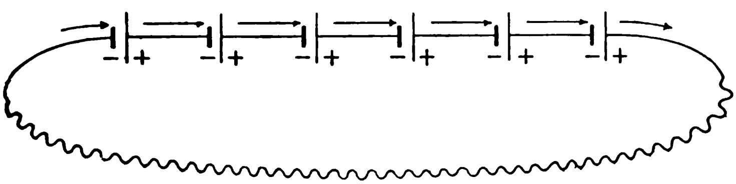


FIG. 37.

series and parallel. If all the cells are placed in series, as shown in Fig. 37, the total internal resistance of the battery is

$$B = s\,b.$$

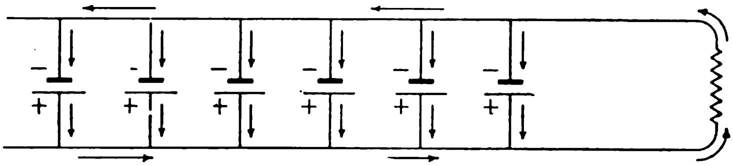


FIG. 38.

If all the cells are in parallel, as shown in Fig. 38,

$$B = \frac{b}{p}.$$

If the cells are arranged in a combination of both series and parallel, as in Fig. 39,

$$B = \frac{s\,b}{p}. \qquad \textbf{(10.)}$$

In the arrangement shown in Fig. 39, $s = 2$, $p = 3$, $N = 6$, $E = 2\,e$, and the total internal resistance of the battery $= \frac{2\,b}{3}$.

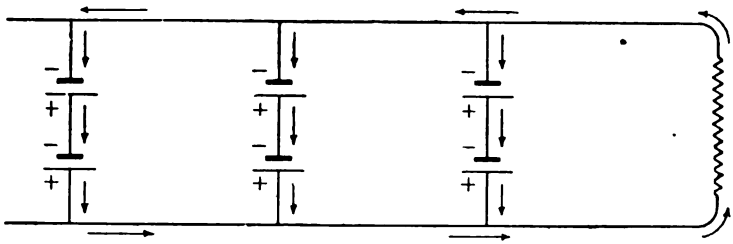


FIG. 39.

137. The current that will flow in any circuit may be calculated from the formulas:

$$C = \frac{s\,e}{\frac{s\,b}{p} + r + l}. \qquad \textbf{(11.)}$$

$$C = \frac{s\,e}{\frac{s\,b}{p} + R}. \qquad \textbf{(12.)}$$

EXAMPLE.—If, in Fig. 40 (*a*) and (*b*), the electromotive force and internal resistance per cell are 1 volt and 2 ohms, respectively, what will be the current flowing in the circuit ?

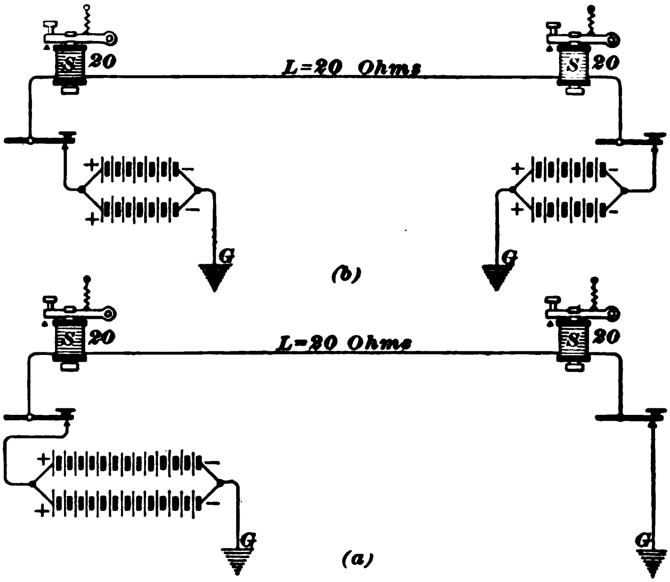


FIG. 40.

SOLUTION.—In both diagrams in this figure, $s = 13$, $p = 2$, $r = 40$, $l = 20$. By formula **11**,

$$C = \frac{13 \times 1}{\frac{13 \times 2}{2} + 40 + 20} = .17+ \text{ ampere. Ans.}$$

This is sufficient current to operate the 20-ohm sounders.

138. Small External Resistance.—From formula **12**, it may be seen that when $R = 0$,

$$C = \frac{p\,e}{b}.$$

That is, the current is proportional to p, the number of cells in parallel, and is independent of the number in series. From this, it may be seen that, *whenever the external resistance is very small and negligible in comparison with the*

internal resistance of the battery, the number of cells in parallel must be increased in order to increase the current. Increasing the number of cells in series in such a circuit will not increase the current. This is in spite of the fact that the electromotive force increases directly as the number of cells in series increases and remains constant, no matter how many are connected in parallel; for, connecting more cells in series, in this case, increases the total resistance of the circuit as fast as the electromotive force increases, and so the current remains practically constant. On the other hand, if the number of cells in parallel is doubled, the resistance will be reduced to one-half its previous value, but the electromotive force is the same, and, consequently, the current will be twice as great.

139. Large External Resistance.—When the external resistance R, in formula **12,** is very large compared with the internal resistance $\frac{s\,b}{p}$ of the battery, then

$$C = \frac{s\,e}{R}.$$

In this case, when $\frac{s\,b}{p}$ is entirely negligible in comparison with R, the current is directly proportional to s, the number of cells in series, and is practically independent of the number in parallel. From this, it may be seen that, *whenever the external resistance is very large compared with the internal resistance of the battery, the number of cells in series must be increased in order to increase the current.* Increasing the number of cells in parallel will not appreciably increase the current, although it does decrease the internal resistance.

140. We may summarize the above as follows:

If R is very *large* compared with $\frac{s\,b}{p}$,

$$\begin{cases} C = \frac{s\,e}{R}, & \text{when cells are in } \textit{series}. \\ C = \frac{e}{R}, & \text{when cells are in } \textit{parallel}. \end{cases}$$

If R is very *small* compared with $\frac{s\,b}{p}$,
$$\left\{\begin{array}{l} C = \frac{e}{b}, \text{ when cells are in } \textit{series.} \\ C = \frac{p\,e}{b}, \text{ when cells are in } \textit{parallel.} \end{array}\right.$$

141. It may readily be shown, also, that, when the resistance in a circuit is very large, the insertion of an extra relatively small resistance will only decrease the current by a correspondingly small fraction.

For instance, suppose there is a telegraph line such that the total resistance, including the line, relays, and battery, is 4,000 ohms and the electromotive force of the battery is 120 volts. How much will the current be decreased by inserting an extra 150-ohm relay at some intermediate station? Originally the current $= \frac{120}{4,000} = .03$ ampere. After inserting the extra relay, the current $= \frac{120}{4,150} = .0289$ ampere. That is, the addition of 150 ohms has only decreased the current between 3 and 4 per cent. To bring the current up to .03 ampere will require only five more cells connected in series with the other cells.

142. Maximum Current.—It has been proved that a maximum current is obtained through a given external circuit from a given number of cells, when the external resistance and the grouping of the cells is such that the internal resistance of the battery can be made equal to the external resistance. That is, so choose s and p that

$$\frac{s\,b}{p} = R.$$

Where a number of cells are so arranged as to give the largest possible current through the circuit, half the energy is expended in the external circuit and the other half in the battery itself.

NOTE.—This can easily be shown in the following manner:

Let W = watts expended in the external circuit;
and w = watts expended in the battery itself.

Then, $W = C^2R,$

and $w = C^2\frac{sb}{p}.$

But, in this case, $R = \frac{sb}{p};$

therefore, $W = w.$

The method of making the internal resistance of the cells equal to the external resistance gives a maximum output, but the efficiency is low, and this arrangement is wrong for the rapid working of electromagnets. For the rapid working of electromagnets, the time-constant $\frac{L}{R}$ for the circuit should be small. In this expression, L is the inductance and R the resistance of the whole circuit. In order, therefore, to make the ratio $\frac{L}{R}$ small, L being a quantity that cannot conveniently be altered, R should be made large. In this expression, R is the total resistance of the circuit, and therefore includes the internal resistance of the battery and the resistance of the connecting wire and all electromagnets connected in series in the same circuit. That is, $R = l + r + B$, and, consequently, the larger B is, the larger will R be.

Even when rapid working does not enter as a consideration, the maximum output solution is not at all economical. The efficiency is not over 50 per cent., because half the energy, as already stated, is used up in heating the battery alone.

143. The maximum current that can be sent through a given external resistance, when the electromotive force and internal resistance per cell are known, and the proper method of arranging the cells will now be determined.

Now, it has been mathematically proved that the expression $\frac{sc}{\frac{sb}{p} + R}$ (see formula **12**) has a maximum value, for a given number of cells N, when $\frac{sb}{p} = R$.

From the latter equation, we obtain

$$s b = p R,$$

or

$$s^2 b = p s R;$$

and, since $p s = N$, then $s^2 b = N R$;

whence,

$$s = \sqrt{\frac{N R}{b}}, \qquad (13.)$$

and

$$p = \sqrt{\frac{N b}{R}}. \qquad (14.)$$

By substituting in formula **12,** R for $\frac{s b}{p}$ and the value given for s in formula **13,** and simplifying, we get

$$C = \frac{e}{2}\sqrt{\frac{N}{R b}}. \qquad (15.)$$

From formulas **13, 14,** and **15,** the values of s, p, and C may be calculated when R, b, N, and e are known.

If C is known and it is desired to find the total number of cells N, the number in series s, and the number in parallel p, formula **15** may be put into the following form:

$$N = \frac{4 C^2 R b}{e^2}. \qquad (16.)$$

Thus, N may be calculated from formula **16,** s from **13,** and p from **9** or **14.** The values so calculated will give the least number of cells and the number to be connected in series and in parallel, in order to furnish a given current.

144. In working problems with these formulas, the value for N may come out a fraction or a number that cannot be divided into any number of parallel sets, each containing the same number of cells in series. In this case, use the nearest larger number that can be so divided.

EXAMPLE 1.—The resistance of a line and all relays is 4,000 ohms. How many cells will be required, and how must they be arranged to give a current of .02 ampere if the electromotive force is 1 volt and the internal resistance 2 ohms per cell?

SOLUTION.—Since the internal resistance of all the cells will, evidently, be much less than the external resistance, 4,000 ohms, the

formulas derived by assuming that the internal and external resistances are equal will not hold, and would, moreover, if used, give absurd results. Therefore, if $p = 1$, formula **12** reduces to

$$C = \frac{s\,e}{s\,b + R}.$$

Solving for s, we get $$s = \frac{C\,R}{e - b\,C}.$$

Substituting in this last equation the numerical values for C, R, e, and b, given in the example, we get

$$s = \frac{.02 \times 4{,}000}{1 - .02 \times 2} = 84 \text{ cells. Ans.}$$

EXAMPLE 2.—Suppose the resistance of the external circuit is 15 ohms and the current required is $2\frac{1}{2}$ amperes. What will be the total number of cells, and how many must be connected in series and how many in parallel?

SOLUTION.—By formula **16**,

$$N = \frac{4 \times (\frac{5}{2})^2 \times 15 \times 2}{1} = 187.5 \text{ cells.}$$

By formula **13**, the number in series in each set or row,

$$s = \sqrt{\frac{187.5 \times 15}{2}} = 37.5;$$

and by formula **9**, the number in parallel, i. e., the number of rows,

$$p = \frac{187.5}{37.5} = 5.$$

The arrangement will require, therefore, 190 cells, divided into 5 parallel rows, with 38 cells connected in series in each row. Ans.

145. If the total internal resistance of the whole number of cells that must be connected in a one-series set (in order to give the necessary electromotive force to furnish the required current) is less than the external resistance, it is impossible to arrange them in any better way than in a one-series set. This will be the case in most all main-line circuits where only one or two circuits are supplied from the same battery.

146. Maximum Economy.—The arrangement of cells that gives the maximum current is *not the most economical.* The most economical arrangement as far as the

consumption of battery material is concerned is that in which the internal resistance of the battery is very small compared with the external resistance. The materials of the battery will be consumed slowly, and the current will not have its greatest possible strength, but the energy wasted in the battery itself will be a minimum. This would generally require such a large number of cells that the initial cost of the cells and the room occupied by them would entirely prohibit such an arrangement.

147. Resistance of All Relays Equal to Combined Resistance of Line and Battery.—The plan commonly accepted and heretofore adopted quite generally and wherever practicable, has been to make the combined resistance of all telegraph electromagnets, such as relays, main-line sounders, etc. that are connected in series in the same line circuit, equal to the combined resistance of the line and the batteries.

This is a more economical arrangement than that in which the maximum current output is obtained. For, in that case, less than half the energy was consumed in the relays, while, in this case, half the energy is consumed in the relays; hence a larger proportion of the energy is useful. This arrangement cannot, however, be always adhered to on long lines, especially where there are but few offices on the same circuit, nor is it the best arrangement on long lines having many relays, unless the insulation of the line, even in wet weather, is very good indeed—much better than is usually the case.

During the last few years, there has been a movement, especially on long railway lines, to use lower resistance relays—37.5-ohm relays, for instance—in place of the usual 150-ohm relays. During wet weather and on all poorly insulated long lines with many relays in one circuit, there is considerable advantage in the use of the lower resistance relays, in spite of the fact that the expenditure of a great deal more electrical energy, at the expense of more cells and the consumption of more battery material, is required. The idea

is to expend a greater proportion of the total energy in the line where it can supply the unavoidable leakage losses without reducing the current in the relays too much. The use and advantage of low-resistance relays on long, heavily loaded lines can be better explained after the working efficiency of the line has been treated.

148. To obtain the number of cells in series and in parallel, and the total number of cells to satisfy the condition that the resistance of all relays shall equal the combined resistance of the line and battery, we must make

$$\frac{s\,b}{p} + l = r,$$

then $$s = \frac{(r-l)p}{b},$$

but $$p = \frac{N}{s};$$

hence, $$s = \sqrt{\frac{N(r-l)}{b}}. \qquad \textbf{(17.)}$$

By substituting r for $\frac{s\,b}{p} + l$ in formula **11**, we get another expression for s, namely

$$s = \frac{2\,C\,r}{e}. \qquad \textbf{(18.)}$$

Substituting these two different expressions for s in $s\,p = N$, we get two formulas for p, namely

$$p = \sqrt{\frac{N\,b}{(r-l)}}, \qquad \textbf{(19.)}$$

and $$p = \frac{N\,e}{2\,C\,r}. \qquad \textbf{(20.)}$$

By substituting for s, in formula **18**, the value found for it in formula **17**, we get

$$C = \frac{e}{2\,r}\sqrt{\frac{N(r-l)}{b}}. \qquad \textbf{(21.)}$$

EXAMPLE.—It is required to send $\frac{1}{4}$ of an ampere through two 20-ohm magnets and a line whose resistance is 30 ohms. The cells to be used have an electromotive force of 1 volt and an internal resistance of 2 ohms per cell. How many cells will be necessary, and how arranged in series and parallel, in order that half the energy may be expended in the relays?

SOLUTION.—By solving formula **21** for N and substituting the values given in the example, we get

$$N = \frac{4 \times (\frac{1}{4})^2 \times (40)^2 \times 2}{1 \times (40 - 30)} = 80 \text{ cells.}$$

By formulas **17** and **9**,

$$s = \sqrt{\frac{80 \times (40 - 30)}{2}} = 20,$$

and

$$p = \frac{80}{20} = 4.$$

Therefore, 80 cells will be required, arranged in 4 parallel rows of 20 cells each in series. Ans.

If arranged so that half the energy is wasted in the battery, one set of 35 cells connected in series would be sufficient. A set so arranged, however, would not last near so long. Considering the first cost of the additional cells and the extra room required for them would perhaps make the arrangement requiring the 35 cells more desirable in this case than that requiring the 80 cells.

149. In the case of very long lines, and especially when such long lines have comparatively few relays in their circuits, it is not feasible to make the combined internal and line resistance equal to that of all the relays, for relays of impractically high resistance would be required in order to make $B + l = r$.

Thus, if l is very large, it may be practically impossible to make r equal to l, much less equal to $B + l$. Furthermore, in such a case, the internal resistance of the battery B, even with all the cells in series, would generally be a negligible quantity compared with l. So that in the case of long or high-resistance lines, the cells must all be connected in a one-series set.

150. A general solution for the best arrangement of primary cells in all cases would be too complicated, even if

possible. To determine the best arrangement, the formulas already given must be used with discretion and not blindly. On submarine cables and very long lines, the resistance of the line circuit is already so large that connecting the cells in series does not appreciably increase the total resistance.

TELEGRAPH LINES SUPPLIED FROM ONE BATTERY.

151. When primary cells that have an appreciable internal resistance, such as gravity cells, are used, no more than one or two or possibly three lines should be connected to the same set of cells. The more lines that are connected to the same battery, the more will the current in one line vary as the other circuits are opened and closed. Thus, with many lines connected to one battery, the current in one line may fluctuate so much, when the keys in the other lines are opened and closed, as to operate the relay in the first-mentioned line.

With dynamos and storage cells, the number of lines that may be supplied from the same source is limited only by the output capacity of the dynamo or storage battery. The reason for this lies in the fact that the internal resistance of dynamos and storage cells is extremely small, and especially so in comparison with the resistance of the line circuits.

152. Several Lines Supplied by the Same Battery.—Let us consider a general case, as shown in Fig. 41, in which there are three circuits of resistances, x, y, and z ohms, respectively, joined at a common point T and connected to one battery B, consisting of s cells joined together in series.

Let the electromotive force and internal resistance per cell be e volts and b ohms, respectively, and the currents in x, y, and z be C_x, C_y, and C_z amperes, respectively. The current in each branch circuit, when *the other two are open*, will be given by the following formulas:

$$C_x = \frac{s\,e}{s\,b + x}. \qquad \textbf{(22.)}$$

$$C_y = \frac{s\,e}{s\,b + y}.$$

$$C_z = \frac{s\,e}{s\,b + z}.$$

When all three circuits are closed at the same time, the total current flowing out of the battery will be

$$C'_x + C'_y + C'_z = \frac{s\,e}{s\,b + \left(\dfrac{1}{\dfrac{1}{x} + \dfrac{1}{y} + \dfrac{1}{z}}\right)}$$

$$= \frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}.$$

Then the current in each branch circuit, *when all three circuits are closed*, will be given by the following formulas:

$$C'_x = \left(\frac{y\,z}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right). \qquad \textbf{(23.)}$$

$$C'_y = \left(\frac{x\,z}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right).$$

$$C'_z = \left(\frac{x\,y}{x\,y + x\,z + y\,z}\right)\left(\frac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}\right).$$

NOTE.—A current will divide among the various paths between two points inversely as the resistances of the paths; hence, formula **23** follows from the proportion

current in 1 branch		total current		total resistance		resistance of 1 branch
C'_x	:	$\dfrac{s\,e}{s\,b + \dfrac{x\,y\,z}{x\,y + x\,z + y\,z}}$	=	$\dfrac{x\,y\,z}{x\,y + x\,z + y\,z}$	:	x

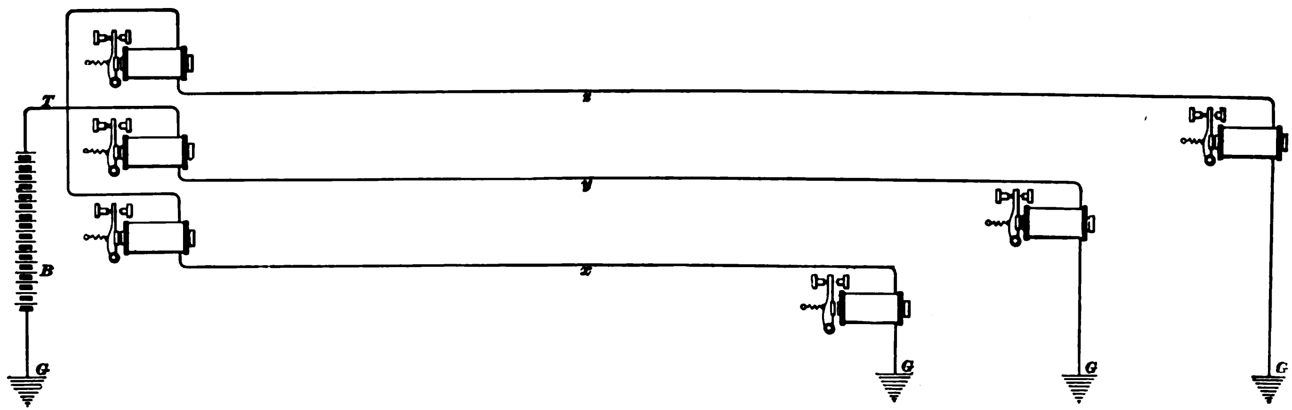


FIG. 41.

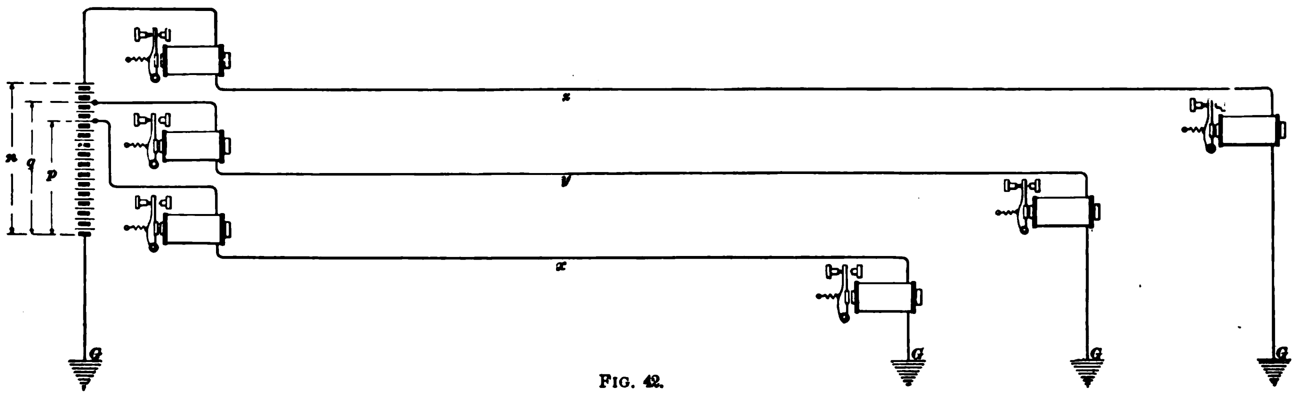


FIG. 42.

153. Now, it is desirable that the strength of the current in any line shall not change too much as the other circuits are opened and closed. In other words, it is desirable to have $C_x = C'_x$, $C_y = C'_y$, and $C_z = C'_z$, or the differences $C_x - C'_x$, $C_y - C'_y$, and $C_z - C'_z$ so small that they will not cause serious trouble in any of the circuits. Evidently, as b or $s\,b$ approaches zero, that is, becomes smaller and smaller, the value for C'_x given in formula **23** approaches that given for C_x in formula **22**, and, when b becomes zero, $C_x = C'_x$, $C_y = C'_y$, and $C_z = C'_z$. Consequently, when $b = 0$, the strength of the current in any one line will remain the same theoretically, no matter how many circuits are joined in parallel with it. In other words, when two or more circuits are connected in parallel with each other, and all are joined to the same terminal of one battery, the current in any line is unaffected when one or all the other circuits are opened or closed, *only* when the internal resistance of the battery is zero, or infinitely small in comparison with that of the several parallel circuits. And the larger $s\,b$ becomes in comparison with the external resistance, the more will the current strength in any one circuit fluctuate as one or all the other parallel circuits are opened or closed.

154. If cells having an appreciable internal resistance are in use, then, increasing the number of cells in series as the number of parallel circuits to be worked by this one battery is increased, is not the correct thing to do. For, while the total external resistance is being decreased by the addition of parallel circuits, the internal resistance is being increased by the addition of more cells in series, and, consequently, the strength of the current in any one line will fluctuate more than ever as the other circuits joined in parallel with it are opened and closed. It would be better to decrease the internal resistance of the whole battery by increasing the number of parallel rows of cells, and not by increasing the number of cells in series.

EXAMPLE.—There are three line circuits, having resistances of 3,000, 3,500, and 4,000 ohms, respectively, to be supplied from one battery.

Gravity cells having an electromotive force of 1 volt and an internal resistance of 2 ohms per cell are to be used. What will be the number of cells required to give .05 ampere in the 4,000-ohm circuit when it alone is closed? What will be the current in the 4,000-ohm circuit when the other two circuits are also closed?

SOLUTION.—The number of cells required to supply .05 ampere to the 4,000-ohm circuit when it alone is closed can be determined by substituting the values given in the example in formula **22,** and then solving for *s*. Doing this, we get

$$.05 = \frac{s}{2\,s + 4{,}000},$$

from which $s = 222$ cells. Ans..

When all three circuits are closed, the current in the 4,000-ohm circuit will be given by formula **23.**

$$C'_x = \left(\frac{3{,}000 \times 3{,}500}{4{,}000 \times 3{,}500 + 4{,}000 \times 3{,}000 + 3{,}500 \times 3{,}000}\right) \times$$

$$\left(\frac{222}{444 + \dfrac{4{,}000 \times 3{,}500 \times 3{,}000}{4{,}000 \times 3{,}500 + 4{,}000 \times 3{,}000 + 3{,}500 \times 3{,}000}}\right) = .040 \text{ ampere. Ans.}$$

When, therefore, the other two circuits are also closed, the current in the 4,000-ohm circuit decreases from .05 to .04, or 20 per cent.

It would be best to employ separate batteries in such a case, but the example has been worked out in order to show how much the current will decrease in the one line after the other two circuits are closed.

155. To Obtain the Same Current in Each Branch Circuit.—Where there are a number of line circuits using the same resistance relays, about the same current is needed in each circuit. Where the several lines are joined to the same terminal of the same battery, this can only be obtained by inserting enough extra resistances, in all but the one having the highest resistance, to make the resistances of all equal. When several lines must be worked from the same pole of the same battery, the current in one line will fluctuate less if all the circuits have the same resistance.

EXAMPLE.—Taking the same circuit as in the preceding example, suppose we desire to have .0416 ampere in each circuit when all three are closed. How many cells will be required in a one-series set,

and what will be the current in one circuit when only that one circuit is closed, and by what per cent. will the current change in value?

SOLUTION.—There must be inserted in the 3,000-ohm circuit 1,000 ohms, and in the 3,500-ohm circuit 500 ohms, in order to bring each up to 4,000 ohms. The number of cells s required may be determined by substituting in formula **23** the values given and solving for s.

$$.0416 = \frac{1}{3}\left(\frac{s}{2s + \frac{4,000}{3}}\right),$$

from which $s = 222$ cells. Ans.

When only one circuit is closed, the current in that circuit will be

$$C_x = \frac{222}{444 + 4,000} = .05 \text{ ampere. Ans.}$$

The current in one line has therefore changed about 17 per cent. instead of 20 per cent., as in the preceding example. This smaller change in the current is due to the fact that the combined resistance of the three lines in parallel is greater in the last example, and, therefore, the internal resistance of the battery is a smaller proportion of the whole resistance. Ans.

156. A better way in which to connect the three lines to one common battery would be to connect the 4,000-ohm line across the whole battery, and the 3,500- and 3,000-ohm lines at such intermediate points as would give the necessary electromotive force to supply the current desired in each branch circuit. Fig. 42 shows three lines arranged in this manner.

157. The expressions given in Art. **152** for the currents C_x, C_y, and C_z in each circuit *when the other two circuits are open*, may be put into the following form, in which p, q, and n represent the number of cells between each line and the ground.

$$C_x = \frac{e}{b + \frac{x}{p}}.$$

$$C_y = \frac{e}{b + \frac{y}{q}}.$$

$$C_z = \frac{e}{b + \frac{z}{n}}.$$

From these equations, it is evident that $C_x = C_y = C_z$, when $\frac{x}{p} = \frac{y}{q} = \frac{z}{n}$. Therefore, if an equal current is wanted in each line circuit, the lines must be joined to the battery at such points that the relation $\frac{x}{p} = \frac{y}{q} = \frac{z}{n}$ is satisfied. In other words, if the same current is wanted in each circuit, the lines should be attached to the battery at such points that the number of cells by which a line is worked has the same relation to the resistance of that line as the whole number of cells has to the resistance of the longest line.

EXAMPLE.—In the case of three line circuits having resistances of 3,000, 3,500, and 4,000 ohms, respectively, at what points in one common battery of 222 cells should the circuits be joined in order to have the same current in any one when the other two circuits are open? The longest line (4,000 ohms) is to be connected across all the cells.

SOLUTION.—The lines must be joined to the battery at such points that the relation $\frac{x}{p} = \frac{y}{q} = \frac{z}{n}$ shall be satisfied. Then we have

$$\frac{3{,}000}{p} = \frac{3{,}500}{q} = \frac{4{,}000}{222}.$$

By solving this we get $q = 194$ and $p = 167$. That is, between the ground and the circuit x, there must be 167 cells, and between the ground and the circuit y, 194 cells. Ans.

NOTE.—The expressions for the current in each circuit in Fig. 42 when all three circuits are closed are very complicated, and the problem has no practical value. Consequently, for this case, no expressions for the current in each circuit have been given.

158. Effect of Leakage.—Theoretically, the arrangement indicated in the example in Art. **157** is correct, but there is more leakage on the longer lines; that is, a larger percentage of the current that starts on the longer line leaks to the ground without going through the distant relay where the battery is all at one end, or through the middle of the line in case one-half the battery is at each end. Consequently, the longer the line, the larger must be the current from the battery, in order to have the desired current at a certain distant place, and, hence, the electromotive force on the longer lines must be somewhat greater to make up for the increased leakage. That is, if we made p and n to

satisfy the equation $\frac{x}{p} = \frac{z}{n}$, and there was much more leakage on the line z than on x, then, practically, n would be too small compared to p, and the currents in the two lines would not be equal at certain distant points on the two circuits, as intended.

EXAMPLE.—A telegraph circuit of 4,000 ohms resistance is supplied with current from 222 cells connected in a one-series set at one end of the line. Assume the electromotive force and internal resistance per cell to be 1 volt and 2 ohms, respectively. (*a*) What will be the current when there is no leakage? (*b*) What will be the current when only 70 per cent. of the total current reaches the far end? (*c*) What will be the percentage increase in the total current and the percentage decrease in the current at the far end when the leakage increases so that only 70 instead of 100 per cent. of the current reaches the distant office?

SOLUTION.—(*a*) When there is no leakage, the current throughout the circuit will be $\frac{222}{444 + 4,000} = .05$ ampere. Ans. (*b*) The leakage path is a circuit in parallel with more or less of the line circuit, and we will assume it to be in parallel with the whole line circuit. Then, according to the law for branch circuits, the resistances of the leakage path and line circuit will be to each other inversely as the currents through each. Hence, the resistance of the leakage path will be $\frac{70}{30}$ of 4,000, which is $\frac{28,000}{3}$ ohms. The total resistance of the circuit is equal to $\dfrac{\frac{28,000}{3} \times 4,000}{\frac{28,000}{3} + 4,000} + 444 = 3,244$ ohms. Then, 70 per cent. of the total current is equal to $\frac{7}{10}\left(\frac{222}{3,244}\right) = .0445$ ampere. Ans. (*c*) The total current is equal to $\frac{222}{3,244} = .0684$ ampere. Thus, the total current, .0684, is 37 per cent. greater than .05, but, nevertheless, the current through the distant relay, .0445, is 11 per cent. less than the current, .05, when there was no leakage. Ans.

159. The preceding articles show how necessary it is to employ cells of low internal resistance where one battery is used to supply more than one or two lines, if we wish to avoid a fluctuating current in each line circuit as the others are opened and closed. The internal resistance may be reduced by coupling more cells in parallel, or by using cells

having a lower internal resistance. For the latter reason, one of the great advantages of storage batteries and dynamos for supplying current to a large number of telegraph circuits is apparent. Furthermore, during wet weather, the resistance of all the lines may not only decrease considerably, but some may decrease a great deal more than others. Consequently, if several lines are supplied from one battery having an appreciable internal resistance, and if the leakage current on one line increases more in proportion than on the others, due to wet weather, partial grounds, or crosses, then the division of the current among the several branch circuits will be greatly altered, especially when the resistance of the line on which there is most leakage is small. The variation in the current in the good lines will be proportional to the amount of leakage on the defective lines. When the leakage on several lines is not about proportional to their lengths, those on which the leakage is extra large should be worked by separate batteries.

CIRCUIT ACCESSORIES.

160. Before taking up storage batteries, dynamos, and the more complex systems of telegraphy, *protective devices*, and *intermediate* and *main-line switches* will be considered.

LIGHTNING ARRESTERS.

161. A **lightning arrester** is a device designed to protect telegraph offices and their instruments from injury, during lightning storms, due to atmospheric electricity, which, when it charges or strikes the line wires, follows them into the offices. If unprotected, the fine-wire coils of instruments would often be burned out, and the operators might also be injured, fatally or otherwise.

162. The Point, or Saw-Tooth, Arrester. — The simplest form of arrester, but one whose efficiency is much to

be doubted, is the so-called point, or saw-tooth, arrester, one of which is shown in Fig. 43. Part of the adjacent surfaces is made in saw-tooth form, with the intention of facilitating the passage of the spark across the gap. For this reason, this form is called the **saw-tooth lightning arrester.**

In this, the line wires a' and b' are attached to the upper binding posts on the plates y and z, respectively, and the wires a and b leading to the local instruments are attached to the lower posts on the same plates. The center plate p is grounded by the wire g. The circuit is thus normally complete through the instruments, but, if a plug is inserted in x, the line will still be continuous, but the instruments will be cut out. This is the condition in which the office should be left while the operator is away. A ground may be thrown on either side of the line by placing the plug in one of the holes at the right- or left-hand side of the ground plate.

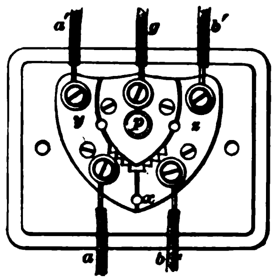


FIG. 43.

163. Action of Lightning Arresters.—The resistance offered by the air gap between the plates y or z and p is the same for alternating currents of high or low frequency as it is for steady direct currents. Now, lightning discharges are oscillatory in character, that is, the current surges back and forth thousands of times per second. A coil of wire, especially when wound on an iron core, has an apparent resistance that is enormously greater for such an oscillatory current than for a steady direct one. The excess resistance that a coil of wire offers to an alternating current over a direct current is due to that property of the coil called its *inductance*. Inductance, or the coefficient of self-induction, as it is also called, is usually denoted by the letter L. For a given coil and a given intensity of the magnetic flux, L is constant, but the apparent resistance opposing the current increases rapidly as the number of alternations of the current per second increases. That is, the higher the frequency of

alternation, the greater will be the so-called apparent resistance of the coil of wire.

To a steady direct current, the resistance of a given circuit is found by Ohm's law to be $R = \frac{E}{C}$. But when E and C are alternating in character, the relation between E and C will have so changed that the quotient $\frac{E}{C}$ will no longer give the same value for the resistance as found above, but will give some other value, which we will call Z. It has been shown in treatises on alternating currents, and is a well-recognized fact, that for a simple alternating current the value of Z may be found from the following formula:

$$Z = \sqrt{R^2 + (2\pi n L)^2}, \qquad \textbf{(24.)}$$

in which R = ordinary resistance that the circuit would offer to a steady direct current;
L = inductance of the circuit;
π = 3.1416;
n = the frequency.

The frequency is the number of complete cycles per second, or twice the number of alternations per second. This quantity $\sqrt{R^2 + (2\pi n L)^2}$ is called the *impedance* of the circuit whose simple resistance is R and whose inductance is L for an alternating current whose frequency is n. The value of this expression evidently increases if any one of the quantities R, n, or L increases, and, conversely, decreases if any one of them decreases. For a lightning discharge, n is very large, but, for an air gap, even if the air space is replaced with mica or any insulating material, L is zero. Consequently, the impedance of the air gap is always equal to R, no matter how large n is, because $2\pi n L$ is zero when L is zero. Therefore, $\sqrt{R^2 + (2\pi n L)^2} = R$ when $L = 0$. But for the coils on the instrument, L has an appreciable value; it may amount to 5 henrys or even more. (A *henry* is the name of the unit in which the inductance of a coil or circuit is expressed.) Consequently, when n has a very large value and L is not too small, the value of

$\sqrt{R^2 + (2\pi n L)^2}$ will be very large, and, as a matter of fact, n is large enough in lightning discharges to make the value of R^2 generally insignificant compared to $(2\pi n L)^2$. Therefore, for a lightning discharge for which n is very large, the impedance of the air gap remains equal to R, because L is zero, as already stated; but the impedance of the coils of wire on the instruments increases so much in value that the air gap becomes, for a lightning discharge, a path of low resistance in comparison with it, and, consequently, since a current will always take the easiest path, the discharge will jump the air gap in its effort to reach the ground in preference to going through the coils on the instruments.

164. This is a very fortunate property of lightning, for, if it were compelled to go through a coil to earth, it would invariably burn out the fine wire in the coil and also ground the coil to the iron core. It would thus ruin the coil, and, in its effort to reach the ground, probably do a great deal more damage.

Direct- and low-frequency currents will not jump the air gaps between any of the plates, because the difference of potential is not usually great enough, and because to them the coils offer an easier path. The electromotive forces of lighting and power circuits ordinarily in use, and against which the telegraph wire may come into contact, are not usually high enough to start an arc across the air gap.

165. Plate Arrester.—This form of arrester is largely used in this country, and is built in a great variety of forms. That shown in Fig. 44 consists of a large plate *g* connected to the ground *G*. On top of this plate, but separated and insulated from it by thin paraffined paper, are the line plates *a*, *b*, and *c*, to which the line wires *d*, *h*, and *j*, and the instrument wires *l*, *i*, and *k*, are attached by means of the binding posts, as shown. The lightning discharge will jump from the line plate through the paraffined paper to the ground plate and escape to earth. In doing so, it punctures the paper. Mica is also used, and it is the best form of insulation between the plates, as it may be divided into

sheets of extreme thinness, and, moreover, it does not carbonize under the effect of sparking. Where paper is used, it should be renewed after every lightning storm.

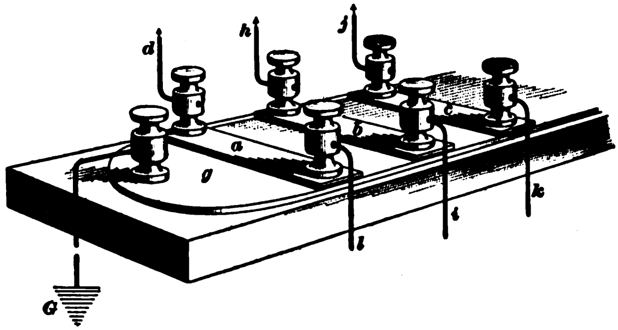


FIG. 44.

166. Button-Plate Arrester.—In Fig. 45 is illustrated a convenient form of arrester, called the **button-plate arrester.** The arrester is shown as it is mounted at the top of a way-station switch. In the lower part of the figure is shown a cross-section through the center of the buttons *d*, *d*. The metallic disks or buttons *d*, *d* overlap on the front of the board the vertical straps *a*, *a*, *a*, *a*, to which the line wires are attached, but are insulated from them by paraffined paper or thin pieces of mica. These buttons have screws that pass through the board and into a grounded plate *g* on the back of the board.

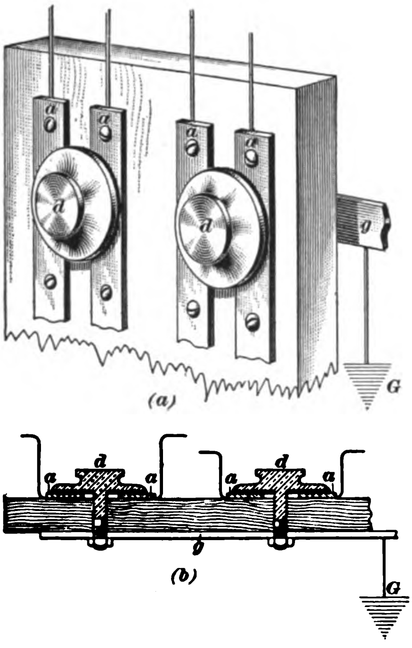


FIG. 45.

This grounded plate runs horizontally the length of the board, so that all buttons screw into the same plate. A convenient feature about this device is the ease with which the distance between the line plates and the grounded buttons *d*, *d* can be adjusted and the buttons removed for cleaning and for the insertion of fresh paraffined paper or mica washers between them and the line plates *a*. A lightning charge coming in over a line will jump from the vertical line strap, through the thin insulating washer, to the button, and then pass to earth *G* through the grounded plate on the back of the board.

167. After lightning storms, it is always well to examine the lightning arresters and to repair any damage that may have happened to them. If a lightning arrester that has a thin piece of paper between the ground and line plates is in use, the paper should be renewed, even if no damage is apparent, for the paper may be invisibly punctured and carbonized at or around such punctures, thus forming more or less of a ground between the plates. With saw-tooth and plate arresters, the lightning sometimes not only jumps the air gap, but also goes through the coils.

168. Quadruplex Lightning Arrester.—Fig. 46 shows another form of lightning arrester used to protect quadruplex apparatus. It is known as the **Bunnell quadruplex lightning arrester,** and is used in addition to the ordinary fuse and plate arresters in the line circuit. This arrester is placed directly on the desk with the quadruplex apparatus. The various parts of the arrester are mounted on a wood or hard-rubber base. To the binding posts *a* and *b* are connected, respectively, the line wire and the wire leading to the quadruplex apparatus. The binding posts stand on plates that have serrated

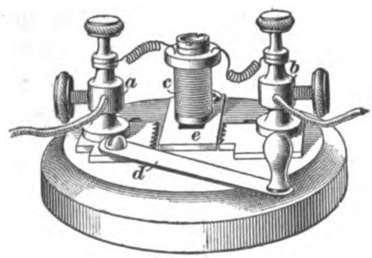


FIG. 46.

edges close to the grounded plate *e*, thus forming a saw-tooth lightning arrester. In addition, there is a short coil *c* of insulated wire, wound on a hollow metal cylinder that fits over another metal cylinder joined to or forming one piece with the plate *e*.

If a lightning discharge reaches the coil, it may jump across from the serrated edges of the binding-post plate to the ground plate. It may also melt the fine wire with which the coil is wound, and open the circuit. But the chances are that it will also fuse the fine wire to the metal cylinder in its attempt to reach the ground, thus forming an easy or very low-resistance path to earth for the discharge. The fine-wire coil is, of course, destroyed, but the switch *d* may be immediately closed to prevent any serious delay in the work on the line. The burned-out bobbin, or coil, is replaced by a new one as soon as convenient. New ones are kept on hand for this purpose.

PROTECTING DEVICES.

169. For protection against comparatively low tension currents, the above arresters are useless, and some other form of protecting device is necessary. Fuses or other protecting devices are therefore used to protect the apparatus from the damaging effects of heavy currents that will flow through the circuit when a telegraph line becomes crossed with some electric-light or power wire.

170. Magnetic Protecting Device.—In Fig. 47 is shown a protecting device called a **magnetic protector,** designed to open the line circuit if the current exceeds a certain strength. The line wire is brought to the binding post *a* and the telegraph instrument is connected to the binding post *d*. The circuit between these two binding posts is completed by the brass arm *b*, which is hinged at *n*, the armature lever *c*, hinged at *o*, and the magnet coil *m*. *s* is a tension and *r* a compression spring. The spring *r* tends to push the arm *b* away from *c*. The spring *s* is so

adjusted that the normal pull of the magnet on the armature is not sufficient to make the catch *c* release the arm *b*, and, consequently, the circuit is normally kept closed between the armature lever and the arm *b* at the catch *c*. But a current over a certain strength flowing through the coil *m* is able to pull the armature down, causing the catch *c*

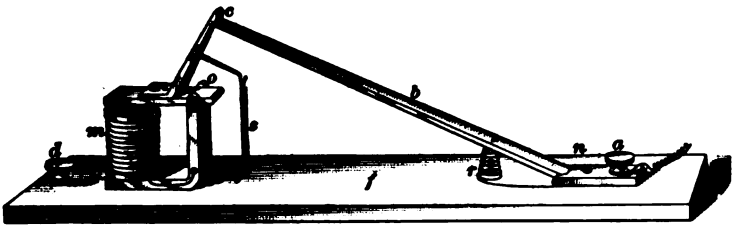


FIG. 47.

to release the lever *b*, which then flies up, owing to the pressure of the spring *r* on it. The circuit is thus broken suddenly, and a wide gap is made between the arm *b* and the catch *c*, across which it is impossible for an arc to continue. Consequently, if the device has acted promptly enough, the telegraph instruments will be protected from injury.

171. Fuses.—Fuses can generally be depended on to melt and open the line circuit, if the current exceeds for a short time a certain maximum value. For telegraph circuits, it is desirable that fuses should be melted by about 1 ampere. The larger the current above the limiting value, the quicker the fuse will melt.

When a simple fuse melts, it merely opens the line circuit and does not ground it, and, consequently, a fuse cannot be considered a lightning arrester unless it is arranged in some manner to automatically ground the line when it melts. For protection against crosses it is fairly satisfactory, though it should not be relied on as a protection against lightning, but in addition to it a plate arrester should also be used.

172. A protecting device largely used by telegraph companies consists of a small fuse block on which is mounted a very fine fuse or German silver wire about 1 to 1½ inches

long. In order to prevent the breaking of the fine fuse wire, it is usually mounted on a thin fiber, or mica, strip, on the ends of which are fastened, by rivets or otherwise, thin metal terminals. The fine wire is soldered to the metal terminals. These thin metal terminals are generally made of German silver, brass, or copper, and of such a shape (see *d* and *e*, Fig. 48) that they may be readily slid between the

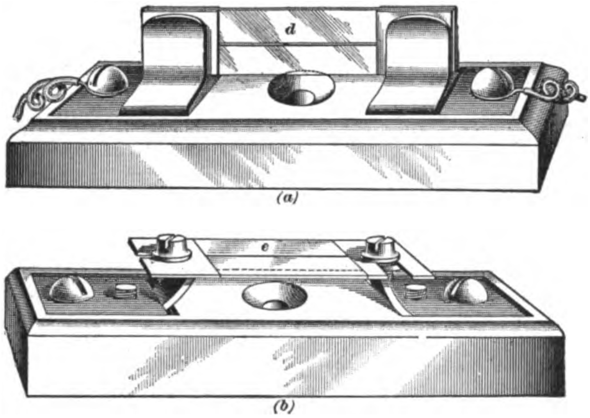


FIG. 48.

clips or under the screws of the fuse blocks. In Fig. 48 (*a*) and (*b*) are shown two slightly different forms of fuse blocks. In Fig. 49 is shown the form of office fuse used by the Postal Telegraph Company at the cable heads, that is, where the wires emerge from the underground street cables. This fuse is rated at 1 ampere, and is made of German silver wire. The ratings of fuses, especially soft alloy fuses, are not very reliable, and it is not an unusual thing for a fuse to carry a current considerably over its rated capacity. Fine

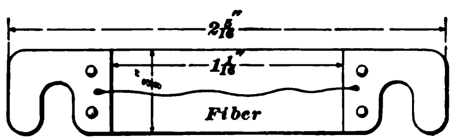


FIG. 49.

German silver and copper fuses are more reliable than alloy fuses, but such fine wire is required that it is easily broken and hard to fasten properly in place.

173. Western Union Fuse Protector.—The protecting devices used on the main lines by the Western Union Telegraph Company consist of a short piece of No. 20 fuse wire, around one end of which is wound a number of turns of No. 30 silk-covered German silver wire. If the current through the German silver wire becomes abnormally large, the heat developed by the coil and in the fuse wire itself combines to melt the fuse wire and thus open the circuit. It is said to be capable of such accurate adjustment that it will open the circuit on any desired current with great certainty. For the main lines, these protecting devices are adjusted to open the circuits if the current exceeds $\frac{3}{4}$ ampere.

174. In Fig. 50 is shown a fuse of the kind just described, but mounted on a separable fuse holder made of fiber, with round brass end pieces that fit into corresponding holes in the binding-screw terminals. These terminals are mounted on a porcelain base. The fuse holder in this make

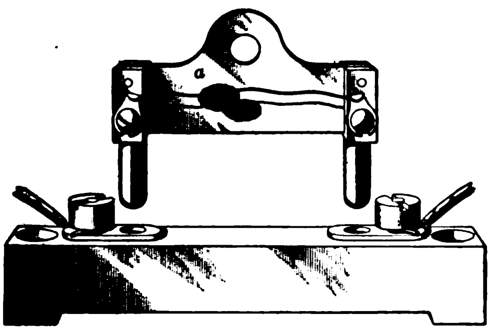


Fig. 50.

takes a fuse $1\frac{1}{2}$ inches long. A coil of insulated German silver wire *a* is wrapped about a portion of the fuse and included in the circuit in series with the fuse. When a fuse melts, the fuse holder can be quickly removed and replaced by a good one.

175. Enclosed Cable Fuse.—A fuse protector that is extensively used by telephone companies for protecting

the wires in their underground cables from excessive currents, which are caused by crosses on the open overhead lines beyond the cables, is shown in Fig. 51. It consists of a hollow cylinder of enameled wood or fiber, about 4 inches long and ½ inch in diameter, to the ends of which are secured metal terminals of the form shown in the figure. The fuse is inside the tube and has one end soldered to each terminal. The tube prevents the scattering of the melted

FIG. 51.

metal. The tube is entirely closed, thus protecting the fuse from air-currents and making it operate more uniformly by the current for which it was designed to melt. For telephone circuits, a fuse that will be melted by 5 amperes is commonly used. There is no reason why this should not prove an excellent form for protecting telegraph cables where they join overhead pole lines, as well as for telephone cables.

176. As fuses frequently allow lightning currents to pass through without melting them, they cannot alone be depended on to afford protection. The fuse and the plate, or *static arrester*, as the latter is often called, are often combined in one apparatus.

COMBINED STATIC AND FUSIBLE ARRESTERS.

177. In Fig. 52 is shown a **combined lightning arrester** and **fusible cut-out.** The usual grounded plate *o* is separated from the line plate *a* by paraffined paper or mica. The line plate *a* has fastened to it a binding post *b*, and a similar binding post *d* is fastened to the dry wood base *B*, which insulates it from other parts of the apparatus. By securing the fine fuse wire *c* in the binding posts in the manner shown in the figure, it is not damaged as it would be if

fastened in the same holes with the other wires. If a lightning charge comes along the wire *l*, it will jump from the plate *a* to the ground plate *o*, and it may also melt the fuse. If the line becomes crossed with a lighting or power circuit whose potential is not high enough to start an arc between the line and ground plates, it may still cause an injuriously large

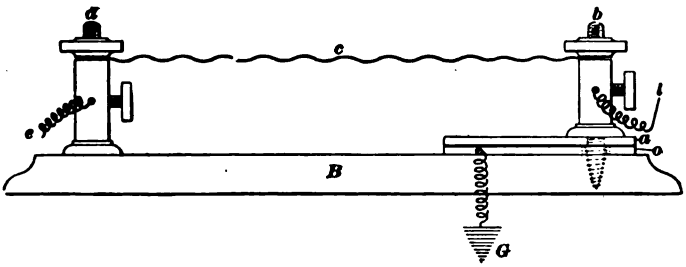


FIG. 52.

current to flow through the regular circuit, and the fuse is adjusted to melt when the current reaches such a value as would be injurious to the telegraph instruments. A No. 33 to No. 35 B. & S. bare German silver wire is commonly used as a fuse wire in this type of protector.

178. In Fig. 53 is shown an arrester designed to give protection from both low- and high-tension currents. It is

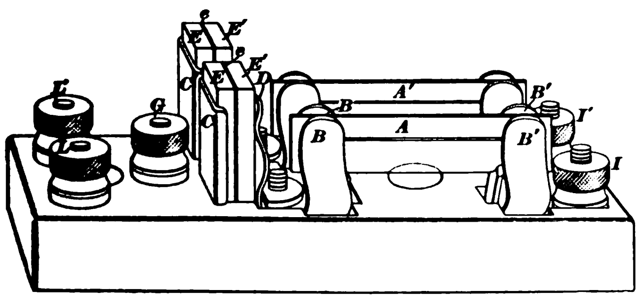


FIG. 53.

used in telephone circuits and should also prove useful in telegraph circuits. This one is for two line circuits. The fuses are mounted on mica strips *A*, *A'*, which are held in

place between the metallic clips *B*, *B* and *B'*, *B'*. *C*, *C'* are upright strips of brass permanently connected to the binding post *G*, which is grounded. Between the clip *C* and the upright spring *D*, which latter is in metallic connection with the fuse clips *B*, *B*, and also with the binding post *L*, are placed two carbon blocks *E* and *E'*, held apart by a thin strip of mica *e*. This strip of mica often has a small piece cut out of it near its center, in order to allow the arc between the two carbons to start a little easier and to permanently ground the carbon *E'* by fusing it to the grounded carbon *E*. This may not be quite so desirable in a telegraph circuit. The line wire should be attached to *L*, and the wire going to the telegraph apparatus or switchboard to *I*. *L'* and *I'* are the binding posts for another line circuit.

The normal circuit through this arrester is from the post *L* to the clips *B*, *B*, then through the fuse wire to the clips *B'*, *B'*, and to the binding post *I*. A current of sufficient strength will melt the fuse on *A* and open the circuit. If the current is of sufficiently high voltage, it will jump across the small gap between the two carbon blocks *E*, *E'* formed by the mica strip *e*, and pass to the plate *C* and thence through the binding post *G* to ground. The carbon blocks can be easily and quickly slipped out, cleaned or repaired, and returned to their places, or new ones substituted.

179. Rolfe Protector.—Fig. 54 shows a form of arrester or strong-current protector invented by Mr. C. A. Rolfe, of Chicago. *a* and *b* are the terminal screws to which the line and the switchboard or instrument wires are joined. On the insulating strip *f*, usually made of fiber, are fastened the metal ends *d* and *c*. A coil *e*, called a *heat coil*, an enlarged view of which is shown to the right, consists of a small coil of fine German silver wire embedded in a mass of some easily fusible substance resembling plumber's wax. The small end of the embedded coil extends through a ring *n*, which is fastened to the fiber strip *f*. The head of the coil,

or ***button***, as it is sometimes called, is held against the ring *n* by the spring *s*, the spring and button being hooked together at *r*. The terminals of the heat coil *e* are attached by small

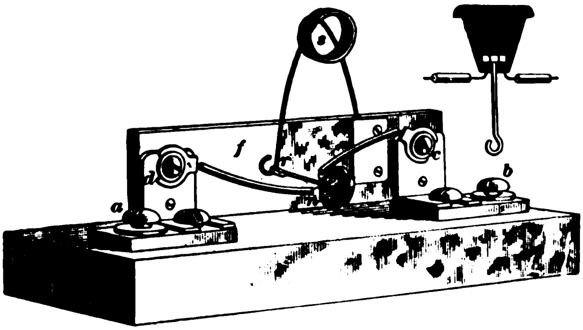


FIG. 54.

screws and washers to the metal end pieces *d* and *c*. The wires leading to the coil are shown covered with a very small rubber tube, this being a convenient and good way to insulate them.

When an unduly strong current passes through the fine German silver coil, enough heat is generated to soften the fusible material, and the spring *s*, pulling the coil through the ring *n*, flies upwards and breaks the wire forming the

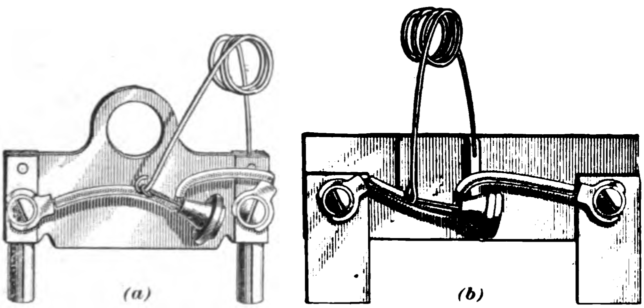


FIG. 55.

coil, thereby making a wide gap in the circuit. These coils can be made quite uniform and are guaranteed by the maker to operate within 30 seconds with a rated load. The

heat-coil holder, as the fiber strip *f* is called, is removable, so that it can be replaced or refitted with a new heat coil after the device has operated.

In Fig. 55 are shown two forms of heat-coil holders, but quite a variety has been designed in order that they may be applied to the various forms of fuse holders already in use. (*a*) will fit into the porcelain base shown in Fig. 50, and (*b*) into the base of (*a*), Fig. 48.

The Rolfe protector is coming into use somewhat on fire, police, and telephone systems.

180. Rolfe Static- and Strong-Current Protector.—A sectional view of this protector is shown in Fig. 56. The heat coil *h*, made of fine German silver wire, is embedded in an easily fusible composition. The *button*, as it is called, rests, as shown, in the center of a hard-rubber piece *t*. Two pieces of carbon *f* and *e* are separated only by a thin layer of a special insulating paint, and not by an air gap, mica, or silk, as is usually done in other makes. The rectangular block of carbon *e* is grounded, and the carbon *f*, which is cylindrical in shape, is connected by a flat German silver strip to the binding post *m* and through the split brass leg or spindle *o* with one line-wire binding nut beneath

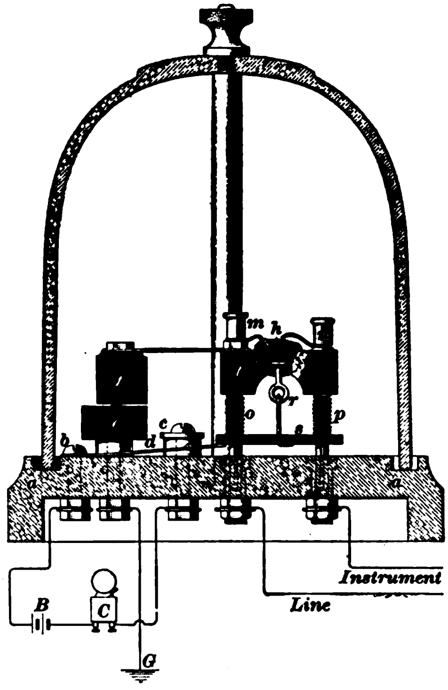


FIG. 56.

the porcelain base. The legs *o* and *p* are surrounded with strong spiral springs tending to push *s* and *t* apart.

The protector operates in the following manner: If a lightning discharge or a current, at a potential over 2,000 volts, comes in over the line, it passes through *o*, *m*, *f*, jumps across to *e*, and goes to ground *G*. From the line wire, the usual circuit is through *o*, *m*, the heat coil *h*, the binding post *n*, and the spindle *p* to the instrument, and to ground. If, from any such cause as a cross between the line wire and some power or lighting circuit, a current strong enough and of sufficient duration comes in over the line, the heat generated in the coil *h* will soften the composition and allow the springs at *o* and *p* to pull the piece *r* out of the composition; and, furthermore, the whole piece *t*, now being released, will be forced up and clear out of its normal position by the strong springs at *o* and *p*, leaving between the line and instrument wires a clear air gap equal in length to the distance between the instrument and the line binding nuts under the base *a a*. The line is thus opened so as to prevent the continuance of an arc across the opening, and the lightning arrester is also opened. When the piece *t* has thus sprung up out of place, the German silver spring *d* comes in contact with the metal piece *c* and thus closes a local circuit, which, if connected as shown, rings the bell *C* and calls attention to the fact that the heat coil has operated and that it needs to be replaced. The heat coil may be designed to operate with almost any reasonable strength of current. This particular form with the glass cover is made for two lines, and is used principally on private telephone circuits. For this purpose, the heat coil is made so that it will operate if acted upon by a current of $\frac{1}{4}$ ampere for 30 seconds.

SWITCHES.

181. Plug Switch.—This is a form much used, and commends itself both on account of its reliability and its simplicity. This form of switch, which is shown in Fig. 57, is made up of alternate brass plates P, P_1, etc., and rows of

brass buttons or disks B, B_1, etc. This board is erected in a vertical position, and the disks in the same horizontal row are connected together. Thus, any one wire from the horizontal side may be connected to any one on the vertical side by inserting a plug, such as is shown at M, into the proper aperture, as at N. The lower part of the plug M is of brass, and should be slotted to insure elasticity, while the upper part is of hard rubber. The circuits in a large station are all appropriately numbered, so that wires *1* and *1*, for instance, as well as *2* and *2*, may be connected together by inserting plugs at the junction of B_2 and P, and at the junction of B_1 and P_1, respectively. In order to insure a good firm connection, the plugs should always be firmly pushed into the holes with a twisting motion. The switches used in a telegraphic circuit should be substantial and all contacts must be good and firm. A loose or faulty connection at any point will often render the adjustment of the springs governing relay armatures, etc. exceedingly difficult and annoying, if not impossible.

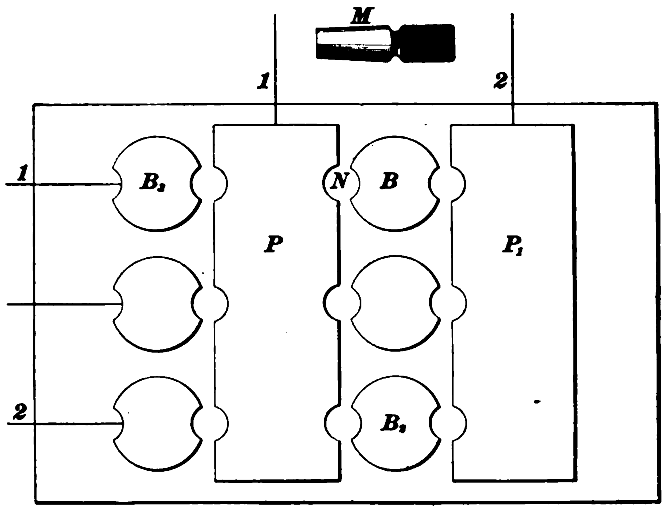


FIG. 57.

SWITCHES AT INTERMEDIATE OFFICES.

PLUG SWITCH FOR ONE MAIN LINE.

182. In Fig. 58 is shown the arrangement of apparatus at an intermediate office or way station. *K* is a plug switch adapted to make the necessary changes in connections between the east and west lines, the ground, and the instruments an easy matter. The switch is fastened to the office wall in a vertical position. The two long brass strips *e* and *f*, each of which has a binding post fastened to its upper end, are screwed to a thoroughly dry and seasoned wooden baseboard, and are insulated from each other and from all other metal parts of the switch. To the binding post on *e* is fastened the east line, and to the one on *f* the west line. The button *d* has a screw extending through the wooden base into a metal strip that is connected behind the board with the binding post *m*, and, since this binding post is connected to the ground plate *G*, then *d* is also grounded. This button *d* extends over, but is insulated from, both *e* and *f* by a thin sheet of paraffined paper or mica, thus forming a lightning arrester that has already been explained and illustrated in Fig. 45.

The small brass pieces, or disks, *a*, *b*, and *c* are connected by wires behind the board, as indicated by the dotted lines, to the binding posts *m*, *n*, and *o*, respectively. The disk *a*, being connected to the binding post *m*, is grounded; while *b* and *c*, which are connected to the binding posts *n* and *o*, respectively, and thus to the key and relay upon the table, as shown, form the terminals of these instruments on the switch. There are three plugs like *p*. The lower part of the brass plug is slotted to insure elasticity. The plugs, which, when not in use, are kept in the holes on the left side of the board, may be inserted in any of the holes *1*, *2*, *3*, *4*, *5*, *6*, *7*.

The various changes that may be made by means of the switch and plugs for different purposes will be explained in the following articles.

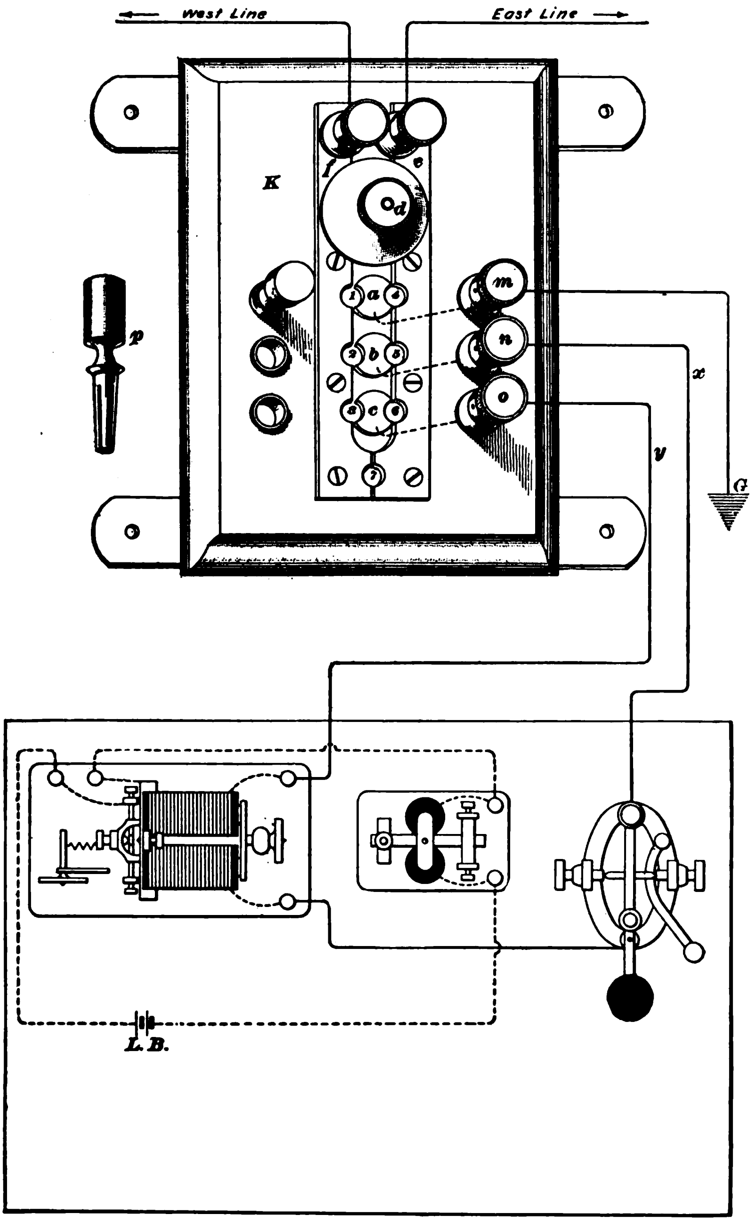


FIG. 58.

183. To Cut Out the Key and Relay.—If a plug is inserted in hole *7*, all the other holes being left open, the east and west lines are connected directly together, and the current can pass from the east to the west line, or *vice versa*, without passing through the instruments at this intermediate office. When arranged in this manner, the grounded disk *a* and the disks *b* and *c* (the terminals of the office set) are entirely disconnected from the main line. The office or desk set is then said to be cut out. When leaving the office, or during a thunder storm, the switch should be arranged in this way, so that no current can pass through this office relay.

184. To Cut In the Key and Relay.—Assuming that the east and west lines are connected together directly by a plug in hole *7*, the key and relay may be cut in without opening the main-line circuit, even for an instant. To do this, proceed as follows: Insert plugs in holes *3* and *5*, and then remove the plug from hole *7*. All holes except *3* and *5* should be open. Before removing the plug from hole *7*, see that the key is closed. The key and relay are now in series with the main line, and current from the east line, for instance, will pass down the strip *e* through the plug in hole *5* to the disk *b*, to binding post *n*, through the key and relay, to the binding post *o* and disk *c*, through the plug in hole *3* to the strip *f*, and out to the west line.

The key and relay could be cut out by putting plugs in holes *2* and *5* or *3* and *6*, instead of one plug in hole *7*. If the key and relay are cut out by plugs in *3* and *6*, then, in order to cut them in, put a plug in hole *2*, and after doing this, remove the plug from hole *3*; or put a plug in hole *5* and remove the plug from hole *6*. This is the only way to do it in that form of switch in which the strips *e* and *f* are cut off immediately below disk *c* and no connecting hole is provided at *7*.

185. To Ground Either Line.—To ground the west line alone, put a plug in hole *1*, all other plugs being removed. Similarly, to ground the east line, put a plug in hole *4*.

186. To Determine if Either Line Is Open.—In case no signals are obtained, due to an open circuit somewhere in the main line, proceed as follows to determine whether the open circuit is on the east or west line. Before doing this, however, it is well to look over the connections at the key, relay, and switch for an open circuit. If, after careful inspection, the main circuit in the office seems to be all right, then, in order to test the east line, insert plugs in the holes *1*, *3*, and *5* or in holes *1*, *2*, and *6*. This grounds the east line after having passed through the relay and key. If the east line is not open, signals can now be sent over that line. Similarly, the west line can be tested by putting plugs in holes *4*, *3*, and *5* or in holes *4*, *2*, and *6*; that is, by simply shifting the plug from hole *1* to hole *4* if this test follows the preceding one. If no signals can be obtained over either line, then both lines are open, or, what is more likely, the trouble is in the apparatus or circuit at the intermediate or way office where the test is being made.

187. To Locate an Open Circuit or Cross in the Way-Office Circuit.—If it is not certain that the office instruments and circuits are all right, put a plug in hole *7* of the switch, remove all other plugs, and then test the relay, key, and connections for an open circuit somewhere; or, perhaps, there may be a short circuit or cross in the relay coils or in the wiring. An open circuit may be tested for as follows: Disconnect the wires of the local set from the binding posts *o* and *n*, and fasten these two wires *x*, *y* to the terminals of a battery having sufficient electromotive force to send the regular working current through the relay. For instance, for a 150-ohm relay whose normal working current is 20 milliamperes, the electromotive force of the battery should be about $150 \times .02 = 3$ volts, so that three or even two gravity cells may be sufficient.

The key should then be opened and closed. If the relay is properly adjusted, no movement of the armature will indicate an open circuit somewhere, or a short circuit or cross in the relay coils, or between the two wires running to the

relay. To locate the trouble, close the key, disconnect the wire *x* from the key, and touch it first to the other terminal of the key. A movement of the relay armature would indicate that the open circuit was in the key. If there is no movement, the battery wires should be applied directly to the relay terminals. A movement of the armature would indicate that the trouble was in the wiring somewhere external to the relay. No movement would locate the trouble in the relay. In the latter case, the relay should be overhauled and repaired or a new one obtained.

188. One of the quickest ways for an operator at a way station to find out whether the opening in a circuit is in his own instruments or office connections is to insert a knife blade loosely across the cut-out hole 7 at the bottom of the board. If the opening should happen to be within the room, a spark will be seen between the edge of the blade and the brass pieces every time the contact is broken. His relay, of course, will not close, but the circuit will be all right to all the others on the line, so long as the knife makes a good connection. Some prefer to feel for the current at each of the top binding posts, but, as the sensation, if the lines are all right, is not always very pleasant, the above process is not only just as satisfactory, but it is frequently more certain, for the reason that a spark will appear on "breaking" a circuit, although the current may be too weak to be felt with the fingers.

It may be well to state here that, in feeling for a current, it is a dangerous practice to use both hands. Use the two fingers of *one hand* across the points to be tested, and keep the other hand in the pocket or somewhere else where it cannot touch the circuit or a ground. If this precaution is observed and some time the fingers are placed across a circuit whose potential is dangerously high, no doubt the sensation will be disagreeable and the fingers may be burned, but if both hands had been used, the current would have had a good opportunity to flow through some of the vital organs, especially the heart, with perhaps more or less serious results.

PLUG SWITCH FOR TWO THROUGH LINES.

189. It frequently happens that two or more through main lines pass through the same way office, and a switch whereby various combinations may be made between these wires and the office instruments is very desirable and even necessary. A convenient form of switch for two main lines and two office sets is shown in Fig. 59. The binding post *u* is connected to the disks *a* and *b* by wires behind the base-board; similarly, *v* is connected to *c* and *d*, *w* to *l* and *i*,

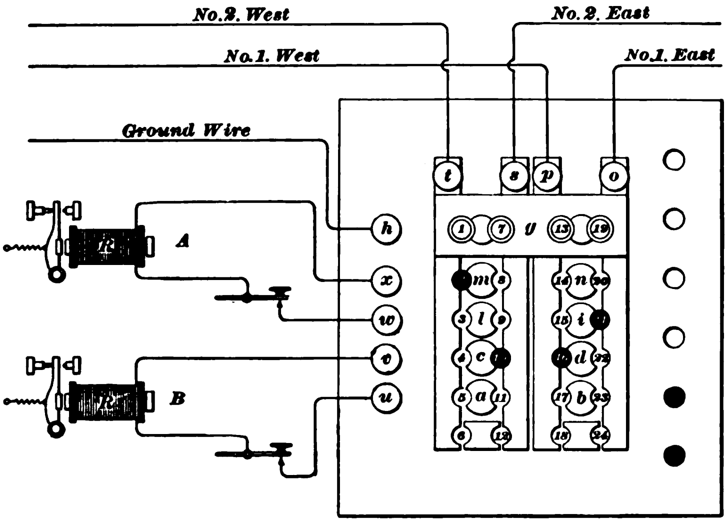


FIG. 59.

and *x* to *m* and *n*. The post *h* is connected to the plate *g*, which, being separated and insulated from the vertical strips by a thin piece of mica or paraffined paper, forms the ground plate of a lightning arrester. Any vertical strip and the line wire connected to it may be grounded by inserting a plug in the proper hole in the top horizontal row. Two sets of instruments located in the way office and the two through main lines, ordinarily called No. *1* and No. *2* lines, are connected to binding posts on the switch, as shown.

190. Instruments Cut Into Both Line Circuits. To loop the set *A* in line No. *1*, that is, to connect the set *A* in series with the line wires No. *1* east and No. *1* west, and also to connect the set *B* in series with the wires No. *2* east and No. *2* west, insert plugs in holes *21*, *14*, *11*, and *4* or in holes *20*, *15*, *10*, and *5*. Similar connections, whereby one office set was cut into a line circuit, have already been explained, so no explanation seems necessary here.

191. Cross-Connections.—To cross-connect the line wire No. *1* east to No. *2* west, and No. *2* east to No. *1* west, with or without an office set in each circuit is easily done. In the figure, the plugs are shown in holes *21* and *2* in order to connect line wire No. *1* east and No. *2* west with the office set *A* cut in, and in holes *10* and *16* in order to connect line wire No. *2* east to No. *1* west without an office set. The set *A* may be cut out by simply shifting the plug from hole *21* to *20*, and set *B* may be cut into circuit with line wires No. *2* east and No. *1* west by shifting the plug from hole *16* to *17*.

192. Two East-Line Wires Joined Together.—This is called *looping*, and an office set may or may not be included in the loop. For instance, if it is desirable to connect the set *A* in the loop between line wires No. *1* east and No. *2* east, then insert plugs in holes *20* and *9*. Furthermore, if No. *1* west and No. *2* west are to be looped directly together without an office set, then insert plugs in holes *16* and *4*. Other combinations may be made between the various line wires and the office sets, but the above sufficiently illustrates the manner of using this form of switch.

PLUG SWITCH FOR A LARGE NUMBER OF LINES.

193. The plug switch described for two main lines that enter a way station may be extended almost indefinitely. In Fig. 60 is shown a plug switch for four pairs of line wires that are brought to the binding posts at the top of the switch. Just below the line-wire binding posts are the circular

lightning-arrester plates or buttons. These buttons are all connected through a horizontal brass strip behind the

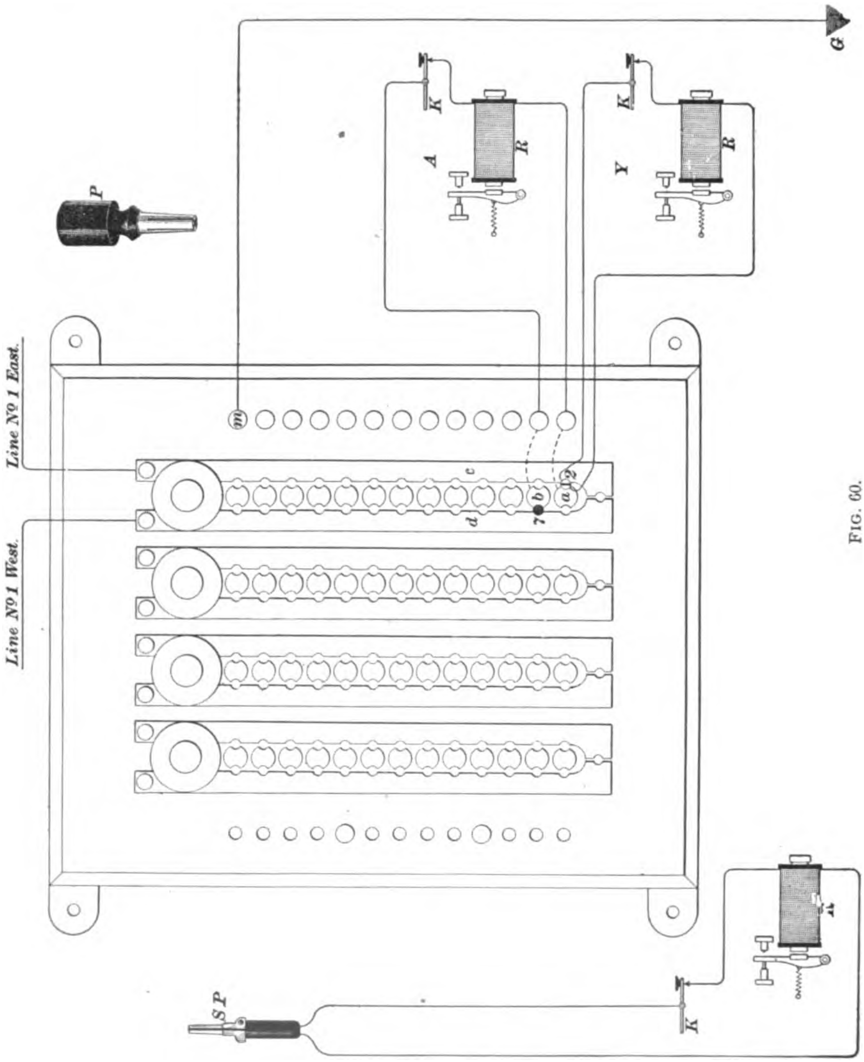


FIG. 60.

board to the top binding post m, which is connected to a ground plate G.

To the binding posts at the right side, excepting the top one, are connected the office sets. Each one of the side binding posts is connected behind the board with all the circular disks in the same horizontal line with it.

194. Split Plug and Its Use.—A very convenient device by means of which an extra office set may be connected in series with a line and another office set, or looped in, as it is commonly called, is the split plug *S P* shown at the left of the figure. The plug consists of two brass strips, insulated from each other by a center strip of hard rubber and a handle of the same material. To the brass strips are connected the two wires running to an office set, as shown. For instance, suppose it is desired to connect in series with the No. *1* line and the office set *A* another set *Y*. To do this, put an ordinary plug *P* in hole *7* and a split plug *S P* in hole *2*, being careful when this split plug is in place that the same brass piece on one side of the plug does not touch both the disk *a* and the vertical strip *c* of the switch. When the plugs have been properly inserted in the holes indicated, the circuit is as follows: From line No. *1* east through the vertical strip *c* to one side of the split plug, through the set *Y*, back to the other side of the same split plug, to the disk *a*, through the office set *A*, back to the disk *b*, through the ordinary plug in hole *7* and the vertical strip *d* to line No. *1* west. In this manner, an extra set can be looped in with any of the regular office sets.

195. The capacity of a given switch of this form may be increased up to double its former capacity by bringing the east wires, for instance, to the binding posts on the right side of the switch, reserving the top binding posts for the west wires. When arranged in this way, all the office sets must end in split plugs. In Fig. 61 is shown a portion of a switch and two office sets arranged in this manner. If ordinary pin plugs are placed in holes *1*, *2*, *3*, and *4*, then the following wires are connected through the switch without any office sets in circuit with them: No. *1* east to No. *1* west, No. *2* east to No. *2* west, No. *3* east to No. *6* west,

No. *4* east to No. *3* west. If a split plug is properly inserted in hole *5*, then the office set *A* is looped in between No. *5* east and No. *5* west.

There is an objection to this arrangement, in that the office instruments that are connected in circuit with the

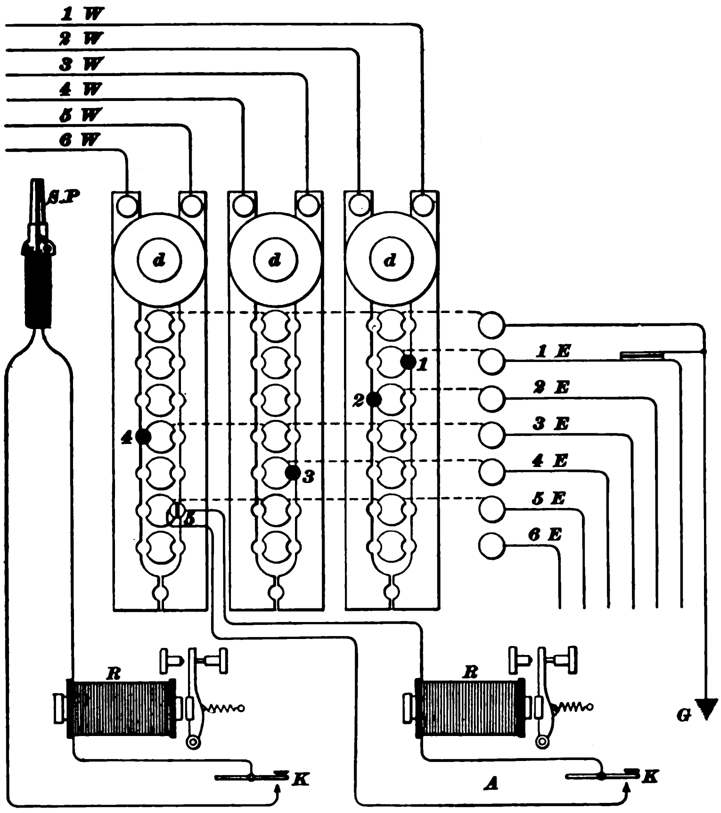


FIG. 61.

line wires are not protected by the regular lightning arresters *d*, *d*, *d* at the top of the switch from lightning discharges that may come in over the *east lines*. However, a simple plate or button arrester could be connected to each east line before it reached the switchboard. A plate arrester

is shown connected in this manner to line No. *1* east. The heavy black line between the line and grounded plates represents the intervening insulation, mica, or paraffined paper. In order to loop an office set in circuit with two west wires, *without rendering useless one east wire*, there must be one or more extra rows of disks that do not connect with any line wires, and furthermore, an office set cannot be looped in circuit with two east wires, *even with the extra rows of disks, without rendering useless one west wire.*

SPLIT-PLUG CUT-OUT.

196. In Fig. 62 is shown an older form of switch, called a **split-plug cut-out** or, simply, a **plug cut-out.** It

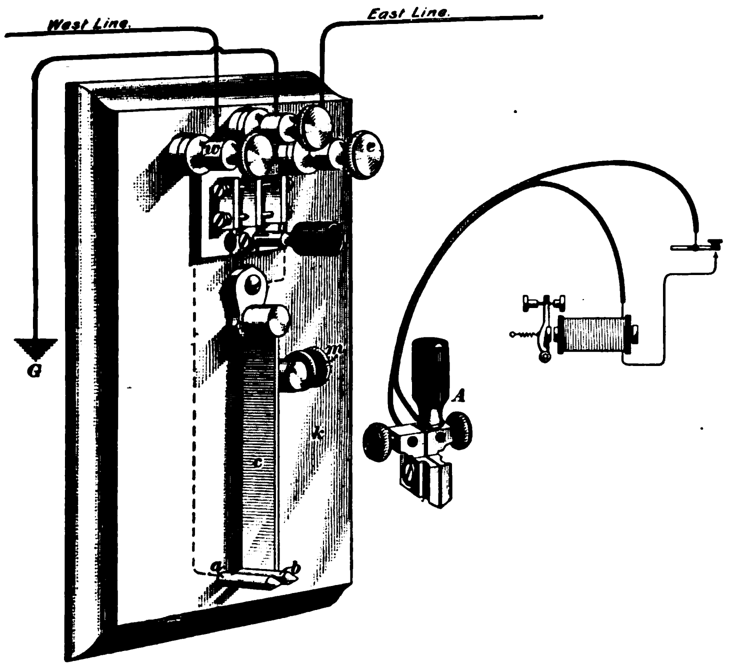


FIG. 62.

consists of a flat, flexible spring *c* fastened to the baseboard at the upper end and to the lower end of which is attached

a pin *b*, opposite to which is a similar pin *a* set in the baseboard. The pressure of the spring *c*, which presses *b* against *a*, is regulated by the screw *m*. The binding posts *c* and *w* are connected by wires beneath the base with the spring *c* and the pin *a*, respectively, as shown by the dotted lines. The split wedge *A* is grooved on its sides so as to fit the pins *a* and *b*. The two brass halves are insulated from each other by hard rubber. By means of the binding posts, the office instruments are connected by a flexible cord with the two sides of the split wedge. If the wedge is inserted between the pins *a* and *b*, the office instruments are almost instantaneously cut into the main line without interrupting the signals that may be passing over the line. On withdrawing the wedge, the office instruments are cut out and the line circuit is automatically closed. At the top of the switch is a lightning arrester slightly different in construction from any that have been described, but the principle is the same. The middle plate and binding post is connected to the ground plate *G*. The two line plates have screws through them, the points of which can be adjusted to almost touch the ground plate. These screw points are supposed to afford a ready path for the lightning charge coming in over either line to jump to the middle grounded plate.

MAIN-OFFICE SWITCHBOARDS.

197. At terminal stations, provision must be made, not only for interconnecting in various ways the lines and office sets, but also for connecting the main-line and intermediate batteries in the circuit with either or both the above. At large telegraph centers, where thousands of wires terminate, and where all kinds of apparatus, such as repeaters, duplex and quadruplex sets, and ordinary relays and keys, and batteries of various potentials, are in use, the connections are apt to be, and especially to appear, very complicated. In order to make it as clear as possible, the various devices that, collectively, would form the complete

arrangement at a terminal station, will be taken up gradually. It would be very confusing, even if possible, to show all the connections in one diagram.

DOUBLE SPRING-JACK SWITCHBOARD.

198. In Fig. 63 is shown a portion of a terminal switchboard. In some respects, it is quite similar to a way-office switch. All the disks in the same horizontal row are connected behind the board to the same brass strip, so that, behind the board, there are long *horizontal* brass strips, and, in front, long *vertical* brass strips, or *straps*, as they are called. By the insertion, therefore, of a plug in the front of the board, any horizontal row of disks can be connected to any vertical strap, as in the switches already described. The bottom row of disks is usually grounded and the lightning arresters are not attached to the switch, as on way-station switchboards, but are placed at the point where the lines first enter the building.

199. Double Spring Jacks.—Beneath each vertical strap is a switching device called a **double spring jack.** In the lower part of the figure are shown side views of only three of these double spring jacks, and, in order to show them at all, they had to be drawn in a plane at right angles to that in which they actually belong. Such a switchboard is called a **double spring-jack switchboard.** The springs *n*, *n* normally keep the movable brass parts *j* and *k* firmly pressed against the brass piece *p*. The terminal *m* is connected to the vertical strap above it, and *o* is connected to a line wire. The brass pieces *j* and *k* are hinged, as shown, so as to allow the insertion of one or two *wedges*.

200. Wedges.—In connection with these spring jacks, two kinds of **wedges,** the single and double, are used. The double wedge consists of two flat pieces of brass, insulated from each other by a central strip of hard rubber, and having a handle of the latter material. To the brass strips on each

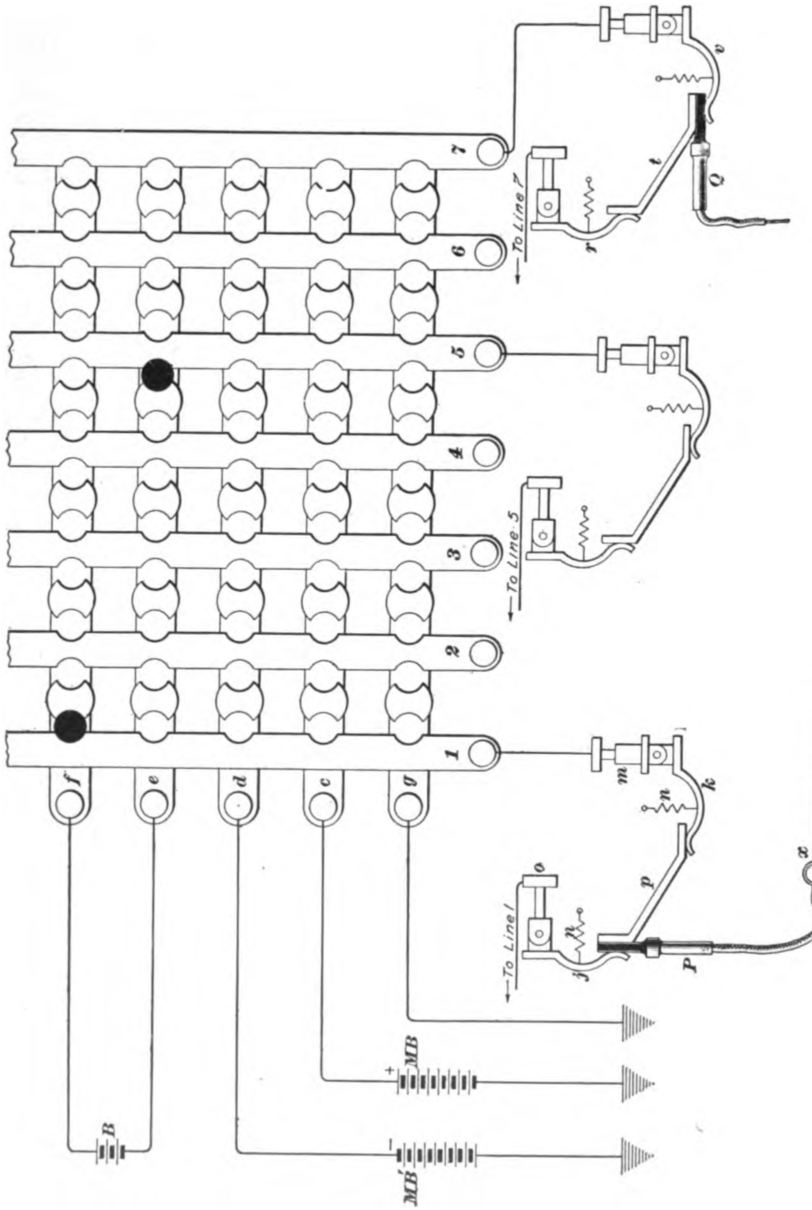

To Line 7
To Line 5
To Line 1
Set A
MB
MB'
B
1
2
3
4
5
6
7
f
e
d
c
g
m
n
k
o
p
j
P
x
y
r
t
v
Q

FIG. 63.

side of the wedge are fastened the ends of two wires, forming a flexible cord that leads through the binding posts *x* and *y* to office sets or other apparatus. The single wedge is like the double except that there is a brass strip on only one side of the insulating strip, and, consequently, only one wire is brought to the wedge. Wedges of this kind connect to duplex or quadruplex sets. The high-potential dynamo or battery leads for operating the duplex and quadruplex sets are run directly from the dynamo or battery to the desks, and not to the main switch. Consequently, the circuit is from the ground to the dynamo or battery, to duplex or quadruplex sets, to the wedge, spring jack, and out to line.

The cords should be, and usually are, so connected to the wedges that no strain can come upon the conductors themselves, especially not at the point where they are fastened to the brass part of the wedges. Otherwise, they would be continually causing trouble at these points through the breaking and crossing of the flexible conductors. The wedges are about 4 inches long, $\frac{1}{2}$ inch wide, and $\frac{3}{8}$ inch thick. The binding posts *x* and *y* are placed below a horizontal shelf or table that projects out just below the spring jacks, and on this shelf the wedges rest when not in use. The binding posts and wedges are connected together by flexible conductors, or cords, as they are called. On this shelf there are generally placed several keys, relays, and sounders for the use of the chief operator in testing out lines and circuits.

201. When a double wedge *P* is inserted as shown in the figure, *p* connects with one side and *j* with the other side of the wedge, thus connecting, in the same circuit with the spring jack, whatever apparatus is joined through the binding posts *x* and *y* to the two sides of the wedge. A single wedge *Q* is also shown inserted in a spring jack. In this case, the wedge connects through *t* to *r* and to the line, while *v*, which rests against the hard-rubber side of the wedge, is thereby insulated and on open circuit. The

double spring jack renders the insertion of additional sets of instruments into the circuit an easy matter, for another wedge can readily be inserted between *p* and *k*.

202. A so-called **intermediate battery** *B* is shown connected to the two top rows of disks. An intermediate battery is one used to insert in a line that does not terminate at this particular office. By inserting, in this manner, an intermediate battery, two offices can communicate with each other if their own batteries are too weak, or even if they have no batteries at all. Thus, for circuits about town, the current that can be generated so much more economically by dynamos at a large central office than in any other manner can be used. As a rule, the local circuits at the small offices are not supplied with current from the central office, as are the line circuits. In large offices, many dynamos of different potentials are in use as intermediate batteries on lines that merely pass through the office.

203. In this switchboard, the positive pole of one main battery *M B* and the negative of another main battery *M B'* are connected to separate horizontal rows of disks, and the other poles of both batteries are grounded. In offices having two or more switchboards and two sets of main-line dynamos, each set consisting of several dynamos of different voltages, one board would be connected only to the positive poles of one set of dynamos, and another board would be connected to the negative poles of the other set of dynamos. This avoids the injurious short circuits that are apt to occur through careless plugging on the switchboard when both positive and negative poles of the dynamos are brought too near each other on the same board.

Where dynamos are used in the place of gravity cells for the main batteries, the disks in the rows to which the dynamos supply current are not joined together directly by a horizontal strip back of the board. Instead, each disk is connected through a separate incandescent lamp or other non-inductive resistance to the dynamo lead or bus-bar. The reason for using a resistance and arranging the connections

somewhat differently when dynamos are used in place of gravity cells will be explained in connection with the use of dynamos for supplying telegraph circuits.

204. Possible Connections.—Since, in the ordinary spring-jack switchboard, all the line wires terminate at one of the spring jacks and all the office sets end in wedges, it is evident that any office set may be connected in circuit with any line; or several sets may be connected in the same line; two lines may be joined in one continuous circuit; either positive or negative pole of the main-line battery may be put to line; and, furthermore, an intermediate battery may be inserted in a line circuit. All this and more may be done by the mere shifting of wedges and plugs.

Any hole in the switchboard may be designated by specifying the vertical strap and the horizontal row of disks at the intersection of which the hole lies. For instance, to plug hole *7—c* means to insert a plug in the hole between the vertical strap *7* and the disk in the horizontal row *c*.

205. Suppose it is necessary to connect at the switchboard shown in Fig. 63 the two lines *1* and *5*, the office set *A*, and the intermediate battery *B* (positive pole to line *1*) together. To do this, insert the double wedge *P* in the spring jack belonging to line *1*, as shown, and located below strap *1*, and put plugs in the holes *f—1* and *e—5*. The circuit is then closed through the following path: From line *1*, through one spring *j* and the office set *A*, back to the brass piece *p* of the same spring jack, through *k* and *m* to the vertical strap *1*, through the plug in hole *f—1* to the disk in the row *f*, through the intermediate battery *B* to the *e* row of disks, through the plug in hole *e—5* to the vertical strap *5*, through the double spring jack below strap *5* to line *5*. Two wedges may be inserted under the same spring of one jack, and two more, if necessary, under the other spring of the same jack.

206. Western Union Switchboard.—In the New York office of the Western Union Telegraph Company, there are five main-line switchboards, each having 30 horizontal

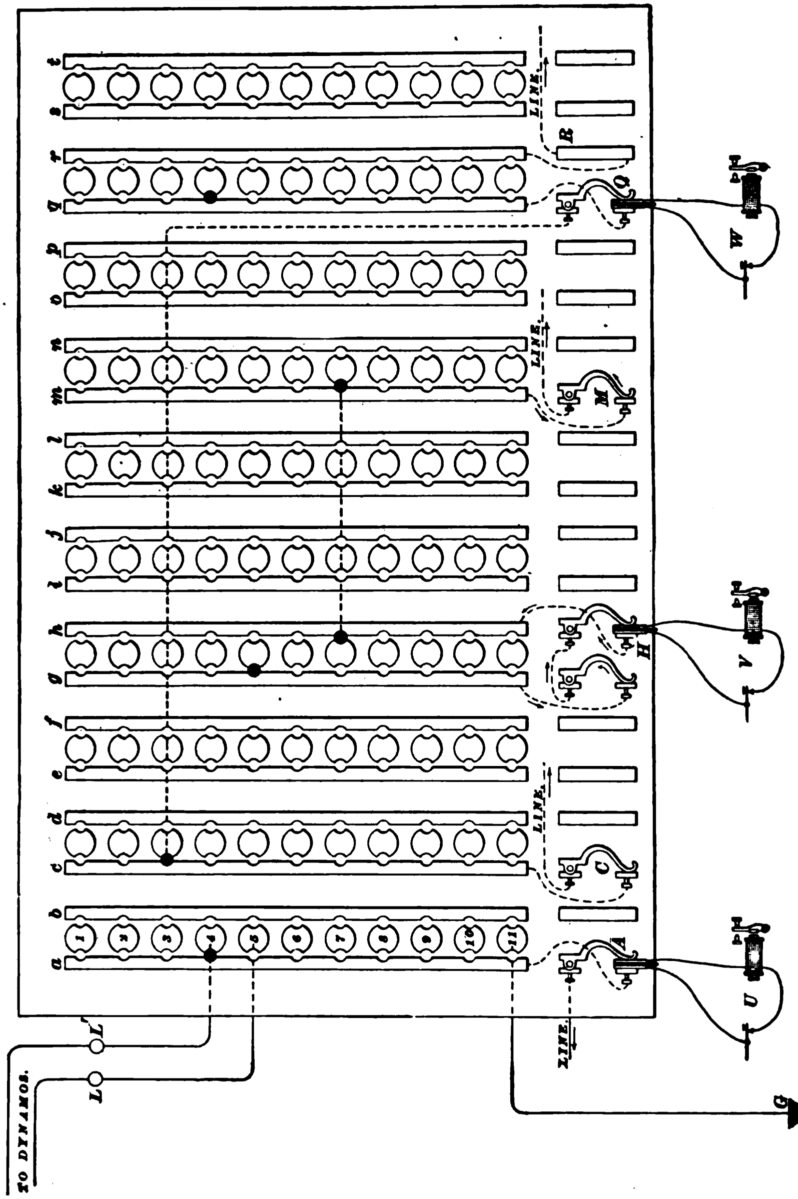


FIG. 64.

rows of disks, and all together there are 1,025 vertical straps. These five boards are in different parts of the operating department. The local city lines, the eastern, western, northern, and southern lines are collected at separate boards. The rows of disks are usually numbered from top to bottom at the extreme left.

For the convenience of the chief operators at the different switches, there are communicating circuits, containing a key and sounder at convenient intervals on the switch tables. These switchboards are supported by means of fireproof iron frames with clear glass panels from the floor to the shelf at the front and two ends, and, above the switch proper, are frames containing the lamps that are used as resistances. There are about 2,100 such lamps.

207. Office Desks for Instruments.—In telegraph offices, even in comparatively small ones, the office sets are placed in groups of four on one table. The tables are about 4 ft. × 6 ft., and are divided into four sections by intersecting screens. From each section, the wires from the line instruments are run to the switchboard, but all the local circuit wires go directly to the battery or dynamo leads.

SINGLE SPRING-JACK SWITCHBOARD.

208. In Fig. 64 is shown a **single spring-jack switchboard** for use in a terminal office. Only two rows of disks, the fourth and fifth, are shown connected to the dynamos that supply current to the lines, but many more rows are usually connected in this manner. The disks in each row are not joined directly together behind the board, in this case, where dynamos are used, but are first connected to incandescent lamps or non-inductive resistance coils, and the other terminal of the lamp or coil is then joined to the dynamo lead or bus-bar, as mentioned in Art. **203.** To avoid making the figure too complicated, only two disks are shown connected through lamps to the bus-bars. All disks in the same horizontal row, excepting

those connected through lamps to the main-line dynamos, are joined together, as usual, by brass or copper horizontal strips behind the board. The bottom row is connected to the ground.

209. The bottom part of each spring jack is invariably connected to the vertical strap immediately above it, but the top terminals are connected in various ways. Some of the spring jacks have their top terminals connected to line wires, as shown at *A*, *C*, *M*, and *R*, and are called *line jacks;* some have their terminals joined to one horizontal row of disks, as shown at *Q*, and are called *single flips;* and some are joined together, as shown at *H*, and are called *double flips*. The single flip is connected permanently to some one horizontal row of disks, but the double flips, being connected to vertical straps instead, have the advantage of being available for connection with any unused row of disks. The office sets terminate at the board in double or single wedges, as already described. These boards are generally so long that the flexible conductors of a wedge cannot conveniently be made long enough to reach to any spring jack, and, for this reason, the double and single flips are necessary, and the manner of using them will now be shown.

210. Suppose, for instance, that the office set *V* is to be connected to the line that is permanently joined to the spring jack *M*, and that the cord is not long enough to enable the wedge of the set *V* to be inserted directly in the jack *M*, and also that the voltage required is furnished by the dynamo connected to the fifth row of disks. The wedge of the office set *V* should be inserted in a double flip within its reach, as *H*. Then plugs would be inserted in holes *m* — 7, *h* — 7, and *g* — 5, as indicated by the solid black circles at the holes designated. The circuit is then complete from the line through jack *M*, strap *m*, plug in hole *m* — 7 to the seventh row of disks, through the plug in hole *h* — 7 to strap *h*, through office set *V* and double flip *H* to strap *g*, through the plug in hole *g* — 5, through the disk, its lamp, and the dynamo to ground.

211. Suppose it is desired to connect a set *W*, terminating in a wedge near *Q*, to the line coming to spring jack *C*, and to use the potential of the dynamo supplying the fourth row of disks. Now, the upper part of the jack *Q* is permanently connected behind the board to the third row of disks. To make these connections, put the wedge in the jack *Q* and insert plugs in the holes *c* — *3* and *q* — *4*. The circuit may be traced as follows: From the line terminating at the jack *C*, through the jack to strap *c*, through the plug in the hole *c* — *3*, through the back horizontal strip connecting together all the disks in row *3*, through the wire connecting this third row to the spring jack *Q*, through jack *Q* and the office set *W* to the strap *q*, through the plug in the hole *q* — *4*, the disk, its lamp, and the dynamo to the ground.

212. Office Set, Dynamo, and Line in One Circuit.—Suppose that an office set *U* and the dynamo joined to the fourth row of disks are to be connected in series with the line coming to the spring jack *A*. The wedge of the office set *U* is inserted in the jack *A* and a plug is put in the

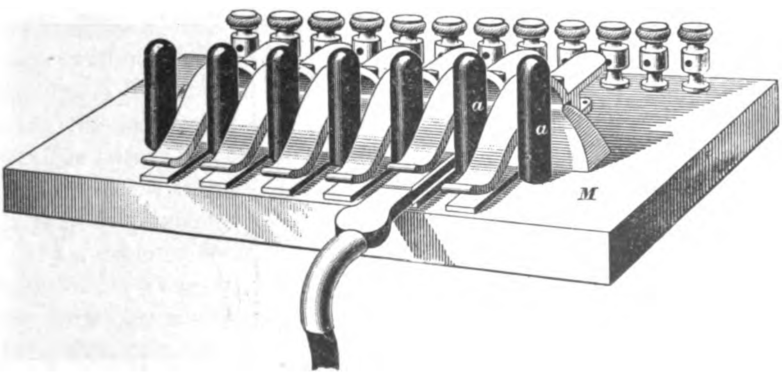
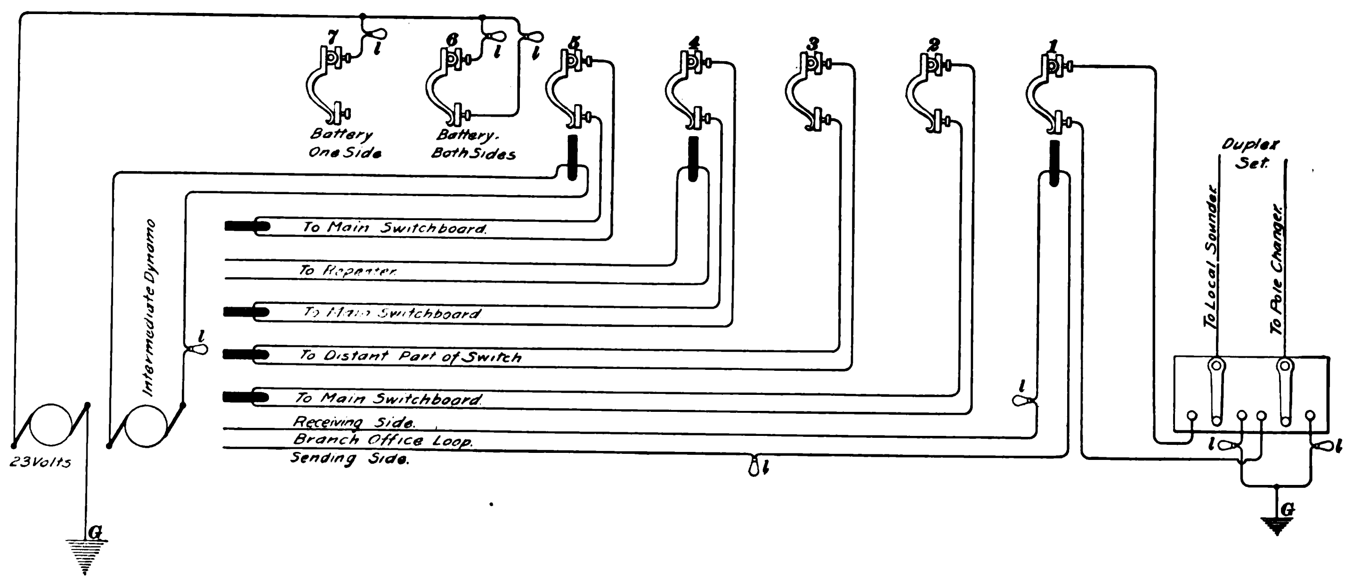


FIG. 65.

hole *a* — *4*. The student should now be able to trace out the circuit for himself. Both single and double wedges may be used with this board, and the intermediate batteries may be connected as on the preceding switchboard, or, as is often



7
6
5
4
3
2
1
l
Battery
One Side
Battery.
Both Sides
Duplex
Set.
To Local Sounder.
To Pole Changer.
To Main Switchboard.
To Repeater.
To Main Switchboard
To Distant Part of Switch
To Main Switchboard.
Receiving Side.
Branch Office Loop.
Sending Side.
Intermediate Dynamo
23 Volts
G

FIG. 66.

done, the leads from the intermediate battery or dynamo may be terminated in a double wedge.

213. Single Spring Jacks.—A row of six single spring jacks, mounted on a separate base, is shown in Fig. 65. The base *M* is made of good insulating material, such as hard rubber or thoroughly dried and seasoned wood, and the jacks are separated by pillars *a*, *a* of hard rubber. There are two binding posts for each jack, one being connected to the top or movable part of the spring jack, and the other to the flat under piece. The spring that keeps the two parts of a jack firmly pressed together is under the movable part and hidden from view. A wedge is shown inserted in one of the jacks.

LOOP SWITCHES.

214. Western Union Loop Switch.—In addition to the terminal switches already described, the very large offices have what are called **loop switches.** These loop switches vary quite a little in arrangement. In the New York office of the Western Union Telegraph Company, the loop switch consists of five horizontal rows of spring jacks, making a total of about 375. These spring jacks are of the usual construction, and 126 of them are the terminals of flexible cords, the other ends of which terminate in wedges for insertion in the jacks at the main switches. These latter wedge circuits are called *flying* loops.

On a table or shelf in front and below the jacks are about 450 double wedges with flexible two-wire conductor cords of the form already shown and described. These wedges form the terminals of the branch-office and newspaper loops, Milliken repeaters, intermediate dynamos, and other circuits and apparatus. A branch-office or newspaper loop is simply two wires running to the same branch or newspaper office. In these 450 loop circuits there are inserted 900 lamps, one lamp in each side. These lamps vary in resistance from 20 to 80 ohms, a lamp of such a resistance being used in

each side as will bring the resistance of that side up to 92 ohms, or as near to that as is convenient.

215. A good idea of a loop switch may be obtained from Fig. 66. Those circuits lettered *To Main Switchboard* are the flying loops. One jack, as indicated, is connected to a wedge for use at a distant part of the same loop switchboard. Every duplex, quadruplex, and certain repeater sets in the office are connected to jacks at this board. A branch-office loop is shown terminating in a wedge just below a jack in which the wedge would be inserted for use in connection with a duplex telegraph set. One wire is called the *sending side* because, by means of a key at a branch office, an operator there controls the pole changer of a duplex set located at the main office. In the receiving side at the branch office and at the main office are sounders controlled by the duplex apparatus located at the main office. Thus, all the complicated instruments of the duplex sets are kept at the main office, while only keys and sounders are necessary at the branch offices. A quadruplex set can be used in much the same way.

216. Dynamo in Loop Circuit.—A 23-volt dynamo, for use on loop circuits to branch offices, is shown connected through lamps to one side of jack No. 7, and to both sides of jack No. 6. This allows one or both sides of a branch-office loop to be supplied with current from the 23-volt dynamo. In some cases, several branch offices, even as many as ten, are connected up in one circuit.

217. Dynamos as Intermediate Batteries.—A number of special dynamos used as intermediate batteries are connected to wedges at this board. In the figure, only one dynamo is shown connected in this manner. By means of the flying loops, these dynamo circuits may be thrown as required into any of the main-line jacks. These intermediate dynamos deliver current at from 50 to 125 volts.

The repeater, duplex, and quadruplex circuits that are brought to this board will be better understood after such systems have been explained.

POSTAL TELEGRAPH LOOP SWITCH.

218. The Postal Telegraph Company's loop switches are arranged in a somewhat different manner, there being only one wire in a branch-office loop, as wili be seen in connection with the descriptions that will be given later of this company's duplex and quadruplex systems.

219. Loop switches make an extremely convenient and flexible system whereby many changes and combinations may be made between the lines and the various telegraphic apparatus. It allows the concentration of the various multiplex and repeater sets in one room, under the supervision of a few experts, and yet, by means of the loops, the branch offices can receive or send through these sets. It also makes possible the interconnection of every variety of repeater, both with the lines and the multiplex sets. The use and advantages of loop switches will be better understood and appreciated after repeaters and multiplex sets have been explained.

POSTAL TELEGRAPH COMPANY'S LATEST SWITCH-BOARD.

220. There was installed in 1899 in the New York office and in 1900 in the Philadelphia office of the Postal Telegraph Company, a new system of switches, the invention of the assistant manager, Mr. J. F. Skirrow. In a large office, the flexible switching cords cause considerable trouble. They become tangled and their available length thus shortened, and a defective cord not only causes delay before it can be replaced, but may be the cause of a disastrous fire.

Where a number of line switchboards are used in a large office, it has been customary to bring the loops and desk sets in one part of the room or building to a board that contains a given number of main-line wires, these loops and sets being used on these wires. It is often desirable, however, to connect loops and desk sets to other boards than those under which they are connected. On the boards previously in use by this company, this was usually done by transferring the

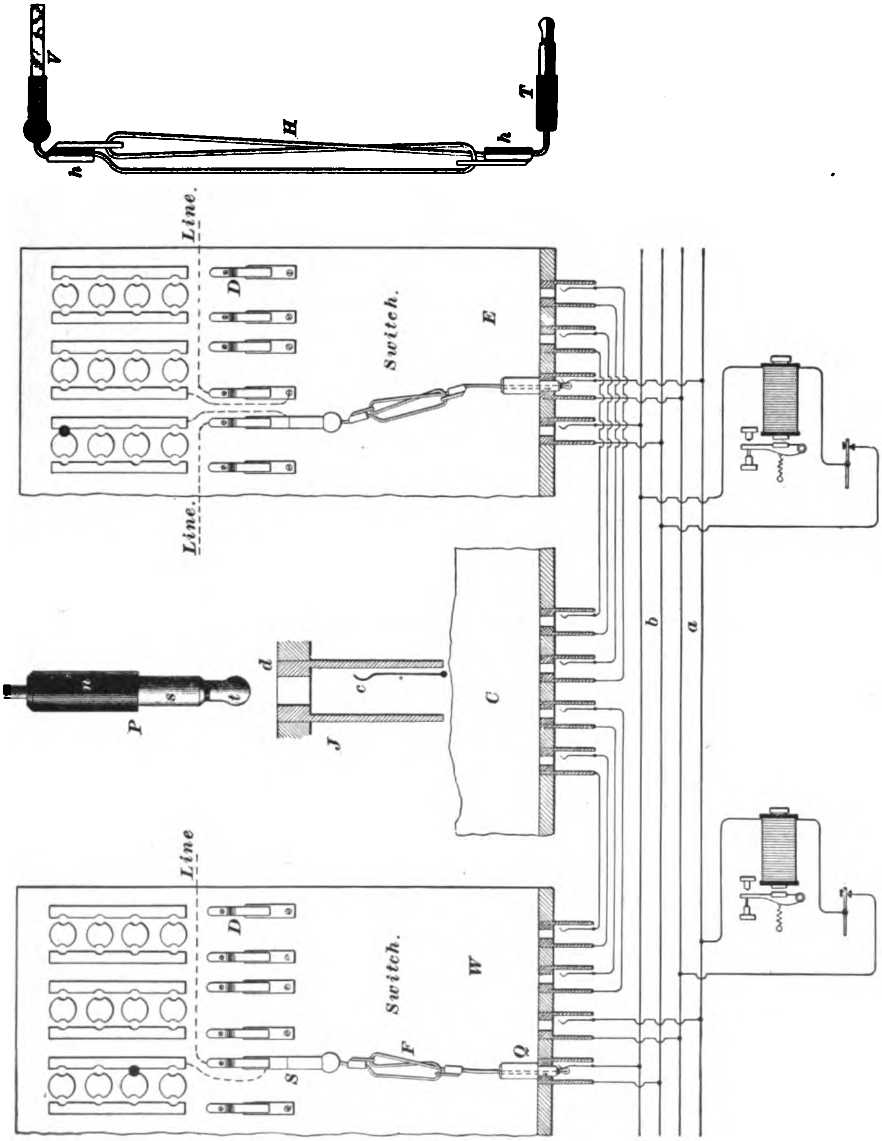


FIG. 67.

loop or line to another board by means of the rows of disks running horizontally through each board, the connection being made by placing an ordinary pin or plug at both boards on any given row of disks. Before using the row of disks, it would be necessary to see that this row was not in use at any other part of any board. The number of such transfer connections is necessarily limited, and, where many boards are used, special wires are run from board to board where most needed.

221. The new arrangement is about as shown in Fig. 67. *W* and *E* represent small sections of two main-line switchboards, and *C* a central switchboard, the function of which is similar to that of a central exchange telephone switchboard, and will be explained presently. In the table, or shelf, at the switchboards, specially designed pin jacks are placed. An enlarged view of a pin jack and pin plug is shown. To the shell of the jack *J* is attached one wire and to an insulated spring *c* within the shell another wire is attached. The spring and shell never touch each other, whether the plug is out or in, so that the two wires brought to it never touch each other. A row of these pin jacks is shown in the figure in the shelf below the switchboard. To fit into these pin jacks, there are special plugs called *pin plugs*. *P* is one of these pin plugs. It has two wires running into it, one of which is fastened to the rounded tip *t* and the other to the sleeve *s*, the tip and sleeve being insulated from each other. The plug is furnished as usual with a hard-rubber handle *n*.

222. When the plug *P* is inserted in the jack *J*, the tip of the plug *t* makes contact with the spring *c*, and the sleeve *s* makes contact with the shell or sleeve *d* of the jack. At the right of the figure is shown one pin plug *T* and an ordinary double wedge *V* connected together by two flexible wires enclosed in a flexible covering *H*. The double-contact wedge *V* has already been described in connection with other main-line switchboards. By an ingenious device, the cord *H* can be very quickly extended to about three times

its normal length, and as readily shortened again. This adjustability is attained by placing on the cord sliding blocks *h*, *h* having a ring or eye through which the cord is looped. These sliding blocks *h*, *h* consist of a cylinder or tube arranged to slide easily on the exterior of the cord *H*. By causing the sliding blocks *h*, *h* to approach and recede with respect to each other, the loop may be shortened or lengthened, and the distance between the wedge *V* and the plug *T* is increased or decreased to suit the requirements of any particular case. By taking the wedge *V* and the plug *T*, one in each hand, and pulling in opposite directions, the cord is lengthened, the loop shortens, and the sliding blocks *h*, *h* move toward each other as the loop contracts. By taking the two sliding blocks *h*, *h*, one in each hand, and pulling them in opposite directions, the loop in the cord is lengthened, and the plug and wedge approach each other till the minimum extent is reached. When a plug is inserted in a pin jack, as at *Q*, and the double wedge is inserted in the ordinary spring jack, as at *S*, then the circuit, to which the two wires ending in the pin jack *Q* connect, is extended through the flexible cord *F* to the spring jack *S*.

223. *D*, *D* are rows of ordinary single spring jacks for use with the double wedges. They are connected as usual, the lower side to the vertical brass strip immediately above it, and the upper terminal to a line wire. Above these are the usual vertical brass strips and disks. But there is needed in this form of switchboard only those horizontal rows of disks that are connected to the main batteries or dynamos. Consequently, instead of 20 or 30 horizontal rows of disks, as is usual in large boards, only a few are necessary, 4 being shown in this figure.

When the switchboards are in use, all idle cords are removed from the board, and it is evident that a defective cord can be very quickly replaced by a good one, since the cord is in no way permanently connected to the board. Furthermore, there are no cords, slack or otherwise, under the shelf, as in the older form of switchboards. One pin

jack at each board is connected to the same pair of wires. Consequently, there are as many pin jacks connected in multiple to the same pair of wires as there are main-line boards. To each such pair of wires, as *a* and *b* in this figure, there is connected one set of office instruments, or one loop circuit running to a district, branch, or newspaper office. Consequently, it is possible to bring every loop and desk set in an office in multiple to every board, thus making them available at each board without transferring and consequent loss of time. Under a 50-wire spring-jack board of the present type, it is possible to place from 1,000 to 2,500 of these pin jacks, representing from 2,000 to 5,000 wires, and, by a modification of the present shelf system, the number of such multiple circuits may be very largely increased. This is evident from the fact that on a telephone switchboard it is very common to have 3,000 to 4,000 jacks of even more complicated design placed on one section of a switchboard, all within the reach of one operator, seated in a chair.

224. In addition to the above arrangement, there could be a row of these pin jacks at each board, the wires from which run to similar jacks at a central board *C*. At this board, the jacks could be combined as desired, and it would be possible, by this means, to quickly transfer any or all the main-line wires from one board directly to other boards. The connecting link to be used between two pin jacks at the central board *C* would have a flexible cord similar to that shown in the figure, but terminating in two similar plugs, and not in one plug and one double wedge. In the new Philadelphia office there is a so-called leg board, made up of 4 rows of ordinary spring jacks, 50 in each row. The local connections to every quadruplex set in the room and all branch-office and newspaper loops terminate at this leg board. Rows of pin jacks are placed at the base of each board, all being connected in multiple; one row is used for making transfer connections, another for repeaters, another for desk sets, another for loops, etc., with sufficient spare jacks for future growth.

TELEGRAPHY.

(PART 2.)

THEORY OF ELECTRIC CIRCUITS.

CHARACTER OF ELECTRIC CURRENTS.

1. Any electric current may be classified either as a *direct current* or as an *alternating current*. The abbreviations for these are D. C., direct current, and A. C., alternating current.

DIRECT CURRENT.

2. A **direct current** may be defined as a current that always flows in the same direction through the conductor or circuit. A direct current may be *continuous*, so called, or *pulsating*.

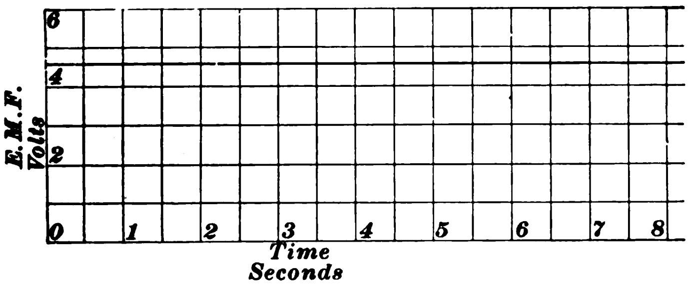


FIG. 1.

Strictly speaking, a **continuous current** is one in which the electromotive force has an absolute constant value

during succeeding intervals of time, which would therefore cause a perfectly steady current to flow through a circuit of constant resistance. A continuous current would then be represented by the heavy straight line parallel to the axis of abscissas, as in Fig. 1. Constant-potential dynamos, which are used for direct-current incandescent lighting and primary and storage batteries, furnish continuous currents.

3. A **pulsating current** is one that always flows in the same direction, but the electromotive force varies, so that the current consists of distinct impulses, or rushes of current.

In Fig. 2, (*a*), (*b*), and (*c*) represent three possible curves of pulsating currents. In (*a*), the fluctuations of the electromotive force, or current, occur between a maximum and zero, while in (*b*) the minimum is about .7 of the maximum; (*c*) represents a slightly different type of curve, in which the minimum is about .85 of the maximum. It will be seen that either of the last two quite closely approaches a strictly continuous current.

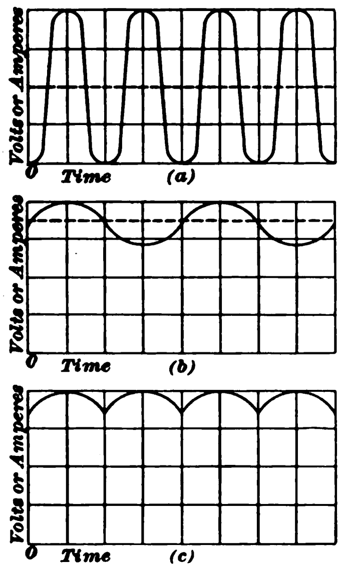


Fig. 2.

4. Current in a Telegraph Circuit.—The current in a simple Morse telegraph circuit is a form of pulsating current. It is caused by alternately applying a constant electromotive force to, and withdrawing it from, a circuit of constant resistance by the closing and opening of the circuit at the telegraph key. Such a current is illustrated in Fig. 3, in which the current rises almost instantly from zero to its maximum strength when the key is closed; it then remains constant or continuous about the duration of a signal, and

finally falls suddenly to zero when the key is opened. During the interval of a signal, unless the speed of transmission is very rapid indeed, or the product of the resistance and electrostatic capacity of the line is very large, the current is practically continuous and its strength may be calculated by Ohm's law. If the circuit possessed only resistance, and no inductance or capacity, the current would rise and fall instantly, as shown in Fig. 4.

As the speed of telegraphing is increased, the flat portions at the top of the curve decrease in length and may disappear entirely. The current may commence to decrease before it reaches the maximum value it otherwise would attain, on account of the time interval of one signal being short compared to the time-constant of the circuit. A very rapidly pulsating or fluctuating current follows more nearly, in some respects, the law for alternating currents than that for direct currents. If the zero horizontal axis be shifted to a position midway between the minimum and maximum values of such a pulsating current, as shown by the dotted lines in Fig. 2 (*a*) and (*b*), the current may be looked upon as a direct current up to that line, above and below which it increases and decreases, respectively, according to the laws for alternating currents, which will be given later.

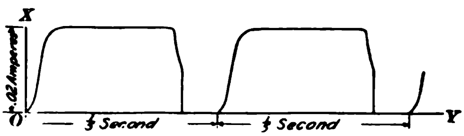


FIG. 3.

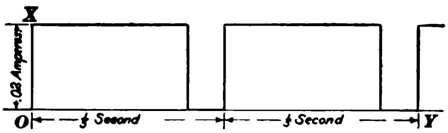


FIG. 4.

ALTERNATING CURRENTS.

5. An **alternating current** may be defined as a current that is continually reversing its direction in the circuit; consequently, the electromotive force, as well as the current, alternates between two opposite maximum values. The curve of electromotive force, and also the curve of the

current, would therefore be on both sides of the axis of the abscissas.

In cable telegraphy, the currents are alternating in character, although the curves representing such currents are very irregular in shape. Several very rapid telegraph systems have been devised, in which alternating or reversed currents are employed; and as it is probable that some such systems may soon come into use, it is desirable that the student should be prepared to understand them.

By Delany's automatic chemical method, employing currents flowing alternately in opposite directions, from 2,000 to 3,000 words per minute have been transmitted. By the system of Crehore and Squier, in which simple sine alternating currents (to be explained presently) are employed, over 600 words per minute have been sent by using their own transmitter and the Wheatstone recording receiver. With their own transmitter and receiver, they have sent messages at the rate of 1,200 words per minute, and claim to be able to send 3,000, and by duplex transmission, which is possible with this system, twice that many, or 6,000 words per minute. By the system invented by Pollak and Virag, of Austria, messages at the rate of 1,000 words per minute were actually sent between New York and Chicago on December 3, 1899. Pollak and Virag claim to be able to send over 1,700 words per minute. In order, therefore, that the student may understand such systems, as well as others that require some knowledge of the properties of a very rapidly fluctuating or pulsating current, a few pages will be devoted to the consideration of alternating currents. In order to treat alternating currents, it will be necessary to first explain what is meant by *simple harmonic motion* and the *sine curve*.

SIMPLE HARMONIC MOTION.

6. Such a curve as that shown in Fig. 5 represents what is termed **simple harmonic motion,** which is a most important form of vibration, not only in alternating currents,

but in all branches of physics relating to wave motion. If a pin head *p'* (Fig. 6) on a disk *D* revolving at a uniform speed is allowed to cast a shadow perpendicularly on a plane at right angles to the disk, the movement of this shadow will be a simple harmonic vibration. The movement of the shadow, of course, will be in a straight line, as shown at *p p*. Starting at one end of its path, the shadow will move slowly

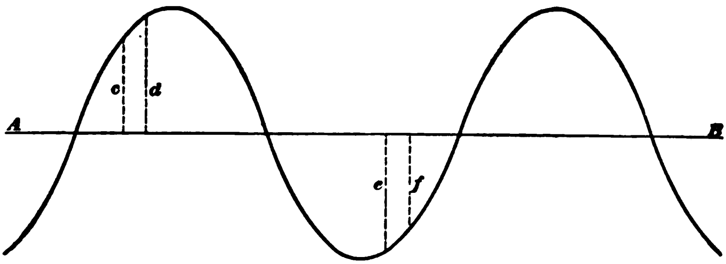


FIG. 5.

at first, but with increasing velocity, until the middle point of its path is reached. Here the velocity will be a maximum, and after passing this point, it will decrease more and more rapidly, until it comes to rest momentarily at the other end of the path. The direction of motion will then be reversed, and the shadow will again attain its maximum velocity in the other direction at the center point in its path, and will again come to rest momentarily at the starting point.

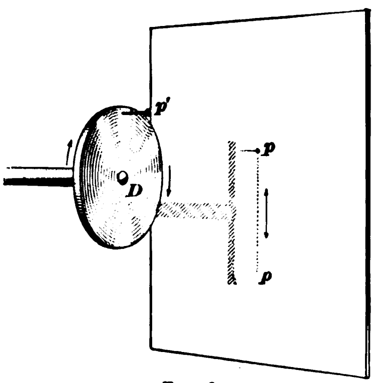


FIG. 6.

7. Simple harmonic motion may be defined as the movement of the projection on a fixed straight line of a point moving uniformly in a circular path. This definition will perhaps be made more clear by considering Fig. 7. Let *p'* be a point moving with a uniform velocity in a circular path of which the center is *O*, the

direction of motion being as indicated by the curved arrow. The projection p of the point on the vertical diameter of this circle will, it is evident, move from one end of this diameter to the other in exactly the same manner as did the shadow of the pin head in Fig. 6. If, while the projected point p is moving along the vertical diameter with harmonic motion, it should be caused to trace its course on a sheet of paper by drawing the paper with a uniform motion from right to left under the point, the path on the paper would be as indicated by the curved line. The beginning A of the curve corresponds to a time when the point p' was at the point A' on the circumference. As the movement progressed, the curve gradually rose to a maximum height at B, which was reached when the point p' had been rotated from its original position A' through 90° of the circle to its highest position p'''. The curve then descended and reached the zero line at C, when the point p' had been rotated through an angle of 180° to p''''. The next half of the revolution of the point p' caused its projected point p to trace a curve below the line exactly similar to that traced by the first half above the line.

CURVE OF SINES.

8. The curve shown in Fig. 7, which is used to represent simple harmonic motion, may also represent all the values

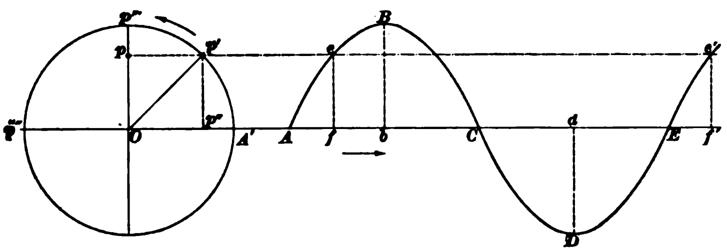


FIG. 7.

of the sine of an angle, while the angle is uniformly increasing from 0°, and is therefore termed the **curve of sines**, or the **sine curve.**

The distances from the point A in a horizontal direction may be considered as measures of the angle through which the point p' or the line $O\,p'$ has rotated. Similarly, the ordinate at any point of the curve $A\,B\,C\,D\,E$, that is, the perpendicular distance from any point in the curve to the base line, as $e\,f$, is a measure of the sine of the angle represented by the horizontal distance of that point from the reference point A, as $f\,A$, for

$$\sin A'\,O\,p' = \frac{p'\,p''}{O\,p'},$$

or $$p'\,p'' = O\,p' \sin A'\,O\,p' = r \sin A'\,O\,p',$$

where r is the radius of the circle, or the amplitude of vibration, as it is called.

Now, $p'\,p'' = O\,p$, and as any ordinate $e\,f$ at any point on the curve is always equal to the distance $O\,p$ for the corresponding angle, it follows that any ordinate on the curve will be

$$e\,f = r \sin A'\,O\,p',$$

where $A'\,O\,p'$ is the angle corresponding to the position of the point e on the curve.

DIAGRAMMATIC REPRESENTATION OF ELECTRICAL WAVES.

9. Analysis of Curves.—The successive values of an alternating current or of an alternating electromotive force may be represented by means of curves, as we have already done in the case of pulsating currents. In the right-hand portion of Fig. 7, the horizontal line $A\,E$ may be considered to represent time, while the vertical lines $f\,e$, $b\,B$, $d\,D$, and $f'\,e'$ may be considered to represent the instantaneous values of the current or electromotive force at corresponding particular moments. The curve $A\,B\,C\,D\,E$ will be first assumed to represent the values through which the current passes in the course of a complete cycle. The distance $A\,E$ along the horizontal line then represents the time taken

for the current to pass through a complete cycle, and the distance *A f* will represent the time in which the current has risen from zero to a value represented by the line *e f*. *A b* will represent the time taken for the current to pass through a quarter cycle, and the line *B b* will represent the maximum positive value of the current. During the time represented by the distance between *b* and *C* the current decreases, its value at any time being represented by the perpendicular distance, or ordinate, between the horizontal line *A E* and the curve. At the point *C*, which corresponds to the end of the first half cycle, the current passes through zero and begins to increase in a negative direction. The distance *A d* represents the time of three-fourths of a cycle. At the point *D*, the current has reached its maximum negative value; after passing beyond this point the current gradually decreases to zero at the point *E*, which marks the end of the first complete cycle.

10. Amplitude.—In the case of simple harmonic motion, the amplitude of vibration is the maximum displacement of the point *p* from its center position *O*. Thus, in Fig. 6, the amplitude would be represented by one-half the length of the line *p p*, and, in Fig. 7, by the radius of the circle, or by the line *b B* or *d D*. Similarly, in the case of an alternating current or an alternating electromotive force that follows a sine curve like that in Fig. 7, the maximum value is represented by the amplitude of the curve, that is, by the line *b B*.

11. Cycle.—A complete vibration up and down of the point *p*, corresponding to one rotation of the point *p'* through 360°, is termed a **cycle.** A complete cycle would, therefore, be represented by the part *A B C D E* of the curve, *E c'* being part of the next cycle. It is seen that in its vibration the point *p* in Fig. 7 has completed one full cycle and has started on the next, being at the time shown at the point *c'* on the curve. The distance *A E* is the length of one complete wave, and is called the **wave length.**

If the curve in this figure represents an alternating current or electromotive force, then, when the alternating current or electromotive force starts at A, passes through all the positive values (that is, along the curve $A\,c\,B\,C$ above the axis), returns to the axis at C, passes through all the negative values (that is, along the curve $C\,D\,E$ below the axis), and returns to the axis at E, it is said to have made one complete cycle.

It is evident that simple harmonic motion, although taking place in a straight line, is very closely allied to circular motion, and it is therefore customary to deal with it by means of angular measure. Thus, a complete cycle would be represented by 360°, or by $2\pi r$, where r is the radius of the circle, or the amplitude of vibration. One-fourth of a cycle would be represented by 90° or $\frac{\pi r}{2}$.

12. Alternation.—An **alternation** is represented by that portion of the curve which in Fig. 7 is included between A and C, or between C and E. A cycle is therefore equivalent to two alternations.

13. Frequency.—The number of complete cycles occurring in 1 second of time is called the **frequency** of the vibration or of the alternation. The term frequency is often *misused* by making it represent the number of alternations, half vibrations, or half cycles that occur in 1 second.

14. Period.—The **period** of a vibration is the time that elapses during one complete cycle; thus, if P represents the period and n the frequency, it is evident that $P = \frac{1}{n}$. In Fig. 7, the time required for the wave to move from A to E is the period of vibration.

The horizontal distance measured along the line $A\,E$ in Fig. 7 may be taken as a measure of the time elapsing during the passage of the point p from any point on the diameter of the circle to any other point, or it may be taken as a measure of the angle through which the point p' has

rotated from its original position A'. Thus, if it takes the point p just 4 seconds to pass from the center point O through a complete cycle back to that point, it is evident that the distance $A\ E$ will represent the time of one complete cycle, that is, 4 seconds. It may also represent the angular rotation of the point p', and in circular measure, would be 360°, or $2\ \pi\ r$. In a like manner, the distance $A\ b$ would represent a time of 1 second, since it is $\frac{1}{4}$ of $A\ E$, or an angular rotation of 90°; the distance $A\ C$ a time of 2 seconds, or an angular rotation of 180°; and the distance $A\ d$ a time of 3 seconds, or an angular rotation of 270°.

15. Phase.—The portion of a cycle through which a vibrating point has passed at a given time is called the **phase** of the vibration, and is usually expressed in angular measure. Thus, the point B on the curve in Fig. 7 would represent a phase of 90°; the point C a phase of 180°; the point D, 270°; and the point E, 360°, or a complete cycle.

ELECTRICAL PROPERTIES OF A CIRCUIT.

SELF-INDUCTION.

16. Electromagnetic Induction. — Self-induction has already been briefly described in *Principles of Electricity and Magnetism*, but, as its influence is important in telegraphy, it will here be described at greater length. Whenever there is such a relative movement between a conductor and the lines of force of a field as to cause the lines of force to cut the conductor, an electromotive force will be set up in the conductor that tends to cause a current to flow. The direction of the electromotive force will depend on the direction of the lines of force and on the direction of the cutting, and its value will depend on the rate of the cutting. The field of force may be set up either by a magnet or by a conductor carrying a current. This phenomenon is termed

electromagnetic induction, and self-induction is one of the phenomena directly attributable to it.

17. Mutual Action Between Turns of a Coil.—In *Principles of Electricity and Magnetism*, it was shown that every conductor carrying a current is surrounded by a magnetic field or magnetic whirl. It is evident that in a coil of wire carrying a current, each turn is surrounded by such a field or whirl, and if the various convolutions are close together, each will lie more or less within the field of the others. Each turn will therefore have an inductive action on the other turns, because, when the strength of the current is varying, the lines of force in the field surrounding each turn will, so to speak, contract or expand, thus cutting the wires in the adjacent turns and setting up electromotive forces in them.

In two wires lying side by side, an increase in the current in one of them will induce an electromotive force in the other, tending to cause a current to flow in a direction opposite to the original current. On the other hand, a decrease in the current flowing in one of them will induce an electromotive force in the other, tending to cause a current to flow in the same direction as the original current.

The convolutions or turns of a coil form practically parallel wires, and in order to show the effects of self-induction, we will consider the action of one particular turn on the neighboring turns. When the current flowing in this particular turn suddenly increases, the lines of force set up around the wire of this turn will expand, and in so doing, will cut the wires of all the neighboring turns. This will induce an electromotive force in the neighboring turns that will tend to cause a current to flow in the opposite direction to the original current. On the other hand, when the current flowing in this particular turn diminishes, the lines of force will contract, and in so doing, induce electromotive forces in each of the other turns that will tend to produce currents in them in the same direction as the original current. Each turn of wire in the coil also acts on all the others

in the same manner as the particular turn that we have considered, thereby greatly magnifying the result. This phenomenon, i. e., the action of one part of a circuit on the other parts of the same circuit, is termed **self-induction.** As an increase in the current flowing in one direction through a circuit always tends to induce a current in the opposite direction, while a decrease in the current tends to induce a current in the same direction, self-induction may be said to be that property of a circuit *that tends to prevent any change in the strength of a current* flowing in it. Self-induction has, therefore, been defined as the "inherent quality of an electric current that tends to impede the introduction, variation, or extinction of an electric current passing through an electric circuit." The circuit acts as if it possessed magnetic inertia which resists any change, and especially a sudden change, in the strength of the current flowing. It is evident, since self-induction tends to oppose any change being made in a current flowing in a circuit, that the effect will be to make any change in current strength occur slightly later than it would if the circuit possessed no self-induction.

18. Coefficient of Self-Induction. — The total amount of cutting or interlocking of the lines of force and the turns of a coil that is set up by a current of 1 ampere flowing through the coil, is called the **coefficient of self-induction.** This coefficient is usually represented by L. If we represent the number of lines threading through the coil when 1 ampere is flowing by n, and the number of turns by T, then the cutting or interlocking when n lines are removed will be Tn, since each line cuts through each of the T turns. Evidently, therefore, for 1 ampere of current, $L = Tn$, and for a current of C amperes, the total number of lines will be C times larger, or Cn, since the total induction or number of lines of force surrounding a conductor increases directly in proportion to the current, provided the coil does not contain iron. When C amperes flow in a coil containing no iron, we then have

$$CL = TCn, \text{ or } L = \frac{TCn}{C}.$$

Now $C n$ is the total number of lines threading the coil for a given current C; therefore, by representing this quantity by N, we get

$$L = \frac{T N}{C}.$$

The practical unit of self-induction is the *henry*, and corresponds to a cutting of 100,000,000 lines of force when the current turned on or off is 1 ampere; hence,

$$L \text{ (in henrys)} = \frac{T N}{10^8 C}. \qquad \textbf{(1.)}$$

This formula is true for any coil in which N is the total number of lines when the current is C amperes. For a coil containing no magnetic material, such as iron, L is entirely independent of the current C, because N is exactly C times as large as for unit current. When the coil contains an iron core, the lines of force do not increase in direct proportion to the magnetizing force or to the ampere-turns in the coil. However, by representing the actual total number of lines of force set up by a current of C amperes by N, as we have done above, the formula given holds for coils with or without iron in or surrounding them.

It will be evident from formula **1** that the coefficient of self-induction L may be increased by increasing T, the number of turns, or by increasing N, the total number of lines of force set up through the coil by a given current. The number of turns may be readily increased by winding more wire on a coil, and in order to do this where a limited amount of space is available, it is usually necessary to wind with a smaller wire. The number of lines of force set up through a coil depends not only on the strength of the current but also on the character of the magnetic substance in and around the coil. A coil having no iron in its core will have a very much lower coefficient of self-induction than a coil having a core of iron, for the reason that the number of lines of force set up by a given magnetizing current is much greater in iron than in air. We may say, therefore, that a large amount of iron in the core of a coil serves to greatly increase the

coefficient of self-induction, and where the return path for the lines of force is also made of iron, the coefficient of self-induction is still further increased, because the entire magnetic circuit is made of iron.

19. Electromotive Force to Overcome Self-Induction.—The electromotive force that is required to counteract the effect of self-induction in a circuit is called the **electromotive force necessary to overcome self-induction,** in order to distinguish it from the impressed electromotive force or pressure, which, as its name indicates, is that impressed on the circuit by the generator that is causing the current to flow. The impressed pressure in a circuit containing only inductance and resistance is the resultant of the pressure necessary to overcome self-induction and the pressure, called the *active electromotive force*, that is necessary to overcome the simple resistance. It is convenient to speak of the electromotive force that is equal and opposite to that component of the impressed electromotive force that overcomes the self-induction as the *electromotive force of self-induction.* The electromotive force of self-induction is proportional at all times to the rate of change of the current flowing in the circuit, and not proportional to the current itself. Therefore, the electromotive force of self-induction is a maximum when the current is passing through zero, because at that time the current is changing faster than at any other time. Likewise, the electromotive force of self-induction is zero when the current is a maximum, for when the current is a maximum the rate of change of the current is zero.

ELECTROSTATIC CAPACITY.

20. Condensers.—It has been stated in *Principles of Electricity and Magnetism* that all bodies have, to a greater or less extent, the power of accumulating charges of electricity on their surfaces, and that two such charges mutually repel or attract each other, according to whether they are of the same or opposite sign. It was further stated

that the amount of charge that a given conductor would take would be greatly increased by the proximity of another conductor. Two conducting bodies placed close together, or insulated from each other, form what is called a **condenser,** of which the Leyden jar is probably the best known example. Condensers, however, for commercial work are usually made of a large number of sheets of tin-foil, laid one upon the other, each sheet being insulated from those adjacent to it by sheets of paper impregnated with insulating compound. The alternate layers of tin-foil are connected together at one side and to a point forming one terminal of the condenser, while the remaining plates are similarly joined to a point forming the other terminal of the condenser. The result of this construction is to give two conducting surfaces of large area separated from each other by a thin insulating medium.

21. Capacity of Condensers.—The amount of electricity that a condenser is capable of receiving when its terminals are subjected to a certain difference of potential determines the **capacity** of the condenser in exactly the same manner as the amount of gas that could be forced into a vessel under a given pressure would determine the capacity of the vessel. The analogy can be carried further by stating that the amount of gas that can be forced into a given chamber will vary directly as the pressure that is applied in forcing the gas into the chamber, and that the amount of charge that a given condenser will receive will vary directly as the electric pressure between the condenser terminals.

The capacity of a condenser varies directly as the size of its conducting surfaces, and inversely as the square of the distance between the conducting surfaces. It also depends on the character of the insulating medium or dielectric between the conductors. The unit of capacity is called the **farad,** in honor of Michael Faraday, the celebrated scientist. A condenser having a capacity of 1 farad would have the pressure across its terminals raised to 1 volt, if a current

of 1 ampere flowed into it for a period of 1 second; in other words, the terminals of a condenser having a capacity of 1 farad would have a difference of potential of 1 volt when the condenser has a charge of 1 coulomb of electricity.

22. Specific Inductive Capacity.—In the preceding paragraph it was stated that the capacity of a condenser depended, among other conditions, on the character of the insulating medium between the conductors. Some insulating mediums are better adapted to allow inductive action through them than others, and the extent to which a substance possesses this quality is called its **specific inductive capacity.** As an illustration, assume two condensers having plates of equal size and at equal distances apart; if the dielectric in one of them is dry air, while in the other it is paraffin, it will be found that the latter condenser has just twice the capacity of the former. The specific inductive capacity of dry air is always taken as unity; it is lower than that of any other known substance, excepting, perhaps,

TABLE 1.

TABLE OF SPECIFIC INDUCTIVE CAPACITIES.

Materials.	Specific Inductive Capacity.
Air	1.000
Paraffin (solid)	1.994
India rubber	2.220 to 2.497
Ebonite	2.284
Gutta percha	2.462
Sulphur	2.580
Shellac	2.740
Glass	3.013 to 3.258
Mica	5.5 to 8.0

NOTE.—Wilkinson states that the capacity of the best quality of gutta-percha compound that was made in 1896 for insulating submarine cables is .0541 microfarad per cubic knot at 75° F.

hydrogen. Inasmuch as a given thickness of paraffin is capable of allowing twice as much electrostatic induction through it as the same thickness of dry air, its specific inductive capacity is 2. That is, a given condenser whose conducting surfaces are separated by a certain thickness of paraffin will have twice the capacity that it would have if the same thickness of air were used in place of the paraffin.

Table 1 gives the specific inductive capacities of several of the more common insulating materials.

The question of specific inductive capacity plays an important part in the construction of submarine telegraph cables and in all telephone cables.

23. If a condenser *C* is placed in the circuit of a generator *G* of alternating currents, as shown in Fig. 8, its terminals will be subjected to electromotive forces varying rapidly from a maximum in one direction to a maximum in the other direction. As the condenser receives a charge from the lines or discharges itself back into the line, currents will flow into or out of it, according to whether the pressure at its terminals is increasing or decreasing.

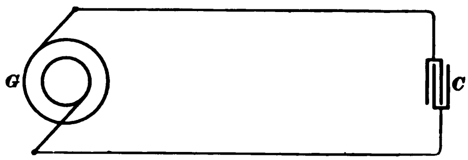


FIG. 8.

The amount of current flowing into or out of the condenser depends on the rate of change of the electromotive force at its terminals; but the amount of the charge in the condenser depends on the instantaneous value of the electromotive force, and not on its rate of change. Evidently, as long as the electromotive force at the condenser terminals does not change, no current will flow into or out of the condenser, but if the electromotive force across the condenser terminals is gradually raised, a current will flow into the condenser, and if gradually lowered, a current will flow out of the condenser. The faster these changes in the potential across the condenser terminals take place, the greater will be the current flowing into or out of the condenser.

ALTERNATING-CURRENT LAWS.

24. Opposition Due to Resistance.—The following explanations of the laws for alternating currents are based on an article on the subject by Mr. D. C. Jackson in "Science and Industry," June, 1900. Ohm's law asserts that a continuous current is equal to the electrical pressure in a circuit divided by the electrical resistance of that circuit. This law is nothing more than a special statement of a condition that may be recognized as universally applicable to the phenomena of nature. The general statement may be put thus: The result of an effort is equal to that effort divided by the opposing resistance. For instance, if we stretch an elastic material, the amount of stretch will depend on the ratio of the pull to the elastic resistance of the material; if we try to push a heavy block along the floor, the velocity of the block will depend on the ratio of the force exerted to the frictional resistance opposing the motion; and so we could go on indefinitely illustrating the general applicability in nature of this statement that the result is dependent on the ratio—effort divided by resistance.

We then have for the flow of continuous currents the rule that the current flowing ("result") is equal to the pressure ("effort") divided by the opposition to the current flow ("resistance"); but in the case of continuous currents, there is no opposition to the flow of the current except electrical resistance, that is, the resistance that is determined by the nature, temperature, and dimensions of the conductor, whence we have Ohm's law, $C = \frac{E}{R}$, for the flow of continuous currents.

25. Opposition Due to Resistance, Inductance, and Capacity.—The fundamental law of the flow of alternating currents follows directly from what has gone before. The alternating current flowing in a circuit is equal to the pressure divided by the opposition to the flow of the current. The total opposition or the apparent resistance offered to the

flow of an alternating current by a circuit possessing inductance or electrostatic capacity, or both, in addition to the electrical resistance, is called its **impedance.** The total opposition is made up of two components, the electrical resistance and the opposition due to inductance or to capacity, or to both. That part of the opposition due to other than the electrical resistance is called the **reactance.**

26. Fundamental Law of Alternating Currents. The fundamental law governing the flow of alternating currents in circuits may be briefly stated as follows:

The current flowing in a circuit is equal to the alternating electromotive force divided by the impedance.

This law can be put into the following very simple mathematical formula:

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\text{impedance}}.$$

27. Effect of Resistance.—Resistance is that property of a circuit that tends to obstruct the passage of a current. The effect of resistance on direct or continuous currents has already been described in *Principles of Electricity and Magnetism.* The relation between the values of the current, electromotive force, and resistance is defined by Ohm's law, which may be stated as follows: The current in amperes is equal to the electromotive force expressed in volts divided by the resistance of the circuit expressed in ohms. The effect of resistance, when not modified by any other properties of the circuit, such, for instance, as self-induction or capacity, is the same for alternating and rapidly fluctuating currents as for direct currents. Its only effect is to diminish the amplitude of the current wave. This diminution in amplitude is, under these circumstances, in exact accordance with Ohm's law.

28. Effect of Self-Induction.—A retardation of the current by electromagnetic inertia or inductance occurs when the current changes in value, and it therefore exercises

a marked influence on the ever-changing alternating current. Faraday showed that the value of the changing current was retarded or lagged behind the value that it might be expected to attain and that a uniform current in the same circuit would attain. The amount of the lag depends on the electromagnetic character of the circuit. Thus, a straight wire causes less retardation or lag than the same wire wound in a helix, because the helix increases the magnetic effect. Inserting an iron core into the helix may increase the retardation enormously, since the presence of the iron again increases the magnetic effect.

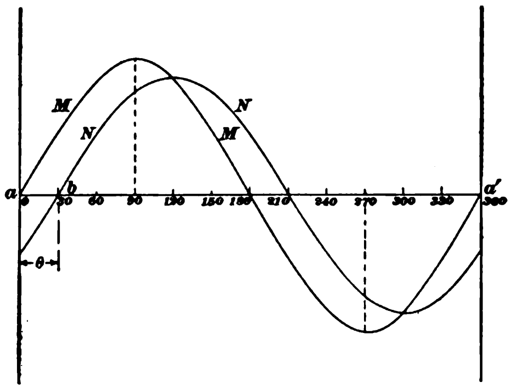


FIG. 9.

The electrical resistance of a wire composing a circuit depends, as is well known, on the material and temperature of the wire and on its length and cross-section; and it is not affected by the flow of current, provided the temperature is not affected thereby. The inductive resistance is dependent on the self-induction (i. e., the electromagnetic condition of the wire) and the frequency of the alternating current. The effect of the self-induction is to retard the rise and fall of the current so that it attains its maximum later than the maximum of the alternating pressure that sets it up; and it also increases the apparent resistance to the flow of the alternating current in the circuit. Thus, if the curve M in Fig. 9 is taken to represent the alternating

current that flows in a circuit supposed to contain no self-induction, then N can be taken to represent the current that flows when there is self-induction. N is retarded with respect to M and reaches a smaller maximum value.

In this figure, the distance θ from a to b, expressed in degrees, is called the angle of lag θ. For $a\,a'$ represents one complete period, that is, 360°; consequently, each $\frac{1}{360}$ part of the distance $a\,a'$ is equivalent to 1°. In this figure, the curve N lags 30° behind the curve M.

29. In the case of a circuit that possesses inductance and resistance, the total opposition or impedance is made up of two components, one the electrical resistance and the other the opposition to self-induction, called the **inductive reactance.** The law for calculating the current in a circuit possessing only inductance and resistance is expressed as follows:

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\sqrt{(\text{resistance})^2 + (\text{inductive reactance})^2}}.$$

The impedance of a circuit possessing only resistance and self-induction for a simple sine-wave current is expressed by the following formula:

$$\text{Impedance} = \sqrt{R^2 + (2\,\pi\,n\,L)^2}, \qquad (2.)$$

in which R = simple resistance of circuit in ohms;
π = 3.1416;
n = number of complete periods per second, or the frequency;
L = coefficient of self-induction—often called simply inductance—expressed in henrys.

The term $2\,\pi\,n\,L$ is the inductive reactance.

If E is the impressed electromotive force and C the alternating current, we have the formula

$$C = \frac{E}{\sqrt{R^2 + (2\,\pi\,n\,L)^2}}. \qquad (3.)$$

NOTE.—The derivation of the formula for the impedance of circuits cannot well be given here and is not essential to the proper understanding of the subject. They can be found in most complete treatises on alternating currents.

EXAMPLE.—Suppose we have a circuit with a resistance R of .4 ohm, an inductance L of .001 henry, and an impressed electromotive force E of 1 volt. What will be the current when the frequency n is 60 periods per second?

SOLUTION.—By formula **3**

$$C = \frac{1}{\sqrt{(.4)^2 + (2 \times 3.1416 \times 60 \times .001)^2}} = 1.818 \text{ amperes. Ans.}$$

30. From formula **3** it is evident that a given circuit possessing inductance reduces currents of high frequency more than those of low frequency; for the larger the value of n in the formula, the smaller will be the value of the current C. Furthermore, the larger R or L, the smaller will be C for a given frequency n.

31. Effect of Capacity.—A condenser placed across a circuit produces an effect opposite in direction to that produced by self-induction. It is known that the value of the changing current in a circuit containing a condenser tends to occur earlier, or to lead the value that it would attain if the opposition to its flow consisted only of simple electrical resistance. When, in addition to resistance, a circuit possesses only capacity, an alternating current will be reduced in amplitude or strength and will also lead the impressed electromotive force. Where we have only resistance and capacity, we have

$$\text{Alternating current} = \frac{\text{impressed electromotive force}}{\sqrt{(\text{resistance})^2 + (\text{capacity reactance})^2}}.$$

The impedance of a circuit possessing only resistance and capacity is expressed, for a simple sine wave current, by the formula

$$\text{Impedance} = \sqrt{R^2 + \left(\frac{1}{2 \pi n Q}\right)^2}, \qquad \textbf{(4.)}$$

in which Q is the electrostatic capacity in farads, the other letters having the same meaning as given in Art. **29.** Then the current is given by the expression

$$C = \frac{E}{\sqrt{R^2 + \left(\frac{1}{2 \pi n Q}\right)^2}}. \qquad \textbf{(5.)}$$

32. From formula **4** it is evident that for a given circuit, the impedance is smaller the greater the frequency n of the alternating current, and from formula **5** we see that the current increases in strength as the frequency increases. Furthermore, the greater the capacity, the smaller will be the impedance and the greater the current for a given frequency and resistance.

The foregoing formulas for capacity apply to circuits in which the condensers are in series with the line and other apparatus. Distributed capacity, which cannot be treated in so simple a manner, produces effects that will be considered later.

33. Effect of Combined Resistance, Self-Induction, and Capacity.—When, in addition to resistance, a circuit possesses both capacity and inductance, the impedance and the current are given by the following formulas:

$$\text{Impedance} = \sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n Q}\right)^2}, \qquad \textbf{(6.)}$$

$$C = \frac{E}{\sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n Q}\right)^2}}. \qquad \textbf{(7.)}$$

These formulas assume that the resistance, self-induction, and capacity are all in series with the line and apparatus, and that the current curve is a sine curve.

34. For any given frequency of alternation, the effect of the inductance of a circuit may be neutralized by the application of a capacity of the proper value. That this is true may readily be seen from the foregoing formulas. From formula **7** it is quite evident that $C = \frac{E}{R}$, when $2\pi n L - \frac{1}{2\pi n Q} = 0$. For a given circuit having a definite inductance L and electrostatic capacity Q, it is quite plain that this expression can be made equal to zero for only one particular value of the frequency n.

When, therefore, $L = \frac{1}{4\pi^2 n^2 Q}$, the current follows Ohm's law and the current will not lag behind nor lead the impressed electromotive force. Thus, by properly proportioning the inductance and the capacity of a circuit, the electromotive force due to self-induction may be made to neutralize the electromotive force due to capacity, thus allowing only the impressed electromotive force to be active in driving the current through the circuit. In this case, the impressed electromotive force and the active electromotive force are the same, and the maximum value of the current will occur at the same instant as the maximum value of the impressed electromotive force, as it would do were no self-induction or capacity present.

35. Unfortunately, it is distributed capacity that we have to neutralize in telegraph lines and cables, and to do this requires a distributed inductance. So far, no commercially successful method for doing this throughout a cable or line wire has been put in use. It is well known that a cable with an inductive shunt or leak at a point near its middle will transmit signals more rapidly and distinctly than one not so compensated. The method of wrapping an iron wire or ribbon around the copper conductor in order to increase the induction has been proved to be of some benefit, but far too small to be of any practical value.

In a paper read before the American Institute of Electrical Engineers, in May, 1900, Doctor Pupin gives a method for increasing the efficiency of a cable or line for telephonic or telegraphic transmission. His method promises to be of much practical value. By inserting inductance coils of a certain calculated value at certain definite intervals along the wire or cable, the smoothing out or retardation of the electrical waves is very much reduced. The inductance coils must be carefully calculated and distributed for each cable or line, or their use may do more harm than good. For further information on this subject, the student is referred to Doctor Pupin's paper, for it is too long and complex to give a satisfactory abstract here.

Alternating electromotive forces and currents do not necessarily vary in such a simple way as to give an exact sine curve. In fact, some are exceedingly complex. However, only those that follow the curves of sines have been considered here, for it is not practical to make any calculations concerning those that follow more complex curves. For complex curves, approximate results only can be obtained by using the formulas given.

THEORY OF TELEGRAPH LINES.

ELECTRICAL PROPERTIES OF TELEGRAPH LINES.

36. Resistance.—The **resistance** of a telegraph circuit has two components: *First*, the resistance of all apparatus connected in the circuit, and, *second*, the resistance of the line wire itself. The resistance of the line wire may be determined from tables, which will be given later, or by direct measurements by the methods outlined in *Electrical Measurements*. A moderate amount of resistance does not in itself seriously interfere with telegraph transmission, but resistance in combination with electrostatic capacity may impose a very serious obstacle, as will be pointed out later.

37. Inductance.—The **inductance** of a telegraph circuit is almost entirely concentrated in the electromagnets connected in its circuit, and its effects are, therefore, so far as the line wire is concerned, but slight. It has been shown in connection with alternating currents that inductance tends to increase the apparent resistance of a circuit to alternating currents, this increase of apparent resistance being due to the electromotive force of self-induction, which tends to oppose the electromotive force impressed on the line, and, therefore, to cut down the current flowing, in much the

same way as an increase of actual ohmic resistance would do. It has been found by experiment that, for line circuits of copper, impedance is but little more than the actual resistance.

A copper wire .104 inch in diameter has a resistance of 5.2 ohms per mile. This resistance is, of course, the actual resistance of the wire. The apparent resistance or impedance of this wire to alternating currents having a frequency even as high as 1,500 alternations per second is only about 1.4 per cent. greater, or about 5.27 ohms. So that the difference between the resistance and the impedance of a line wire due to inductance is so small as to be practically negligible.

38. Capacity.—The effects of a condenser bridged across a circuit carrying alternating currents have already been dealt with. It has been shown that the condenser tends to make the current flowing in the line lead the impressed electromotive force in phase. Like inductance, it has the effect of increasing the apparent resistance of the line by introducing an electromotive force that the impressed electromotive force must overcome.

39. Distributed Capacity.—Every telegraph line may be considered as one plate of a condenser. If the circuit is a grounded one, the single line wire corresponds to one plate of the condenser, the insulation or atmosphere to the dielectric, and the earth or surrounding conductors to the other plate. If the circuit is metallic, one wire forms one plate of the condenser, the air between the two wires is the dielectric, and the other wire forms the other plate. The capacity of a line is distributed throughout its entire length, and is therefore termed **distributed capacity**; each element or short piece of the line wire may be considered as forming one plate of a condenser, the other plate of which is formed by corresponding portions of surrounding conductors and the ground. The line circuit may therefore be considered as an infinite number of small condenser plates,

each acting on the currents flowing over the line, according to the laws already pointed out in the consideration of alternating currents.

40. The action of distributed capacity may be made more clear by considering a number of condensers bridged across a metallic circuit, as shown in Fig. 10, instead of considering each successive element of the line wire as a portion of a separate condenser. If the electromotive force of the generator *G*, placed across the line circuit at one end, is suddenly raised, a current will be sent over the line, a portion of it flowing into each condenser, the condenser plates keeping at the same potential as that point of the wire to which each plate is connected. Condenser *1* will receive the greatest portion of the charge, because it is subjected to the highest difference of potential. Condenser *2*, owing to the resistance of the line wires between *1* and *2*, will be subjected to a slightly smaller difference of potential, and

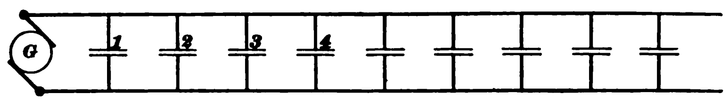


FIG. 10.

hence will receive a slightly smaller charge, and so on throughout the entire number, the current flowing into each condenser, of course, detracting from the amount flowing into the more distant portions of the line. If the electromotive force continues long enough in that direction, a sufficient quantity of current will flow through the line to charge all the condenser plates to the full amount, but if the electromotive force continues only long enough to allow enough current to flow through the line to charge condenser *1*, the charge in each successive condenser will be less and less, and the last few condensers may receive practically no charge.

When it is stated that condenser *1* will be charged before condenser *2*, it must not be imagined that this slowness on

the part of *2* in taking its charge is due to the speed at which an electric wave may travel along a conductor. This speed is practically equal to that of light, 186,000 miles per second, and, on the longest line obtainable, the time necessary for an electric impulse to flow through it would be almost too small to measure. It should rather be looked at in the following light: The amount of electricity in coulombs that will flow through a conductor depends on the number of amperes flowing and on the length of time the current continues to flow. The charge of a condenser may be measured in coulombs, 1 coulomb being that amount of electricity represented by a flow of 1 ampere for 1 second. Obviously, here is a time element that is not dependent on the actual velocity of electricity. If 1 ampere flows into a condenser for ½ second, the charge assumed by the condenser during that time will be ½ coulomb, and in ¼ second will be ¼ coulomb. Similarly, the amount of electrical energy that can flow through a conductor depends on the strength of the current, the voltage, and the time of the flow.

41. If, at a given instant, an electromotive force in one direction is impressed on such a line as is shown in Fig. 10, there will be a rush of current into the line wire that will tend to charge the condensers; the potential at the terminals of condenser *1* will be greater than that at the terminals of condenser *2*, and similarly, that at *2* will be greater than that at *3*, and so on, this difference of the potential across the various condenser terminals being due to the drop caused by the ohmic resistance of the line wire. Condenser *1* will therefore take the greatest charge, condenser *2* a somewhat smaller charge, and so on through each successive condenser. If condensers *1*, *2*, *3*, and *4* have the capacity to take a certain amount of charge when subjected to the potentials mentioned, and the electromotive force impressed on the line acts only long enough to allow that amount of current to flow from the source, and then reverses, then it is evident that condensers *1*, *2*, *3*, and *4* will each take their respective charges, and the small amount of electricity that flowed from

the generator is insufficient to charge the condensers beyond. There will therefore be no appreciable flow of current in the line wires beyond condenser *4*, for, on the reversal of the electromotive force, the charges of the various condensers will merely flow back to the source. It is not difficult to see, therefore, that a rapidly alternating electromotive force may be impressed on one end of such a line without any of the current impulses ever reaching the other end, the time between the successive impulses being insufficient to allow a sufficient *quantity* of electricity to flow through the line to charge all the condenser plates. If, now, each small portion of the line wire be considered as a condenser plate, it will be seen that the effect will be practically the same as that illustrated in Fig. 10.

42. The K R Law.—From the foregoing, we may conclude that the length of time necessary for an impulse of current to reach the distant end of a line depends not only on the distributed capacity K of the line, but also on the resistance R of the line wire. It has been proved by extensive experiments in telegraphy that the length of time required for a current to reach its maximum strength at the distant end of the line varies directly as the product of the capacity K of the line and its resistance R. Since both the capacity and the resistance are proportional to the length of the line or cable, it follows that the product $K R$, which is called the **time-constant** of the line or cable, increases as the square of the length of the line or cable.

Let us see the effect of the frequency on the current in submarine cables. For cable work, the positive and negative poles of the battery are alternately put to the cable and to ground. At 45 words per minute, there are about 17 alternations per second. At 75 words per minute, there would be about 28 alternations per second. With the same electromotive force, the amplitude of the current curve traced on the receiving paper by the siphon recorder [on a cable for which the product of the total capacity and total resistance, called the KR of the cable, is 2.42] would be about 13.6 per

cent. greater when there are 17 alternations per second than when there are 28 per second.

The essential features of a portion of an article by Mr. Willis H. Jones in "The Telegraph Age," May 16, 1900, concerning the limiting value of the $K R$ law for land line wires on which quadruplex systems may be worked, are as follows.

An experimental test was made in the quadruplex department of the Western Union Telegraph Company that showed that a quadruplex circuit worked efficiently between New York and Buffalo, over a line having a value of 17,000 for the product $K R$. On a direct circuit between New York and Chicago, having approximately the same resistance but a $K R$ of 32,000, the quadruplex system would not work satisfactorily. The large value of $K R$ on this line is doubtless the reason for its failure to give satisfactory results with quadruplex apparatus.

It would appear from the tests mentioned that the dividing line between efficient and poor quadruplex work lies somewhere between a $K R$ of 17,000 and 32,000, probably about half way; the latter suggestion, however, is but a guess.

The failure did not appear to be due to an insufficiency of current, for when the full battery or "long end" was closed and the apparatus inactive, the neutral relay gave evidence of being strongly magnetized, but the moment an attempt was made to start working, the margin of current for the No. 2 side, or neutral, relay seemed to become absorbed or totally destroyed by the effects of the static charge so developed. The terms used above and applying to the quadruplex system will be clear to the student when the quadruplex is explained later.

From this it appears that 500 miles of No. 11 or 12 B. W. G. copper wire, having a resistance of 4 to 5 ohms per mile, is about the limit for a satisfactory quadruplex circuit. Wires somewhat inferior to the above are frequently assigned to long quadruplex circuits for the want of anything better, but the great amount of care and attention they require in order to be kept workable makes it most advisable to employ duplex apparatus on such circuits.

SPEED OF SIGNALING.

43. In Art. **40** it was shown that a perceptible time was required for a cable or line possessing distributed capacity to become fully charged or discharged in spite of the fact that electricity travels with the speed of light. The following discussion on the speed of signaling has been, by permission, partially taken from, or based on, an excellent treatment of this subject in Jenkin's "Electricity and Magnetism." It is a well-known fact that when a signal is sent through an Atlantic cable, it does not produce any effect in Newfoundland simultaneously with the depression of the key in Ireland. The distance divided by the time occupied in the transmission of the signal may be called the **velocity** with which that particular signal was transmitted. It might even be termed the velocity with which a certain quantity of electricity traversed the cable; but it is not the velocity proper to or peculiar to electricity, for under different circumstances the same quantity of electricity may be made to traverse the same distance with almost infinitely different velocities.

For about $\frac{1}{5}$ second after contact is made at Newfoundland, no effect can be detected in Ireland, even by the most delicate instrument; after $\frac{2}{5}$ second the received current is about 7 per cent. of the maximum permanent current that will ultimately flow equally through all parts of the circuit. The current will gradually increase until 1 second after the first contact is made, when the current will have reached about half its final strength, and after about 3 seconds it will have attained nearly its maximum strength; during all this time, the maximum current is flowing into the cable at the sending end. The velocity with which the current travels even in this one case has therefore no definite meaning; the current does not arrive all at once, like a bullet, but grows gradually from a minimum to a maximum.

44. Fig. 11 shows the curve representing the law of increase of the received currents, which is the same on all lines. The vertical ordinates parallel to $O\ Y$ represent

strengths of current, the maximum or permanent current flowing through the circuit after equilibrium has been reached being called 100. Hence the vertical ordinates are really percentages of the maximum permanent current.

The horizontal distances along OX represent intervals of time, measured from the moment at which contact was

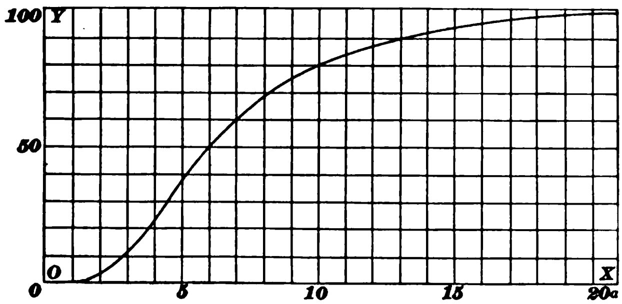


FIG. 11.

first made at the sending station, and expressed in terms of an arbitrary unit a, different for different circuits, but constant for any one circuit.

For a uniform cable or line of length l in knots, a resistance of r ohms per knot, and an electrostatic capacity of q microfarads per knot, the value of a is given in seconds by the following formula:

$$a = \frac{.02332\, q\, r\, l^2}{1,000,000}. \qquad \textbf{(8.)}$$

From this formula, it is evident that a is proportional to the square of the length of the cable, which bears out the remark made to that effect in Art. **42.** The total electrostatic capacity is equal to $q\,l$ and the total resistance to $r\,l$. Hence, the $K\,R$ of the cable is $\frac{q\,r\,l^2}{1,000,000}$. The 1,000,000 in the denominator is necessary to reduce microfarads in which q is expressed to farads.

NOTE.—The derivation of formula **8** requires the use of higher mathematics, so that it cannot be given here.

For the French Atlantic cable, q = .43 microfarad per knot, r = 2.93 ohms per knot, and l = 2,584 knots. Substituting these values in the formula just given, we get for this cable, a = .196 second.

45. In terms of a, the arrival curves for the received current of all lines are identical, and the same curve shows the law according to which the current at the receiving end dies away when at the sending end *the line has been put to earth.* A succession of contacts with the battery and with

TABLE 2.

t in Terms of a.	Strength of Current in Percentages.	t in Terms of a.	Strength of Current in Percentages.	t in Terms of a.	Strength of Current in Percentages.	t in Terms of a	Strength of Current in Percentages.
.40	.00000000271	1.1	.041406	3.5	18.4843	7.8	66.9600
.50	.00000051452	1.2	.089276	3.6	19.8437	8.0	68.4283
.55	.0000033639	1.3	.17048	3.7	21.2134	8.5	71.8289
.60	.000016714	1.4	.29600	3.8	22.5902	9.0	74.8717
.62	.000029252	1.5	.47634	3.9	23.9707	9.5	77.5913
.64	.000049412	1.6	.72079	4.0	25.3522	10.0	80.0200
.66	.000080817	1.7	1.0369	4.2	28.1076	10.5	82.1876
.68	.00012835	1.8	1.4303	4.4	30.8381	11.0	84.1214
.70	.00019845	1.9	1.9044	4.6	33.5290	12.0	87.3840
.72	.00029937	2.0	2.4608	4.8	36.1689	13.0	89.9775
.74	.00044152	2.1	3.0997	5.0	38.7481	14.0	92.0384
.76	.00063776	2.2	3.8185	5.2	41.2603	15.0	93.6757
.78	.00090371	2.3	4.6156	5.4	43.7003	16.0	94.9763
.80	.0012580	2.4	5.4866	5.6	46.0645	17.0	96.0095
.82	.0017227	2.5	6.4270	5.8	48.3507	18.0	96.8302
.84	.0023233	2.6	7.4316	6.0	50.5577	19.0	97.4822
.86	.0030892	2.7	8.4954	6.2	52.6850	20.0	98.0000
.88	.0040536	2.8	9.6126	6.4	54.7331	21.0	98.4113
.90	.0052539	2.9	10.7780	6.6	56.7029	22.0	98.7381
.92	.0067316	3.0	11.9858	6.8	58.9502	23.0	98.9976
.94	.0085325	3.1	13.2309	7.0	60.4116	24.0	99.2038
.96	.010706	3.2	14.5080	7.2	62.1544	25.0	99.3675
.98	.013308	3.3	15.8123	7.4	63.8252		
1.00	.016394	3.4	17.1392	7.6	65.4264		

the earth at the sending end, prolonged each for times equal to about 25 a, would cause the received current to follow or trace the series of curves shown in Fig. 12, each curve

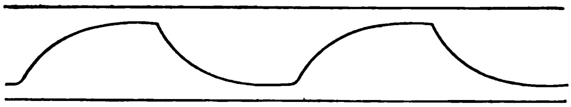


FIG. 12.

being a complete arrival curve. Table 2 shows the value of the vertical ordinate corresponding to successive multiples of a, the maximum current being 100.

46. To find the strength of the current at the receiving end in percentage of the maximum permanent current at any time t after first making contact at the sending station, divide the time t in seconds by a. This will give the time in terms of a. Then the strength of the current in percentage of the maximum permanent current may be obtained from Table 2, or by determining the length of the vertical ordinate at that point on the curve in Fig. 11 that corresponds to this time in terms of a.

EXAMPLE.—What will be the strength of the current at the receiving end of a cable whose $K R$ is 4.67, .66 second after closing the key at the sending end, if the maximum permanent current that would flow is 5 milliamperes? The time given corresponds to a speed of about 40 words per minute, or about 15 alternations per second.

SOLUTION.—By formula **8**, the value of a for this cable $= 4.67 \times .0233 = 1.088$. Then the duration of one signal in terms of a $= \frac{.66}{1.09} = .6$. From Table 2, the strength of the current in percentage of the permanent value corresponding to .6 a is about .0000167. Then the actual strength of the current at the receiving end .66 second after closing the key $= .0000167 \times 5 = .0000835$ milliampere. Ans.

47. When the line is put to earth at the sending end before the current reaches its maximum value, the falling curve is superimposed on the ascending one and a derived curve is produced, as shown in Fig. 13. This figure shows

the effect of making contact with the battery and keeping the circuit closed until the increasing current reaches the point *b* on the ascending curve, then putting the line to earth until the decreasing current reaches the point *c* on the descending curve, and finally again putting the line in contact with the battery, causing the current to start upwards from the point *c*.

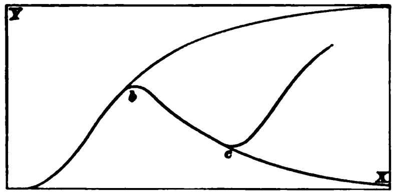


FIG. 13.

A series of rises and falls may be produced in this manner that grow smaller and smaller as the length of the contacts diminish, and when the alternate contacts are made short compared with *a*, no sensible variation can be detected in the current that flows from the cable at the receiving end. As the contacts are lengthened, the amplitude of variation increases. Table 3 gives some amplitudes due to a succession of simple dots or equal contacts with a battery and with the earth.

TABLE 3.

Length of a Pair of Contacts in Terms of *a*..	2.90	3.00	3.50	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Amplitude of Variation of Current in Percentages of Maximum	2.69	2.97	4.52	6.31	10.42	14.85	19.67	24.42	29.11	33.68

NOTE.—If the student desires to go further into the theory of signaling and to know how the above tables and formula **8** were calculated, he is referred to a paper on this subject by Sir William Thomson in the "Philosophical Magazine" for February, 1856. Professor Fleming experimentally verified the theoretical results of Sir William Thomson. This verification by Fleming is contained in the "Philosophical Transactions" for 1862. There is also an important paper on the subject in the "Philosophical Magazine" for June, 1865.

48. Influence of a **on Speed of Signaling Through Cable.**—If it were necessary for the current at the receiving end of a submarine cable to reach a large fraction of its maximum value before a signal could be detected, as on land lines, submarine telegraphy would be exceedingly slow. On the French cable, from 15 to 17 words a minute can be sent. The Mackay-Bennett cable, laid in 1894 and having a KR of 4.671, has a speed of 40 words a minute, and the Anglo-American cable, also laid in 1894 and having a KR of 2.47, has a speed of 47 words per minute. Making allowance for the difference in the KR of the two cables, it has been calculated that the speed on the Mackay-Bennett is theoretically 63 per cent. greater than on the other. This difference in speed is undoubtedly due to the different terminal arrangement and apparatus used by the two companies. At 15 words per minute, the duration of a dot is about .27 second or 1.28 a on the French cable. Many of the dots must produce no more variation in the strength of the received current than is equivalent to $\frac{1}{1000}$ of the maximum permanent value, and the effect of a dot probably depends on the 20 or 30 preceding signals, so that even very regular sending produces irregular results at the receiving end.

Such signals cannot be detected by an electromagnet, such as a relay, but require an instrument that can detect and show every change in the strength of the current. For this purpose, a delicate receiving instrument, such as a Thomson reflecting or D'Arsonval galvanometer, is necessary. The Thomson galvanometer causes a spot of light to wander over a scale and the D'Arsonval galvanometer (an essential part of the siphon recorder) causes a wavy ink line to be made on a moving paper ribbon; each instrument indicates every change in the strength of the arriving current. When the Thomson galvanometer is used, the first dot will cause the spot of light to almost cross the scale, the second moves it a little farther, the third or fourth hardly causing a perceptible motion, but the operator by experience knows that the four different effects

each indicate a simple dot, each sent by the operator at the other end in a precisely similar manner. The speed of signaling, with the same receiving and transmitting instruments, will be inversely proportional to the product $K R$ for the cable on which they are used. The speed of signaling on any cable will, however, differ greatly, according to the kind and arrangement of the transmitting and receiving instruments employed. Submarine telegraph systems will be treated later.

49. Influence of a on Speed of Signaling Through Land Lines.—Signals sent on land lines last such a long time compared to the very small value of a for such lines, that in all ordinary cases the current rises practically to its maximum value and falls to zero for each dot. A certain land line has a value of .00126 second for a. Now, this value is so small that even with $20\,a$ for each contact with the earth (the Morse open-circuit system is here referred to) and $40a$ for each dot, the dot would only occupy .05 second, or 20 dots could be made in a second; and for every dot the current would rise almost to its maximum and fall almost to its minimum. The above would give about 80 words per minute as a speed at which the effect of what is called *retardation* would be insensible in diminishing the rise and fall of the received current.

INSULATION OF THE LINE.

DISTRIBUTION OF POTENTIAL ALONG A LINE.

50. Line Open at One End.—A very common and good way of illustrating the potentials along a circuit is by a line whose height at each point is proportional to the potential at that point in the circuit. In Fig. 14, the lines $A\ B\ C$ are drawn as follows: At A, the potential is the same as that of the ground, but at the contact between the zinc electrode and the solution of the battery, the potential

rises abruptly about 1 volt, for it is positive relative to the earth, and hence a vertical line whose length represents 1 volt is drawn at this point. Again, at the second cell there is an abrupt rise of 1 volt, or 2 volts in all, above the potential of the earth, and so on to the end of the battery at *b*.

Since the distant end of the line is represented as open, the potential along the whole line wire will be the same. Since the wire and the earth form a condenser, and the charge in a condenser is proportional to the difference of potential between the plates, then the charge on the wire at any point is proportional to the vertical height of the line *A B* above the wire at that point. In this case, where the distant end is open and not grounded, and the line is perfectly insulated, the charge is uniform all along the wire. If, for each unit length of the line wire we were to erect one

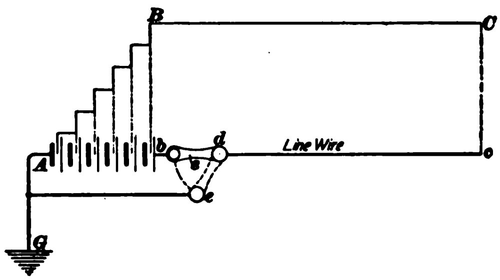


FIG. 14.

vertical line, or *ordinate*, as it is often called, proportional to the charge or quantity of electricity on that unit length, then the total charge on the whole wire would be proportional to the sum of all the ordinates so erected. Since, in the case represented in this figure, the charge is uniform throughout the wire, it follows that the total charge is equal to the charge on one unit length multiplied by the length of the line wire. Now, the length of the vertical line *b B* was made proportional to the difference of potential at that point, but the charge per unit length is also proportional to this difference of potential; hence, the charge per

unit length is proportional to, and may be represented by, this line *b B*. Furthermore, the total charge is proportional to *b B* multiplied by the length *b c*. But this is the area of the rectangle *b B C c*, hence the total charge may be represented by the area enclosed between *B C* and the line wire *b c*.

If the battery were removed and the line instantly grounded by suddenly shifting the switch *s* so as to connect *d* with *e* instead of with *b*, the total charge flowing to earth would be proportional to the area of the rectangle *b B C c*. This charge would all flow to earth through *d* and, furthermore, if the line were long and possessed much resistance and electrostatic capacity, it would require an appreciable time before the whole charge would reach the earth and leave the line neutral.

51. Line Circuit Closed.—Suppose, now, that the distant end is directly grounded; then the potential difference between the various points in the circuit and the ground, still assuming the line to be perfectly insulated between the two ends, will be represented by the line *A B C* in Fig. 15. There is now a continuous flow of current through the circuit. Assuming that the resistance from *C* to *A* through

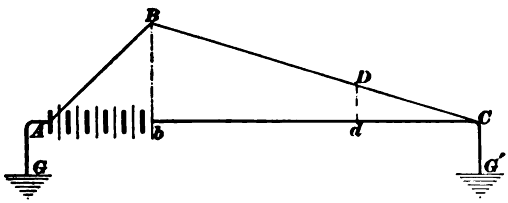


FIG. 15.

the earth is zero, or at least entirely negligible compared to the resistance of the line, then *C* and *A* have the same potential. From *b*, which is the point having the highest potential above the earth, there is a gradual fall of potential each way to *A* and *C*. *B b* represents the difference of potential between the point *b* and the earth, and, similarly, *D d* represents the difference of potential between the point *d*

and the earth. If, at the center of each unit length of the line *b C*, we erect *ordinates* from *b C* to *B C*, each ordinate will represent the charge on that unit length of the line and, evidently, the sum of all these ordinates will represent the total charge on the line. Since the line *B C* slopes uniformly, the sum of all these ordinates is equal to the average ordinate multiplied by the length of the line. Now, the average ordinate is equal to one-half the ordinate *b B*, plus one-half the ordinate at *C*; but the ordinate at *C* in this case is zero, therefore the average ordinate is equal to one-half of *b B*. The total charge is then represented by the product of ½ *b B* and *b C*, but this product is the area of the triangle *b B C*. Similarly, it can be shown that in any case, the total charge on a wire may be represented by the area of a figure constructed by erecting ordinates at each point along the wire, which shall represent the potential at that point, and joining their tops together by a line.

52. Battery at Each End.—Let us now consider a general case where there are *p* cells at one end and *q* cells at the other end of the line, the two batteries being connected in series as usual. Fig. 16, which represents the state of affairs when the circuit is closed, was constructed by erecting at *b* an ordinate representing the difference of potential

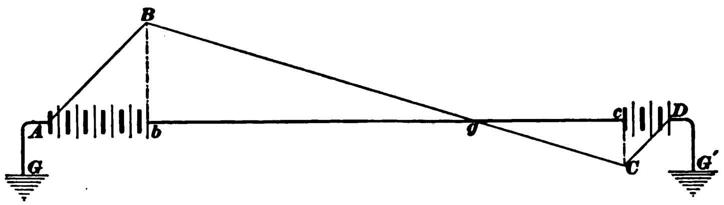


FIG. 16.

between *b* and the earth when the current is flowing. This ordinate is above the line *b c*, because the potential at *b* is positive relative to the earth. But at *c*, the potential is negative relative to the earth, and therefore the normal *c C* was drawn downwards to represent the potential at *c* when the circuit is closed. If the line is perfectly insulated, then *B C*

will represent the value of the potential and charge along the wire, both in polarity and intensity.

The point *g* in the circuit, which is at the intersection of the lines *B C* and *b c*, has the same potential as the earth. That there is some point in the line that has the same potential as the earth is evident from the fact that the potential at one end of the line is below that of the earth, while the potential at the other end is above that of the earth; consequently, there must be some intermediate point in the line that has the same potential as the earth. That point, which is at *g* in this case, could be actually grounded without in any way altering the potential charges or the amount of current that would flow in the circuit. Actually grounding the line at *g* would, of course, prevent telegraphing between *b* and *c* through this wire, because opening the circuit at *b*, for instance, would not stop the current in the *g c* end of the line wire.

53. The total charge on the line wire when both ends are grounded is represented by the areas of the two triangles *b B g* and *g C c*, one of which is positive and the other negative. If the line is opened instantaneously at *c*, the current will not stop flowing at *b* instantaneously, but will continue, although diminishing very rapidly, not only until all the charge on *g c* has been neutralized by a charge flowing from *b*, but also until the whole line *b c* becomes fully charged to the potential *b B*, as represented in Fig. 14. Evidently, then, the larger the capacity of the line, the longer is the time it requires for the current at *b* to fall to zero. This does not contradict the known fact that electricity travels at the speed of light, 186,000 miles per second, for the charge represents a certain number of coulombs, and the number of coulombs that will flow past a point to charge a line wire depends on the number of amperes flowing and on the length of time the current continues to flow. This time element does not depend on the velocity of electricity. This has been explained more fully in connection with the distributed capacity of line wires.

From what has been said, it follows that a long line that has a large electrostatic capacity cannot be worked at as high a speed as a short line that has a low electrostatic capacity, because the current does not attain its full strength as quickly when the key is closed, nor fall to zero as quickly when the key is opened. Furthermore, the better the line is insulated, the slower does it work. For when the line is not perfectly insulated, the charges, when the keys are opened and closed, can redistribute themselves more quickly, because they can flow, not only over the line wire, but also through the leakage paths. Hence, a poorly insulated line, due to poor construction or to very wet weather, may work faster, if it will work at all, than a perfectly insulated line.

54. Line Not Perfectly Insulated.—Let us now represent the line as supported on glass insulators and open at the distant end. Each insulator would have a resistance of at least 4 megohms, so that at each pole there would be a leakage of current to the ground. The escaping current would be equal to the difference of potential between the

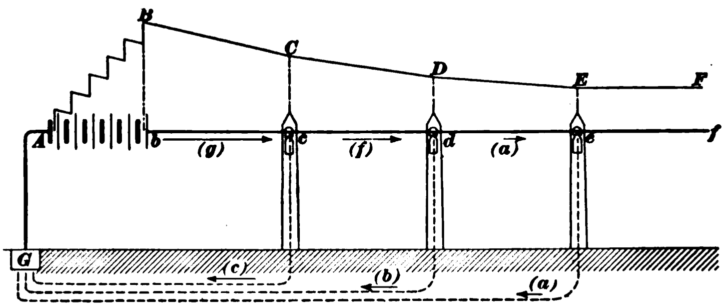


FIG. 17.

line at that point and the earth divided by the sum of the insulator and pole resistance. While the escaping current at each pole would be very small, still, on a line 100 miles long, having 40 poles per mile, the insulation resistance at each pole being 4 megohms, the resistance of the line wire 10 ohms per mile, and the battery all at one end, the total

leakage would amount to about 35 per cent. of the total current. All supports for a telegraph line form by-paths through which a part of the current flows, thus reducing the strength of the current that reaches the distant end of the line.

Such a condition of affairs is represented in Fig. 17. With the distant end of the line open, the current flowing from *d* to *e* is the amount that leaks away to earth at or to the right of *e*. This current causes a slight fall in potential from *d* to *e*, which is represented in the figure by the slope of the line *D E*. Since the potential is slightly higher at *d* than at *e*, there will be slightly more current escaping at *d* than at *e*. The total current flowing in the section *c d* is equal to the sum of the currents that leak to earth at *d* and *e*. Hence, the fall in potential is greater from *c* to *d* than from *d* to *e*. This is represented by giving the line *C D* a greater slope than *D E*. Similarly, a greater current will escape at *c* than at *d* and the fall in potential from *b* to *c* will be greater than from *c* to *d*. There is also a fall in potential in each cell equal to the product of the internal resistance of the cell and the current, thus lowering the effective or useful pressure of each cell by that amount. The broken line *A B* has been drawn to represent this.

55. Insulation Resistance of Line.—The total resistance from *b* by way of all the leakage paths to the ground, when the line is open at the distant end, is called the **insulation resistance of the line.** The insulation resistance of a line may also be defined as the degree to which the line is insulated from the ground and all other conductors. It can be readily measured by methods to be explained later, but could be calculated step by step as follows:

Suppose the poles to be uniformly spaced and the resistance between the line wire and the earth at each pole to be equal; let this resistance be *s*, and let *r* be the resistance of the line wire between two consecutive poles. Then, starting at *e*, the resistance to earth would be *s* ohms. From *d* it

would be $s + r$ ohms, and, including d, it would be, from the law for parallel resistances, $\frac{(s+r)s}{2s+r}$. Similarly, from c it would be $\frac{(s+r)s}{2s+r} + r$, and, including c, it would be

$$\frac{\left[\frac{(s+r)s}{2s+r} + r\right]s}{\frac{(s+r)s}{2s+r} + r + s}.$$

In this way, the resistance could be calculated for any number of poles. However, the expression soon becomes very complex, and to carry it through would be rather laborious.

56. Even if the insulation resistance at each pole is very high, it is evident that the sum of all the currents leaking away at all the supports may be considerable if the line is long enough, and consequently only a fraction of the total current will be useful. On the 100-mile line cited in Art. **54,** only about 65 per cent. of the total current would reach the distant end of the line; hence, closing the key at the battery office increases the current at the distant office relay from zero to only 65 per cent. of the total current flowing from the battery. Opening the distant key does not reduce the current at the battery office to zero but to a strength somewhat greater than 35 per cent. of the total current. It is somewhat greater than 35 per cent. when the distant key is open, because the current flowing is less and the product CR, that is, the fall or drop in potential along the line, is less, and therefore the potential at each support is somewhat greater, causing a somewhat greater leakage at each support.

The lower the insulation resistance at each support, the lower will be the total resistance of the circuit and the larger the current. Thus, during wet weather the total current in a given line increases; but, with the battery all at one end, the current at the distant end is less, and, with

equal batteries at the two ends, the current near the middle of the line is less than in dry weather. Furthermore, the margin or change in current strength at any station, which represents the working efficiency of the line, may be very much diminished in wet weather, especially on a long line.

57. Suppose we have one long and one short line, the line resistance of both being equal (the wire larger, of course, on the long line), and the insulation resistance at each pole equal. In good weather, a quadruplex set may work satisfactorily on both lines, but in rainy weather, as a matter of fact, it may be impossible to continue working the quadruplex on the long line, a duplex being used instead, but the quadruplex may still be worked on the short line. This is due to the fact that enough increase or decrease in the current cannot be produced to work the neutral relay on account of the excessive leakage. On the long line, although the resistance is no greater, there are still so many more points of escape that the ratio of the conductivity of the line wire to the conductivity of the leakage paths is less than on the short line, and when it rains, this ratio may decrease enormously. That is, the long line is much less efficient in wet weather, and therefore the effective current is much less, although the total current may be much greater. If the ratio between the resistance of the insulation and the resistance of the line becomes too low, the line will not work satisfactorily, although the trouble from static charging and discharging may be much less.

58. Insulation.—If the resistance measured through the insulating materials from the line wire to the ground, or to other conductors, is very high, the insulation is said to be good; if very low, it is said to be poor. A properly constructed aerial telegraph line should, in dry weather, have an insulating resistance of from 2,500 to 3,000 megohms per mile. This means that the resistance of all the leakage paths from a line wire (not purposely grounded) to other conductors and to the ground measures from 2,500 to 3,000 megohms for one mile of wire. In wet weather, the insulation

resistance may fall to 100,000 ohms per mile or even less. Prescott says that a line 300 miles in length of No. 4 B. W. G. iron wire works well with an insulation resistance of 200,000 ohms per mile. The advantages to be obtained by very high insulation on long lines are in a measure offset by the fact that a certain amount of leakage tends to reduce the condenser action between the line and the ground by allowing the static charges to leak across, and thus prevent, in some measure, the injurious effects of capacity on the speed of transmission of telegraph signals.

59. Working Efficiency of Line.—By the **working efficiency** of a telegraph line is meant the variation of the strength of the current at any station when the key at another station is alternately opened and closed. The working efficiency depends on the ratio between the resistance of the line (including all relays) and the insulation resistance. This working efficiency can be increased by decreasing the resistance of the line wire and the relays, or by increasing the resistance of the insulating supports, or by both methods. The resistance of the line may be reduced by using a larger wire, or better still, by using a wire made of better conducting material, for instance, by replacing an iron wire by a copper wire. The resistance of the line circuit may also be decreased by using lower resistance relays. The insulation resistance may be increased by using a higher resistance insulator or by using fewer poles per mile, or both. Less than 20 poles should not be used, and better construction requires from 30 to 40 per mile. The number of poles per mile will depend on the number and size of wires on the poles and the character of the country through which the line is run. In northern climates, where snow, sleet, and wind are common, more poles per mile are required than in southern localities.

60. Let n be the number of poles per mile, l the length of the line in miles, r the resistance of the line wire between two adjacent poles, that is, the resistance of $\frac{1}{n}$ of a mile of

the wire, and s the resistance of one insulating support from the wire to the ground. Since the insulator resistances are all in parallel, then the insulation resistance per mile is evidently $\frac{s}{n}$ and the line resistance per mile is $r\,n$, from which we get $\frac{r\,n}{\frac{s}{n}}$ or $n^2\left(\frac{r}{s}\right)$, as the ratio on which the working efficiency of the line per mile depends. Then, the ratio on which the working efficiency of the whole line depends is

$$l^2\,n^2\left(\frac{r}{s}\right).$$

There are usually a number of relays in the line, and in order to get the total ratio on which the working efficiency of a telegraph circuit depends, the resistance of the relays must be considered. Let R be the total resistance of all the relays in one line. Where the relays, as usual, are all of equal resistance, R will be equal to the resistance of one relay multiplied by the number of relays. Then, the ratio on which the working efficiency of the circuit depends equals

$$\frac{n\,l\,(r\,n\,l + R)}{s}.$$

If the line resistance is 8.56 ohms per mile (about a No. 12 B. & S. hard-drawn copper wire), and there are 35 supports per mile, each of which has an insulation resistance of 25 megohms, then $n^2\left(\frac{r}{s}\right) = 35 \times 8.56 \times \frac{1}{25{,}000{,}000} = \frac{1}{83{,}450}$ as the ratio on which the working efficiency per mile depends. In the United States, $\frac{1}{10{,}000}$ is probably as good a value for $n^2\left(\frac{r}{s}\right)$ as can be relied on during a rain for the most carefully constructed glass-insulated line, and this figure is a fair representative value for the actual condition of lines at present.

Mr. Varley, the famous telegraph engineer, considers that no line is well insulated if the ratio of the line resistance per mile to the insulation resistance per mile, that is, $n^2\left(\frac{r}{s}\right)$, is greater than $\frac{1}{80,000}$.

61. Percentage of Total Current Received at Distant End.—When the resistance r of the line between every two poles is constant, and the insulation resistance at each pole is also constant, then the ratio P of the total current sent into the line to the current received at the farther end, when the battery is all at one end, or to the current at the middle, when the battery is equally divided between the two end stations, may be determined as follows: Let C be the total current sent into the line and C_1 the current received at the distant end when the battery is all at the home end, n the number of poles per mile, l the length of the line in miles, r the resistance of the line wire between two adjacent poles, that is, the resistance of $\frac{1}{n}$ of a mile of the wire, and s the resistance of one insulating support.

$$P = \frac{C_1}{C} = \frac{2}{w + \frac{1}{w}}, \qquad \textbf{(9.)}$$

in which $$w = 2.718^{nl\sqrt{\frac{r}{s}}}.$$

NOTE.—Formula **9** is based on a similar formula given by Jenkin in his "Electricity and Magnetism." The derivation of the formula, which is not even given by Jenkin, cannot be given here because it depends on higher mathematics with which the student is not likely to be familiar. Unless $nl\sqrt{\frac{r}{s}}$ comes out an integer or a simple fraction, an exact solution for w requires the use of logarithms. However, an approximate solution that will usually answer the purpose can generally be made without the use of logarithms.

Where an equal number of cells are used at each end, formula **9** gives the percentage of the total current that

flows through a point midway between the two end offices, and l in that case is half the length of the line. Where the battery is not all at one end, it is some point between the two ends that has the same potential as the earth and through which the least current is flowing.

62. Efficiency of a Cable.—On submarine and underground circuits, the insulation depends entirely on the resistance of the gutta-percha or other insulating covering that opposes the flow of current across this sheath from the conductor to the water or ground. Leakage from submarine telegraph cables is extremely small indeed, owing to the high and perfect insulating qualities of the gutta-percha covering. Formula **9** is applicable to cables, in which case $\sqrt{\frac{r\,n}{\frac{s}{n}}}$ is the square root of the ratio of the resistance per mile of the conductor to the insulation resistance per mile of the covering. If the insulation resistance of a cable is 1,000 megohms per mile, then $\frac{s}{n} = 1{,}000{,}000{,}000$.

EXAMPLE 1.—What percentage of the total current will reach the distant office in the following line circuit? The line is 200 miles long, battery all at one end, 40 poles per mile, resistance of each insulating support 4 megohms, and the resistance of the iron line wire 10 ohms per mile.

SOLUTION.— $r = \frac{10}{40} = \frac{1}{4}$, $s = 4{,}000{,}000$, $n\,l = 200 \times 40 = 8{,}000$.

Hence, in formula **9**, $w = 2.718^{8{,}000\sqrt{\frac{1}{4} \times \frac{1}{4{,}000{,}000}}} = 7.388$,

and $$P = \frac{C_1}{C} = \frac{2}{7.388 + \frac{1}{7.388}} = .266.$$

Hence, only 26.6 per cent. of the total current reaches the distant end. Ans.

EXAMPLE 2.—Suppose we take an iron wire having twice the cross-section of that used in the preceding example, or a copper wire of such size that the resistance per mile is reduced to 4.44 ohms. What will be the percentage of the total current reaching the distant end?

SOLUTION.— $r = \frac{4.44}{40} = \frac{1}{9}$, $s = 4{,}000{,}000$, and $n\,l = 200 \times 40$; hence, in formula **9**, $w = 2.718^{8{,}000\sqrt{\frac{1}{9} \times \frac{1}{4{,}000{,}000}}} = 3.793$,

and $$P = \frac{C_1}{C} = \frac{2}{3.793 + \frac{1}{3.793}} = .493,$$

or 49.3 per cent. of the total current reaches the distant end. Ans.

EXAMPLE 3.—In the same example, instead of increasing the conductivity of the line wire, we could increase the insulation resistance by spacing the poles a little farther apart and using better insulators. If we use 9-megohm insulators instead of 4, what would be the percentage of the total current that would reach the distant end?

SOLUTION.— $r = \frac{10}{40}$, $s = 9{,}000{,}000$, and $n\,l = 8{,}000$. Then, $w = 2.718^{8{,}000\sqrt{\frac{1}{4 \times 9{,}000{,}000}}} = 3.793$, and hence $P = 49.3$ per cent., as in the preceding example. Ans.

63. Reducing the Resistance of Relays.—As already mentioned, the working efficiency of a circuit may be increased by decreasing the resistance of the relays. This is especially true on railway-telegraph lines containing, as they sometimes do, as many as 30 to 40 relays in one circuit. It has been customary on railway lines to use 150-ohm relays, but by connecting the two coils of such a relay in parallel instead of in series, it is a very simple matter to reduce the resistance to 37.5 ohms, requiring, however, double the former current in the line in order to get the same current in each coil, and therefore the same number of ampere-turns as before. A relay connected in this manner is shown in Fig. 18. Instead of one path for the current, as in a 150-ohm relay, there are now two, as will be seen in the figure. The current is assumed to enter at the binding post A, where it divides, one half passing

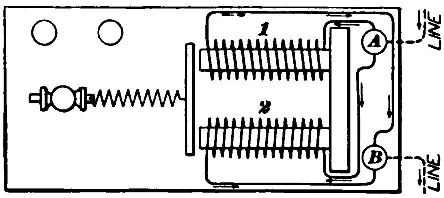


FIG. 18.

through coil *1* and the other half through coil *2*, reuniting at the binding post *B*. The result of providing two paths in parallel, each of 75 ohms resistance, is to reduce the resistance of the relay to 37.5 ohms. In changing a 150-ohm relay to a 37.5-ohm relay in this manner, care must be taken to so connect the coils that their magnetizing forces do not oppose each other.

64. The following benefits may be derived from connecting the relays in this manner on a line 160 miles in length, containing thirty-six 37.5-ohm relays. This data, most of which is taken from an actual line, will enable us to compare the results of equipping the same line with 150- or 37.5-ohm relays. The internal resistance and electromotive force per cell is taken as 3 ohms and 1 volt, respectively.

TABLE 4.

	150-Ohm Relays. Current = .03 Ampere.			37.5-Ohm Relays. Current = .06 Ampere.		
	Ohms.	Volts = *CR*.	Watts = C^2R.	Ohms.	Volts = *CR*.	Watts = C^2R.
Line 160 miles.......	3,451	103.5	3.100	3,451	207.06	12.42
36 relays............	5,400	162.0	4.860	1,350	81.00	4.86
Total for line and relay	8,851	265.5	7.960	4,801	288.10	17.28
292 cells battery.....	876	26.3	.789			
351 cells battery.....				1,053	63.10	3.79
Total for whole circuit	9,727	291.8	8.750	5,854	351.20	21.07

65. A 150-Ohm Relay Equipment.—From this table it is seen that with 150-ohm relays the total energy expended in the line is 3.1 watts, and in the relays, 4.86 watts; the total in the line and relays, 7.96 watts. Probably half the total energy is generally lost through leakage, and the resultant energy available to operate the distant

relays is reduced correspondingly. On account of the high-resistance relays, the current is readily choked or shunted off into the ground through the poor insulating supports, and little is left to get through to the distant relays. While it is true that, in case of excessive insulation losses, the battery is usually capable of supplying, and usually does supply, an additional quantity of current to the line, it is also true that, with a heavily loaded 150-ohm relay equipment, none of this additional current gets through to the distant relays. It merely supplies the losses due to leakage.

66. A 37.5-Ohm Relay Equipment. — In the 37.5-ohm relay equipment, the number of watts expended in the relays is 4.86—the same as in the 150-ohm relay equipment—and in the line, 12.42, the total number of watts in the line and relays being 17.28. From this it will be seen that the energy expended in the line is four times greater than in the 150-ohm relay equipment, where it was only 3.1 watts. The 37.5-ohm relay equipment therefore gives us energy to spare; and when wet weather comes, it is partly wasted, but owing to the increased conductivity of the relay portion of the circuit, an ample quantity will usually get through to the distant relays. The percentage loss of current due to defective insulation is the same whether the current is large or small, *only so long as the ratio of conductor resistance to the insulation resistance remains constant.* Reducing the relay resistance reduces the resistance of the conducting circuit, and hence increases the working efficiency of the line.

As the object of reducing the relay resistance is to improve the working efficiency of the circuit, especially during wet weather, let us illustrate by an example the advantages of the low-resistance relay equipment.

EXAMPLE.—Suppose that the insulation resistance of the line quoted above is 10,000 ohms during wet weather. What will be the ratio on which the working efficiency of the line depends when equipped with 150-ohm relays? What will it be with 37.5-ohm relays, and what will be the gain in the ratio on which the working efficiency depends?

SOLUTION.—The working efficiency depends on the ratio of line and relay resistance to insulation resistance. With 150-ohm relays, this ratio (see Table 4) is $\frac{8,851}{10,000} = .885$; and, with 37.5-ohm relays, it is $\frac{4,801}{10,000} = .48$. Ans.

These values have an inverse meaning; the smaller the ratio, the higher the value of the ratio. The gain is the difference between the two ratios, or $.885 - .48 = .405$, and the percentage gain in the ratio on which the working efficiency of the 37.5-ohm equipment depends over that of the 150-ohm equipment is $\frac{.405}{.885} = .46 = 46$ per cent. Ans.

67. According to the article in *Telegraphy*, Part 1, headed the "Resistance of All Relays Equal to Combined Resistance of Line and Battery," the watts expended in the relays should equal the watts expended in the line and battery; but even if these conditions could be fulfilled by limiting the number of 150-ohm relays in the circuit, the working margin in wet weather would not be up to what it is in the low-resistance equipment. Reducing the relay resistance therefore improves the working efficiency of the circuit in two ways; *First*, by reducing the leakage losses by reducing the ratio between the resistance of the line circuit and the insulation resistance, and, *second*, by supplying a surplus of energy so as to provide for unavoidable leakage losses and still leave a good margin for the distant relays. The additional energy expended in the battery is an incidental and unavoidable loss. With high-resistance relays, there is little if any advantage to be gained by increasing the current, because it is choked off into the ground by reason of the high resistance of the relays.

Of course the battery is now called on for double duty; it must supply each wire with 60 milliamperes of current instead of 30, as with the 150-ohm relay equipment, so that only about one-half the usual number of wires can be supplied from a given battery. The battery expense, both for installation and maintenance, is, therefore, approximately doubled.

68. Aside from the considerations given, there is another matter that can be considered briefly. Owing to the reduced resistance of the relays, the static charge and discharge of the line will take place more quickly. On a line wire that has considerable resistance, it is known that the relays act more quickly when their resistance is reduced; that is, the time-constant of the circuit is lower. The changed relation between the capacity of the line and the inductance of the low-resistance relays probably has more to do with it than anything else. The practical advantage of the lower resistance relays is shown by the fact that a number of prominent railroads have changed their 150-ohm relays, by connecting the two coils in parallel, into 37.5-ohm instruments, and that the new arrangement is giving better satisfaction, enabling them, in wet weather especially, to keep their lines working much better than formerly.

TABLE 5.*

DISTANCE IN MILES TO WHICH A STATED PERCENTAGE OF ENTERING CURRENT WILL REACH, THE LINE WIRE HAVING A RESISTANCE OF 18 OHMS PER MILE, AND SUPPORTED ON INSULATORS OF VARIOUS RESISTANCES.

Per Cent. of Entering Current Received.	Insulation Resistance per Insulator in Megohms. 30 Insulators per Mile.							
	1	4	9	16	36	100	1,000	1,600
	Distances in Miles to Which a Stated Percentage of Entering Current Will Reach.							
10	125	258	386	516	774	1,290	4,094	5,160
25	89	178	267	356	534	890	2,837	3,560
50	58	116	174	232	348	580	1,850	2,820
75	36	73	109	146	219	365	1,161	1,460
90	22	45	67	90	135	235	766	900

* From "The Telegrapher," Vol. V, page 269.

69. As a general rule, it is more economical to increase the efficiency of a line by increasing its insulation resistance rather than by increasing the conductivity of the line wire. However, this would have to be determined in every case by calculating the cost of doing it both ways.

Table 5, computed by Mr. Moses G. Farmer, shows very conclusively the good effects obtained by increasing the insulation resistance on long-line circuits.

70. It has been shown by Mr. F. L. Pope in "The Electric Telegraph" that, where the ratio of line to insulation resistance per mile is as poor as 1 to 10,000, and where there is consequently a great deal of leakage, a material advantage is gained by placing all the cells at the *sending end* instead of dividing them equally between the two end offices. On an open-circuit system, using an electromotive force of 200 volts at the sending end, the current at the receiving end varied from 0 to .055 ampere, thus giving an effective current of .055 ampere. On a closed-circuit system, with half the battery at each end, the current at the receiving end varied from .087 to .116, an effective current of only $.116 - .087 = .029$ ampere. However, on the closed-circuit system, when sending from a station that has no battery, in which case the battery is always in the circuit, it has been shown that the working efficiency is the same whether the cells are equally divided between the two end offices or are all concentrated in the middle of the line.

71. Best Position of Batteries in Circuit.—With a perfectly insulated line, it would evidently make no difference where the battery was placed in the circuit; but, as this is never the case, it is not best, except on relatively short lines, to put all the cells at one end. For, with all the cells at one end, the effective current at the office where the battery is located when the other end is sending will be less than the effective current at the other or distant end when the battery end is sending. Therefore, it is generally better to put half the total number of cells at each end. However,

sending in one direction may be accomplished over a line from which the leakage is unusually large, and over which it may be impossible to work satisfactorily in both directions, by concentrating all the battery at the sending end. Enough cells must be used to force through the line a current of sufficient strength to work the relay at the distant end.

72. Effect on Signals of the Position of a Fault. When the batteries and instruments are alike at both ends, the worst position for a fault, such as contact with wet trees, is midway between the two end offices. When the partial ground or fault is nearer one end, the station nearest the fault receives the strongest signals. Where the fault is not at the middle of the line, experience has shown that the signals received at the end farthermost from the fault, where they are the weakest, may have their intensity increased by increasing the number of cells at the end nearest the fault.

RESISTANCE OF THE EARTH.

73. If we have a long telegraph circuit composed of two line wires, the earth not being used as a return path, we shall get a certain current with a given battery in the circuit. If, now, we use the earth as one path in place of one line wire, and make good ground connections at both ends by means of large plates of the same material placed in moist soil or running water, the current with the same battery will be almost doubled. Hence, the resistance of the circuit has been reduced to about one-half its former value, from which we conclude that the earth has but very little resistance. But if the line is short, and the line resistance small as a result, then the resistance of the earth may be quite appreciable, showing that the earth resistance is not zero and is only a negligible quantity when the resistance of the line circuit is large.

The resistance R of a piece of any material may be expressed by the formula

$$R = \frac{k\,l}{q}, \qquad \textbf{(10.)}$$

in which l = length of piece;
q = sectional area, that is, area at right angles to the direction of current;
k = specific resistance of material, that is, the resistance of a piece of the material of unit length and unit sectional area.

The material of which the earth is composed has, in comparison with iron or copper, a very large specific resistance. The specific resistance of water is about forty million times that of ordinary copper, and the specific resistance of moist earth may even be greater. Furthermore, the shortest distance between the two earth plates may not be much shorter than the line wire, hence l is an appreciable quantity. But the cross-section of that part of the earth through which the current may flow is almost infinite compared with the sectional area of the largest line wire that is ever used. Hence, although k is very large and l quite an appreciable quantity, still q is so very much larger that R is usually quite small and generally negligible compared with the resistance of a line wire of average length.

74. There are several things that may cause the resistance of the earth circuit to be appreciable. In the first place, when the current flows to earth, it meets with more or less opposition in passing from the plates to the earth, and it is quite clear that this opposition is entirely independent of the distance between the two ground plates. It depends only on the surface area, the material of the plates, and the nature of the soil in which they are buried. Since the resistance of the earth itself is usually very small, the resistance from plate to plate, if they are always buried in the same kind of soil, will be about the same for all distances, and this resistance will be practically the contact

resistance between the ground and the two plates. Therefore, in the case of a long line of necessarily high resistance, the ground resistance is so small in comparison that it is negligible; but, in the case of a short line of low resistance, the resistance of the earth circuit may not be at all negligible.

75. According to a measurement made by DuMoucel, the resistance of the earth under favorable circumstances was about 108 ohms. (Experience in this country indicates a much lower resistance than this for a good earth return circuit.) A resistance of 108 ohms is equivalent to a 7-mile circuit of No. 9 B. W. G. iron wire. Hence, considering the electrical efficiency only, it would not pay to use the earth as a return circuit if the resistance of one line were less than 108 ohms. Commercial efficiency, however, is another thing. Where cost of construction and of maintenance of the second line wire must be considered, an earth return can be used prôfitably on a much shorter line circuit. The resistance of the ground return on a circuit of average length, or over, should not exceed about 10 ohms where the intervening region is not too rocky or full of coal.

76. When the ground plates are placed in dry earth, and especially in a region where the soil and substrata are very much poorer conductors than usual, the earth circuit may have quite a large resistance. If the plates are too small, the contact resistance between the plates and the earth may also be appreciable, and, furthermore, there may be some polarization and chemical action between the plates and the material in which they are buried, especially if the two plates are not of the same material. For instance, if one plate is copper and the other zinc, there would be a difference of potential of about 1 volt, and if this happened to oppose the battery, there would be a reduction in the current on account of this opposing electromotive force. In making an ordinary measurement, this would appear as a simple but probably an annoying variable resistance in the earth circuit. Even if the plates were so connected as to

help the battery, they would be eaten away, and the contact resistance would then increase enormously.

77. From long experience, it has been found that the resistance of the earth varies considerably. In a sandy soil, at about the level of the sea, Sinclair says it is almost impossible to get anything like a good ground, while with a clay soil it is almost impossible not to get a good ground. He also says that it is easy to establish an earth connection between two points 50 to 100 miles apart, but it is an altogether different matter to do so when they are only ½ mile apart.

In some regions, on account of their geological character, it is very difficult to secure a sufficiently good ground connection. In such a case, a return line wire may be advantageously used part of the way, until a locality is reached where a good ground can be obtained. Cases are on record in certain anthracite-coal regions, and in some rocky, mountainous districts, where it was found almost impossible to make grounds that would not offer an abnormally high resistance.

MEASUREMENT OF GROUND RESISTANCE.

78. Measurements to determine the resistance of the ground between two points are not very reliable, on account of the presence of polarization or chemical action, which it is quite difficult to eliminate. Moreover, in no two places would the resistances be necessarily equal, even with the same plates and the same distance between them.

79. Measurement by a Voltmeter.—The resistance between two ground plates may be measured by a voltmeter. The method to be given is especially convenient when the two points between which the resistance is to be measured are so near together that the resistance of connecting wires may be so small in comparison with the resistance of the voltmeter itself that their resistance can be entirely neglected.

We will consider the fact that there may be electric street-railway, or trolley, currents flowing between the two plates, thus causing them to be at different potentials. The only instrument required is a reliable voltmeter whose resistance is definitely known. The resistance of the connecting wires, if not small enough to be neglected, would have to be measured and proper corrections made for them. This would render the method rather inconvenient, but it is very seldom that their resistance need be considered.

It may be well to state that the current passing through a voltmeter, multiplied by its resistance, gives the difference of potential at the terminals of the voltmeter. But this is also given directly by the reading of the voltmeter; hence, the reading of the voltmeter, divided by its resistance, gives the current flowing through the voltmeter. A low-reading voltmeter, one whose maximum reading is 3 or 5 volts, will generally prove the best in making this measurement. Very poor and inaccurate results will be obtained by trying to measure one or two volts, for instance, with a voltmeter reading as high as 150 volts.

80. Suppose there are two points A and B in the ground between which we wish to measure the resistance. At these points there may be ground plates, or at one point there may be the rail of an electric street railroad and at the other the lead or iron armor of an underground telegraph cable, or the ground plate of a telegraph office. *First*, connect the voltmeter directly between A and B. Then if a sufficiently large trolley current is flowing from one point to the other through the ground, the points A and B will be at different potentials and we will probably get a small reading on the voltmeter, which we will call V. *Second*, connect a number of cells, the total electromotive force of which must not be greater than the largest reading on the voltmeter, between the points A and B. The voltmeter is also connected between A and B, and it now gives a reading V_1, which is evidently the total difference of potential between the terminals of the battery. *Third*, connect the voltmeter and

the same battery in series between the two points A and B. The voltmeter gives a reading V_2, and the current through the voltmeter in this position we will call I_2. Then, if r is the resistance of the voltmeter and x the resistance of the ground between the two points A and B, we have $I_2 r + I_2 x =$ the difference of potential at the battery terminals $\pm$ the difference of potential between the points A and B that would be caused by the trolley current alone. The sign $\pm$ is used because the difference of potential between the points A and B that the trolley current tends to set up may be in the same direction (+) or in the opposite direction (−) to that due to the battery alone. Then we may write

$$I_2 r + I_2 x = V_1 \pm V,$$

but $$I_2 r = V_2 \text{ and } I_2 x = \frac{V_2 x}{r};$$

hence, $$V_2 + \frac{V_2 x}{r} = V_1 \pm V.$$

Solving this for x, we get

$$x = r\left(\frac{V_1 \pm V}{V_2} - 1\right). \qquad \textbf{(11.)}$$

When there is no electric-railway or other stray current flowing between the two points A and B, then $V = 0$ and the formula reduces to

$$x = r\left(\frac{V_1}{V_2} - 1\right).$$

This formula is identical with that given under the heading "Measurements With Commercial Instruments" in *Electrical Measurements*.

81. This is a very convenient and practical method, and one that is very useful also in determining how much current may be flowing from the lead or iron armor of an underground cable to the surrounding ground. From this it may be determined whether there is much danger to the lead or iron armor from electrolysis, and just where the corrosion is

greatest. The corrosion may be avoided by permanently connecting, at the danger points, the lead or iron armor with the street-railway return feeders or rails by a good, stout copper wire.

This method, using the simplified expression of formula **11**, is very often employed by electric-light and power companies for measuring the insulation resistance of their line wires, especially when the insulation resistance is not very high or when there is a partial ground on one line. It has been explained under the heading "Measurements With Commercial Instruments," in *Electrical Measurements*. In connection with the testing of telegraph lines and circuits, a method will be given later for measuring the resistance of the earth return circuit.

GROUND PLATES.

82. Material for Ground Plates.—The best material for ground plates is *copper*, because it does not corrode or rust away like iron. Ground plates may be made of sheet copper $\frac{1}{16}$ inch thick and having a surface of 4 or 5 square feet. The joint between the wire and the plate should be a good metallic connection, preferably riveted and well soldered and covered with a moisture-proof paint, to prevent local chemical action, which causes an eating away of the metals at the joint. Ground plates may also be made of sheet zinc or heavily galvanized sheet iron, but they will not last, especially the latter, as long as copper plates. To prevent the corrosion of the wire leading to a ground plate, the wire should be coated with a good moisture-proof insulating material, such as rubber. The permanent ground wire at a terminal office should be a No. 8 copper wire.

83. Location of Ground Plates.—When practicable, place the ground plate in a good well. If a constant stream of water can be conveniently reached, that is still better. A cistern, of course, is of no use for this purpose, for it is merely a tight vessel for holding water, and the contents

have little or no connection with the surrounding earth. Where driven wells are used, scrape the top of the well pipe, wrap your ground wire firmly around it, and solder it on if possible. This makes a perfect ground connection, but it may be very difficult or impossible to solder the wire to the pipe, especially if there is any water running through it. Dry earth, sand, gravel, etc. are not conductors of electricity. Contact must be made with damp earth. It is not sufficient to put the ground plate a few feet in the earth, where in the summer the ground becomes dry, and in winter the earth freezes around and below it. Dry ice is an excellent insulator, and a ground plate in frozen earth is absolutely worthless.

If a ground plate must be buried in a sandy, gravelly, or rocky soil, where the moisture is not sufficient to render it a good conductor, place the plate in a pit dug for the purpose and pack scrap tin or other waste metals or crushed coke or charcoal closely around it and lead the discharge from water or drain pipes into the pit.

84. Ground Connections Through Water and Gas Pipes.—Water and gas pipes, on account of their extensive ramifications through the ground, make excellent contact with it, and for this reason make good terminals to which the wire running to the ground may be fastened. It is not very desirable, where there are electric street-railway systems in the neighborhood, to make the ground connection through gas or water pipes. Water pipes used for this purpose on a short telegraph line near a trolley road have been known to become so weak as to burst inside of two months. The weakening was caused by electrolytic action due to the railway current returning through the pipe and the telegraph line circuit instead of through its normal path, the rails and the ground.

If pipes are used, it is advisable to connect the ground wire to both the gas and water pipes. If the wires are grounded by means of a gas pipe, make the connections, if possible, to the pipe on the street side of the meter. For,

if this is not done and the meter is not in place or is later removed, the return line will be open. Moreover, the white or red lead used in iron-pipe joints often makes the joints offer considerable resistance to the current before it can reach the ground.

DISTURBANCES IN TELEGRAPH LINES.

85. Earth Currents.—Disturbances in telegraph circuits are due to the potential of the earth varying at different times and in different places from some known or unknown cause. On account of this variation of the difference of potential between the extremities of a telegraph line, currents called **earth currents** flow in the line wire. These currents vary both in direction and strength, sometimes rapidly, sometimes slowly.

Earth currents may be due to one or more of several causes. The sudden shifting of the earth's magnetic field may cause currents to flow through the line. It is only occasionally, and during what are termed *electric* or *magnetic storms* and during auroral displays that these currents become strong enough to interfere with telegraphing. It has been noticed by some that the earth currents are apparently increased at the time of the appearance of sun spots.

86. Disturbances Due to Trolley Roads.—Earth currents from electric railroads sometimes cause considerable trouble, because the electric railroads nearly all operate on grounded circuits and use very large currents. The potential of the earth for considerable areas is frequently raised above the normal, due to the railway current that returns through the earth. The current, after passing from the trolley line through the car to the earth, seeks the most direct and easiest path back to the power station. If the two ground plates are at different potentials, some of the current passes up through the ground wire at one end of the telegraph line, through the instruments and line to the

ground at the other end. These currents vary in strength according to the position of the car or cars on the line.

The action of trolley currents on the working of simple telegraph circuits is more or less dependent on whether the earth intervening between the rails and the ground plates of the telegraph circuit is moist enough to form a good conducting medium, and becomes serious or harmless according to the conductivity of the track circuit. The longer line circuits, on account of their high resistance and the distance between the two ground plates, seldom come within range of the influence of trolley currents. The shorter lines, however, are apt to suffer considerably without exciting suspicion as to the cause of the trouble, more especially in wet weather, when the effective signaling currents are weakest and the dissemination of the trolley currents through the moist earth is greatest. On some short lines it has been possible to operate by means of the trolley currents alone, the regular working batteries having been removed from the circuit.

87. To Overcome Earth Currents.—The trouble due to earth currents may be avoided by employing a complete metallic circuit, that is, using a return wire in place of the earth return, and disconnecting the ground wires at both terminal offices. In this case, main-line batteries at one or both ends must be connected directly in series with the two line wires, that is, there should be no ground anywhere on the circuit.

Where this arrangement is only occasionally necessary, two line wires may be used for one circuit. This, of course, gives only one telegraph circuit in place of two.

88. Induction From Other Lines.—A neighboring wire carrying fluctuating currents will set up about itself a varying magnetic field of force, which field may embrace the telegraph line under consideration, and cause, by its fluctuations, corresponding variable currents to flow in the telegraph line. Furthermore, there may be a condenser action between the telegraph wire and the neighboring wire

by which the latter may induce in the former fluctuating charges that may develop into currents capable of affecting the relays.

89. To Overcome Induction.—On telegraph lines, the induction is not often serious enough to cause trouble. Where this is the case, however, the only way to cure it is to employ a complete metallic circuit, that is, to use a return wire in place of the earth return, and place the two wires very close to each other, or twist the one about the other so as to maintain a mean average equality of distance between themselves and the disturbing wire or wires. Where two wires of the same circuit are kept at the same average distance from the disturbing wire or wires, however near they may be, the influence of the disturbing circuit on each wire of the other circuit must be identically the same, both in direction and intensity; and these similar influences must therefore neutralize each other.

90. In Fig. 19, *A* represents a wire through which a current is flowing that would cause, either by electromagnetic or electrostatic induction, an induced current to flow in the wire *B*. If, instead of one wire *B* and an earth return, we use two wires and no earth return, then the effect of both electromagnetic and electrostatic induction can be completely

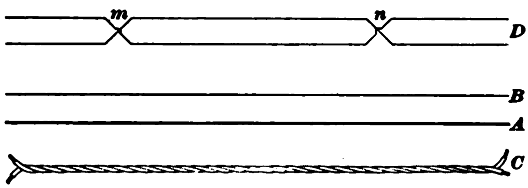


FIG. 19.

neutralized, as far as causing any current to flow in either wire, by twisting the two wires together as shown at *C*. In this case, each wire must have an insulating covering.

The same result is accomplished on bare overhead circuits by transposing the two line wires *D*—the outgoing and

return conductors of one circuit—occasionally, as shown at *m* and *n*. The practical way of making such a transposition

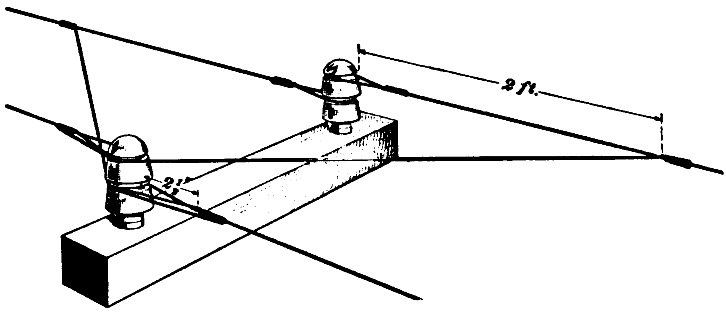


FIG. 20.

on a pole is shown in Fig. 20. Insulators having two grooves, and called *transposition insulators*, are used for this purpose.

91. The effect due to electromagnetic or electrostatic induction of one circuit on another may be reduced by using two wires for each circuit and placing the *two wires of each circuit as near together as possible and the two circuits as far apart as possible.* If the two wires of each circuit are also twisted together or transposed, the disturbing effect may be still further reduced.

If a line consists of a single wire, grounded at both ends like a telegraph line, and is equally distant from the two wires of another circuit with no earth connections, like a complete metallic telephone circuit, for instance, then it will produce no disturbance in the telephone circuit. This would be the case where the telegraph line is directly below or above and equally distant from both telephone-line wires, and there would be no need or use of transposing the telephone wires. But if the telegraph-line wire is on the same cross-arm with the two telephone wires, or arranged in any manner so as to be nearer one telephone wire than the other, then transposing the disturbed telephone wires often enough will eliminate the trouble if due to electromagnetic or electrostatic induction.

On long telephone lines, induction is very troublesome, and transposing the wires in this manner is universally adopted, the transpositions being made about every 1,300 feet.

In cables, electrostatic and electromagnetic induction may be eliminated by twisting the outgoing and return conductor of each pair spirally around each other throughout the length of the cable, as already shown at *C*, Fig. 19. It is not customary to use two wires in each circuit and to twist one around the other in telegraph cables, but it is invariably done and is absolutely necessary in telephone cables, because the telephone receivers are so extremely sensitive to variable currents.

92. Induction and Earth Currents in a Submarine Cable.—The working of an ocean cable at Cape Town, South Africa, was seriously interfered with by the electric railroad that ran more or less parallel to it for about 5 miles, the land cable being quite close to the car line, and the first mile of the shore end of the submarine cable being only at a mean distance of about half a mile from the car line. It was conclusively determined that the most serious trouble was due to the return currents from the trolley line seeking the sea and the sheath of the cable as a return path. However, it had also been observed that the automatic circuit-breakers at the railway power house sometimes broke their circuits, through which 350 amperes were flowing, half a dozen times within 15 minutes, and of course were closed again each time. Prof. A. Jamieson (the consulting engineer in the case) says that such sudden stoppage and starting of a current of 350 amperes at 500 volts undoubtedly causes direct electromagnetic induction in all neighboring parallel electrical circuits, whether they are in the air, as in the case of overhead line wires, or buried in the earth, or laid in the form of a submarine armored cable in the sea. These sudden electromagnetic disturbances are, however, distinguishable by the behavior of the cable instruments from the disturbance due to leakage or stray return currents from the railway circuit.

93. Remedy for Induction and Earth Currents in a Submarine Cable.—The whole trouble has been remedied by running a two-conductor cable some miles out to sea to an island, where one conductor is grounded by soldering it to the cable sheathing. The two conducting cores are insulated from each other and symmetrically twisted about each other, the whole heavily armored, and the land cable also armored and enclosed in a heavy cast-iron pipe laid underground from the cable hut to the cable office, a distance of 430 yards. By twisting the two conducting cores about each other, an anti-induction cable is obtained, as explained in Art. **90,** so that even the making and breaking of the whole trolley current at the railway power house produces no current in the cable conductors by electromagnetic induction. Furthermore, although the trolley current may still flow in the armor, the latter no longer forms part of the cable circuit near the shore, and so the trolley current does not flow in the cable circuit. Neither can the variable trolley current in the armor induce a disturbing current in the cable conductors, because they are twisted spirally about each other, and are hence, on the average, equally distant from the armor throughout the shore end of the cable. Thus the cable conductor is shielded from induction as well as from forming a path for the trolley current. The receiving instruments used with submarine cables are extremely sensitive, requiring an extremely small current to operate them, and for this reason they are much more easily disturbed and need more protection than instruments used on land lines.

To get rid of the disturbances due to trolley currents on the Western Union cable running from Broad Street, New York, to Canso, Nova Scotia, it was necessary, about 1892, to extend the ground wire from Broad Street to a point 1,500 feet from the Coney Island shore. The two wires in this case, the cable conductor and the grounded wire, were not in one core and twisted together, so that it was necessary to heavily insulate the ground wire until reaching the point where it was grounded independently of the cable

sheath from which it was separated as far as convenient. If the two wires had been twisted spirally about each other and enclosed in the same armor, as in the African cable, which is much the surer and better way, this separating of the grounded end from the cable armor would not have been necessary, and the trouble that the above treatment did not entirely eliminate would doubtless have been cured without a change in the receiving apparatus, which was also required.

FAULTS ON TELEGRAPH LINES.

94. Some of the causes of faults or interruptions to which an aerial line is subject are the following: The line wire may come into contact with other wires on the same poles by the position of the pole itself, by falling branches, trees, or rocks, by high loads at crossings, by whip lashes, by kite strings and tails, by careless workmen, and even by the wind itself when very high. Loose or broken arms, brackets, or pins may allow the wire to come into contact with poles, walls, bridges, and trees. Trees, unless they are kept carefully trimmed, may grow up among the wires. Joints may become bad from the absence or failure of solder or from being otherwise improperly made. Malicious or thoughtless persons may twist the wires together or cut them.

In addition to the foregoing causes, atmospheric disturbances, such as rain, fog, and dew, affect the resistance of the line, and the smoke of factories is very liable to cause variations. Subterranean and submarine wires are free from these vicissitudes. The resistance of their insulating covering is practically constant.

95. Most Common Faults.—The most common faults to which telegraph circuits are subject are defective insulation, causing escapes or a partial ground—a dead ground, crosses, breaks, and defective ground connections at one or both terminals.

96. Breaks.—When a telegraph-line wire breaks, one of three things may happen: (1) neither of the broken ends may touch the earth or become grounded; (2) one end only may become grounded; (3) both ends may become grounded. In the first case no current, and, therefore, no signals, can be sent over the line between the offices between which the break occurs. In the second case, no current or signals can be sent from the office toward the open end of the line, but, from the office on the grounded side of the break, the resistance may be much reduced and a large current may flow to earth through the grounded line, giving very strong signals if the key is manipulated. In the third case, an abnormally large current may flow through the two grounded wires from the stations on each side of the break. The offices on opposite sides of such a break cannot communicate with one another, but offices on the same side of the break may communicate with one another. Besides the above three cases, there may be a partial break and a swinging break. A **partial break** occurs when the resistance of the line is greatly increased. It may be caused by a bad joint due to rust or corrosion, by dirty or poor contacts in the instruments, bad connections at binding posts, or elsewhere, or by poor ground connections, or a defect in the main battery or by its not being in proper condition. A partial break weakens the current so much that the instruments in circuit work very weakly. A **swinging break** opens and closes the circuit at regular or irregular intervals of time, and may be caused by the effect of the wind on a loose joint in the line wire or from a loose connection in the office.

97. Grounds.—A telegraph line may become unintentionally **dead grounded** or **partially grounded.** When dead grounded, all of the current, and when partially grounded, but part of the current, escapes to the ground. A dead ground will affect the circuit in the same manner as a break where both ends are grounded. Offices on the same side of a partial ground can communicate with each other about

as usual, but a key in any part of the circuit cannot fully control the current in that part of the circuit beyond the partial ground. Messages may be transmitted past the partially grounded place with more or less difficulty, depending on the magnitude of the current that escapes at the partial ground.

98. To Reduce Leakage Due to Grounds.—Leakage due to a dead ground can only be overcome by locating the dead ground and removing it. Partial grounds due to poor insulation all along the line can only be reduced by improving the insulation of the whole line. It may be only at some one place that the insulation is bad, and a careful inspection from office to office toward the suspected bad place will generally enable it to be located and removed.

99. Leakage From Other Lines.—If the insulation between a telegraph line and a neighboring line is very poor, a part of the current from the neighboring line is likely to pass by leakage to the telegraph line and it may be large enough to affect the relay thereon. This is especially true where both lines are grounded. When, on account of defective insulation due to wet weather, there is leakage from one telegraph line to another supported on the same poles, there is said to be a *weather cross* between the two wires. Another name for it is *cross-fire*. It causes more interference in the working of lines than the mere escape of current to the ground. The tendency is for the current to escape from a long or high-resistance line to a shorter or lower resistance line.

100. To Overcome a Weather Cross.—An escape to the ground, if not too great, may be remedied by a judicious increase in the battery power, but when the trouble is due to a **weather cross,** an attempt to improve the working of one line by using more battery on it produces a more harmful effect on all the other wires on the same poles.

A weather cross may be prevented by running a wire that is *well grounded* at the bottom of the pole up the pole and

along each cross-arm in such a position, however, that the line wires cannot possibly touch or swing against it. The leakage currents will then go to the earth instead of to the neighboring wire. Make a flat coil out of about 10 feet of the wire used for this purpose and place it under the butt of the pole. The branch wires attached to the vertical wire may be wrapped around the central portion of the cross-arms, or run along under the cross-arms.

But this grounded wire should not be fastened to nor touch the steel pins on which insulators are sometimes supported. This would cause excessive leakage to the earth in wet weather, and, in case the wire was not well grounded, it would help the leakage from one wire to another.

This method of overcoming a weather cross will increase the leakage from all the line wires to the ground, but the battery may be increased as much as is necessary on any one wire without interfering very much with the working of the other lines. Cross-fire is much greater near the ends of a line, and especially in cities near the terminal offices and where the insulation is usually poor. It is advantageous, therefore, where cross-fire is troublesome, to apply ground wires to the poles for 15 or 20 miles from each terminal office.

101. Crosses.—**Crosses** may be caused by a permanent contact between two line wires, or they may be what are called *swinging crosses.*

Where two or more telegraph lines are crossed they cannot all be worked at the same time. However, any one line can be worked as if there were no cross, by opening all the others.

102. A **swinging cross** is caused by one wire swinging against another, but remaining in contact only a short time. It is very annoying, for it is very difficult to locate by any tests, on account of its short duration, and usually the only way to locate it is by a careful inspection. When the line swings against a tree, pole, roof, or other partial or good grounded conductor, we have a **swinging ground,** which is also difficult to locate.

TESTS WITH RELAY AND KEY.

103. A few simple tests that may be made to determine open circuits, breaks, and crosses on line wires, requiring only the use of the ordinary relay, key, and battery, will now be given. Such tests should usually be made in the morning, before the day's work commences. If a systematic record of such tests, including the kind and location of the fault as determined by the test and then as actually found when repaired, is kept for a more or less extended period, the student will by degrees learn to distinguish the different troubles that arise and will be able to locate them more quickly and with better judgment and precision.

Unless otherwise stated, the telegraph circuit will be assumed to be a simple circuit consisting of one line wire, a ground return, a relay and key at each office, and equal main-line batteries at the two end offices. It will also be assumed that the student has made sure that there is nothing wrong with his own office instruments and circuits, and that the fault is therefore not in his own office, although if the test indicates a fault in the office, the fact will be stated. In all cases of trouble, the student should suspect that the fault is in his own office and should first look for it there. An office set means an ordinary relay and key. When a relay is inserted in any circuit and no current is indicated by the refusal of the relay to work, it will be taken for granted that the relay has been properly adjusted, either low or high, or both ways in turn, in order to be sure that there is no current, either small or large, through the relay. A current through the relay, whether large or small, may usually be detected by feeling with the fingers for a pull on the armature.

104. No Current in Line Circuit.—No current in the home relay may be due (1) to a break in the line wire; (2) to the main-line batteries at the two end offices being reversed and so opposing each other; (3) to a ground connection or short-circuiting wire that cuts out the home relay; (4) or to an open key somewhere on the line.

In the case of a broken line wire whose free end is grounded or is crossed with a line wire that is grounded somewhere, there would be a current through the line circuit. If the test is being made at a terminal office, reverse the main-line battery; this will obviously show whether the main-line batteries were previously opposing each other, for, if that were the cause, there would now be a current. If the absence of current is due to an open circuit somewhere, reversing the battery will cause no appreciable change. If the test is being made at an intermediate office, determine whether the line is open on one or both sides of the office by connecting the office set first between one line and the ground, then between the other line and the ground. No current would indicate that the line to which the relay is connected is open. If possible, immediately report the result to the proper person, so that if one wire is good, it may be used while the fault on the other is being repaired.

105. Locating a Partial Disconnection.—Where there are two lines running through the same offices, on one of which there is a fault, such as a **partial disconnection,** the fault may be located in the following manner: Commencing at some station on the home side of the fault, have the two lines cross-connected at each station in succession toward the fault, and have an operator at some station beyond the fault make dots all the time on the same line, say on the good line, or he may make dots, always in the same order, first on one wire and then on the other. Then to the operator at the testing station, the fault will remain on the same line, as the various stations on the test-station side of the fault cross-connect the lines, but, as soon as the station just beyond the fault cross-connects, the fault will change to the other line. After a station cross-connects the lines, they should be restored to their original position before the next station is directed to cross-connect. In this manner, the two stations between which the fault occurs may be determined.

106. Electrostatic Test for an Open Line.—The charge an open line will take on account of its electrostatic

capacity may be utilized to test for and approximately locate a break in a line wire. The test may be made at a terminal or intermediate office. It is commonly called the *static test for an open line.* Mr. R. J. Hewett, in "The Telegraph Age," gave the following method, which he says he has used very successfully.

At a terminal station, arranged as in Fig. 21, the operation consists in alternately charging and discharging the line by removing the battery peg from its regular place and tapping it alternately in the connecting holes *1* and *2* of the positive and negative battery disks, so as to connect the line alternately to the positive and negative batteries B and B'. The higher the voltage used for this test the better. Continue this reversal of the battery as rapidly as possible, and at the same time adjust the relay, lower, if necessary, until it responds by a momentary kick at each reversal. The strength of the kick depends on the capacity of the wire. The longer the line to the point where the wire is open, the stronger will be the kick and the higher may the relay be adjusted; and the shorter the line, the more feeble the kick and the lower must the relay be adjusted in order to detect it. If the wire happens to be open near by, there will be no perceptible kick. Care must be taken to tap the pin so as to make a sure connection between the disks and the vertical strap A each time, and to do it very rapidly, otherwise the charge will be more or less dissipated and the effect on the relay reduced. In dry weather, on a well-insulated long line, open at or near the distant end, the intensity of the

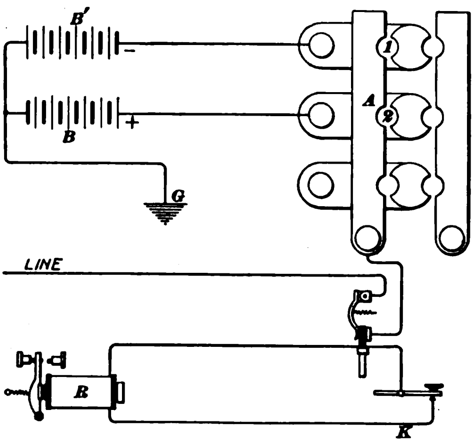


FIG. 21.

charging and discharging currents will be sufficient to cause an ordinary test relay to kick without altering the adjustment very much from normal. If there is some leakage on the wire, whether due to damp weather or to other reasons, the intensity of the charging and discharging current will be less but more prolonged, and a lower adjustment of the relay will be necessary.

With some experience—always considering the weather, the intensity of the kick, and the adjustment of the relay—the distance to the break can be approximately determined, and by at once getting nearer to the office that should be called up for a regular open-wire test, time can be saved that would otherwise be lost in calling up offices too near or too far away.

It is best to use two batteries or dynamos of the highest obtainable voltage, but the test can be made with one battery by substituting the ground for one battery; but, in this case, the intensity of the momentary current will only be one-half as great.

107. Static Test With One Battery.—A very convenient arrangement, requiring only one battery, is shown in Fig. 22. Place a plug firmly in the hole *c* so as to connect the battery to the vertical strap of the line to be tested, and in the spring jack of the same line insert the wedge of an office set. In circuit with this office set is a special key *M*, called a **discharge key,** such as is used in making regular electrostatic capacity tests on cables, lines, and condensers. One wire from the ordinary telegraph key *K* is connected to the lever of the key *M* at *a*. The lower insulated contact *b* of this special key *M* is connected to the ground, and the upper insulated contact *c* is connected to one side of the wedge that is placed in the spring jack of the line to be tested. The lever *h* of the key *M* should be made to touch both contacts *b* and *c* in rapid succession. When the lever *h* touches *c*, the line is connected through the office instruments to the positive pole of the main-line battery *B*; when the lever *h* is pressed

down against *b*, the line is connected through the instruments to the ground *G*. Thus, the line may be rapidly and

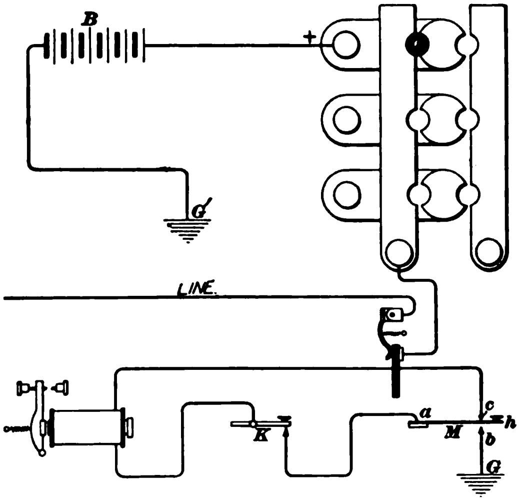


FIG. 22.

repeatedly charged to the potential of *B* and discharged to the ground potential.

108. Static Test at an Intermediate Office.—At an intermediate office, this same test can be made, provided the intermediate office is not too far from the main battery. Suppose that the east wire is open. Then, with the relay and key connected in the line circuit as usual, and as shown in Fig. 23, the test is made by rapidly connecting and disconnecting the ground disk on the battery side of the circuit with a plug at the hole *a*. When there is

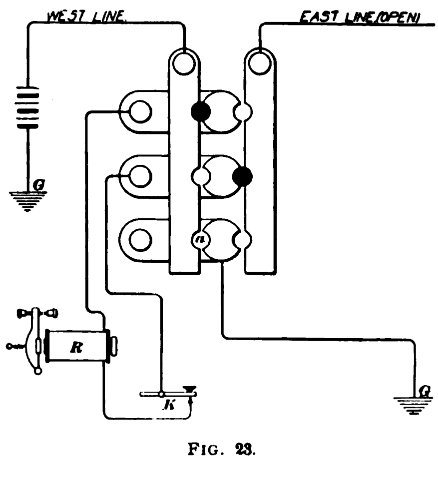


FIG. 23.

no plug in the hole *a*, the line is charged to the potential of the main-line battery, the charge for the open east end having passed through the relay. When the plug is inserted in hole *a*, the discharge from the open end flows through the relay to the ground *G*. If the capacity of the open end is sufficient, and the voltage of the main battery not too low, the relay will respond each time the ground *G* is connected and disconnected.

In any of these static tests, if the relay does not respond with a normal adjustment, it should be turned down until the kick appears, or until satisfied that there is no appreciable charge to or from the line, in which case the line is open near by.

109. To Locate a Cross From a Terminal Office. Suppose there are two lines running through four offices, as in Fig. 24, with a cross somewhere between *A* and *D*, and that the test is to be made at *A*. The *A* office should request the most distant office, in this case *D*, to open line *1* and to make dots on line *2*. *A* will then open his key on line *2*, and if dots are received on line *1*, there is a cross somewhere between *A* and *D*. *A* will then request *D* to

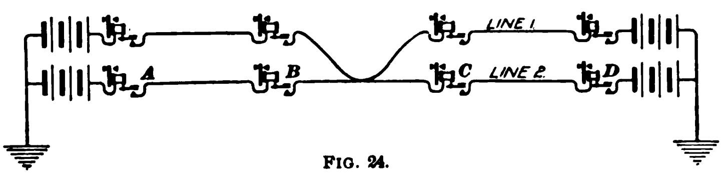


FIG. 24.

leave his line *1* open and close line *2*, and *A* will then open line *1* at his own office and call up office *C* over line *2*, requesting *C* to open line *1* and send dots on line *2*. *A* closes both his keys one at a time, and if the dots sent from *C* on line *2* are received on both lines *1* and *2*, then the cross is between *A* and *C*; if received only on line *2*, then the cross is between *D* and *C*. If the cross is between *A* and *C*, the process described is repeated with *B*, after requesting *C* to leave line *1* open and close line *2*.

110. To Locate a Cross From an Intermediate Office.—In this case, the first thing to do is to determine toward which terminal office the cross occurs. The test is practically the same as given in Art. **109,** except that some intermediate office, as *B*, is now making it. *B* would request the most distant office on one side, say *A*, to open line *1* and to make dots on line *2*, and if with line *2* open at *B*, dots are received on line *1* at *B*, then there is a cross somewhere between *B* and *A*. If there is no cross on the *A* side of *B*, the same process is repeated between *B* and *D*.

Having determined the side on which the cross occurs, the two offices between which it is located may be found as follows: Suppose the cross is between *B* and *D*. *B* will open one of his lines, say line *2*, and then request each office in succession, beginning with *D*, to open line *1* and send on line *2*. The cross will then lie between the two consecutive offices, the dots from the first of which are received, but the dots from the next office are not received.

111. The Part of a Line Rendered Useless on Account of a Cross.—Because there is a cross between two lines, it is not necessary to abandon the whole of either line. The only part that need be abandoned until the cross is repaired is the portion of one line connecting the two stations between which the cross occurs. For instance, if lines *1* and *2* are crossed between *B* and *C*, then leave that portion of either line that connects *B* and *C*, say line *1*, open at both offices, and ground (through office sets) at *B* and *C* those portions of line *1* that run east and west, respectively, from these two offices. This leaves line *2* free to be used all the way through, and line *1* can be used between *A* and *B* and between *C* and *D*.

112. To Locate a Bad Leak.—Where the leaking current is so large at some one point that it is almost impossible to work past it, the fault may be located in the following manner: Suppose, in Fig. 25, that there is a bad leak or escape to ground between *B* and *C*, as indicated by the dotted line, and that office *A* desires to locate it. *A* will

request each office in turn, commencing with *D*, to open his key. Evidently, opening the keys at *D* and *C* will not cut off the current leaking away between *B* and *C*, although it may weaken the current through *A* more or less. But if *B* opens his key, this leakage current will be entirely cut off and there will be little or no current through the *A* relay,

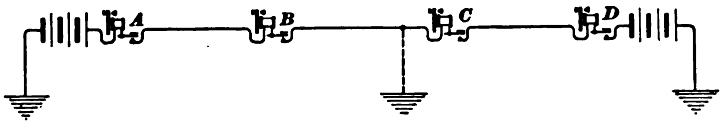


FIG. 25.

assuming the line between *A* and *B* to be in good condition. Hence, the leak is between two consecutive offices, the opening of the key at one of which may somewhat weaken but does not entirely stop the current through *A*, while the opening of the key at the next office does entirely stop or very perceptibly weaken the current through *A*.

113. A Cross Between the Relay Coil and the Iron Core.—If there is a cross between any part of the relay coil and the iron core, and if the armature strikes (which, of course, it should not do), or if any part of it or its support touches the iron core, or if the local circuit has any connection whatever with the iron cores, then a cross exists between the local and main-line circuits. This cross should be removed, for if the local circuit is grounded anywhere, there is an unintentional ground put on the main-line circuit, forming an escape or partial ground that may cause considerable trouble.

114. To Test for a Cross Between the Relay Coil and the Iron Core.—If the free end of a grounded wire is touched to the iron core, and if the intensity of signals is then either greater or less, or if the working of the relay is entirely interrupted, then there is a cross between the relay coil and the core, provided there is a battery at both end stations. The effect produced will depend on the part of the relay coil that touches the iron core. If the test

is being made at an end office where there is no battery, then the signals sent from a distant station will not be affected, provided the cross is located near the end of the relay winding farthermost from the line; but, if such is the case, and provided the cross is a good one, the operation of the home key, if on the ground side of the relay, will not operate the relay properly while the grounded wire is touching the iron core.

DYNAMO-ELECTRIC MACHINES.

ADVANTAGES OF DYNAMOS.

115. Dynamos and storage batteries are rapidly replacing primary batteries, especially in large telegraph offices, being preferable for many reasons. The first and greatest advantage lies in the fact that they are much more economical. One dynamo can replace a very large number of primary cells. The dynamos installed in 1880 in the New York Western Union office replaced 12,000 primary cells, and the new plant, put in after the fire in 1890, displaced all primary cells, doing the work that would have required 22,000 cells. Previous to 1890, the 10,000 cells in use required a space of nearly one entire floor. Furthermore, primary cells must be periodically replenished, and require continual inspection and attention in order to keep their electromotive force even approximately constant, and not over three or four telegraph circuits can be successfully worked from the same set of cells, requiring, therefore, a large number of separate batteries in a main office where a large number of wires terminate. On the other hand, dynamos and even storage cells require less attention, and occupy less space, one dynamo or storage battery being able to supply all circuits needing about the same voltage.

116. Another advantage of dynamos, converters, and storage batteries over primary cells is that the operation of one of several telegraph instruments, if all are connected to any one of the first three mentioned sources of current, will

affect the current strength in the other instruments less than would be the case were the several lines supplied by only one set of gravity cells.

Suppose, for instance, that there are three telegraph lines to be supplied with current at 70 volts, each line requiring 25 milliamperes, in all 75 milliamperes. This would require, approximately, 70 gravity cells connected in one series set. The internal resistance of this battery, assuming 2 ohms per cell, would be 140 ohms. Let us further assume that the resistance of each circuit, including the telegraph relays, is equal to 2,380 ohms. Now, when all three telegraph keys are closed, the current in each will be 25 milliamperes. For the total current will be $\frac{70}{140 + \frac{2,380}{3}} = .075$ and $\frac{1}{3}$ of $.075 = .025$, that is, 25 milliamperes in each line. Now, when only one key is closed, the other two operators having their keys open in the act of making spaces, the current in the one closed line will be $\frac{70}{140 + 2,380} = .0277$. Thus, the current in one line varies from .025 to .0277, or over 10 per cent.

If a dynamo or storage battery were used, the internal resistance would be so very small in either case that it could be entirely neglected, giving practically the same current in each line, no matter whether one or all three keys were closed. Of course, the current may not remain uniform if the machine or storage battery is excessively overloaded and a large number of the circuits are opened or closed at the same instant.

117. Relative Cost of Operation.—It is generally most economical to use dynamos as a source of current supply. Next in order of economy come converters, motor-dynamos, and then storage batteries, and, finally, primary cells.

Mr. Preece, head of the telegraph and telephone systems of the British Government, states that, for telegraph and telephone purposes, electricity produced by primary batteries costs $1.50 per kilowatt-hour, as against 2 cents by the

present system, in which dynamos and storage cells are used. The relative cost will doubtless be as much in favor of the dynamo and storage battery in this country as in England. The relative cost of operating sounders from electric-light mains and from primary cells will be shown later.

DYNAMOS.

118. A **dynamo** is a machine for converting the mechanical energy furnished by a steam engine, waterwheel, or other prime mover into electrical energy by electromagnetic induction. Dynamos may be divided into two general types, depending on the character of their currents. These two types are:

1. *Continuous-current* or *direct-current dynamos*, in which the current through the external circuit flows continuously in the same direction.

2. *Alternating-current dynamos*, the current from which alternates or reverses in direction with great rapidity. In ordinary alternating-current dynamos, the reversals average about 16,000 per minute, but they may be designed to give almost any desired number of reversals per minute.

119. Essential Parts of a Dynamo or Motor.—The parts of an ordinary dynamo or motor may be summarized as follows: (1) A circuit, as complete as possible, of iron. Such a circuit is composed of the cores of an electromagnet, usually an iron yoke or base connecting the cores, and a cylindrical or ring-shaped core of an armature that revolves between the magnet ends or poles, which are shaped so as to partly embrace it.

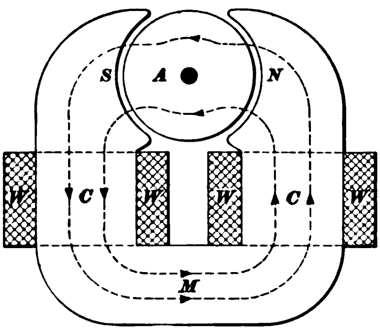


FIG. 26.

This iron circuit is shown in Fig. 26. *C*, *C* are the iron

cores, A the iron part of the armature, and M the iron yoke. (2) Coils of insulated wire W wound around the field-magnet cores C, C. When a current flows through these coils, magnetic lines of force are set up through the iron circuit. The dotted lines represent the path and the arrows represent the direction of the magnetic lines, or *flux*, as they are called. (3) Coils of insulated wire, wound on the iron armature core but carefully insulated from it. When the armature core and coils are rotated between the pole pieces S and N, the coils cut the magnetic lines of force and develop an electromotive force. (4) A collecting mechanism called the *commutator* in direct-current machines, and *collector rings* in an alternating-current machine. The commutator or collector rings are attached to but insulated from the armature shaft and rotate with it. The collecting mechanism consists of rings or segments of rings, to which the wire coils of the armature are connected and on which press copper or carbon pieces called *brushes*.

120. In Fig. 27, E represents the commutator and B, B the brushes of a direct-current dynamo or motor. When used as a dynamo, the electromotive force developed by the cutting of the magnetic lines of force by the wires on the armature shows itself as a difference of potential between the brushes. This difference of potential at the brushes or at the terminals of the machine, to which the brushes are directly connected, usually by short heavy wires or bars, is called the **voltage** of the dynamo, because it is measured in volts.

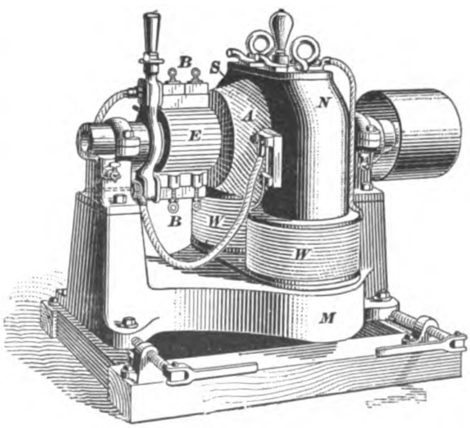


FIG. 27.

If the two brushes *B*, *B* on opposite sides of the commutator *E* are connected with some circuit external to the machine, the potential difference will cause a current to flow in that circuit. By using enough coils on the armature, and properly divided and connected segments on the commutator, the current may be made to flow always in one direction, giving a practically continuous current. Such a machine is called a **direct-current** dynamo. If only two collecting rings are used, the current flows first in one direction and then in the opposite direction. Such a machine is called an **alternating-current** dynamo.

121. The potential difference at the brushes of a dynamo depends on the speed at which the armature rotates, on the strength of the magnetic flux passing through the armature, and on the number of turns of wire on the armature. Consequently, with a given machine in which the number of turns on the armature is fixed, the voltage will remain uniform, provided both the speed and the magnetic flux remain constant. The speed is usually constant within about 2 per cent. By regulating the current in the field coils, the magnetic flux may be varied, and, consequently, the voltage can be regulated.

122. Methods of Exciting the Field.—The requisite number of ampere-turns for exciting the field of a dynamo-electric machine may be obtained in a variety of ways. In the first place, the current that flows through the magnetizing coils may come either from some separate external source, the machine being then said to be **separately excited,** or it may be furnished by the armature of the machine itself, it being then said to be **self-excited.** In some cases, a combination of separate and self-excitation may be used.

SEPARATELY EXCITED DYNAMOS.

123. A **separately excited dynamo** is so named from the fact that its field magnets are excited or magnetized by a current from some external source, as, for instance,

a voltaic battery or another continuous-current dynamo. The connections of a separately excited dynamo are represented in Fig. 28. The magnetizing coils are wound around the cores of a magnet and connected to the terminals of a voltaic battery *B*. The exciting current flows from the battery around the cores of the field magnet in such a direction as to set up lines of force through the armature, and has no connection whatever with the current obtained from the brushes by rotating the armature. If the strength of the exciting current is not changed, the difference of potential between the brushes of the dynamo, when the armature is rotated at a uniform speed, remains constant so long as the external circuit is open; but when the external circuit is closed, the difference of potential gradually diminishes as the strength of the current increases, owing to the internal resistance of the armature conductors and the reactions of the armature current on the field.

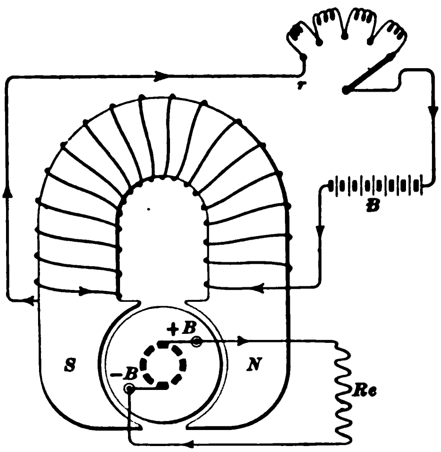


FIG. 28.

An explanation of this can be found in a treatise on the theory of dynamos, but it would require more space here than it is worth to a student in telegraphy.

SELF-EXCITED DYNAMOS.

124. A **self-excited dynamo** is so named from the fact that the exciting current for the field magnet is furnished by the dynamo itself. There are three methods for self-exciting a dynamo.

1. The field coils may be connected across the brushes in

shunt with the external circuit. Such a machine is called a *shunt dynamo.*

2. The field coils may be connected in series with the external circuit and the armature. This is called a *series dynamo.*

3. The field may have two distinct windings on it, one of which is connected across the terminals or brushes and in shunt with the external circuit, and the other in series with the external circuit and the armature. This is called a *compound*, or a *shunt-and-series dynamo.*

125. Shunt Dynamo.—In Fig. 29 is shown a **self-excited shunt dynamo,** or simply a **shunt dynamo,** as it is generally called. One terminal of the magnetizing coil is connected to the positive brush and the other to a binding post on the field rheostat *r*; the negative brush is connected to the arm of the field rheostat. If the resistance of the rheostat is neglected or cut out, it will be seen that

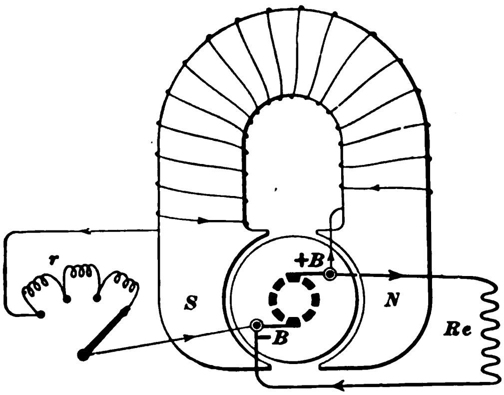


Fig. 29.

the total difference of potential exists between the terminals of the magnetizing coils when the dynamo is generating its maximum electromotive force. The magnetizing coils of a shunt dynamo, however, consist of a large number of turns of fine copper wire, thus making the resistance large in comparison with the difference of potential between the field terminals. In well-designed dynamos, the resistance of the shunt coil is large enough to allow not more than

about 5 per cent. of the total current of the dynamo to pass through the field coils. According to Ohm's law, the strength of current in amperes circulating around the field coils is equal to the difference of potential in volts between the brushes divided by the sum of the resistances in ohms in the field coil and in the rheostat *r*. Since the total resistance in the field circuit is large compared with the voltage between the brushes $+B$ and $-B$, then the current in the field coils will be relatively very small compared to the total current, as just stated.

126. Regulation of a Shunt Dynamo.—The difference of potential between the brushes of a shunt dynamo gradually decreases as the current from the armature becomes stronger, on account of the internal resistance of the armature conductors, and the reactions of the current on the field. A decrease in the difference of potential between the brushes causes a corresponding decrease in potential at the field terminals, thereby weakening the current in the magnetizing coils. In order to compensate for the decrease in the difference of potential at the brushes, a field rheostat *r* of comparatively high resistance is connected in the field circuit, and is so adjusted that when no current is flowing in the external circuit, only enough current flows through the field to produce the normal difference of potential between the brushes. This normal difference of potential between the brushes is kept constant, as the load increases, by gradually cutting out, or short-circuiting, the resistance coils of the rheostat.

As the resistance in the rheostat is decreased, more current flows through the field coils, thus increasing the flux or strength of the field; this in turn causes an increase in the electromotive force generated in the armature, provided, of course, that the speed remains the same.

In telegraph work, the total current from one machine does not change suddenly enough to cause any serious inconvenience on account of the resulting variation in the difference of potential caused thereby. If there is an appreciable

change in the voltage at the terminals of the dynamo, it is the dynamo attendant's business to keep this voltage constant within prescribed limits by properly adjusting the field rheostat.

127. A dynamo of this type was shown in Fig. 27. The shunt dynamo is more extensively used for telegraph purposes than any other one. It is shown in this figure mounted on sliding rails, which are attached to a wooden bedplate. Two adjusting screws, one on each side of the machine, are used to move the dynamo along the rails, thereby loosening or tightening the belt, as the circumstances may require. The current passes from the brush holders through flexible copper cables to two terminals fastened to, but insulated from, the pole pieces; from the terminals, the current divides, a small portion passing through the field coils and the rheostat, which is not shown in this figure, and the rest through the external circuit.

An incandescent lamp is often connected between the main terminals of the connection board, and is used to indicate when the machine is generating its normal electromotive force. A lamp used for this purpose is usually called a **pilot lamp.**

128. Series Dynamo.—Fig. 30 shows a **self-excited series dynamo,** or, as it is more commonly called, a **series dynamo.** The magnetizing coils of a series dynamo are connected directly in *series* with the external circuit; that is, all the current from the armature circulates around the magnetizing coils and flows through the external circuit. The connections of a series dynamo are shown in the figure. The current starts from the positive brush $+B$,

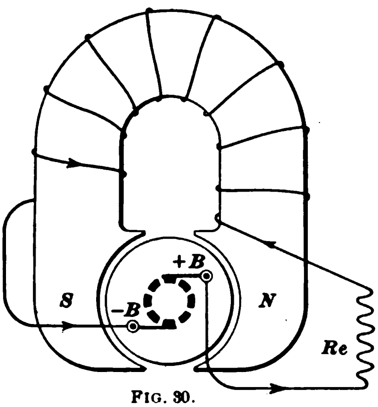


FIG. 30.

circulates around the external circuit *Re*, thence through the magnetizing coils back to the negative brush $-B$. The action of a series dynamo differs widely from that of a shunt dynamo. The difference of potential between the brushes depends on the strength of the current flowing from the armature, but is not necessarily directly proportional to the strength of the current. Compared with the coils on a shunt dynamo, the magnetizing coils of a series dynamo are made of a few turns of a large conductor. This is necessary, because the coils are usually required to carry the total current from the armature; the conductor is made large to carry the current without heating, and only a few turns are necessary to secure the proper magnetizing force.

129. Compound Dynamo.—In the shunt dynamo previously described, the regulation of the difference of potential at the terminals of the machine is not automatic; it is accomplished by a mechanical movement of an arm or contact. This movement of the rheostat arm is sometimes imparted automatically by a magnet controlled by the current in the external circuit. But, more often, when a very constant potential is desired, it is automatically regulated in the dynamo itself by a combination of the *shunt* and *series* magnetizing coils. Such machines are termed compound dynamos, as already stated.

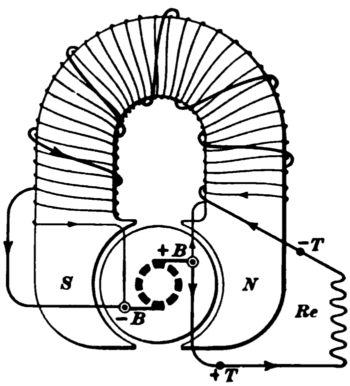


FIG. 31.

In Fig. 31 the shunt coils consist of a large number of turns of fine insulated wire wound on the core of the magnet. The series coils, consisting of a few turns of large insulated wire, are wound over the shunt coils. The main part of the current from the armature flows from the positive brush $+B$ through the external circuit *Re*, thence through the series coils to the

negative brush $-B$. The two terminals of the shunt coils are connected to the two brushes $+B$ and $-B$, respectively. But the series and shunt coils are so wound that the currents in both circulate around the core of the magnet in the same direction when connected as shown in the diagram. The action of both currents, therefore, is to produce the same polarity in the magnet, the shunt current being reenforced by the series current. When the dynamo is not loaded, that is, when no current is flowing in the external circuit and the armature is rotated at normal speed, the normal electromotive force is generated in the armature due to the magnetic field produced by the shunt coils alone. On closing the external circuit, however, the difference of potential between the brushes tends to decrease, and it would continue to decrease, as previously described in a simple shunt machine, if the series coils were neglected. The current circulating through these, however, reenforces the magnetizing force of the shunt coils, and immediately increases the number of lines of force in the field, which, in turn, raise the difference of potential between the brushes to normal. These actions are produced simultaneously, and, to all appearances, the difference of potential between the brushes remains normal for all changes of load in the external circuit. This method of regulating the difference of potential at the terminals of a dynamo is called **compounding.**

The **terminals** of a dynamo are the binding posts to which the external circuit is connected. In a series, or compound, dynamo, one terminal is attached to the outside end of the series coils, as $-T$ in Fig. 31, and the other terminal $+T$ is connected directly to the brush $+B$. In a compound dynamo, the shunt field is connected directly across the brushes.

DIRECT-CURRENT DYNAMOS.

130. Direct-current dynamos may be subdivided into two classes as follows:

1. *Constant-potential dynamos*, in which the difference of

potential at the terminals of the machine remains constant and the strength of current (continuous) changes with the load* or external resistance.

2. *Constant-current dynamos*, in which the strength of current (continuous or pulsating) remains constant and the difference of potential at the terminals of the machine changes with the load.

Compound, separately excited, and shunt dynamos are included under the first head, and rank in their ability to maintain a constant potential in the order named above, and for reasons already explained.

Constant-current dynamos have usually a series field, and at present are used almost exclusively for operating continuous- or direct-current arc lamps. In about the first installation of dynamos for telegraph work, this type of machine was employed, but they were later replaced by shunt-wound dynamos.

Dynamos should be started and brought up to full speed and normal voltage, with the main switch connecting the external circuit open, that is, before any load is put on the machine. It is preferable to apply the load gradually and not all at once.

131. Currents furnished by dynamos for telegraph purposes should preferably be as smooth and continuous as possible, that is, they should closely resemble the continuous, non-pulsatory current obtained from batteries. In order to obtain such smooth currents from dynamo-electric machines, it is best to have a smooth iron armature body on which to wind the wire and a commutator with a large number of segments (at least 48). The revolving armature and commutator should run at a fairly high speed. Armatures with the wires wound in slots produce a current more

* The word *load* as used above is a common expression for *current* in dynamos generating a constant potential. Strictly speaking, however, the load means the product of the current and the voltage, but the voltage is considered constant and, therefore, the load is directly proportional to the current. That is, if the current in the external circuit is doubled, the load is doubled.

pulsatory in character, and are sometimes very troublesome to grounded telephone systems, whose wires run near and parallel, even for a short distance, to telegraph wires that are supplied with currents from such armatures.

ALTERNATING-CURRENT DYNAMOS.

132. At the present time, **alternating-current dynamos** are used but very little in telegraph work. They are used for the Crehore-Squier high-speed and the Roberson quadruplex systems. The fields of alternating-current dynamos must be separately excited, either from a direct-current dynamo or from storage batteries. A large alternating dynamo usually has a small direct-current machine

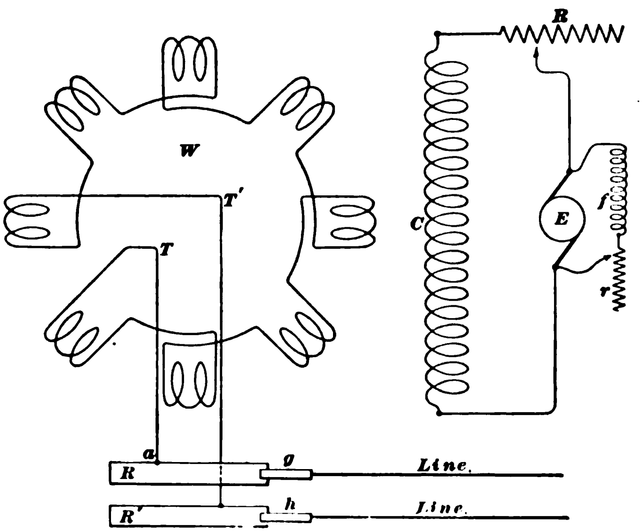


FIG. 32.

associated with it for exciting its field. In Fig. 32 is shown a diagram of connections of a simple alternating-current dynamo with a direct-current machine for exciting the alternator fields. *W* represents the armature winding, the

terminals *T*, *T'* of which are connected to the collecting rings *R*, *R'* connecting to the line wires by means of the brushes *g*, *h*. The field is excited by a set of coils on the pole pieces represented by *C*, and the current is supplied to these from a small continuous-current dynamo, or exciter, *E*. This is a small shunt-wound machine with an adjustable field rheostat *r* in its shunt field *f*. An adjustable rheostat *R* is also placed in the alternator field circuit. When the voltage drops or rises, the fields may be strengthened or weakened by adjusting the resistances *R* and *r*; thus, the voltage may be kept right.

COMBINATIONS OF DYNAMOS AND MOTORS.

133. Reversibility of Dynamo-Electric Machines.—If, instead of forcibly revolving the armature of a dynamo and thereby generating an electric current, we supply the machine with current at the proper voltage, the armature will be revolved with sufficient force to do mechanical work. An electric machine used in this manner is called a **motor.** Combinations of dynamos and motors are rapidly coming into use in telegraphy.

134. Motor-Dynamo.—The term **motor-dynamo** is used to designate the combination of a motor and a dynamo mounted on one base, with their shafts rigidly coupled together, the armature windings being distinct on each shaft, and each armature having its own independent field. The motor is designed to be operated at any required voltage from a power or light circuit, and is started and regulated like any similar but detached motor. The dynamo is operated like any similar dynamo that is driven in any other manner. The voltage at the dynamo terminals may be regulated by adjusting the strength of either the dynamo or motor field current by means of an adjustable resistance in either field circuit. A rheostat in the field circuit of the dynamo is the more common method, however. The motor

may be any kind of direct- or alternating-current motor, and the dynamo may be designed to furnish direct or alternating currents at almost any desirable voltage.

135. Converters.—A **converter** is a rotary dynamo-electric machine that transforms electrical energy from one form into another without passing it through the intermediary form of mechanical energy. For instance, a converter is a dynamo-electric machine having one armature, one field frame, and two commutators, the armature conductors and commutator bars being so connected that a current going in through one commutator at a certain potential is converted into a current of another strength and another potential before it comes out at the second commutator. In reality, a converter is a combination of a motor and a dynamo, the armature windings of the motor and of the dynamo being wound on the same armature core and revolving in the same field. Converters are frequently called **rotary converters** and also **dynamotors.**

136. A converter may be either (*a*) a direct-current converter, converting from a direct current at one potential to a direct current at some other potential, or (*b*) a synchronous converter, converting from an alternating to a direct current, or *vice versa*.

A synchronous converter is shown in Fig. 33. At the left-hand end of the armature shaft is placed the commutator *C* of the motor windings of the armature, to the brushes of which are led the wires from the lighting or power mains, the current from which is to operate the machine. On the other end of the armature shaft are mounted two separate collecting rings *B*, *B'* for the generator windings of the machine, from which is taken an alternating current. By connecting the collecting rings, now the motor side, to an alternating-current circuit, a direct current may be taken from the commutator, now the dynamo side of the machine. These machines are manufactured by several dynamo

builders, and may be wound for any standard voltage on the motor side. The one shown in Fig. 33, however, is the

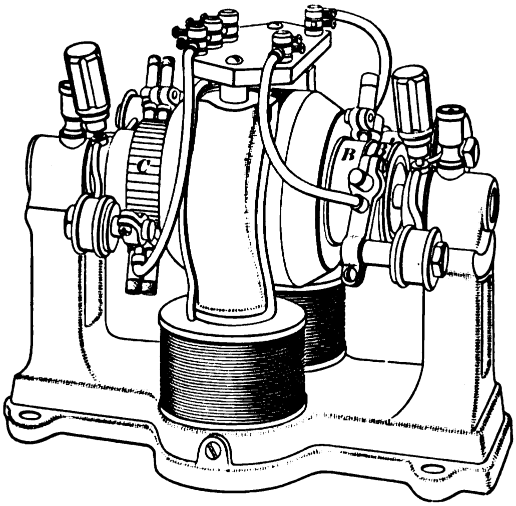


FIG. 33.

product of the Holtzer-Cabot Electric Company, of Boston, Massachusetts.

137. Regulation of Converters.—The voltage of the dynamo side of converters cannot be regulated independently. In order to regulate the voltage on the dynamo side, it is necessary to regulate the strength of the current through the motor-armature circuit by adjusting a resistance in series with the motor armature, the field current remaining constant. Altering the field current alone cannot be used as a means for altering the dynamo voltage, as in motor-dynamos and independently driven dynamos.

Converters are started up in the same manner as motors; that is, the motor side of the machine is connected to the circuit and operated precisely like the corresponding kind of motor. Usually, the motor is a plain shunt-wound machine, supplied with current from a constant-potential light or power circuit.

OPERATING CONVERTERS AND MOTOR-DYNAMOS.

138. Converters are now used so extensively in telegraph offices, at the smaller as well as at the larger ones, that it will be well to consider the methods of connecting and operating them somewhat fully. The motor parts of both converters and motor-dynamos are started up in exactly the same manner; the only difference in operating the two classes lies in the methods used for regulating the voltage on the dynamo side. In motor-dynamos, the two parts being entirely independent electrically, the dynamo side is operated according to the methods already given for dynamos, and the motor side will be operated in the same manner as the motor side of converters and hence it is unnecessary to consider motor-dynamos separately.

STARTING CONVERTERS.

139. A converter must be started up like a motor, that is, with a resistance in series with the armature. The resistance of the converter armature is very small, so that if the machine were connected directly across the circuit while standing still, there would be an enormous rush of current. Take, for example, a converter of which the armature resistance is .1 ohm. If this armature were connected across a 110-volt circuit while the motor was at a standstill, the current that would flow momentarily would be $\frac{110}{.1} = 1{,}100$ amperes, the amount being limited only by the resistance of the armature. After the motor comes up to its proper speed, the current is no longer limited by the resistance of the armature, but by an electromotive force called the counter electromotive force, which is developed in the armature and opposes that in the supply circuit. When starting the motor, it is, therefore, necessary to insert a resistance in the armature circuit and to gradually cut it all out as the motor approaches its full normal speed.

Synchronous converters must have their fields excited from the direct-current side of the machine. Some manufacturers arrange their synchronous converters so that they are started up by connecting a part or the whole field coil temporarily in series with the motor side of the armature.

140. Starting Rheostats.—The **starting rheostat,** or **starting box,** as it is often called, is simply a resistance divided up into a number of sections and connected to a switch arm, by means of which these sections can be cut out as the converter or motor comes up to speed. When the converter is running at full speed, this resistance is completely cut out, so that no energy is lost in it.

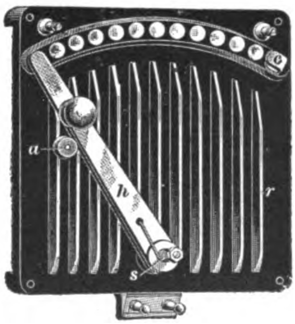


FIG. 34.

Fig. 34 shows a simple form of starting box, the resistance wire being embedded in enamel on the back of an iron plate, while the iron ribs *r* on the front are intended to present a large radiating surface that may be cooled by the air. The handle *h* of the rheostat shown is provided with a spiral spring *s* tending to hold it against the stop *a*, which makes it impossible to leave the contact arm *h* on any of the intermediate points. On the last point, a clip *c* is placed to hold the arm of the rheostat. When the arm is on this last clip, all the resistance is cut out.

141. Converter and Supply-Circuit Connections.—One method of connecting a converter to constant-potential mains is shown in Fig. 35. The wires from the mains leading to the converter are connected through a fuse block *D* to a double-pole knife switch *B*. One end of the shunt field *F* is connected to terminal *1* of the converter, and one brush on the *x* commutator is also connected to the same terminal. The other field terminal is connected to the converter terminal *2*, and the other brush on the *x* commutator

leads to the terminal *3*. One side of the main switch connects to terminal *1*; the other side connects to *3* through the starting rheostat *C*. Terminal *2* connects to the same side of the switch as the starting rheostat. It will be seen from the figure that as soon as the main switch is closed, a current will flow through the field *F*, and thus magnetize it before any current flows through the armature *A* (the first contact at the left on the rheostat being a dead point).

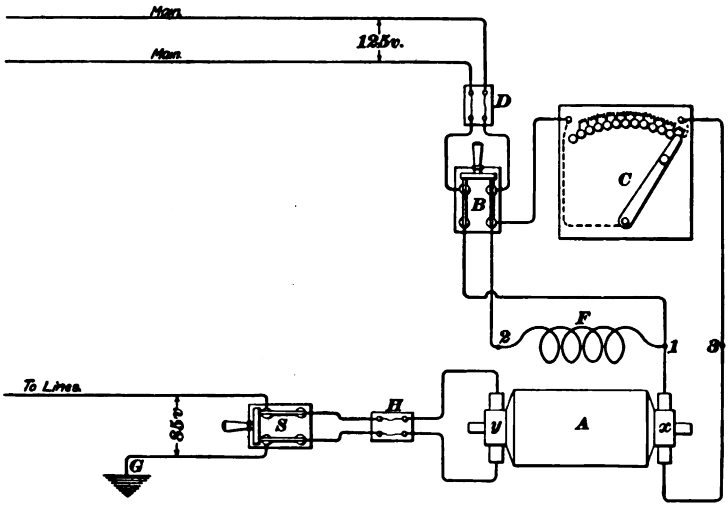


FIG. 35.

When the rheostat arm is moved over toward the right, a current flows through the armature, and a strong starting effort is produced, because the field is already magnetized. The handle is then moved over slowly and left on the last point on the right when the converter has attained its full speed.

The switch *S* and the fuse *H* are on the side of the converter that supplies current to the telegraph lines. The switch *S* should not be closed until the machine is running at its usual rate.

142. The voltage between the two brushes on the *y* commutator side of the converter may be controlled by an

adjustable resistance in the supply mains. Such a resistance or rheostat must be made of wire large enough to carry the whole current for an indefinite length of time without undue heating, and it will take the place of the starting rheostat or box *C* in Fig. 35. Starting rheostats for motors are not designed to carry the current continuously, and are not suitable, therefore, for regulating the voltage of a converter. A regulating rheostat should not have the spring *s*, Fig. 34, which is so necessary on a motor starting box, because it is desirable to have the arm *h* remain in any desired position while the converter is running.

AUTOMATIC SWITCHES.

143. Automatic Starting Box.—When the simple form of starting box is used, it is necessary to see that the handle is moved back to the off-position every time a converter or motor is shut down, so that the resistance will be all in the circuit the next time it is started up. If this is not done, and the switch is thrown in, on starting up again, with the resistance all out of the circuit, there will result such a heavy rush of current as to injure the machine. In order to obviate this, motors and motor-dynamos are now usually provided with automatic starting boxes, the switch lever of which automatically flies back to the off-position when the current is shut off. They are also generally provided with an arrangement for throwing the switch lever back, and thus breaking the circuit, when the motor is overloaded. The same arrangement would be used for a converter where the resistance in the box is not used to regulate the voltage on the dynamo side.

Fig. 36 shows the arrangement of an automatic starting box, made by the General Electric Company, that will serve to illustrate the action of most of these automatic starting rheostats. The resistance is connected between the contact points, as shown, the arm being shown in the running position with the resistance all cut out. The contact arm is

moved over against the action of a spiral spring in the hub and is held in position by a catch *a*, which fits into a notch in the hub of the lever *b*. This lever carries an armature *c*, which is held down against the action of a spring by the magnet *m*. The exciting coil of this magnet, in the case of a shunt machine, is connected in series with the field; in the case of a series machine, it is wound with heavy wire and connected in series with the motor. If the current is cut off in any way, the magnet releases the armature and the switch lever flies back to the off-position.

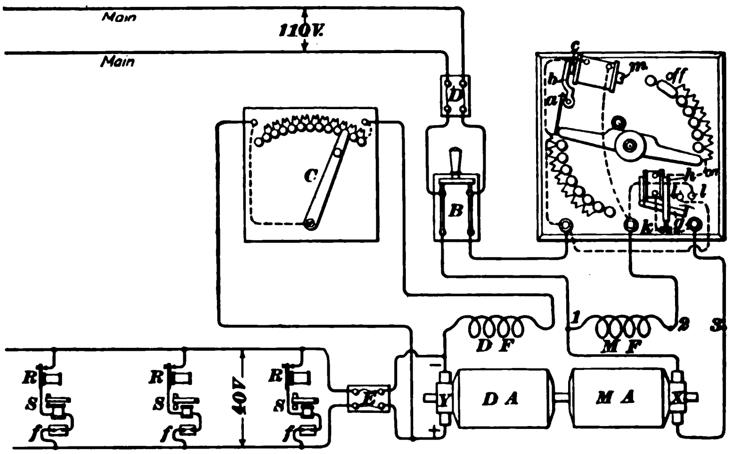


FIG. 36.

The automatic starting box shown in this figure has also a device that will cut off the current from the main circuit should the machine be overloaded. This is necessary in order to save the machine from excessive heating or burning out. An overload is due to an excessively large current being taken from the generator side of the machine; that is, from the brushes against the *Y* commutator. This *overload* device, as it is called, consists of an electromagnet, the coil of which is connected in series with the armature *M A*. This magnet is provided with a movable armature *g*, the distance of which from the pole *h* may be

adjusted by the screw *k*. When the current exceeds the allowable amount, the armature is lifted, thus making connection between the pins *l*, *l*. This connection short-circuits the coil of the magnet *m* and the lever goes to the off-position.

144. In this figure, the connections of the dynamo side of the motor-dynamo have also been shown. In the dynamo-field circuit is the rheostat *C*, by means of which the voltage at the dynamo terminals may be regulated. *E* is a fuse block in the main lines, and *f*, *f*, *f* are fuses in each individual local circuit. A preferable arrangement, if the field coil is properly designed for the high voltage, would be to connect it between *1* and *2* instead of between the brushes of the dynamo armature, the rheostat *C* being retained in series with the dynamo field, as shown here. By so doing the dynamo field would be excited directly by the current from the 110-volt mains, and thus the loss due to the transformation of the dynamo-field current would be avoided.

OVERLOAD AND UNDERLOAD DEVICES.

145. When storage batteries are charged from a lighting circuit or from a dynamo or converter, there should be used in the charging circuit going to the batteries a device that will automatically open the circuit if the current becomes too large, and also in case the current becomes too small or drops to zero. The first is to prevent the batteries from being charged at too high a rate, and it also protects the converter, dynamo, or electric-light mains from being overloaded. When this device is used, no main-line fuses are necessary. A magnetic overload device is much preferable to a fuse because it is more reliable and can be more quickly and more easily reset.

The object of having the circuit automatically opened when the current drops to zero is to keep the storage batteries from discharging back through the charging circuit,

which might cause one of several objectionable things to happen. The current, if discharged back into a dynamo or converter, would tend to run the machine as a motor, thus wasting the energy of the battery; the armature might be burned out by the excessive current discharged back through it from the batteries; if a series dynamo were used, the fields would be reversed, and when the dynamo was next started up, its polarity would be the reverse of what it had previously been. Furthermore, the cells would doubtless be injured by the high rate at which they had discharged back through the charging circuit. For, when the machine stopped running, the storage batteries would be short-circuited by the low resistance of the armature winding. A device that will open the circuit when the current drops to zero is, therefore, very desirable. Of course where there is an attendant constantly on hand watching the charging of the cells, it is not so necessary, perhaps. An underload or no-load device is frequently called an **automatic cut-out,** or simply a **cut-out.**

146. Cut-Outs for Battery Chargers.—Machines for charging storage batteries are often provided with some form of cut-out to automatically open the charging circuit should the machine stop running. These cut-outs are made in several forms. One, manufactured by the Crocker-Wheeler Electric Company, as applied to a rotary converter for charging storage batteries, is shown in Fig. 37.

In this figure, C is the commutator on the motor side of the machine, and C' that on the generator side. The front field pole piece A is hinged at its base, and when the generator is not supplied with current, it is held away from the armature by a spiral spring S. The top of the field core carries the switch contacts b and b', to which the leads a and a', forming a part of the storage-battery charging circuit, are connected. These springs are shown in the small detail view in Fig. 37, and are insulated from each other as long as the pole piece A is held away from the armature by the spring S. As soon as a current is supplied

to the motor side of the machine, the pole piece is drawn toward the armature by the magnetism of the field coils and armature. This connects the springs *b* and *b'* together through the stationary contact *c*, thus completing the charging circuit, which includes the generator winding on the machine and the storage battery. When, for any reason, the source of current fails, the magnetism in the field is reduced and the hinged pole piece is pushed back by the

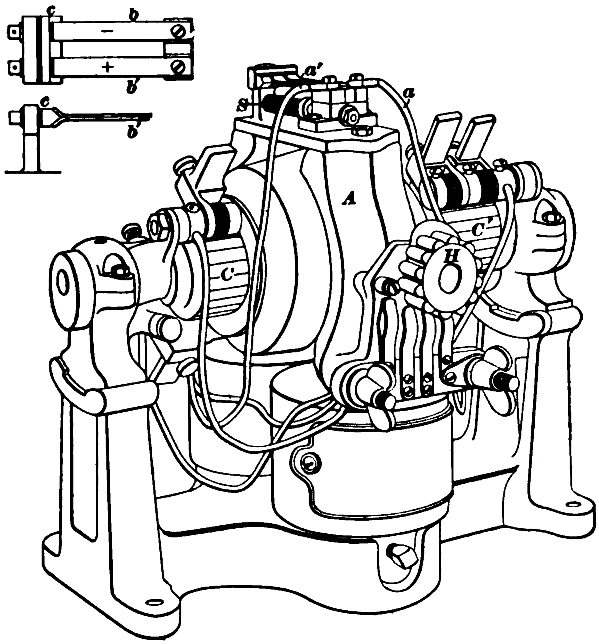


FIG. 87.

spring *S*, thus preventing a discharge of the storage battery through the motor. *H* is the handle of a rotary switch by means of which the machine is started. The contacts on the switch are so arranged that part of the field winding is thrown in series with the armature when the first contact is closed. Thus the field, or at least part of it, acts as a dead resistance to prevent too large a current from flowing

into the armature. As the handle is turned and the machine comes to its usual speed, the field coils are finally connected in their normal position directly across the supply mains.

147. Cutter Overload and Underload Device.— An underload and overload circuit-breaker, made by the Cutter Electrical and Manufacturing Company, is shown in Fig. 38. This device is double-pole, that is, it opens both sides of the circuit like a double-pole knife switch, *o*, *o* being the knife blades. There are two electromagnets *M* and *N*, both connected in series with the main circuit. *N*, which is nearly hidden from view, may be called the overload, and *M* the underload, magnet. The poles of *M* are bridged by the iron keeper *k*. As long as a current flows through the circuit, *k* is held against the pole pieces of the magnet *M*, but if the current drops to zero, *k* is released; this releases a trip and the switch is thrown open by a strong spring. *M* may also be designed to release *k* if the current falls below any given value.

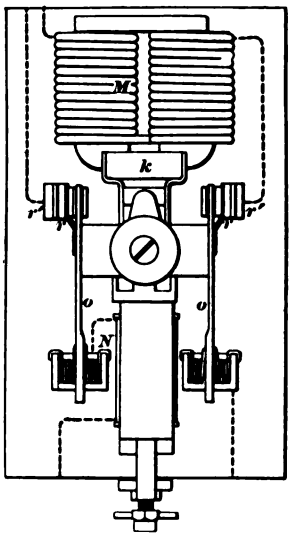


FIG. 38.

If, on the other hand, the current becomes excessive, the magnet *N* draws an iron plunger (not shown in the figure) toward it with sufficient force to release the trip, and the spring, as before, throws open the switch. The main contacts are protected against the ruinous effects of an arc at the breaking of an excessive current by causing the current to be finally broken between flat carbon sticks *r*, *r'*. These carbon sticks when worn out can be easily replaced by new ones.

148. In Fig. 39 is shown a converter connected across a 220-volt power or lighting circuit that furnishes current from the generator side *y*, at 10 volts, for charging storage

cells *S*, *S* arranged in sets, 4 cells in series in each set. In both the 220- and 10-volt circuits, there are overload and underload circuit-breakers of the form already described, each adjusted to open its own circuit in case the current exceeds or falls below predetermined safe values. If the rheostat *C* is used not only to start up the machine, but also to regulate the voltage on the *y* or generator side of the converter, it must have sufficient current-carrying capacity not to become overheated and burned out by the largest current it may be called on to carry for an indefinite length of time.

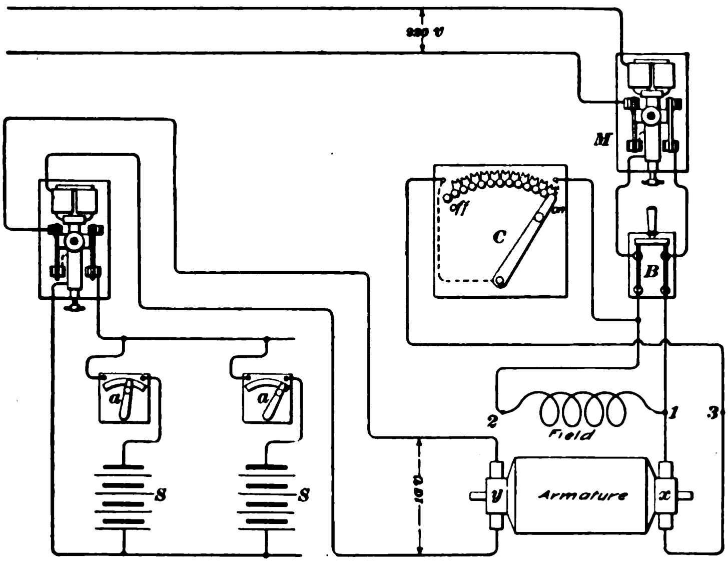


FIG. 39.

Whenever the machine is shut down, whether by the intentional opening of the switch *B* or by the opening of the automatic circuit-breaker *M* in the 220-volt supply mains, the arm of the rheostat *C* should be immediately turned to the off-position. Thus, the danger of injuring the machine, generally due to carelessness by closing the switch *B* and the circuit-breaker *M* before returning the rheostat arm to the off-position, is avoided. However, the overload device

of the circuit-breaker *M* would open the circuit again as soon as *B* is closed, if *C* is not returned to the off-position before attempting to start the machine.

It is desirable to have an adjustable resistance or rheostat *a* in circuit with each group of cells while charging, so that the strength of the charging current may be regulated in each group independently, which is advisable in case they were not all equally discharged.

149. Where motor-dynamos are used, the motor, if supplied with current from alternating-current mains, will be a synchronous motor or an induction motor. The synchronous motor is the reverse of the alternator described in Art. **132.** The field must be excited with direct current from the dynamo side of the motor-dynamo or from some other source. Such a motor, unless provided with some special arrangement for this purpose, will not start itself, but must first be brought up to normal speed in some manner before the current is turned on, and, furthermore, such a machine will stop if the load becomes sufficient to slow it down beyond a certain limit. Synchronous motors are not suitable for small machines, and are used only in the larger sizes, where experienced men are usually employed to look after them.

With induction motors, it is not necessary that their fields should be separately excited. They will start up of their own accord, and are very simple to operate. They are often started up very much like shunt motors, the starting resistance frequently being included in the revolving part of the machine, a handle being provided on the frame of the machine for cutting it out when the machine has come up to speed. So many varieties of satisfactory alternating-current motors are now on the market that no general description that will apply to all can be given. Any reliable manufacturing company, if the voltage, the kind of circuit (whether a single-, two-, or three-phase circuit), the normal load that the motor will have to carry, and the purpose for which the motor is to be used are sent to them by a prospective purchaser, will give

all the necessary directions for connecting and operating the machine of their make that is best adapted to the purpose.

150. Water Motors.—Where electric power is not available, water-power may be resorted to for driving a small dynamo where a sufficient water pressure can be obtained. Water motors of the type shown in Fig. 40 are obtainable for this purpose, and will operate satisfactorily in driving very small generators where a pressure of 40 pounds per square inch can be obtained in the city mains or elsewhere. In Fig. 40, *S* is the supply pipe leading to the motor and *O* the outlet pipe for carrying away the water after its use. This latter pipe should be perfectly straight for a distance of at least 20 feet from the motor. These motors operate by a jet of water flowing through a small nozzle and impinging against buckets on a wheel within the casing. The bore of the nozzle is usually about $\frac{1}{16}$ inch in diameter on the small sizes of machine, but if sufficient power is not obtained with this size, the nozzle may be drilled out to a larger size by an ordinary twist drill.

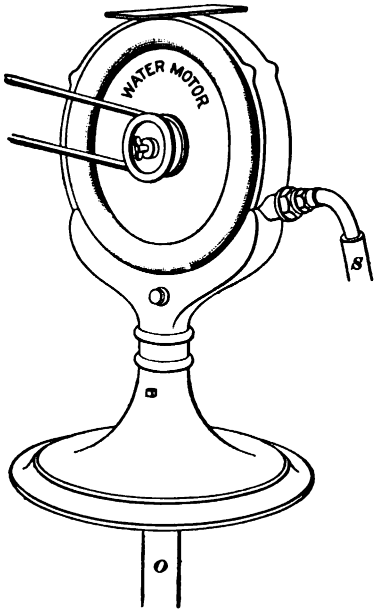


FIG. 40.

151. Another way of driving a small generator is to place it in a factory where there is machinery in constant operation. The generator may be belted directly to some shaft, and the current from it carried to the telegraph office by one or two copper wires. This method is sometimes convenient in places where there may be a shop of some kind near at hand, but no lighting or power plant. Storage

batteries would probably be necessary, however, for operating the telegraph lines during the night and on Sundays when the shop is shut down. These cells can be charged by the same dynamo while the shop is running.

DYNAMOS USED IN TELEGRAPHY.

152. Practically all dynamos, motor-dynamos, and converters now coming into use for ordinary telegraph work are simple shunt machines. However, the fields of several may be excited by one dynamo, instead of each one supplying current for its own field. Electromotive forces varying by irregular jumps from 7 to about 375 and even 400 volts are now in use. At least as many dynamos are needed as there are different electromotive forces required.

Good engineering practice can be best treated by descriptions, which will be given later, of prominent and successful plants installed by the large telegraph companies. The arrangement of apparatus and circuits on the telegraph-line side of converters and motor-dynamos will be exactly the same as for dynamos. Whatever is said concerning dynamo circuits will generally hold also for the telegraph-line side of motor-dynamos, converters, and storage batteries.

SOUNDERS OPERATED BY DYNAMOS.

153. There seems to be a tendency to increase the resistance of sounders that are to be operated by dynamos, or, at least, to increase the resistance of the sounder circuit. First, 4-ohm sounders and 1-volt dynamos were used; now 20-ohm sounders, each in series with a non-inductive resistance of 200 ohms connected across a 40-volt dynamo, and also 100-ohm sounders across a 7-volt machine are used. When an electric-light 110-volt circuit is used, 20-ohm sounders, each in series with a non-inductive resistance of 1,100 ohms, are employed.

154. Fig. 41 shows how all the sounders in one office may be supplied with current from one dynamo. In the New York office of the Postal Telegraph Company, a 40-volt machine is used for this purpose. In series with each sounder, which has a resistance of 20 ohms, is connected a resistance coil *a* of 200 ohms. This resistance coil *a* is made of German silver, and is wound non-inductively on a hollow spool. Thus, each sounder circuit has a resistance of 220 ohms. This resistance across 40 volts will give about 180 milliamperes for each sounder, so that if there were 100 sounders,

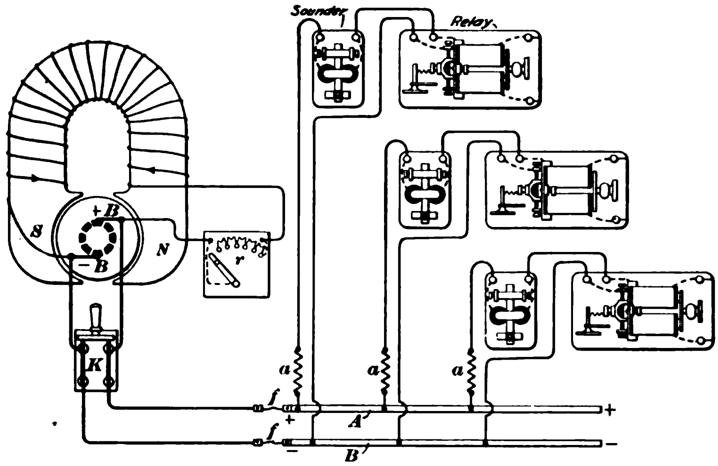


FIG. 41.

the maximum current the dynamo would ever be called on to furnish would be 18 amperes. Thus, to operate these 100 sounders would require a 720-watt or about a 1-horse-power machine. This arrangement is not very efficient, for only 64.8 out of the 720 watts are utilized in the sounders, the rest being consumed in heating the resistance coils *a*. However, this arrangement makes the sounders very quick-acting, for the time-constant $\frac{L}{R}$ is much smaller than would be the case if the total resistance, 220 ohms, were all in the sounder coils, and also much smaller than if the 20-ohm

sounders were connected directly to a dynamo having an electromotive force just high enough (3.6 volts) to send 180 milliamperes through them without any external resistance *a*. Furthermore, since the sounders are continually opening and closing the circuit, and so varying the total current output of the dynamo, there would be a larger percentage variation produced in the voltage at the bus-bars in the case of the lower voltage system, which would perhaps cause the sounders to work with less uniformity.

The dynamo is connected through the double-pole switch *K* and the fuses *f*, *f* to the bus-bars *A* and *B*. In each separate circuit across the bus-bars *A* and *B* there is connected a sounder, the contact points of the relay that controls the sounder, and the resistance *a*. The non-inductive resistance coils *a* are located as near to the bus-bars as is convenient, but each sounder and its relay are placed upon tables distributed throughout the room.

155. In their main office in New York, the Western Union Telegraph Company use 100-ohm sounders connected directly across a 7-volt dynamo. This is a more economical arrangement, for it has no dead resistance in which energy in the form of heat is wasted. This arrangement is the same as that shown in Fig. 41, except that there is no non-inductive resistance *a* in each sounder circuit. It is a good plan to put a fuse in each sounder circuit. While the sounders take .07 ampere, the voltage is only 7, so that the total energy consumed is very much less than in the preceding arrangement—about one-fourteenth as much. The repeating sounders of this company are wound to 20 ohms, and in series with each is inserted a non-inductive resistance of 20 ohms. Such an arrangement makes the sounder act more quickly, a very desirable feature for repeating sounders.

156. Sounders Supplied From Electric-Light Mains.—For several years, a number of the Western Union Telegraph Company's branch offices have been equipped with 20-ohm sounders in series with two 550-ohm incandescent

lamps, all connected across the 110-volt direct-current electric-light mains from the Edison central stations. This arrangement is shown in Fig. 42, in which *S*, *S*, etc. are the 20-ohm sounders, *R*, *R*, etc., the relays that control the sounders, and *l*, *l*, etc., the incandescent lamps, one in each end of each tap. The lamps not only act as visual telltale signals in case of a cross or short circuit anywhere in the sounder circuit, but also, since the total resistance of each sounder circuit is 1,120 ohms, keep the current down to about .1 ampere.

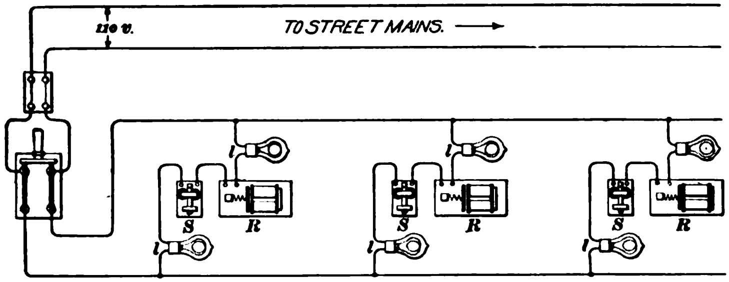


FIG. 42.

It will be instructive to figure out the cost of running one sounder for a day of 10 hours under this arrangement and to compare the result with the cost under a later and more economical arrangement. Assume that a sounder will be closed 60 per cent. of the time, for 10 hours per day, and that the current at 110 volts costs $1\frac{1}{2}$ cents per ampere per hour. This was the cost of current for lamps ($\frac{3}{4}$ cent per 16-candlepower lamp per hour on a 110-volt circuit) in Boston in 1899.

$$\frac{6}{10} \times \frac{110}{1,120} \times \frac{3}{2} \times 10 = .88,$$

or about $\frac{9}{10}$ cent per day of 10 hours.

The chief fault with the above arrangement was the breakage of filaments in the resistance lamps. The filaments burned out very easily when jarred or set into vibration.

157. The arrangement shown in Fig. 42 has been replaced by that shown in Fig. 43, which has proved so economical and satisfactory that it is being introduced in all the telegraph offices of this company in the Boston district wherever the direct 110-volt light service is available. In this arrangement, a 200-ohm sounder in series with a 4,000-ohm non-inductive resistance coil is connected across the 110-volt light circuit. *S*, *S*, *S* represent, in this case, 200-ohm sounders, *R*, *R*, *R* the relays that control the sounders, and *r*, *r*, *r* the 4,000-ohm resistance coils, which are made of No. 32 German silver wire. The current in this case will be $\frac{110}{4,200} = .026$ ampere. However, the number of ampere-turns is about the same in both cases. Making

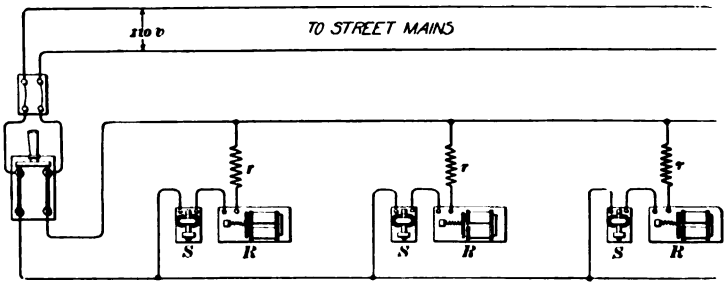


FIG. 43.

the same assumptions as in the preceding calculations, we get $\frac{6}{10} \times \frac{110}{4,200} \times \frac{3}{2} \times 10 = .23$ cent, or less than $\frac{1}{4}$ cent for the 10 hours. This is less than one-third what it cost for current under the preceding arrangement.

For 365 days, of 24 hours each, the current would cost only $2.01 per sounder, and if 10 per cent., the customary discount allowed for prompt cash payment on small electric-light bills, is deducted, the cost is reduced to $1.81. This is less than the cost of maintaining two gravity cells, with the additional saving in attendance, trouble, dirt, and especially space. This last item is very important in city branch offices, where space rents are high.

ARRANGEMENT OF DYNAMOS FOR MAIN-LINE CIRCUITS.

WESTERN UNION ARRANGEMENT.

158. In their main offices, the large telegraph companies use dynamos for working all their telegraph lines and instruments. In the large New York office of the Western Union Telegraph Company, no primary cells are now used. There are three similar sets of dynamos: one set supplies positive and another set negative currents to the main-line circuits; the third set is held in reserve to replace either the positive or negative sets, should either become disabled from any cause. There are five machines in each main-line set.

159. A dynamo used in telegraphy is spoken of as furnishing **positive** currents or as having **positive potential** when the positive brush of the dynamo is connected to the line and its negative brush to the earth; that is, when the direction of the current is from one pole or brush of the dynamo out over the line wires and back through the earth to the other grounded pole or brush of the dynamo. And currents may be spoken of as being positive when the direction of the current is from some point under consideration out over the line, returning through the earth to the starting point. When the current flows into the ground, through the ground to the distant office, and returns through the line, it is spoken of as a **negative** current and the dynamo as having **negative potential** or **polarity.**

160. Fig. 44 shows one of these sets of five main-line dynamos, No. *1*, No. *2*, No. *3*, No. *4*, and No. *5*, and also three other machines furnishing currents at 7, 23, and 45 volts, respectively. The use of the last three mentioned will be explained presently. Each main-line set consists of five 40-ampere dynamos, one, No. *5*, self-excited and the other four separately excited from the No. *5* self-excited machine. The armatures of the five dynamos in one set are

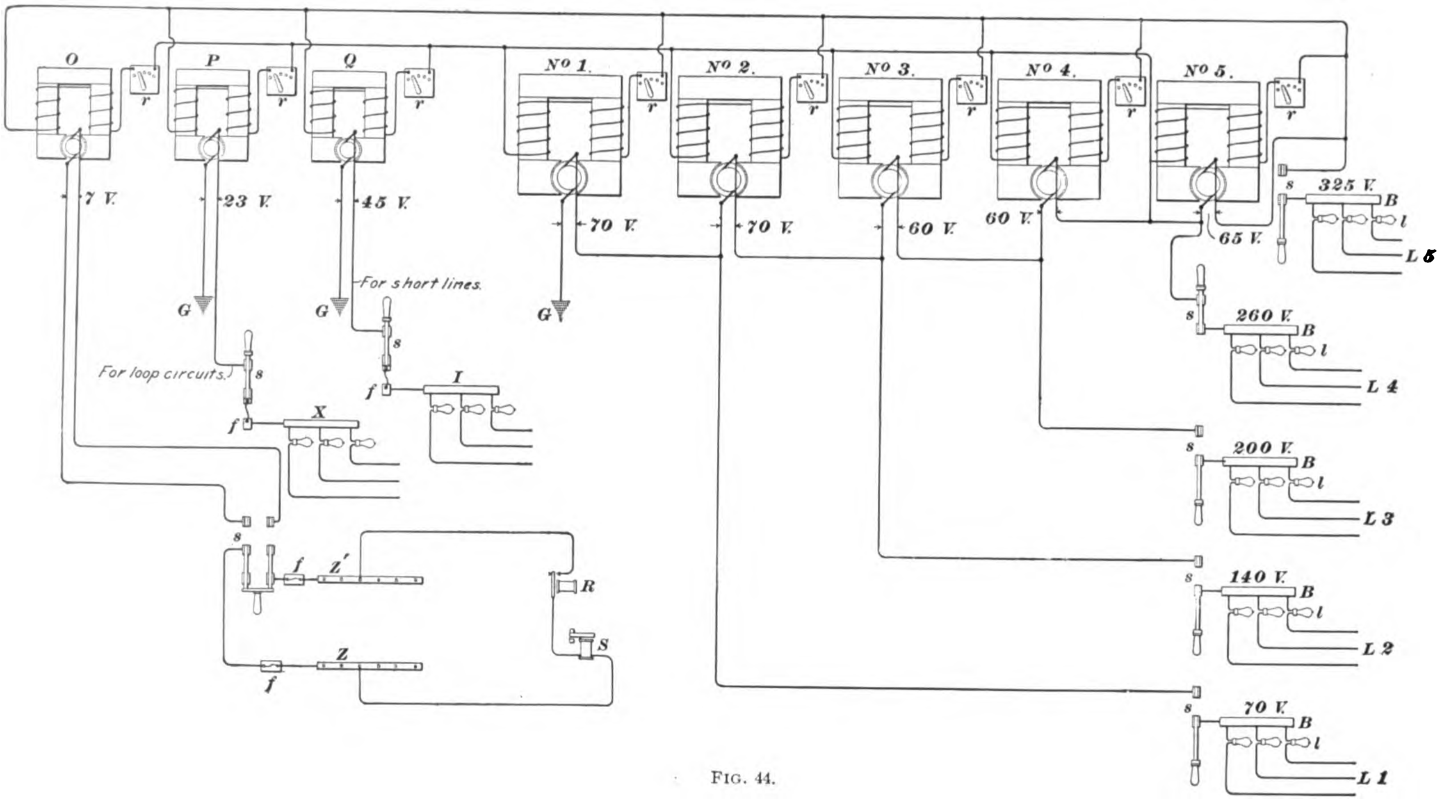

O
P
Q
No 1.
No 2.
No 3.
No 4.
No 5.
r
7 V.
23 V.
45 V.
70 V.
70 V.
60 V.
60 V.
65 V.
325 V.
260 V.
200 V.
140 V.
70 V.
B
l
L 5
L 4
L 3
L 2
L 1
G
For short lines.
For loop circuits.
s
f
I
X
Z'
Z
R
S

FIG. 44.

connected in series. The first and second dynamos in each set generate current at a potential of 70 volts, the third and fourth at 60 volts, and the fifth at 65 volts. Therefore, the difference of potential between the ground and the various leads will be 70, 140, 200, 260, and 325 volts, as indicated at the bus-bars *B*.

NOTE.—A bus-bar is usually a large copper wire or copper bar upon which is fastened or tapped a large number of wires. Thus, the currents from all the wires flow into this bus-bar, and from it to the dynamo, or *vice versa* if the currents flow in the opposite direction.

Between the dynamos and the bus-bars, which are located above and behind the main-line switchboards, are knife-blade switches, the latter being located in a convenient place behind the switchboards, which are in the operating room, so that in case of fire all current can be quickly cut off from the whole board and room. There is also a knife switch (not shown in this figure) in the ground wire leading to the main-line switchboards, to be opened in case of fire. From the main-line bus-bars, a large number of wires are led through non-inductive resistances *l* of from 2 to 2½ ohms per volt. That is, the non-inductive resistance at 2 ohms per volt in each line circuit connected to the 70-volt bus-bar is about 140 ohms; to the 140-volt bus-bar, about 280 ohms, and so on. The Western Union Telegraph Company use incandescent lamps especially made for them for this purpose.

For the sake of simplicity, a main-line switchboard has not been shown in this figure. *L 1*, *L 2*, *L 3*, *L 4*, and *L 5* represent groups of lines with a lamp in each line circuit. In the figure, there are only three lines in each group, but, as a matter of fact, there are hundreds of lines supplied through the 70-, 140-, and 200-volt bus-bars alone.

161. Dynamos Unequally Loaded.—It is evident that the current that goes out over the group of lines *L 1* comes only from dynamo No. *1*, but the current that passes through the group *L 2* passes through both No. *2* and No. *1* dynamos. Similarly, the current in group *L 3* passes

through No. *3*, No. *2*, and No. *1* dynamos, and so on. Thus, No. *5* furnishes less current than any of the others. For instance, if 20 milliamperes are being used in each line, and there are 200 lines in each group, then dynamo No. *5* would be supplying 4 amperes; No. *4*, 8; No. *3*, 12; No. *2*, 16; and No. *1*, 20. Thus, the dynamos are not equally loaded, that is, they are not doing the same amount of work. For a strictly economical arrangement under this assumption, dynamo No. *2* should be smaller than No. *1* in the proportion of about 16 to 20; No. *3* smaller than No. *1* in the proportion of about 12 to 20, and so on. No. *5*, being used only for multiplex sets, would especially be doing but little work in comparison with the others. Consequently, it is utilized to supply current not only for the *L 5* group of circuits, but for the fields of all these five machines and also for the fields of three other dynamos whose use will now be explained.

162. The dynamo *O* is a 300-ampere machine supplying current at 7 volts for local Morse and repeating sounders, transmitters, and pole changers. Two wires, one from each bus-bar *Z*, *Z'*, are run to each desk set having such instruments. One sounder *S* controlled by the relay *R* is shown connected across the bus-bars *Z*, *Z'*. The dynamo *P* has a capacity of 80 amperes at 23 volts, and is used for special local and branch-office circuits, called *loop circuits*. The third *Q* is a 40-ampere 45-volt dynamo for use on city and other short lines. There are two of each of these 7-, 23-, and 45-volt dynamos, but only one of each voltage is in use at one time, the others being held in reserve. One pole of each of the 23- and 45-volt dynamos is grounded. The other pole of the 23-volt machine is carried through a switch and fuse to a bus-bar *X* from which taps are taken to the loop switchboard, and to the various desk sets requiring this voltage. One pole of the 45-volt dynamo is carried to the city switchboard for use on short lines, such as city and local race-track circuits.

As already stated, the fields of the eight dynamos are all excited by current from the No. *5* dynamo. In each field

circuit, there is a rheostat r by means of which the voltage of each dynamo may be regulated independently of all the others.

163. Besides these machines, there are thirty or more small dynamos used as intermediate main-line batteries. They deliver currents at from 50 to 125 volts, each machine having a lamp permanently connected in series with it. This lamp is to prevent injury to the dynamo in case of a short circuit. As each machine feeds only one wire, they normally supply currents of only 30 or 40 milliamperes. They are simply small shunt machines, and since such machines have been considered, it is not necessary to illustrate or to describe them here.

164. In Fig. 45 are shown three complete sets of main-line dynamos and also two sets of 7-, 23-, and 45-volt machines. A is a double-pole, double-throw switch, connected in a special manner, as shown. The object of this switch is to reverse the leads from machine ± No. *5*, so that the whole spare set may be made to furnish currents at either positive or negative potentials. In order to do this, the switch A is arranged to reverse the current through the field coils of the first four machines and also to reverse the terminals of dynamo ± No. *5* with respect to the ± 325- and the ± 260-volt leads. Thus, when the switch A is closed in the upper position, the potentials of all five machines are positive, and when the switch is closed in the lower position, they are all negative. In this figure, the arrows show the direction of the current as a result of the switch A being closed in the upper position. By simply reversing the switch A, the ± leads may be made + or —.

The double-throw switches B and C have been added to this diagram to show how dynamo ± No. *5* in the spare set may be made to supply current for the fields of either O, P, Q or O', P', Q'. In this figure, the negative and spare sets and the dynamos O, P, and Q are represented as in use. The spare set is furnishing positive current and is

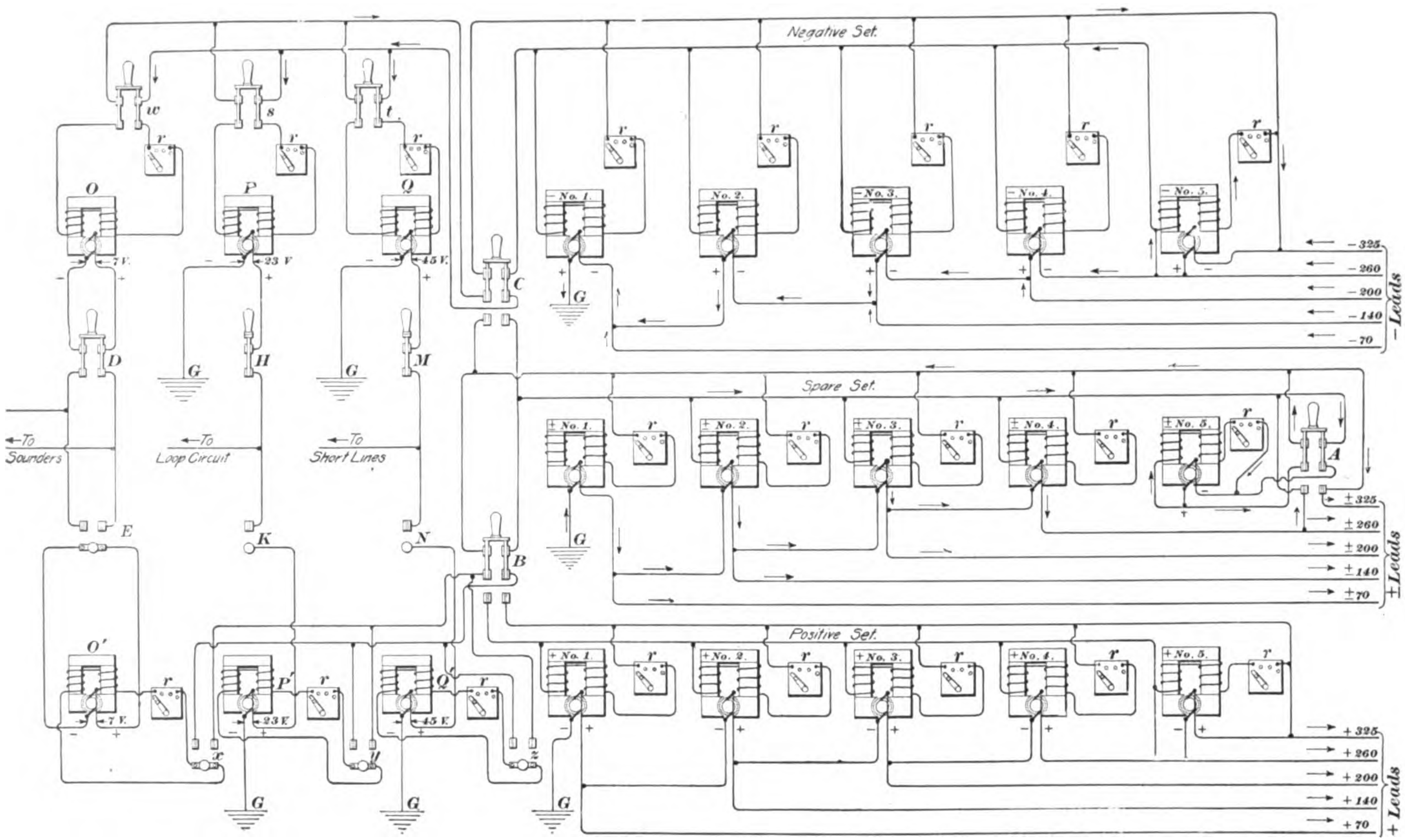

Negative Set.
Spare Set.
Positive Set.
– Leads
± Leads
+ Leads
–325
–260
–200
–140
–70
±325
±260
±200
±140
±70
+325
+260
+200
+140
+70
To Sounders
To Loop Circuit
To Short Lines
7 V.
23 V
45 V.

FIG. 45.

replacing the positive set while the latter is idle. The dynamo — No. *5* is supplying current for the fields of the negative set, and also for the fields of *O*, *P*, and *Q*. Suppose it were desirable to use the dynamos *O'*, *P'*, and *Q'* instead of the dynamos *O*, *P*, and *Q*. To do this, it is merely necessary to open the switch *C*, close the switch *B* in the upper position, as shown, and also close the switches *x*, *y*, and *z*, which are here shown open. The ± No. *5* dynamo then furnishes current in the proper direction for the fields of *O'*, *P'*, and *Q'*, and with *C* open, the fields of *O*, *P*, and *Q* are getting no current.

If the positive set is in use and the spare set idle, and it is desirable to use the dynamos *O'*, *P'*, and *Q'*, the switch *C* should be open on both sides and the switch *B* closed in the lower position. If the spare set were to be used in place of the regular negative set, and it were desirable to use the dynamos *O*, *P*, and *Q*, and not *O'*, *P*, and *Q'*, then the switch *A* would be closed in the lower position so that the spare set would be furnishing negative currents, the switch *C* would be closed in the lower position, and the switch *B* would be open. These two switches *B* and *C* are so connected that, no matter in which position they are closed, provided the switch *A* is closed on the proper side, the polarity of the 7-, 23-, and 45-volt machines is never reversed.

165. By means of the switches *w*, *s*, *t*, *x*, *y*, and *z* in the field circuits of the 7-, 23-, and 45-volt machines, it is possible to use any one or all of these machines at one time. For instance, if it were desirable to use *O*, *P'*, and *Q'*, and the regular positive and negative sets were in use, then the switch *B* would be closed in the lower position, the switch *C* closed in the upper position, the switches *w*, *y*, and *z* in the field circuits of *O*, *P'*, and *Q'* would be closed, the switches *s*, *t*, and *x* in the field circuits of *P*, *Q*, and *O'* would be open, the switches *D*, *K*, and *N* would be closed, and the switches *E*, *H*, and *M* would be open. The switches *D*, *E*, *H*, *K*, *M*, and *N* are so arranged that dynamos in one set can be connected with the leads to the operating room before the

are not connected to the main-line switchboard. Since these two higher potential dynamos are used only for duplex and quadruplex circuits, their bus-bars are connected

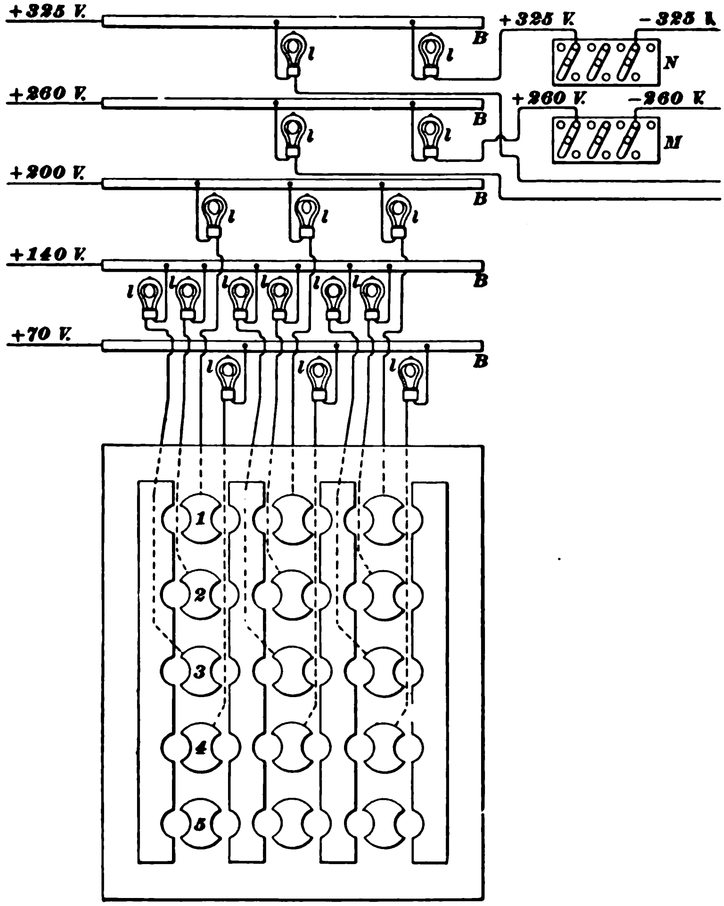


Fig. 47.

through lamps directly to the small switches *M* and *N* on the desks upon which are placed the duplex and quadruplex sets. To these desks it is necessary to bring both positive and negative currents of the same voltage.

SAFETY DEVICES.

168. When gravity cells are used for telegraph purposes, fuses or other safety devices, to prevent the flow of a dangerously large current from the battery itself, are rarely needed or used, because the internal resistance of the battery, especially where the cells are connected in series, as is generally the case, is sufficient to render the generation of such a large current impossible.

The maximum current from a single set of gravity cells connected in series, even if short-circuited, would not exceed $\frac{e}{b}$, that is, approximately $\frac{1}{3}$ ampere if the internal resistance b and the electromotive force e per cell are 3 ohms and 1 volt, respectively. This current would do no damage to the wiring or the cell, although if it continued to flow long enough, it might injure the insulating covering on the wire of the coils. But with dynamos, converters, and storage cells, an injuriously large current will flow if the external resistance approaches near enough to zero. So that, in the use of dynamos, converters, and storage cells, precautions must be taken that are unnecessary with gravity cells. In order to prevent injury to the machines or to storage batteries, provision should be made to limit the maximum current to a safe value, or to open the circuit if it exceeds this safe maximum value, for too large a current might burn out the dynamo armature or throw off the belt, and in the case of storage cells the plates might buckle or disintegrate.

169. Fuses and Circuit-Breakers.—In the main circuits leading from the machines or storage batteries are placed fuses or magnetic circuit-breakers that will open these main circuits should the current exceed a given maximum value. In the supply side of converters and storage batteries, a circuit-breaker is used that opens the circuit not only if the current exceeds a certain maximum value, but also if it falls to zero, as has been explained. One form of an automatic circuit-breaker has already been shown and described.

170. Non-Inductive Resistance.—To keep the current from exceeding a safe value in any one line, it is customary to insert a non-inductive resistance in every telegraph line between the dynamo and the telegraph instruments, so that the current in any line cannot exceed the quotient obtained by dividing the potential used on that line by this non-inductive resistance, even if a short circuit does occur in the line or apparatus beyond this so-called dead resistance. This dead resistance is placed behind or above the switchboard, and as near the generator mains as is convenient. Generally it contains from 2 to 2½ ohms per volt. This would limit the current from ⅖ to ½ ampere. Furthermore, with these coils in circuit, the injurious arcs that would otherwise occur at the telegraph keys, pole changers, and transmitters, in case of a short circuit, are avoided, or are, at least, much diminished in volume.

Non-inductive resistances are also used for various other purposes; for instance, to equalize the resistance in a number of wires fed by one dynamo, to equalize the resistance of loop circuits, and to produce a fall of potential by the introduction in a circuit of a resistance, etc. These will be explained as they come up in connection with various systems.

171. The Western Union Telegraph Company formerly used German silver wire, wound non-inductively, for their resistance coils, but they have replaced the coils by incandescent lamps having the proper resistance. They claim that the German silver wire caused considerable trouble by breaking so often and that the lamps have given better satisfaction. Incandescent lamps form an almost perfect non-inductive resistance. The Postal Telegraph Company do not seem to have had this trouble, for they still use German silver wire. The wire is wound non-inductively on hollow tin spools set upright so that the air can circulate around them, in order to keep them from becoming too hot. A coil is wound non-inductively by doubling

the wire at the middle of the length to be wound on the coil, and then winding the two strands of the wire on the spool together, keeping them as close together as possible. Thus, the current in passing through the coil always circulates through two adjacent wires in opposite directions, the inductive effect of one neutralizing that of the other. All resistance coils and rheostats used in telegraphy are wound non-inductively in this manner, unless something to the contrary is stated. Where an inductance is desirable, as in the case of coils used in simultaneous telegraphy and telephony, they are usually called **impedance,** or **retardation,** or **choke,** coils.

172. If it can be avoided, more than one line should never be connected through the same disk and lamp to the source of current where dynamos are used. Especially is this to be observed in connecting up a long, or high-resistance, circuit and a short, or low-resistance, circuit, and also in the case where both circuits are low in resistance. It is bad enough to supply two high-resistance circuits through the same disk and lamp. If a high- and low-resistance circuit are joined through the same disk and lamp to the dynamo, then, every time the key on the low-resistance circuit is opened or closed, there is very apt to be sufficient variation in the current in the high-resistance circuit to cause trouble. Where both circuits are low in resistance, the operation of either key may affect the strength of current flowing in the other circuit.

173. Suppose, for the sake of illustration, that two circuits, the resistances of which are 4,000 and 1,500 ohms, respectively, are connected through the same lamp to the 140-volt dynamo. These values are extreme, and in practice should never be so connected. The resistance of the lamp in this 140-volt circuit would be about 300 ohms.

When only the 4,000-ohm circuit is closed, the current will evidently be $\frac{140}{4{,}000 + 300} = .0325$ ampere. Now, when both lines are closed, the combined resistance of both circuits

will be $\frac{4,000 \times 1,500}{4,000 + 1,500} + 300 = 1,391$ ohms, and the total current will be $\frac{140}{1,391} = .1006$ ampere. This current will divide through the 4,000- and 1,500-ohm lines inversely as their resistances. Then, if $x =$ current in the 4,000-ohm line, and $y =$ current in the 1,500-ohm line, we have $\frac{y}{x} = \frac{4,000}{1,500}$. Now adding 1 to both sides of this equation, we get $\frac{x+y}{x} = \frac{4,000 + 1,500}{1,500}$. But, $x + y$ is the total current, that is, .1006 ampere; hence, $\frac{.1006}{x} = \frac{5,500}{1,500}$. Solving this, we get $x = .0274$ ampere. Therefore, .0274 ampere will flow in the 4,000-ohm line. Hence, the current in the 4,000-ohm line decreased from .0325 to .0274; that is, the current in the high-resistance line decreased over 15 per cent. when the key on the other line was closed.

174. Suppose both lines were 2,000 ohms in resistance. The current through one when the other is open will be $\frac{140}{2,300} = .0609$. When both are closed, the current in each will be $\frac{1}{2}\left(\frac{140}{1,000 + 300}\right) = .0538$. In this case, the current in the first circuit decreased about 10 per cent. when the second key was closed. Even with two lines, each of 3,000 ohms, the current will vary about 8 per cent. These variations are due to the one lamp that is in series with both lines. For if, instead of one lamp common to both lines, a separate lamp is put between each line and the dynamo, there will be no such fluctuation in the current due to the operation of the key in either circuit.

POSTAL TELEGRAPH COMPANY'S ARRANGEMENT.

175. When installed in 1894, the main-line switchboard of the Postal Telegraph Company in New York City consisted of six sections of 50-wire, double-spring jack-boards

and two spare sections not then required. There were also two sections of four rows of spring jacks constituting a loop, or *leg board*, as it is called. At one side of this board is an equalizing board, by means of which the resistance of all loop circuits can be readily equalized, which is one of the requirements of a dynamo system. All legs, or loop circuits, are generally brought up to a resistance of 150 ohms.

On the main-line switchboard, the bottom row of disks is grounded. The next ten rows above supply the currents varying from 40 to 200 volts, two rows of disks being assigned to each pressure. The upper row of disks for each pressure is drilled only on the right side, the lower only on the left side, as shown in Fig. 48, instead of drilling all disks on both sides as usual. Each disk is connected to a non-inductive coil of German silver wire, located overhead in the rear of the board, the other terminal of the coil being connected to the dynamo bus-bars in the same manner as the lamps shown in Fig. 47. Thus, the possibility, as on the usual type of switchboard, of inserting two plugs in contact with one and the same disk, and therefore of supplying two lines through one coil, is entirely avoided. The coils are all wound on tin cylinders or tubes mounted on heavy slate boards supported by iron frames, so that the construction is as fireproof as it can be made.

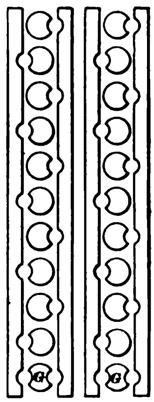


FIG. 48.

176. In all the large offices of the Postal Telegraph Company, the generator plants are of about the following voltages: 40, 85, 130, 200, and 375 volts. In their New York office, there are four machines supplying positive currents at 85, 130, 200, and 375 volts, and four supplying negative currents at the same voltages. There is one 40-volt machine, also, for supplying sounders and other local instruments and branch-office circuits. Five machines are held in reserve to relieve, if necessary, any of the foregoing.

In the larger cities, there are usually spare sets, but in most places a few spare armatures should be sufficient, for the armature is the only part of the machine that is apt to fail. Nowadays, machines are so well built and protected by cut-out devices that an injury to a machine is a rare occurrence.

177. Only two machines are shown in Fig. 49, but the others are connected up in exactly the same manner. One pole of each machine is grounded; the other pole is connected through a switch *s* and fuse *f* to its own particular bus-bar. All line wires are connected through non-inductive resistance coils *l* to the bus-bars. Each line in the group L_1 is supplied with positive current from the 85-volt machine, and each wire in the group L_2 with positive current from the 130-volt machine. It should be noticed that

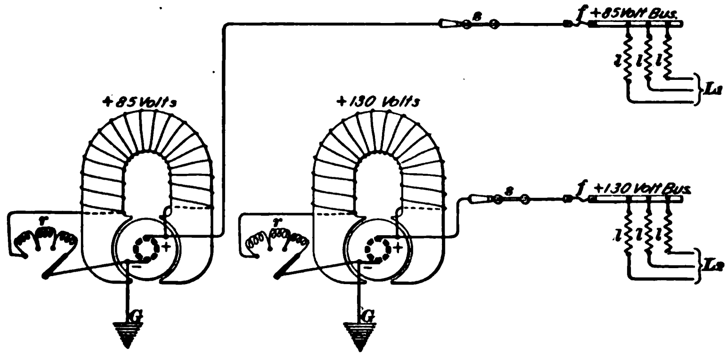


FIG. 49.

the machines shown are entirely independent of each other; an accident to one machine does not affect any other. The machines are converters, but, for the sake of simplicity, the two machines in Fig. 49 are represented as self-excited dynamos. These converters are all run by current from one constant-potential 125-volt dynamo, which is also utilized for lighting the building. In addition to the above, there are six or more machines employed as intermediate batteries and for testing purposes.

In the dynamo room, there are specially designed knife

switches for the rapid exchange of one machine for another on the leads going to the bus-bars above or behind the main-line switchboards in the operating department. The conditions in each city may differ, and no two offices, either Postal Telegraph or Western Union, are necessarily equipped in exactly the same manner.

STORAGE BATTERIES.

178. When gravity cells are used, it is frequently necessary to connect them in parallel as well as in series, because the internal resistance is generally an appreciable quantity compared with the external resistance. But when **storage cells** are used, the internal resistance is always relatively very small compared with the external resistance of the circuit, and the number of cells in parallel (or the number and area of the plates in a cell) is determined by the amount of current that can be taken steadily from a cell without injury to it, and not from any consideration of its internal resistance. The normal discharge rate of a lead storage cell is about .033 ampere per square inch of surface of the positive plates. The total area of the positive-plate surface is the area of both sides of one plate multiplied by the number of positive plates in one cell.

If C is the average current to be taken from the cell, then the area of the positive plate or plates must not be less than

$$A = \frac{C}{2 \times .033} \text{ square inches.} \qquad \textbf{(12.)}$$

There may be one plate this size or any number of plates whose combined area will give the same figure. When a large current output is necessary, it is not customary to use a number of separate storage cells in parallel, as with gravity cells, but rather to employ large plates, or a large number of plates, or both; that is, a large number of plates of large size in one vessel.

The number of cells necessary for any circuit will depend

on the electromotive force required to work the circuit, and the size of the cell on the ampere-hour capacity required or on the rate at which the cell is to be charged or discharged.

179. If the average current to be used in the external circuit is C amperes, and the total resistance of the line and all relays or other instruments connected in series with the line is R ohms, then the number of cells s to be connected in series will be given by the formula

$$s = \frac{C \times R}{1.9}. \qquad \textbf{(13.)}$$

1.9 is the average voltage per cell.

If C amperes will be the average current, and the cells are to be used at this rate for T hours before recharging each time, then the capacity of the battery must be $C\,T$ ampere-hours. The output capacity of different makes and types of cells will vary, but 4.5 ampere-hours per pound of plate (both positive and negative included) may be taken as a fair average figure for lead accumulators. Hence, the weight of the plates per cell will be

$$W = \frac{C\,T}{4.5} \text{ pounds}. \qquad \textbf{(14.)}$$

This must then be checked up to see that the normal discharge rate does not exceed $\frac{C}{2 \times .033}$ ampere per square inch of positive plate (formula **12**). The manufacturer of any good cell will, on request, when furnished with the normal discharge rate in amperes and the length of time occupied in discharging, designate the proper sized cell of his own make that ought to be used.

180. Current Capacity Required.—In estimating the current capacity required of storage cells, and also of dynamos for an office, allow 50 milliamperes for each main line using 150-ohm relays, 100 for each quadruplex set, and add to this total a fair allowance for wet weather and other emergencies. For 4-ohm pole changers and transmitters used in duplex and quadruplex sets, and for 4-ohm sounders,

allow 250 milliamperes. Occasionally, in noisy places like a stock exchange, it is advisable to use ½ ampere for each 4-ohm sounder.

181. Advantages of Storage Batteries. — Although storage cells are not so economical as dynamos or converters, still, in many cases, they may be preferable and even necessary if primary cells are to be done away with. This is the case when it is not feasible or desirable to run the dynamos both day and night to supply current that is necessary at night as well as during the day Often, also, it is practical to charge storage cells at a branch office from the dynamo plant at a main office, thus requiring neither primary cells nor dynamos at the branch office. Furthermore, it is often advantageous and convenient to charge storage batteries from an electric-light or power circuit. Primary cells can be replaced by less than one-twentieth as many storage cells, and thus much room may be saved.

182. Life of a Storage Cell.—If a pasted lead cell is not discharged at an excessive rate, nor to a lower electromotive force than 1.9 volts, the positive plates should last for about 1,200 or more discharges; while, if discharged each time to below 1.8 volts, or at an excessive rate, the life of the positive plate will not ordinarily be more than 400 or 500 discharges. The negative plates, with good care, will usually outlast four or five positive plates. For telegraph work, the positive plates generally last at least two or three years.

There are several kinds of treatment that will injure the cells. Among these is the habit, which should *never be allowed*, of connecting the terminals through a small resistance, or short wire, to see if the battery is in working order, or how much of a spark it will give. A current of great magnitude will flow for a moment and it will be likely to loosen the paste and cause sulphating in the cell. Either a voltmeter or an incandescent lamp of known voltage should be used to determine the condition of the battery, as will be explained shortly.

INSTALLATION AND CARE OF BATTERIES.

183. Setting Up. — After unpacking the plates of a storage battery, they should be carefully dusted off, and all particles of packing material removed. The elements should then be placed in the jars, care being taken that the positive and negative plates do not touch each other. Insulating blocks of one form or another are always provided with cells for this purpose. The cells should then be connected with the circuits in the manner in which they are to be used, before the solution is added. In connecting them up, the lead strips forming the terminals of the positive and negative elements should be brightened at the surfaces that are to be in contact. The cells should be connected in series or in multiple, according to the use to which they are to be put, and, in doing this, great care should be taken that no cell is connected up the wrong way. The positive terminals on most makes of cells are marked, but they may be distinguished by the fact that there is always one less positive than negative plate in each cell. Moreover, the positive plates are usually of a reddish-brown color, while the negative plates are of a light drab. For each group of cells forming a battery, a double-pole double-throw knife switch should be provided. The terminals of this switch connecting with the switch levers should be connected with the terminals of the battery. The upper pair of terminals of the switch should be connected with the wires leading to the source of charging current, while the lower pair of terminals should be connected to the wires through which the storage battery is to discharge.

184. Connections.—Storage batteries for telegraph work are often arranged in duplicate, in order that one battery may be charging while the other is discharging. A simple arrangement of switches, whereby either battery may be switched on to either the charging or discharging circuit, is shown in Fig. 50, in which *B* and *B'* represent two storage batteries, each consisting of seven cells in series. *S* and *S'* are double-pole double-throw knife switches, the

levers of which are connected respectively with the plus and minus poles of the batteries. The upper pairs of contacts on each switch are connected with the positive and negative mains of the charging circuit, while the lower pairs are connected in a similar manner with the two sides of the discharging circuit. Both sides of the charging and

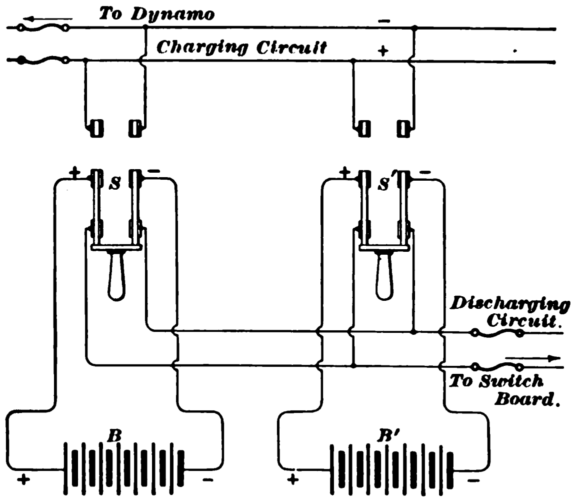


FIG. 50.

discharging circuits should be fused for a current slightly in excess of the maximum charge or discharge rate of the battery, and of course the wires in each of these circuits should be made of ample capacity for carrying these currents without undue heating.

185. Determination of Polarity.—The point of most vital importance in connecting up storage batteries is that the positive lead of the charging circuit shall be connected with the positive pole of the storage battery during charging. There are several easy ways of determining the polarity of a line, but perhaps the one that is least liable to produce error is performed by dipping the wires leading from each side of the charging circuit into a tumbler nearly filled with slightly acidulated water, as shown in Fig. 51.

A little of the solution from the storage battery will answer this purpose well, or if this is not at hand, a tumbler of clear water with a pinch of salt thrown in will serve equally well. If the wires are held about an inch apart in the water, bubbles will rise from each, but at a much greater rate from one than from the other. The wire from which the bubbles rise in greatest profusion is connected with the

FIG. 51.

negative side of the charging circuit, and that side should then be connected with the negative terminal of the battery. This method is dangerous with high potentials, and even with 110 volts should be used cautiously, unless there is considerable resistance already in the circuit besides that due to the solution.

186. Another method of determining the direction of the flow of current is by the use of a pocket compass held

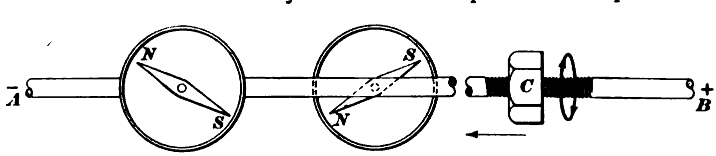


FIG. 52.

just over or just under the wire through which the current is flowing, as shown in Fig. 52. In this figure, *A B* is supposed to be a conductor carrying current. It should be

remembered that around this conductor will be a magnetic whirl consisting of lines of force in the form of closed curves. In order to clearly establish the relation between the direction of the lines of force and the direction of the current, a portion of the conductor is shown screw-threaded and engaged by a nut *C*. If the nut is turned in the direction shown by the arrows, it will move longitudinally along the conductor from right to left, and if turned in an opposite direction, its movement along the conductor will be from left to right. If the nut is considered to be turned in the same direction as the magnetic whirl, then its longitudinal direction will be the same as that of the current flowing in the conductor. The compass needle placed above or below the conductor, as shown, will be deflected in one direction or the other, and its north pole will be deflected in the direction in which the lines of force are rotating. By means of the compass, therefore, one can determine the direction of the magnetic whirl, and by the analogy of the right-handed screw thread and nut, one can readily determine the direction of flow of current. After the direction of the flow has been determined, it should be remembered that the pole from which it is flowing is positive, and this pole should therefore be connected with the positive pole of the storage battery.

187. Solution for Storage Cells.—The solution for all commercial forms of storage cells consists of sulphuric acid and water, but the proportions recommended by different manufacturers vary to a slight extent. The best way to obtain the proper proportion between the acid and water is by means of a hydrometer, which usually consists of a small glass tube enlarged at one end and weighted with .fine shot in the enlargement. One of these, commonly used for storage-battery work, is shown in Fig. 53. The tube when placed in solution will float in a vertical position, and the more acid contained in the solution, the

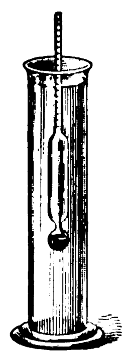


FIG. 53.

higher it will float. By means of graduations on the small portion of the tube, the density can be determined with great accuracy.

188. Hydrometers.—There are two different methods of graduating hydrometers, the details of which need not be considered here. On one of these, known as the **Nicholson** or ordinary hydrometer scale, the density of water is taken as 1, or sometimes for convenience 1,000, while the density of sulphuric acid is 1.8, or sometimes 1,800. With this hydrometer, the proper density for the solution of most storage cells is 1.2 or 1,200, according to whether water is considered to have a density of 1 or 1,000. The other scale, known as the **Baumé,** is graduated according to an entirely different system, in which the density of water is 1° and the density of sulphuric acid 65°. The proper density of the acid for the storage-battery solution when determined by means of the Baumé hydrometer scale is 25°.

189. Mixing Solution.—A large earthenware vessel should be used for mixing the solution, as a considerable amount of heat is always generated when the water and acid are poured together, which is usually sufficient to break a glass vessel. The acid should be poured slowly into the water, and never, under any circumstances, should the water be poured into the acid, as the sudden heat generated is likely to cause the solution to be thrown violently in all directions. Too great emphasis cannot be laid on the care that should be used in handling the concentrated sulphuric acid, as any carelessness in this respect may result in serious injury to the persons performing the work. It is well to have a bottle of strong ammonia close at hand in order to counteract any effects of the acid that happens to be spilled on the skin or on other objects that it would injure. After the solution has been mixed, it should be allowed to cool, and should then be poured by means of a glass funnel into the battery jars to such a height as to entirely cover both the positive and negative plates. Immediately after this is done, the charging current should be

turned on, and should be of such strength as the directions accompanying the cell indicate. As the charging proceeds, the positive plate will assume a dark chocolate color, while the negative plates will retain their original lead color. Where only a few cells are required, and no special room is set apart for them, the surface of the acid solution is often covered with a paraffin oil known as No. 28. This prevents the evaporation of the solution and the sputtering of the acid over surrounding objects.

190. Determination of Condition of Cells.—There are several means of determining when a cell is fully charged: One is by the density of the solution, which should be about 1,200 on the ordinary hydrometer, or 25° on the Baumé hydrometer, or in other words, about the same as that in the original charging solution. A better way of determining when a cell is fully charged is by means of a low-reading voltmeter placed directly across the terminals of each separate cell while the normal charging current is flowing. Under these circumstances, the voltmeter should indicate a pressure of 2.4 volts, and after the charging current has been turned off, the voltmeter should show a pressure of from 2 to 2.1 volts across the terminals of each cell. Discharging should not be continued after the density is lower than 1,150 or after the cells fail to show a terminal pressure of 1.8 volts each. When a storage cell has the acid covered with paraffin oil, there may be at any time a thin white froth on top of the oil, but when this froth develops rapidly to a depth of ¼ inch, the cell is charged sufficiently.

Care should be taken to keep the plates entirely immersed in acid, although it is not necessary to have the acid more than half an inch above the top of the plates. A storage cell will not give its maximum capacity until it has been subjected to from 10 to 15 discharges, but will have at first about three-fourths of its maximum. Cells should not be allowed to remain idle after 75 per cent. of their capacity has been taken out of them. When cells are to remain idle for a period longer than 2 months, charge them up

thoroughly, and then discharge for about two hours at normal rates. Remove the acid from the cells and rinse them out thoroughly with clean water. When next required for use, replace the acid and charge at normal rates for not less than 18 hours.

191. Charging.—The best way to charge storage batteries is from a motor generator or a converter adapted to give the proper amount of current at the proper voltage. By this means there is very little waste of energy, as all the current sent out by the motor generator or converter is used in charging the cells. The voltage across the mains of the charging circuit must be greater than the product obtained by multiplying the number of cells in series by 2.4, which is the maximum voltage with which a cell opposes the charging current.

Frequently storage cells are charged directly from lighting mains, and the most usual plan is to place a rheostat in series with the cells, by which the proper amount of current will be allowed to pass through them. It would not do, of course, to connect, for instance, a storage battery of 7 cells in series directly across the mains of a 110-volt circuit, for then the amount of current passing through them would be excessive. Such a connection would in fact amount practically to a short circuit, as the resistance of such a battery is almost negligible and its opposing electromotive force only about 15 volts. A very convenient rheostat is made of incandescent lamps, and a bank of such lamps may be constructed so as to allow the current to be graduated as desired. Such a lamp bank, constructed for a battery whose maximum charging rate is 5 amperes, is shown in Fig. 54. In this case, the charging current is taken from 110-volt mains and led through the lamp bank and storage battery in series. The lamp sockets are connected in multiple between the terminals of the bank, so that any number of the lamps that are of the ordinary 110-volt 16-candlepower style may be connected in multiple in the circuit. As each of these lamps carries,

approximately, ½ ampere at 110 volts, ten of them will give the desired maximum charging current, and therefore that number should ordinarily be used in charging. If, however, it is desirable to charge at a slower rate, the current may be graduated accordingly by turning on only one or

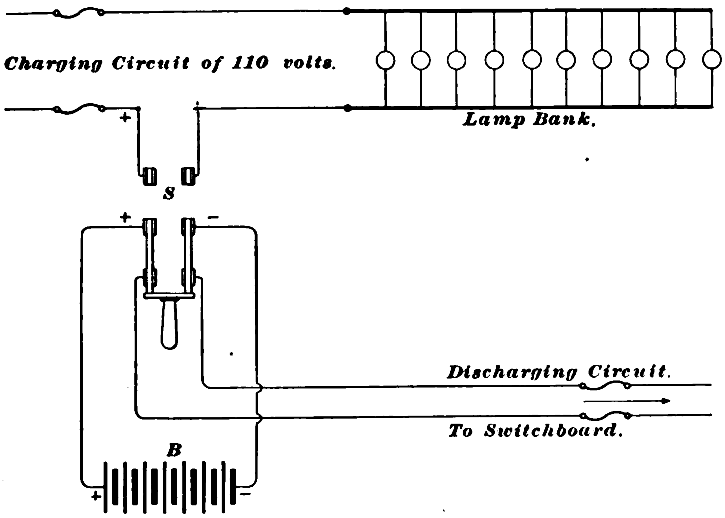


Fig. 54.

more of the lamps. This form of rheostat is very convenient, for it enables the amount of current to be gauged with considerable accuracy.

This method of charging wastes a large amount of energy in the lamps, and as these lamps will burn, when connected as described, at almost their full candlepower, it will be seen that this amount of energy so lost may be an important item.

STORAGE BATTERIES FOR LOCAL CIRCUITS.

192. Sounders Operated From Storage Battery. A method for supplying sounders with current from a storage cell that is charged from a direct-current electric-light circuit is shown in Fig. 55. *S*, *S* are 4-ohm sounders connected in multiple across a 2-volt storage cell *B*; *R*, *R* are the relays

that control the sounders; *f*, *f* are fuses, one in each sounder circuit. In the charging circuit are the main fuses *f'*, *f'*, a double-pole knife switch *K*, and the lamp bank. By means of the switch *K*, the charging current may be kept flowing through the battery as long as is necessary to keep the cell sufficiently charged. The cell can be charging while the sounders are in use or at any other time.

Sometimes, in small towns, the current is shut off from the electric-light circuit early in the morning, and perhaps at other times, and whenever this happens the storage battery must be disconnected from the mains by opening the

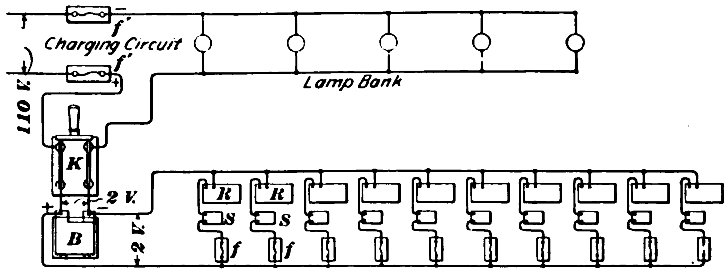


FIG. 55.

switch *K*. In such localities, the switch *K* must not be left closed during the night in order to charge the battery, unless there is in the charging circuit an automatic device that will open the circuit in case the charging current drops to zero. This is necessary in order to prevent the battery from completely discharging itself through the charging circuit, as it might do if there were no such automatic device to open the circuit. In almost any case, it would be better to have the overload and underload circuit-breaker described in Art. **147,** instead of the fuses *f'*, *f'* and double-pole switch *K*.

In the arrangement shown, there are ten 4-ohm sounders, requiring a maximum current of 10 × .25 = 2.5 amperes. A cell whose maximum safe discharge rate is 2½ amperes will be needed. The cell may also be charged at this rate, and in order to do this, five 16-candlepower 110-volt lamps, in

multiple with one another, should be connected in the charging circuit in series with the storage cell, as shown. Each lamp will allow about ½ ampere to flow through it, the five giving, therefore, the desired 2½ amperes.

193. Storage Cell at Branch Office Charged From Main Office.—Where a number of lines run from a main office to one branch office near by, it is sometimes practical to charge a storage cell used at the branch office for operating the sounders by the current coming through the line wires from the main office. This can be done provided there is enough current in all of them to furnish about 20 per cent. more ampere-hours than is required by the branch-office sounders. An arrangement due to Mr. Athearn for charging a storage cell in this manner is shown in Fig. 56. *P R* are polarized relays, and *P C* are pole changers used in duplex and quadruplex systems. In series with the contact points of each polarized relay there are two sounders, one at the main office and one at the branch office. The sounder at the main office enables the attendant there to tell whether that circuit is working all right. The receiving operator at the branch office receives the messages on this receiving side, or **leg,** of the loop, as it is called, by means of the sounder *S*. A sending operator at the branch office controls the pole changer *P C* at the main office by means of the key *K*. This circuit is called the **sending leg** of the loop circuit. These receiving and sending legs are the same as the two circuits marked *receiving side* and *sending side* in Fig. 66, *Telegraphy*, Part 1.

In this last mentioned figure, the small switch at the right connects, as indicated, one wire to the pole changer, the other to the main-office local sounder and the contact points of a polarized relay. This will be understood better when the duplex system has been explained. In Fig. 56, all switches have been omitted, for the sake of clearness. Besides such circuits, there may be lines between the main and branch offices containing simply keys *k*, *k* and sounders *M*, *M* for business merely between the main and branch offices. If

the instruments in each one of these branch-office lines required ¼ ampere, the total current flowing from the main office into the branch office would be, in this case, $5 \times \frac{1}{4} = 1\frac{1}{4}$ amperes. Now a storage cell may be inserted in this circuit, as shown in the figure, so that this current has to flow

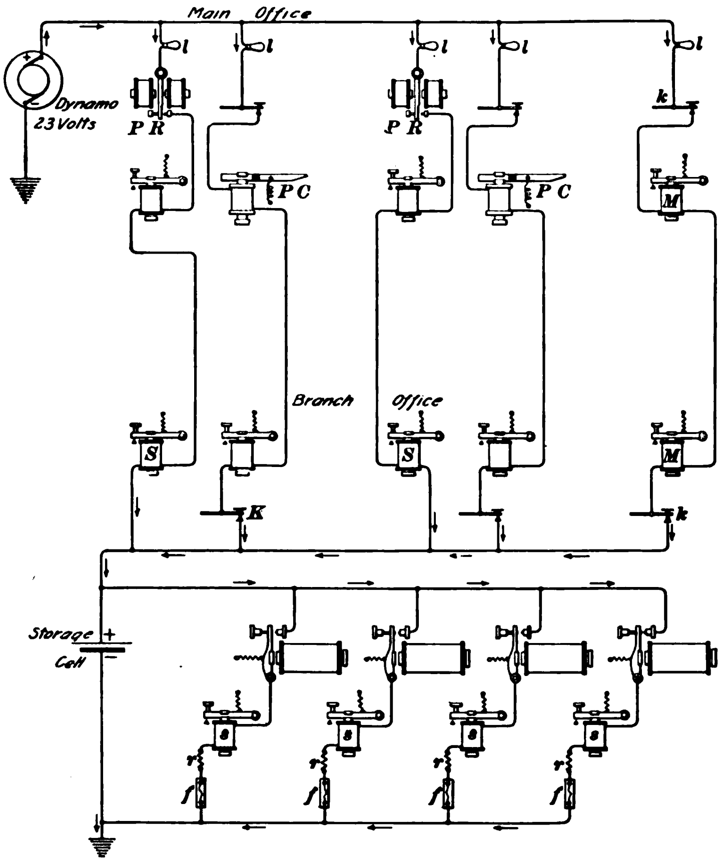


FIG. 56.

through it or the local sounders *s*, *s*, *s*, and *s* before it can reach the ground through which it returns to the main office. The part of the current that flows through the storage cell will tend to keep it charged. Thus, the storage cell is being charged more or less all the time that current is coming from

the main office in excess of that being used by the local sounders *s*, *s*, etc. When the sounders are using more current than is coming from the main office, then the cell must supply this excess current.

194. In order that the current from the main office can charge the cell, it must be connected so that its electromotive force—2 volts—will oppose the 23 volts generated by the main-office dynamo. This would be equivalent to reducing the main-office voltage from 23 to 21 volts. To counteract this, the main-office voltage could be raised to 25 volts, giving an effective electromotive force of 23 volts in the circuits shown in Fig. 56. However, the same object is accomplished in a more convenient manner by reducing the resistance of each lamp in these particular loop circuits just enough so that the ordinary 23-volt dynamo, which supplies other circuits besides these, will still be able to send $\frac{1}{4}$ ampere through each of these branch-office circuits.

195. All the local sounders *s* in the branch office are connected, as shown in the figure, across two leads running to the terminals of the storage cell. Since the electromotive force of a single storage cell is about 2 volts, it will be necessary, if 4-ohm sounders are used, to insert a non-inductive resistance *r* of about 4 ohms in series with each sounder, in order to limit the current in each local sounder to $\frac{1}{4}$ ampere. It is best to put a fuse *f* in each circuit, but one in each lead to the storage cell may be sufficient.

Ordinarily, the number of circuits through which the charging current flows and the number of local branch-office sounders supplied from the cell should be so proportioned that the charging in ampere-hours shall exceed the discharging capacity in ampere-hours by about 20 per cent., provided the rate of discharge is not excessive. In some cases, it may be feasible to leave the charging current on all night and during Sunday. By thus charging at times during which discharging is not taking place, the number of discharging sounder circuits may exceed the number of charging circuits from the main office.

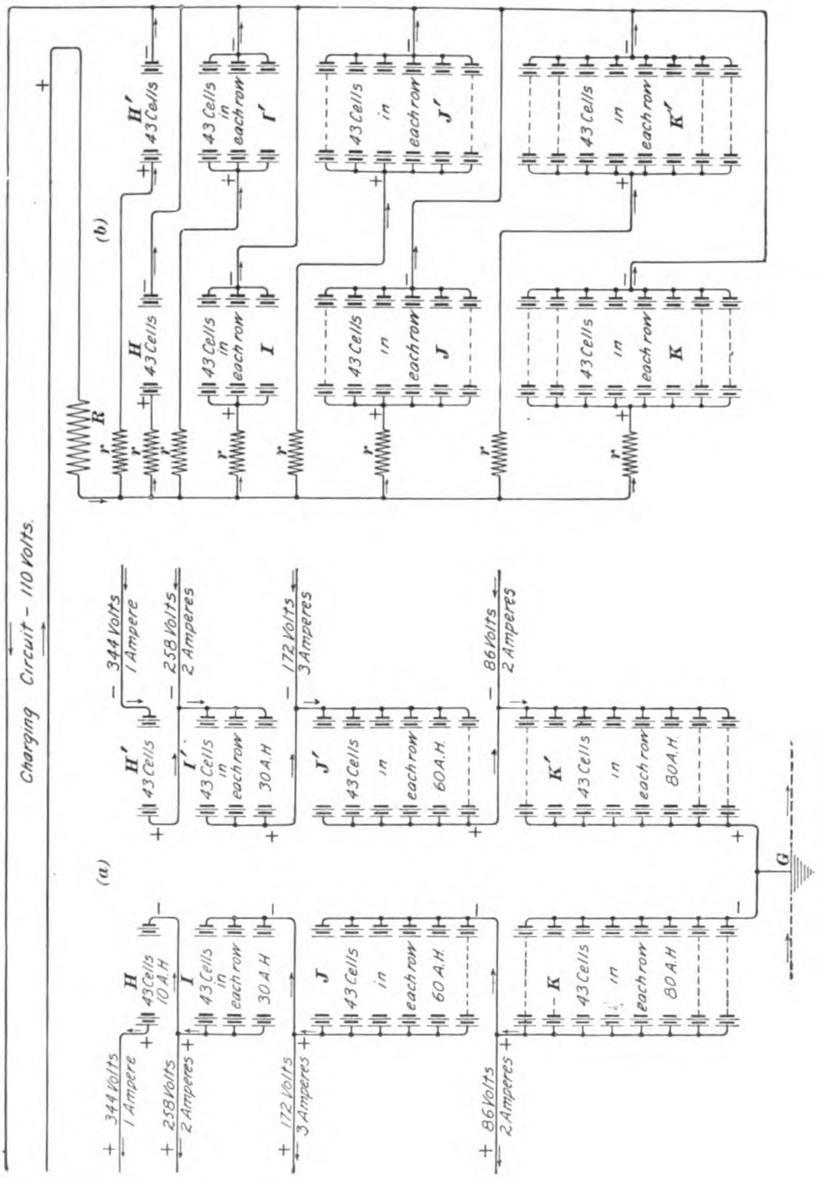

Charging Circuit - 110 Volts
(a)
(b)
344 Volts
1 Ampere
258 Volts
2 Amperes
172 Volts
3 Amperes
86 Volts
2 Amperes
H
H′
43 Cells
10 A.H
I
I′
J
J′
K
K′
43 Cells in each row
30 A.H
60 A.H.
80 A.H.
G
R
r

FIG. 57.

STORAGE BATTERIES FOR MAIN LINES.

196. An arrangement of storage batteries suitable for use on telegraph lines of various lengths is shown in Fig. 57. Each battery in the figure represents 43 cells and therefore about 86 volts, and its size or number of plates in parallel has been made proportional to the required capacity in ampere-hours of the group that it represents. In (*a*) they are arranged in two groups, one furnishing positive and the other negative currents for use on the line wires. All sets furnishing positive currents are joined in series, as are also the negative sets; it is thus possible to get current, either positive or negative, at 86, 172, 258, and 344 volts.

Suppose the current used at 344 volts is 1 ampere, at 258 volts 2 amperes, at 172 volts 3 amperes, and at 86 volts 2 amperes, and, further, that all the batteries are of such an ampere-hour capacity that they all become discharged after the same interval of time, say 10 hours. Then the capacity of the batteries H and H' would evidently be 10 ampere-hours; of the batteries I and I', $(1 + 2) \times 10 = 30$ ampere-hours; of J and J', $(1 + 2 + 3) \times 10 = 60$ ampere-hours; and of K and K', $(1 + 2 + 3 + 2) \times 10 = 80$ ampere-hours. Consequently, the batteries K, K', J, J', and I, I' would require, as represented in the figure, 8, 6, and 3 times the plate area, respectively, of the battery H or H'.

197. In order to charge these batteries from a 110-volt circuit, they should be connected as shown at (*b*), Fig. 57, where each battery of 43 cells is connected directly across the 110-volt mains of the charging circuit. If they were all discharged equally, they would all become charged in the same length of time. There should be an adjustable resistance R in the main charging circuit, and preferably also an adjustable resistance r in each battery circuit. By means of these resistances, the charging current can be suitably controlled, thus preventing the whole battery or any individual set from being charged at too high a rate, which is apt to be the case for a short time after the batteries are first connected to the charging circuit. Some resistance

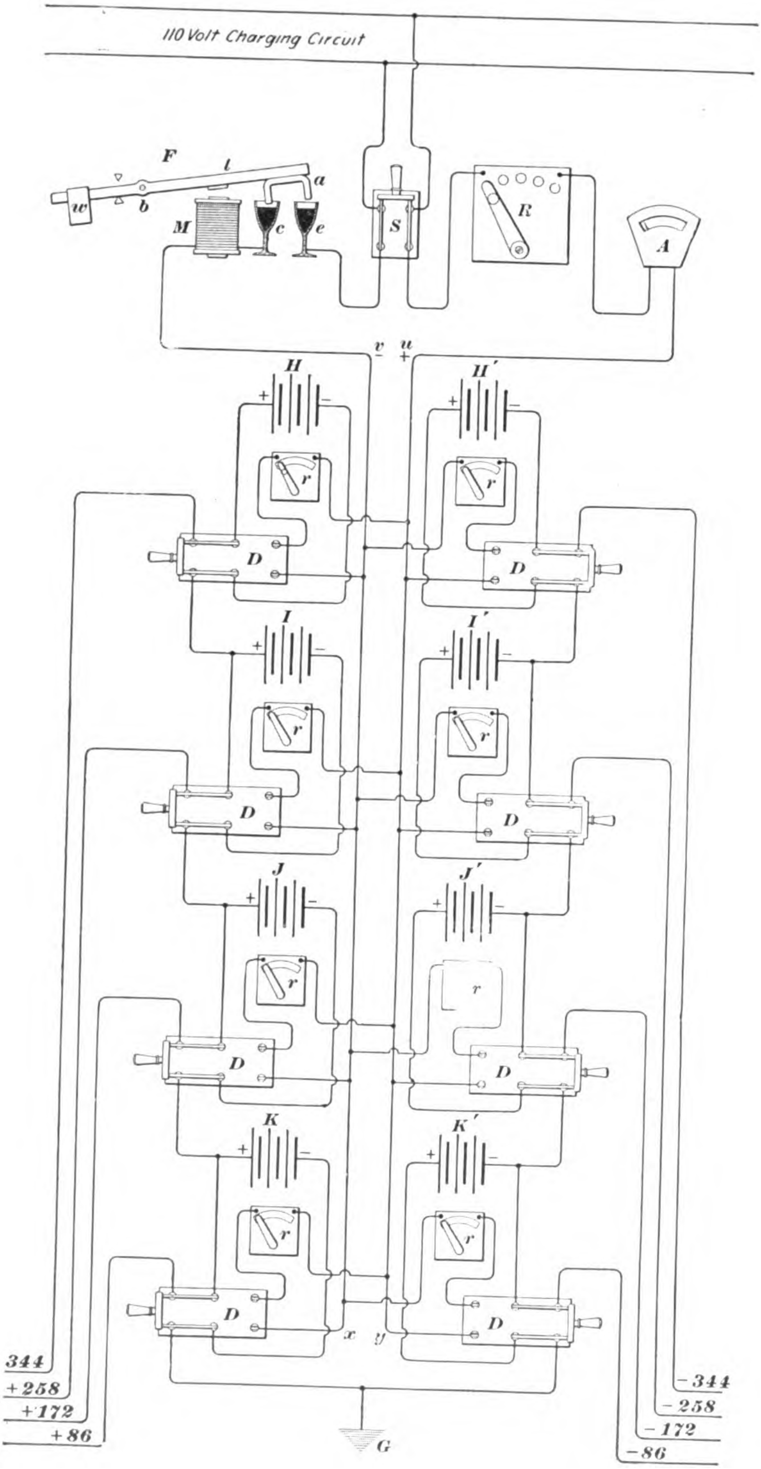

110 Volt Charging Circuit
F
l
a
w
b
M
c
e
S
R
A
v
u
H
H′
I
I′
J
J′
K
K′
r
D
x
y
344
+258
+172
+86
-344
-258
-172
-86
G

FIG. 58.

will be needed at *R* all the time if the voltage across the charging circuit is much above 110 volts.

By connecting a voltmeter across the terminals of the various sets, the attendant can tell when each becomes fully charged, and so will be able to disconnect each set from the charging circuit at the proper time. There is not, however, nearly so much danger of injuring a cell by overcharging it as from overdischarging it. The arrows show the direction in which the currents flow in (*a*) while discharging and in (*b*) while charging.

198. In Fig. 58 is shown a practical way in which the cells may be arranged whereby they can be disconnected from the discharging and connected to the charging circuit by the proper manipulation of knife switches. *S* is a double-pole switch by which the main charging circuit can be entirely cut off from all the cells. With the double-throw switches *D* connecting the center and outside contacts, as shown in the figure, the batteries are connected in two series sets to the discharging circuits.

F is a simple underload or no-load device, consisting of a magnet *M* connected between a metallic cup *c* containing mercury and the wire *v*; a lever *l* pivoted at *b* and having at the forward end an inverted U-shaped copper wire *a*, the two downwardly projecting ends of which can dip, when the forward end of the lever *l* is depressed, into the mercury in the two metallic cups *c* and *e*; and an adjustable weight *w* at the rear end of the lever *l*. The mercury cup *e* is joined to one terminal of the double-pole switch *S*. When the forward end of the lever is pushed down, the two mercury cups are connected together by the mercury and the copper wire *a*, thus closing the circuit between the two cups *c* and *e*. The weight *w* can be adjusted along the lever *l* so as to open the circuit when the current and the resulting pull of the magnet decreases to zero or to any desirable small value.

Each battery, although only 3 cells are shown, consists, in this case, of 43 cells in series, *H* and *H'* having a capacity of 10 ampere-hours; *I* and *I'*, of 30 ampere-hours; *J* and

J', of 60 ampere-hours; and *K* and *K'*, of 80 ampere-hours, as in the preceding figure. *R* and *r*, *r*, *r*, etc. are adjustable resistances or rheostats serving the same purpose as the corresponding resistances in Fig. 57. To charge the batteries, close the *D* switches so that they will connect with the lead wires *u*, *y* and *v*, *x*. In this position, all the batteries are in parallel, in the proper position for charging. Then, with all the resistances in the rheostats *R* and *r*, *r*, *r*, etc., close the switch *S* and also the underload circuit-breaker *F* by pushing down the forward end of the lever *l*, thus connecting the cup *e* with the cup *c*. The circuit is now closed, and the current flowing through the magnet coil *M* will hold the lever *l* down. Now adjust *R* and *r*, *r*, etc. until the correct charging current, as indicated by the ammeter *A*, is obtained. If, for any reason, the current falls to zero, or decreases to such a value that the downward pull of the weight *w* is greater than the downward pull of the magnet *M*, then the lever will fly up, pulling *a* with it, and so open the circuit between the two mercury cups *c* and *e*. In place of the simple underload device *F*, an underload circuit-breaker similar to that shown in Fig. 38 would be preferable. Any one of the *D* switches may be opened from time to time, as the battery to which it belongs becomes fully charged. This state is conveniently determined by the indication of a voltmeter connected directly across the set.

TELEGRAPHY.

(PART 3.)

LINE CONSTRUCTION.

THE POLE LINE.

SELECTION OF ROUTE.

1. The first important consideration in the erection of a pole line is the selection of the route. After the general route has been determined, right of way must be secured, and this is a matter involving as much business tact as engineering ability. If cross-country lines are being constructed, the most direct route is usually the most desirable, although, of course, the selection of the route must always be governed by the considerations arising in securing the right of way, by the configuration of the country, and by the nature of the soil. Telegraph lines are commonly run alongside the railroads as well as along the highways.

2. If a line is to be built along a country road, a reliable map of the country, showing the various turns in this road, should be obtained, if possible, and if not, one should be constructed by the best means available. A fairly accurate survey may be made by counting the revolutions of a wagon

wheel driven over the road, or, better, by means of a reliable cyclometer on a bicycle. Notes should be taken at every bend in the road, and, in fact, every other landmark as to the distance passed over and as to the direction of the road, its grade, soil, etc.

POLES.

3. Selection of Poles.—The poles used to the greatest extent in this country are of the following kinds of wood· white cedar, Norway pine, chestnut, and cypress. The average lives of these under average conditions are placed by good authority at the following values:

TABLE 1.

Norway pine	6 years.
Chestnut	15 years.
Cypress	12 years.
White cedar	10 years.

White cedar is probably used to the greatest extent for telegraph purposes and is, all things considered, the most satisfactory timber. Considering their strength, they are light in weight, and by some authorities these poles are considered the most durable, when set in the ground, of any American wood suitable for pole purposes.

Chestnut is a tough and strong wood, and for that reason is often used at street corners and bends, while other poles are strong enough for the rest of the line. Chestnut poles are apt to be badly bent, and hence are not quite so good for nice pole lines in a city, although often used for such lines. Many prefer second-growth chestnut in preference to white cedar. Red cedar poles are undoubtedly the most durable, but they are usually too dear, or too difficult to obtain. Tamarack poles are used in certain sections. The red variety will last from 12 to 15 years in upland soil, and, in such localities where 25-foot 6-inch top poles can be delivered at 60 cents each, they are said to be, even in the long run, cheaper than white cedar.

Slow-growth timber, i. e., timber that grows on barren soil, is found to be the best for poles. The selection of poles, however, must be governed to a large extent by the facility with which the various kinds may be procured in the particular locality under consideration. The poles should be well seasoned, straight, free from serious knots or cracks, and sound throughout. They should be cut in winter when the sap is down, for, with the sap in them, dry rot is sure to take place and the poles, although looking strong and fair, will have lost their strength on account of rotting at the heart.

4. Sizes of Poles.—The best telegraph lines in this country use no poles that have tops less than 22 inches in circumference. If the poles taper at the usual rate, the specification that a pole shall have a top 22 inches in circumference, or, approximately, 7 inches in diameter, is usually

TABLE 2.

SIZES OF POLES.

Length of Pole. Feet.	Circumference at Top. Inches.	Circumference 6 Ft. from Butt. Inches.	Depth of Pole Set in Ground. Feet.
30	22	33	5½
35	22	35	5½
40	22	37	6
45	22	41	6½
50	22	44	7
55	22	48	7
60	22	52	8
65	22	56	8

sufficient, for the diameter at the butt will then be approximately correct, no matter what the length of the pole may

be. As the taper of poles varies considerably, however, it is well in ordering poles to make the specifications conform to Table 2, taking one measurement at the top and one at a distance of 6 feet from the butt.

Some engineers apply Table 2 to second-growth chestnut and require white (Michigan) cedar poles, because they are not so strong, to be from 3 inches larger in circumference for the smaller sizes to 6 inches larger for the larger sizes, at a distance of 6 feet from the butt, but about the same at the top as given in the table. Sometimes 25-foot poles with a circumference at the top of only 20 inches are used. The holes for such poles need be only 5 feet deep.

5. Weight of Poles.—For white cedar and Norway pine poles, the weight in pounds and the number of poles to a carload are approximately as given in the accompanying tables. Chestnut poles will be about 50 per cent. heavier than the cedar. Poles 35 feet and over must be loaded upon two cars.

6. Height of Poles.—Where a pole line is to carry but few wires, it is unnecessary to make the poles as heavy as those specified in the table, and, in some cases, poles with a 5-inch top will answer. Poles that are to carry 6 wires, or less, should be 6½ inches in diameter at the top and 25 feet long. Poles at wagon crossings should be 30 feet long, and for crossing railroad tracks, about 50 feet. In determining the height of poles, several considerations must be borne in mind. The number of wires to be carried, and therefore the number of cross-arms, determines to some extent the general height of the pole to be used. A general rule to be followed in making this determination is to specify that at no point shall the wire be less than 18 feet from the ground. When crossing railroad tracks, the lowest wire must be at least 25 feet above the rails.

Where these rules are followed, the number of cross-arms on a pole, the distance between them, and the depth of the pole hole make the determination of the pole length an easy matter. The length of the pole must, however, be varied

TABLE 3.

ROUND WHITE CEDAR POLES.

Size of Poles		Weight. Pounds.	Number to Carload.
Length. Feet.	Diameter of Top. Inches.		
25	7	335	55 to 70
25	8	430	
30	7	475	40 to 45 (475–690)
30	8	644	
30	9	690	
35	7	720	
35	8	936	
35	9	1,020	
50	8 and upwards		20 to 22

TABLE 4.

NORWAY PINE POLES.

Length. Feet.	Diameter of Top. Inches.	Weight. Pounds.	Number to Carload.
40	7	1,100	90
45	7	1,200	80
50	7	1,350	72
55	7	1,500	65
60	7	1,700	55
65	7	2,000	45
70	7	2,400	50
75	7	2,800	45
80	7	3,400	35
85	7	3,800	30

according to the lay of the land, as will be shown later, in order that the line of the pole tops may be as evenly graded as possible. Obstructions, such as the branches of trees, other wires, and buildings, must be avoided, and it is a good rule, wherever possible, to have the telegraph line go over rather than under all such obstructions.

7. Treatment of Poles.—Many attempts have been made to increase the life of poles by such processes as creosoting and vulcanizing, and some of these processes are used to a considerable extent in foreign countries. In this country, these processes are coming somewhat into commercial use, but, as a rule, the poles are set without any preparation whatever against the action of the elements. The poles should be cut at least a year before using, in order to give them time to dry and season, and they should be peeled, preferably before seasoning and while the sap is down, and all knots should be smoothly trimmed at the same time. The bark should be stripped off as soon as the tree is cut, to get rid of the insects under it, and also because the bark retains more moisture than the wood and thus tends to hasten the rotting of the sound wood. In order to prevent to as great an extent as possible the action of the weather at a point just at the surface of the ground, the poles are sometimes coated with pitch for a distance of 6 or 7 feet from the butt, according to the depth to which they are to be set in the ground. The point on the pole at the surface of the ground is termed the *wind-and-water line*, and at this point, poles usually, if not specially treated, first begin to rot, this action being due to the fact that the combined effects of the air and moisture are greatest at this point.

8. Rotting of Poles in the Ground.—In countries where there is a large average rainfall, it is difficult to protect telegraph poles from rotting in the ground, in spite of the precautions sometimes taken to render the wood impermeable. The following plan, invented by Mr. M. Dubois,

is said to prolong the life of the poles very much: The portion of the pole in the ground is surrounded by an earthenware pipe, very similar to a drain pipe. The end of the pipe should extend slightly above the surrounding soil. Into the space between the pole and the pipe put a mixture of sand and resin, the latter being poured into the space in a melted state. When the resin solidifies, the mixture of sand and resin prevents the entrance of moisture and the rotting of the pole.

Another method for the preservation of the butt ends of poles, given by Mr. J. C. Duncan, of Knoxville, Tennessee, is as follows: *First*, char the pole for the first 4 to 6 feet on the butt end, ½ inch in depth. *Second*, mix 1 gallon of 25-per-cent. crude carbolic acid with 5 gallons of coal tar. Put on one or two coats of this mixture after the pole is dried out; it should not be put on when the pole is green. The decay of poles, except red cedar, is generally caused by worms boring into the poles. This preparation will kill all eggs or worms that may be in the poles and prevent others from being deposited.

9. Spacing of Poles.—Practice varies as to the spacing of poles. Of course, the number and sizes of the wires to be carried are the most important considerations in determining this point, but the climatic conditions, especially with regard to heavy wind and sleet storms, should also be considered. In general, it may be said that the best lines carrying a moderate number of wires use 30 to 40 poles to the mile, while, for exceptionally heavy lines, the use of 52 poles to the mile, or 1 pole to every 100 feet, is not uncommon practice. On the other hand, many pole lines carrying but few wires use only 25, and sometimes as low as 20, poles to the mile. As a general rule, which it is well to follow, in nearly all cases 35 or 40 poles to the mile should be used. For city work, the poles should be set on an average not farther apart than 125 feet, and they should be painted and provided with steps.

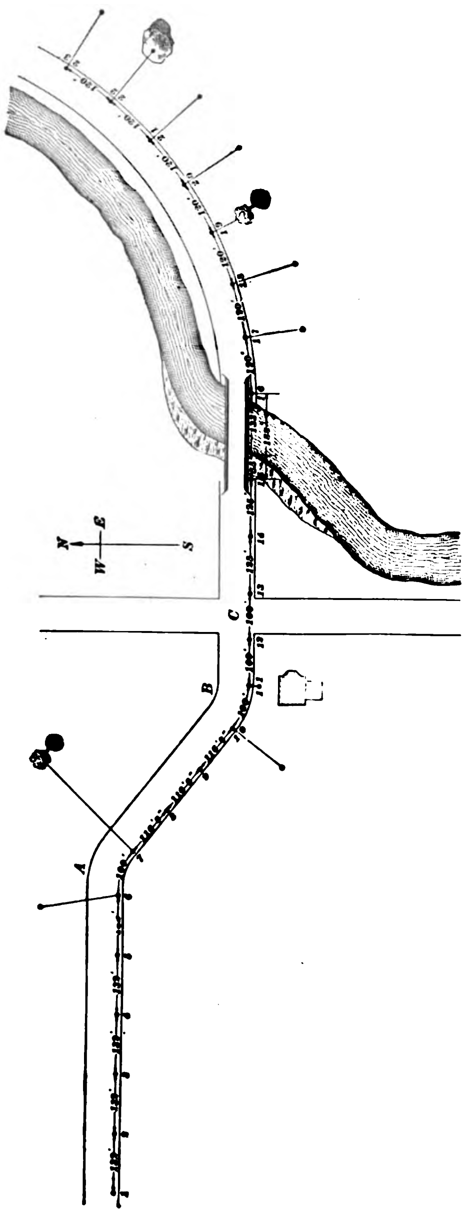


FIG. 1.

LAYING OUT POLE LINES.

10. Marking With Stakes.—Having selected the general route, the location of each pole should be determined and marked with a stake before the hauling of poles or other material is begun. In doing this, a 150-foot steel tape line is desirable. Several marking flags of white cloth, about 2 feet square and mounted on 10-foot poles, sharpened at one end, together with a light ax, will be the only other tools necessary in locating the poles. Assuming that the line to be constructed is to follow the southern side of the roadway shown in Fig. 1, that the average number of poles to the mile is to be 40, and that the

maximum allowable distance between the poles under ordinary circumstances is 140 feet, the average being 132 feet, the work should proceed as follows:

Beginning at position *1*, drive a stake into the ground at a proper distance from the road center or fence, and measure off a convenient number of 132-foot lengths. In this case, it may be convenient to measure in this way as far as the first bend in the road at *A*. Make a mark on the ground at each 132 feet, and leave a stake at each mark. Now have a helper place his flag at the position for the sixth pole, due care being taken that the distance from the center line of the road or from the adjacent fences is correct. As the section of road between positions *1* and *6* is straight, the intermediate stakes may be located directly in line with *1* and *6*, a sight being taken by the eye between a flagpole held on stake *1* and the flag at stake *6*. The helper locates the proper position for each stake by holding a flag in an approximate position and moving it to the right or left, according to signs given by the party sighting at stake *1*. After the proper location of stakes from *1* to *6*, all should be driven home and numbered, either by an ordinary tag, or, better, by marking with soft lead directly upon the stake. Convenient stakes for this purpose are made of yellow pine, 20 inches in length and about 1¾ inches square. At *A* a sharp bend occurs in the road, and as a side strain will be caused upon the poles at that point, it is well to locate the two poles that are to stand this strain closer together. Stake *7* will therefore be placed at a distance of, say, 100 feet from stake *6*, and located at the proper distance from the road center.

Before locating the next poles, the conditions at the bend *B* in the road and at the cross-road *C* should be investigated. It will be better, as before, to make the turn at *B* on two poles placed at about 100 feet apart. Therefore, these two poles at *B* are located at proper distances from the road center, and in such manner that the distance between them will be nearly bisected by the angle in the road. The distance between the western pole at *B* and

pole *7* is then measured and found to be 350 feet. This will make three spans 116⅔ feet long, and as this short section of the road is straight, the two intermediate stakes *8* and *9* are located in a straight line between poles *7* and *10* by the method already indicated. Then, 132 feet from pole *11*, which is already located, would bring pole *12* into the center of the cross-road, while the span would be longer than 140 feet if pole *12* were located at the other side of this road. Therefore it will be necessary to make another short span, and pole *12* is located 100 feet from pole *11*, as shown. The next span of 132 feet would more than clear the roadway, but inasmuch as this is a cross-road, where it is particularly desired not to have broken wires, it will probably be better to make another short span across it of, say, 100 feet. From pole *11* to the river is a straight stretch, and from pole *13*, located just on the east side of the cross-road, the distance is 250 feet.

11. The poles on the banks of the river must be located with great care, due consideration being taken of the nature of the soil, the elevation of the banks, and the length of the span across the river. The distance from water edge to water edge of this river at this point is found to be 133 feet, but the soil on the west bank is so marshy for a distance of 50 feet as to afford no proper footing for a pole. The nearest firm ground on the west bank is at a point 55 feet from the water edge, just near the entrance of the iron bridge spanning the river. A pole should therefore be located at that point. On the opposite side of the river, a solid rock rises abruptly from the water edge back for about 50 feet. This rock will make an excellent foothold for a pole, although, of course, powder or dynamite must be resorted to in blasting the hole. The pole is located therefore as close to the river as possible, its location being marked by a cross-mark scratched upon the rock.

Upon measuring this span across the river, it is found that the distance between the poles is 188 feet, but as it is impracticable to locate them closer together, and as the bridge may

afford no facilities upon which to mount a bracket, this span must be tolerated, great care being taken, of course, in properly securing it in the future operations. The distance from the pole on the western bank of the river to pole *13* is found to be 250 feet, thus giving two 125-foot spans. From pole *11* to pole *16* is a straight line, and, therefore, the intermediate poles *12*, *13*, *14*, and *15* should be accurately located in line by sighting between the flags. After crossing the river, the roadway follows the river bank for about a quarter of a mile in an even curve northwards. It should be made a rule to place the poles somewhat closer together than the average on curves; but inasmuch as this curve is a gradual one, the normal length of span need not be reduced to a great extent. A distance of 120 feet between poles will therefore be decided upon for all the spans on this curve. The succeeding poles are therefore located 120 feet apart, and each at a proper distance from the road center. If the roadway were not a smooth curve, the poles on all straight portions should be alined as described, while those on the curves should be made to follow curves as nearly smooth as possible.

The stakes should be located on a map, such as shown, and the distance between them clearly marked either on the map or on a separate table.

12. Locating Guy Stubs.—All poles upon which turns are made should be securely guyed in such a manner as to entirely counteract the side strain produced by the line wires. In locating the poles, it is also well to mark the position of the **guy stubs,** or anchors, to which the guy wires are to be attached. In doing this, much judgment must be exercised, and right-of-way privileges must also be consulted. It is frequently a much more difficult matter to obtain permission to anchor a guy wire on a piece of property than it is to locate a pole. The anchor for the guy wire should always be located so that the direction of the guy wire will bisect the angle made by the line wires on that pole. It is evident that poles *6*, *7*, *10*, *11*, *17*, *18*, *19*, *20*, *21*,

22, and *23* will need to be guyed, and note is made of this fact in locating the poles, and the guy stubs located by stakes in the same manner as the poles. The stubs should also be marked on the map. Poles *6*, *10*, *17*, *18*, *20*, *21*, and *23* will be guyed to stubs placed at positions located. Poles *7* and *19* will be guyed to tree trunks, as indicated in the map, while the guy wire of pole *22* will be anchored in the convenient ledge of a rock, the ground at that point being too stony to erect a guy stub without undue trouble. At pole *11*, which is opposite a residence, no permission could be secured from the owner to plant a guy stub in his front yard, and, therefore, an anchor is provided, as will be described later, close to the base of the pole.

13. Grading Line of Pole Tops.—Where the line passes through a level country, all the poles may be of the

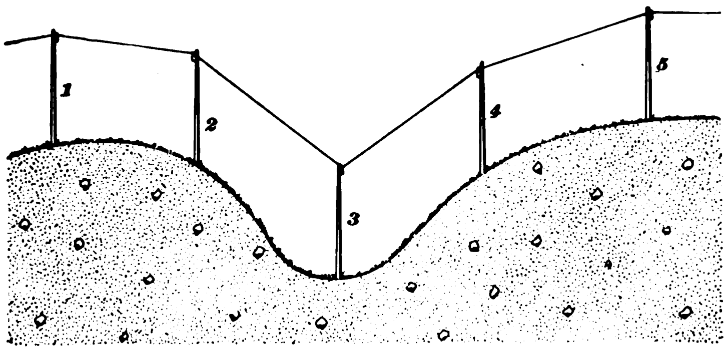


FIG. 2.

same length, except where changes are necessarily made in order to avoid obstructions. In a hilly country, however, it is important that the line of the pole tops should be as nearly on a level as possible, and this necessitates the putting of long poles on the low ground and short poles on the high ground. That this is important may be seen by comparing Figs. 2 and 3. In Fig. 2, where all the poles are of the same length, a very heavy strain would be brought upon poles *2* and *4*, and pole *3* would probably have an upward

instead of a downward pull upon it by the wires, thus serving to increase the strain upon the poles *2* and *4* rather than diminishing it. Cases have been known where, owing to such faulty construction as that indicated in Fig. 2, the

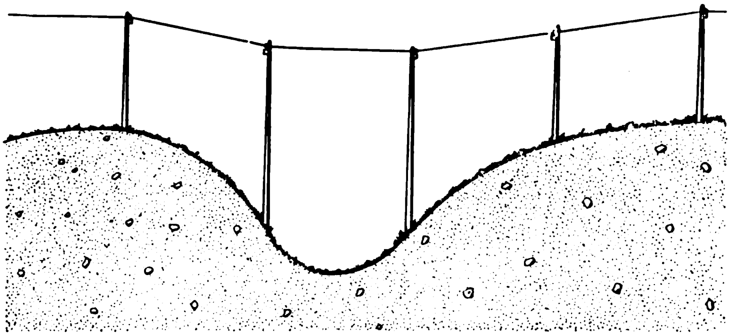


FIG. 3.

insulators were pulled off and even the pole in the hollow was lifted entirely out of the ground and hung suspended by the line wires. At any rate, a pole in such a position is much more likely to do harm than good.

14. In Fig. 3 the unevenness in the profile of the line is corrected to some extent by the use of poles of varying length and by a different arrangement of the poles with respect to the configuration of the ground. As will be noted, two poles are used in the ravine, one on each side, instead of one in the bottom of the ravine, as in Fig. 2. Moreover, these poles are made longer and the poles on the hilltops shorter, thus maintaining a very fair grading of the pole tops without subjecting any of the poles to undue strain.

15. In a country having only slight undulations, the length of a pole required at any particular place can usually be determined by a mere inspection with the eye. If the country is very undulating, it is a good plan, and one that should be carried out if possible, to make a profile map of the entire pole line with a surveyor's level and leveling rod.

For this purpose, the level should be set up between stakes *1* and *2*, and a sight taken at the leveling rod while held above stake *1* by the helper. The helper should then go to stake *2*, and a sight should be taken on the rod when held above it, the level remaining at the same point. The readings so obtained are called *backsights* and *foresights*, respectively, and the difference between them indicates the difference in level between stake *1* and stake *2*. In the same manner, the difference in level between stakes *2* and *3* may be obtained. After the levels of all the stakes have been determined, an accurate profile of the country over which the line passes may be mapped out upon a piece of section paper, and, after this is done, the profile of the line of pole tops may be drawn in such a manner as to remove all undue vertical bends, this being accomplished, of course, by varying the length of poles, as already described. After this, the lengths of poles may be scaled and a table made so that the proper length of pole may be hauled to each stake.

This method is not usually followed, and is unnecessary if the country is gently undulating, but, in a very hilly country, a careful following of this plan will result not only in a better line, but will actually save labor and expense.

ERECTING POLE LINES.

16. Distribution of Poles. — After these preliminaries are arranged, the poles may be distributed by any means available. They should be laid with their butts near the stake and with their small ends pointing up hill, if there is a grade at that point. By following the latter point, much labor on the part of the raising gang will be saved. Another point that should be observed in the distribution of poles is that the heavier poles should be placed on the corners and on all points where a heavy strain is likely to occur.

17. Distribution of Poles Along a Railroad.— The poles should be dropped at the right place. Where

heavy poles are handled, it is quite a saving in the expense of construction to avoid carrying the poles when the setting is being done. One plan of distributing from a car along a railroad is the following: The circumference of the driving wheel is previously measured or calculated from its diameter. Then, by dividing the distance by which the poles are to be separated by the circumference of the wheel, we have the number of revolutions to be made by the driving wheel between two poles. Hence, by placing a man on the engine pilot, he can tell, by counting the revolutions of the driving wheel, where to drop off a pole. When he reaches the proper point, he makes a long mark with an iron rod in the ballast alongside the track and the men on the car drop off the pole at that spot. In building a line parallel to or near railroad tracks, never set the poles less than 12 feet from the nearest track.

18. Gaining and Trimming.—When the pole is received, its butt should be approximately flat. If this is not the case, it should be made so before setting. Poles set in gravel or quicksand should always be pointed at the lower end, to make them stand well. Experience has proved that, when not pointed, the wind will vibrate the pole more or less, and the loose gravel or quicksand will keep working under the bottom of the pole and thus gradually lift it and render it less secure each year. Unpointed poles set in barrels in quicksand have been known to rise from 1 to 2 feet in a few years, on account of the vibration of the wind and the action of the quicksand.

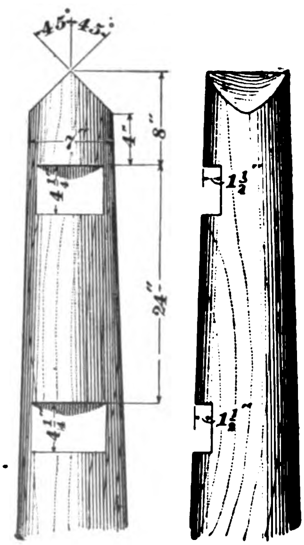


FIG. 4.

Before raising the pole, the gains for the cross-arms should be cut and the small end of the pole made wedge-shaped by chamfering the top to an angle of 45°, the direction of the wedge being in a line parallel with the wires. It is customary to place the top edge of the upper gain 8 inches from the apex of the roof, and to make the distance between the tops of the cross-arms 24 inches. A pole top prepared in this manner is shown in Fig. 4. The roof and the gains should be painted with two or three coats of best white lead before the cross-arms are fastened in place. This treatment prevents the entrance of moisture into the grain of the wood and greatly prolongs the life of the pole. The gains should not exceed 1¼ inches in depth in round cedar poles only 6 inches in diameter at the small end, and need not exceed ¾ inch in sawed redwood poles, or where braces are used.

19. Pole Steps.—Poles that are to be provided with **steps** should have the holes bored to a depth of 4 inches. Use galvanized-iron pole steps ⅝ inch in diameter and 9 inches long, placed on each side of the pole at right angles to the cross-arms. The steps should be staggered 30 inches on centers on each side of the pole, extending downwards from the lowest cross-arm to within 10 feet of the ground. If poles having a circumference exceeding 60 inches are used, then the steps should be staggered 24 inches on centers on each side.

20. Cross-Arms.—The **cross-arms** should be made of sound, well-seasoned, straight-grained timber. Some prefer red or black cypress. However, yellow pine, especially the long-leaf variety, creosoted white pine, Oregon fir, and yellow poplar make excellent cross-arms. All cross-arms should be painted with two coats of good oil paint before leaving the factory. A good paint for this purpose consists of 7 pounds of Prince's metallic paint mixed with 1 gallon of pure linseed oil.

21. Size of Cross-Arms.—The size and length of cross-arms depend on the load they are to carry. Two

regular sizes, however, are made, one termed the *standard cross-arm*, and the other the *telephone cross-arm*. The standard cross-arm is used for all heavy work and in constructing a line that is expected to last well. Standard cross-arms are $3\frac{1}{4} \times 4\frac{1}{4}$ inches and vary in length from 3 to 10 feet. They are usually bored for $1\frac{1}{2}$-inch wood pins or for $\frac{1}{2}$-inch steel pins and provided with holes for two $\frac{1}{2}$-inch bolts, as shown in Fig. 5. The number of pins and the dis-

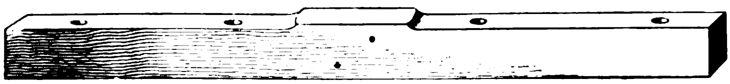


FIG. 5.

tance between them for the various lengths of standard cross-arms are given in Table 5.

TABLE 5.

STANDARD CROSS-ARMS.

Length. Feet.	Number of Pins.	Spacings.		
		End. Inches.	Center. Inches.	Sides. Inches.
3	2	4	28	
4	4	4	16	12
5	4	4	18	17
6	4	4	22	21
6	6	4	16	12
8	6	4	18	$17\frac{1}{2}$
8	8	4	16	$12\frac{1}{2}$
10	8	4	$17\frac{1}{2}$	$15\frac{3}{4}$
10	10	4	$16\frac{1}{2}$	$12\frac{3}{4}$

The best sizes to use are as follows:

For two wires, $3\frac{1}{4}'' \times 4\frac{1}{4}'' \times$ 3 feet.
For four wires, $3\frac{1}{4}'' \times 4\frac{1}{4}'' \times$ 6 feet.
For six wires, $3\frac{1}{4}'' \times 4\frac{1}{4}'' \times$ 8 feet.
For eight wires, $3\frac{1}{4}'' \times 4\frac{1}{2}'' \times$ 10 feet.

22. The so-called telephone cross-arms are lighter, being made from $2\frac{3}{4}'' \times 3\frac{3}{4}''$ stuff, sometimes $3'' \times 4\frac{1}{2}''$, and bored for $1\frac{1}{4}$-inch pins, and provided with two $\frac{1}{2}$-inch bolt holes. For light lines, these arms give excellent satisfaction, but are not, of course, as durable as the heavier arms, and are seldom used for telegraph lines. On the telephone cross-arm, the centers of the end pins are 3 inches from the ends of the arm, the distance between the centers of the two middle pins being 16 inches, and between all others, 10 inches.

23. Lagscrews.—Cross-arms are usually fastened to the poles by two $\frac{1}{2}$-inch lagscrews, such as shown in Fig. 6,

FIG. 6.

of sufficient length to pass nearly through the pole, the length on standard constructions being, usually, 7 inches. For arms carrying 6 wires or more, the lagscrews should be $\frac{5}{8}$ inch in diameter by 7 inches long. It is much better to bore holes for the lagscrews than to drive them in. The latter method tears the fiber of the wood, and the lagscrews will not hold as well as when the holes are bored. The bit used should be $\frac{1}{8}$ inch smaller than the lagscrew, which should always be screwed up for the last 2 inches with a wrench.

24. Carriage Bolts for Fastening Cross-Arms.—It has been found that the entrance of a lagscrew destroys

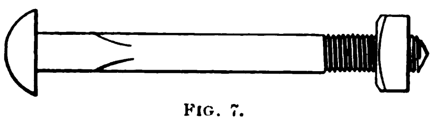


FIG. 7.

the grain of the pole to such an extent that it is seldom possible to put on new cross-arms after the pole has been in service for several years. A more recent and much better plan, therefore, than the use of lagscrews is to secure the cross-arms to the pole by a **carriage bolt,** such as shown in Fig. 7, the carriage bolt being $\frac{5}{8}$ inch in diameter and long

enough to extend entirely through the pole and cross-arm. A washer not less than $2\frac{1}{2}$ inches in diameter should be used under both the head and the nut of this bolt.

25. Cross-Arm Braces.—In order to further secure the cross-arms, braces, called **cross-arm braces,** are used.

FIG. 8.

All cross-arms over 6 feet long should be braced and 6-foot arms should also be braced on curves. One of these braces is shown in Fig. 8. They are made of galvanized iron from 20 to 30 inches long and usually $1\frac{1}{4}$ inches wide by $\frac{1}{4}$ inch

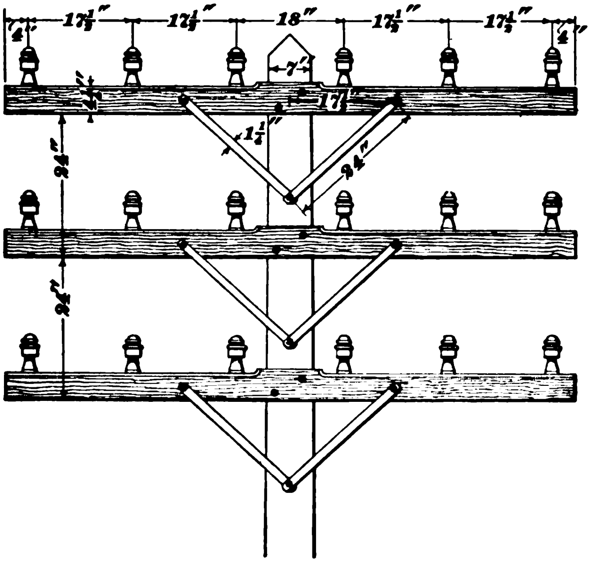


FIG. 9.

thick. The method of attaching these to the pole and cross-arm is shown in Fig. 9, which represents a pole top equipped with three 6-pin standard arms. Each pair of cross-arm braces is secured to the pole by a single $3'' \times \frac{5}{8}''$ lagscrew

and washer, while the other ends are each secured to the cross-arm above by a 4″ × ⅝″ carriage bolt passing entirely through the cross-arm. A washer is provided under the head of the lagscrew and under the head and nut of each carriage bolt.

When wires are heavily loaded with sleet, experience has proved that there is much less damage by broken cross-arms when they are braced than when they are not. A shallow gain can be used with braces, and this is certainly an advantage, because a deep gain reduces the strength of the pole, and the older the pole, the more damage results from deep gains during storms. The brace should be fastened to the front of the cross-arm opposite the pole. Some advise locating the bolt for holding the brace to the arm ½ inch above the center of the arm instead of at the center, claiming that this holds the arm better, and especially when subjected to a heavy load of sleet or wet snow.

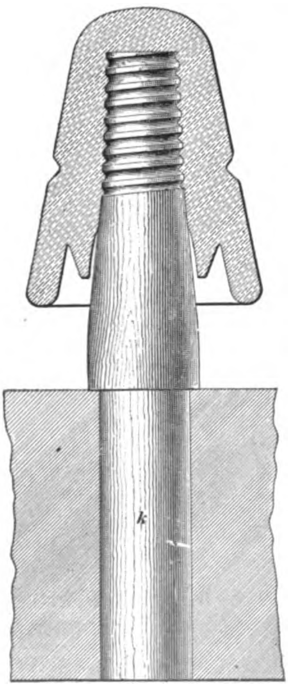


FIG. 10.

26. Double Arms.—Double arms, that is, an arm on each side of the pole, should be used on all office poles, at all railway and river crossings, on corners, and on unusually long sections. On heavy lines, the first pole back from a corner should have double arms in order to carry guys for strengthening the corner-pole guys. Only the arms on the front or lead side of a pole need be braced. Double arms should have two blocks between the arms. A carriage bolt should pass through the block and both arms just outside of the end pins, and should be placed their width above the center of the arm. The nut should be firmly screwed up.

27. Wood Pins.—The **wood pins** by which insulators are mounted upon cross-arms are shown in Fig. 10. They may be made of locust, chestnut, or oak, preferred in the order named, and are turned up with a coarse thread on the end on which the insulator is to be secured. The shank *k* is turned to 1¼ or 1½ inches in diameter, according to the hole in the arm. Standard cross-arms are usually bored for the 1½-inch pins and the telephone arms for the 1¼-inch pins. The other dimensions of the pins are as follows:

Length of pin from base to shoulder......	3⅞ to 4 inches.
Length of pin from shoulder to top.......	4⅛ to 4½ inches.
Total length of pin...........................	8 inches.
Length of thread..............................	2⅛ inches.
Number of threads to the inch.................	5
Depth of threads..............................	⅛ inch.

The pin should be secured in the hole by driving a nail through the arm and through the shank of the pin. This renders it difficult to extract the shank of the pin in case a new one is required, but, on the other hand, prevents the pin from pulling out, which sometimes occurs where this precaution is not taken.

28. Steel Pins.—**Steel pins** are now being used instead of wood pins on the best constructed telegraph lines. They are usually ½ inch in diameter. On corners, or where there is a heavy strain, the pins should be ¾ inch in diameter. They are fastened by a nut on the under side of the cross-arm.

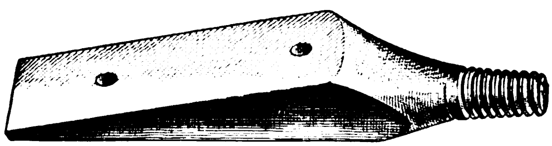


FIG. 11.

29. Brackets.—If only one or two wires are to be placed on a pole, **brackets,** of the kind shown in Fig. 11, are used. These are shaped at their lower end in such a manner as to

allow the pins to project from the pole at an angle, and are each provided with two holes through which heavy spikes are driven to secure them to the pole.

30. Where a pole carries but few cross-arms, it is usually better to secure the arms and pins in place while the pole is on the ground, as it can be done much easier then than later, and the extra weight does not interfere seriously with the raising of the pole. In very heavy work, however, this cannot be done, nor can it be done in cases where a pole must be raised through a network of wire, such as is frequently found in cities.

31. Lightning Conductors.—It is a good plan to protect the line wires from lightning discharges by putting conductors not less frequently than every fifth pole. Some telegraph engineers advise putting them on every pole. All office poles should be provided with such protecting wires. Heavy galvanized No. 8 B. W. G. iron wire should be used. At least 6 feet of it should be formed into a flat coil, placed in the pole hole under the butt end of the pole, and the wire should be carried up and stapled to the pole on the side opposite the cross-arms, about 3 inches projecting above the top of the pole.

Where a pole has a bracket, this grounded wire should be put one quarter way around the pole from the bracket and not opposite the bracket. This allows another bracket to be put up opposite the first without having to move the grounded wire.

32. Depth of Pole Holes.—After the poles are on the ground and ready for raising, the pole hole should be dug. No absolute rule can be laid down for the depth to which pole holes should be dug, as this depends on the nature of the soil, the height of the poles, the number of wires to be carried, the number of poles to the mile, and the frequency of heavy wind storms, and must, therefore, be left to a large extent to the judgment of the engineer. For average conditions, however, the following table, taken

from Table 2, will serve as a guide for the depth of pole holes for various lengths of poles:

Length of Pole.	Depth of Hole.
25 feet.	5 feet.
30 to 35 feet.	5½ feet.
35 to 45 feet.	6 feet.
45 to 50 feet.	6½ feet.
50 to 60 feet.	7 feet.
60 feet and over.	8 feet and over.

33. Digging Pole Holes.—A hole should be started with the marking stake as a center, and should be of sufficient size to allow the pole to slip easily into place. About 2 inches all around each pole is the proper space to allow for tamping. That is, make the hole 4 inches larger in diameter than the base of the pole. If the holes are dug smaller than this, the probabilities are that they will not be properly tamped at the bottom.

34. Number of Men Required.—In the construction of a pole line, it is a good plan to so proportion the work of the gang that poles will be set in all the holes dug at the close of each day. Assuming that the average length of pole is 35 feet, a gang of about 6 men will be required for raising. For longer and heavier poles, as many as 15 men may be necessary. These men may be all employed in digging holes in the morning, and, under average conditions, the same gang can in the afternoon set poles in all the holes dug in the morning.

35. Tools Required.—It will be well to provide as many sets of digging tools as there are men, each set consisting of the following: 1 long-handled digging spoon; 1 long-handled round-pointed shovel; 1 combined crow and digging bar.

The digging spoon, shown in Fig. 12, should preferably have an 8-foot handle; the round-pointed shovel, shown in Fig. 13, a 7-foot handle; and the digging bar, shown in Fig. 14, should be 8 feet long and constructed of 1$\frac{1}{8}$-inch

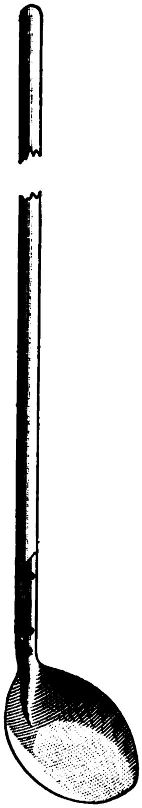


FIG. 12.

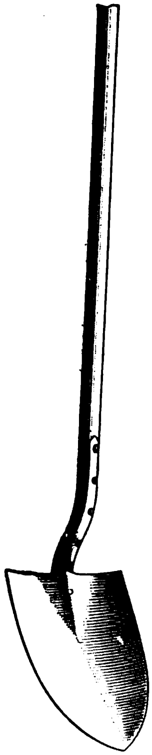


FIG. 13.

FIG. 14.

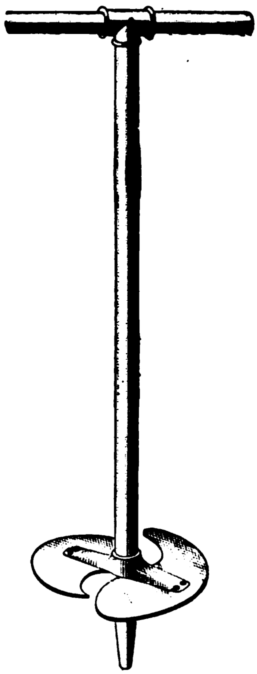


FIG. 15.

octagonal steel. It should be flattened at one end and pointed at the other. In some cases, various forms of post-hole augers have been found advantageous. One form is shown in Fig. 15. They are made 10, 12, and 14 inches in diameter. The use of 14-inch post augers in fair earth or in

low wet places is by far the quickest and cheapest way of digging holes.

36. Number of Poles Raised Per Day.—In average soil, 1 man can dig eight 6-foot holes in one day. However, in very hard or rocky soil, this rate cannot be even approached, so that it is a difficult matter to give a general estimate on work of this kind. Probably 6 holes might be taken as a fair average. The 6 men would, at the rate first mentioned, dig 24 holes in half a day; and to raise and set that number of poles in the afternoon of the same day should be the aim of the foreman of the gang.

37. Use of Dynamite.—Dynamite in small charges has been used to very great advantage in moving "hard pan" and frozen earth, and is very much cheaper than digging it with bar and spoon. The student is cautioned against the danger of attempting to thaw out dynamite by placing it on or near a stove. People are sometimes killed by the explosion resulting from ignorance or carelessness in this matter. The best way to apply the dynamite is to bore a hole with a 2-inch auger bit, having a 4-foot stem and suitable handle, to the proper depth, say 3 feet. Then place in the bottom of the hole ¼ pound of 40- or 60-per-cent. dynamite, with an electric exploder and a wire properly attached to it; tamp the shell in carefully with fine loose dirt, and explode the charge. Generally, no more digging will be required and it is only necessary to spoon the dirt out of the hole, which, in most cases, will be found large enough.

38. Raising Poles.—The following list of tools will usually comprise all those needed for an ordinary raising gang: 2 12-foot pike poles; 2 14-foot pike poles; 2 16-foot pike poles; 2 dead men, 6 and 8 feet in length, respectively; 1 cant hook; 2 tamping bars; 1 short-handled shovel; 2 carry hooks; 2 iron digging bars or crowbars, or, 1 piece of oak plank, 9 inches wide, 1½ inches thick, and 7 feet long; 1 set of 4-inch double-sheave block and tackle, with about 250 feet of ½-inch rope.

The **pike poles,** shown in Fig. 16, are frequently of pine, and about 2½ inches in diameter at the largest end. At this end is carried a pike of pointed steel, which projects from the end of the pole about 3½ inches and is secured in place by a strong iron ferrule. The **dead man,** shown in Fig. 17, consists of a short, heavy, oak bar about 4 inches in diameter and provided with a two-tined fork having a sharpened projection at the center to prevent slipping. This is used to support the pole during raising while the men handling the pike poles are securing new holds. The **cant hook,** Fig. 18, consists of a short, stout bar of oak or hickory to which is pivoted, at a point about 1 foot from the end, an iron jaw provided with a spike, as shown. These are used in rolling the pole on the ground, or in turning it to the required position after it is raised. The **carry hook,** shown in Fig. 19, consists of two iron jaws pivoted and swiveled to the center of a stout oak handle about 5 feet long. These are used when it is necessary to carry the pole for short distances or to swing one end around into the proper position for raising. They are used mostly along railroads. In other places where poles have to be moved, it is better to use a "dinky" or small running two-wheel truck for placing the pole exactly where it is wanted. The oak plank is

FIG. 16.

FIG. 17.

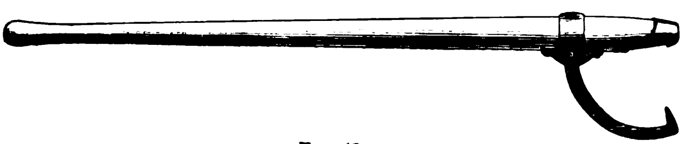


FIG. 18.

used for preventing the butt of the pole from crumbling

away the earth on the side of the hole during the process of raising. However, it is more customary, because more convenient, to use two digging bars instead of the plank, in order that the butt of the pole may go in the hole easily. The block and tackle is frequently found convenient in pulling a pole up an embankment upon which it could not be placed directly from the wagon.

Before raising the pole, it should be rolled by cant hooks, or by any available means, so that its butt lies over the hole. The oak plank, or digging bars, should be placed in the hole

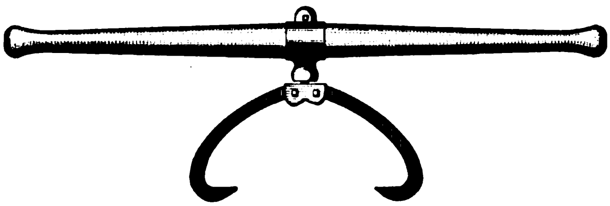


FIG. 19.

on the side farthest from the pole, in such a manner as to form a guide for the butt of the pole in its descent. One man should then be assigned to the dead man, four to the pike poles, and one should be stationed at the hole, provided with a crowbar and cant hook so as to be able to guide the pole into the hole in the proper manner, and at the same time to instruct the raisers. The small end of the pole should then be raised by hand and supported by the dead man while the men obtain a new hold. As they raise it higher and higher, the dead man is moved toward the butt, at all times inclining slightly toward the butt, in order that it may have a tendency to push the pole toward the hole. When the pole is high enough to enable the use of the shorter pike poles, the pikes of these should be planted firmly on the under side of the pole and the pole raised still higher, the dead man at all times being kept in position in such manner as to ease the work of the men and also to prevent accidents. As the pole is raised higher, the longer pikes may be used.

39. The method of using pike poles and the dead man is shown in Fig. 20. The lower end of the pike pole is placed

directly on the shoulder and held in that position by the hands. The pike pole should always have its upper end inclined toward the hole, and should be about in line with the body of the user, so as to allow him to push to the greatest advantage. The men should work as nearly under the pole as possible, but should spread out slightly, so as to steady the pole from falling sidewise. As the pole is raised, the men

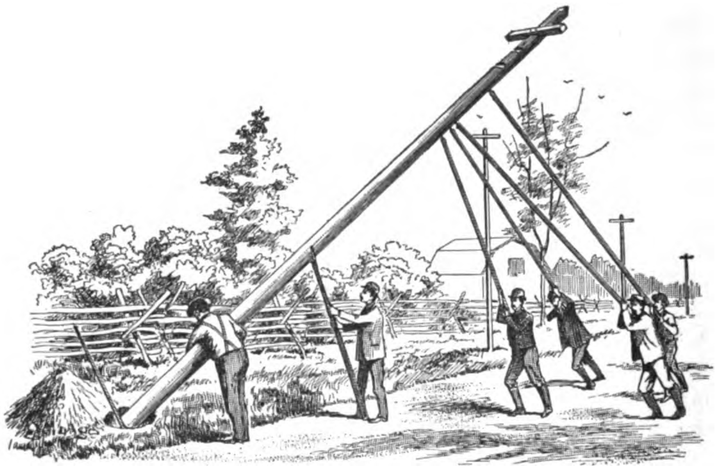


FIG. 20.

should, one at a time, shift to a lower hold, in order that an undue strain may not be placed upon the others. The dead man should at all times be kept in position to take its share of the load. When nearly raised, the longer pike poles may be used to advantage, the change, of course, being made by one man at a time, as before.

An excellent way of raising poles, especially in towns and cities, is to do it with a derrick wagon, the pole being pulled up by the horse or horses.

40. Bracing Pole.—After the pole is brought to a vertical position, it should be turned by means of a cant hook until the cross-arms assume a position at right angles to the direction of the line. In doing this, it should be

remembered that the alternate poles should have the cross-arms face in the opposite direction. The reason for this will be pointed out later. When in the proper position and vertical, the pole may be braced by means of four of the pike poles, having the pikes struck in the pole at a distance of about 8 feet from the ground and their other ends planted firmly in the ground.

41. Filling In and Tamping.—The pole is now in proper position for filling in, and this should be done slowly by one man using the short-handled shovel. Meanwhile, the earth, as thrown in, must be thoroughly tamped by two men so that it is firmly packed around the pole on all sides through the entire depth of the hole. Much trouble is often caused by inattention to this detail, and it is therefore better to provide only one shovel in order that but one man may fill in, while the others are tamping. If the earth is thrown in more rapidly than it can be properly tamped, it will soon settle and result in a loose pole and subsequent trouble. The earth should be banked up around the pole at least 1 foot above the level of the ground.

While three of the men are engaged in the filling in and tamping, the others may proceed to the next pole, in order to place it in the proper position for raising. By an intelligent handling of the men, much time and expense may be saved, and, therefore, too much attention cannot be given to the proper proportioning of the work among them.

42. Pole Foundations. — When marshy ground is encountered, it is frequently necessary to provide a suitable foundation for the pole. The method shown in Fig. 21 is often used, and for most cases will prove effective. The foot-plate is formed of 2-inch oak planks about 3 feet long and 12 inches wide, fastened together by heavy spikes. The hole is dug much larger than usual, and, after its bottom is properly leveled, the foot-plate is put in place and the pole set upon its center. Frequently, a framework of 4″ × 4″ oak lumber is built around the pole on the surface of the ground

after the pole is raised, and it is securely fastened to the pole by long spikes, and braced according to any available method.

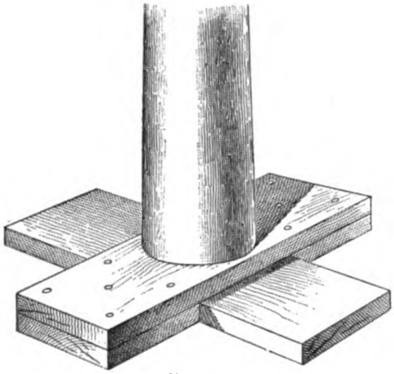


FIG. 21.

Poles set in swamps or low wet places should, on straight lines, be guyed or braced alternately from each side. In case braces are used, they should be as nearly the same length as possible and set at exactly the same angle.

43. In many cases, it is impossible to dig a pole hole to the depth required in the specifications. This is especially true in cities where subways, sewers, or pipe lines frequently run close to the surface and directly under the position that the pole must occupy. When this is the case, the hole should be dug as deep as possible and from 4 to 5 feet in diameter. A layer from 6 inches to 1 foot deep of good cement concrete should be placed in the bottom, after which the pole should be raised, and the hole filled in with concrete thoroughly tamped in place. The concrete used for this and similar purposes should be mixed according to the following formula:

Hydraulic cement	1 part.
Sand	2 parts.
Screened gravel, broken stone, or broken brick	5 parts.

The cement and sand should first be thoroughly mixed while dry, and then a sufficient quantity of water added to form a soft mortar; the gravel, stone, or brick should then be added and thoroughly mixed with it. The greatest diameter of the gravel, broken stone, or brick should not exceed 2 inches.

When the pieces of broken stone or gravel are not of uniform size, the concrete requires less cement, and is at the same time fully as strong as where the pieces of

stone are of uniform size. The reason for this is that the smaller pieces help fill the interstices between the larger ones, thus requiring less space to be filled with cement. All poles set either in marshy ground or in conditions requiring a cement foundation, should, if possible, be heavily guyed in order to render them still more secure.

44. Guying.—It has already been stated that all poles upon which a turn in a line is made should be guyed in a direction to resist the strain of the line wires upon them.

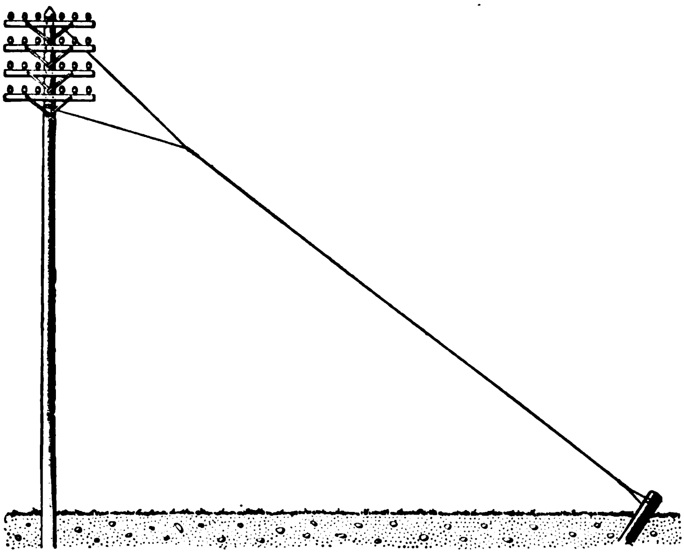


FIG. 22.

Guying is much preferable to bracing. The guying should be done before any wires are strung, the guy wires being pulled up tight enough to give the pole a slight lean toward the guy stub or anchor. The methods of guying are numerous, and much must be left to the judgment of the construction man for its proper execution. The best form of side guy is that shown in Fig. 22, which is commonly known as the **Y** guy. Where the guy is attached only to the top of the pole, there is a tendency for the pole to bend, brought

about by the strain of the line wires attached below it. This strain is so great as to frequently cause poles guyed in this manner to break, the break usually occurring at the gain of the lower cross-arm. In a similar manner, if the guy wire extends to one point only, and that below the lower cross-arm, a similar strain in an opposite direction is placed upon the poles, which is likely to produce the same result. The **Y** guy effectually remedies this difficulty by evenly distributing the strain throughout the pole.

45. The strains brought about by the line wires at every turn in the pole line are not the only ones that must be provided against. The side pressure, due to wind, is often very severe, and in countries subject to severe wind storms, side guys should be placed on both sides of the pole line at frequent intervals. This is especially true where heavy sleet storms occur, for the coating of ice formed upon wires often reaches 2 or 3 inches in diameter, and this not only adds enormously to the weight carried by the poles, but also to the wind resistance.

46. Head Guying.—Very heavy strains occur in the direction of the pole lines and must be provided against.

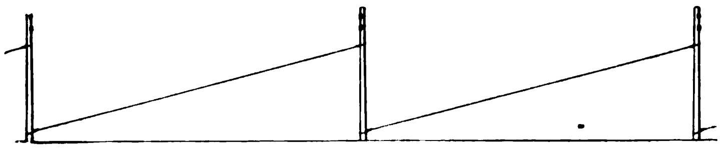


FIG. 23.

Of course, the line wires themselves tend to assume a large portion of this strain, but in heavy wind storms they do not form a sufficient protection, and it is therefore well to guy the poles at frequent intervals against these strains. A system of guying commonly termed **head guying** is chiefly resorted to for this purpose, and is shown in Fig. 23. In this system, the top of each pole is guyed to the base of the next one to it in the manner shown. The guy should be fastened just below the top cross-arm and run to a point on the next pole 10 or 12 feet above the ground.

After about three poles have been guyed in this manner, the direction of the guy wires should be reversed on the next three, so that the longitudinal strain of the line wires will be met in either direction. Another method of

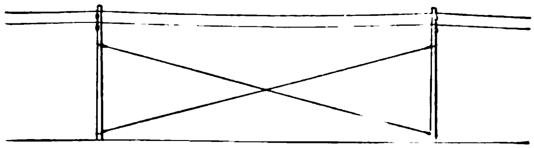


FIG. 24.

guying to resist longitudinal strains in either direction is shown in Fig. 24, and is known as **double head guying.**

On lines carrying but few wires, head guying is not, under ordinary circumstances, used, but for heavy lines extending over long distances, it is an exceedingly important matter. It frequently prevents a long section of line from going down in wind storms, for, obviously, if one pole gives way a severe strain is produced on all the poles, not only by the weight and tension of the line wires, but also by the wind if it happens to be in that direction.

47. Facing of Cross-Arms.—The arrangement of cross-arms on opposite sides of alternate poles, which has already been mentioned, is a matter of great importance, and, when done, greatly assists in the prevention of undue longitudinal strains in the line. If a pole goes down on a line, and the cross-arms are all set in one direction, it is obvious that the cross-arms on all the poles on one side of the break might be pulled off the poles, while if they were alternately on opposite sides of the poles, only one span at most would fall, unless the pole should break, and this, of course, should be guarded against by head guying.

48. Anchors for Guy Wires.—The method of anchoring guy wires must be varied according to existing conditions. The most common method is the **guy stub,** which is placed in the ground as shown in Fig. 25. The guy stubs should conform to the same specifications as the poles regarding quality of wood, and are usually made from

the parts of poles too crooked to be used as poles. For ordinary purposes, a guy stub should be not less than 8 inches in diameter at the small end, and its length from 7 to 10 feet. It is well, in setting, to wedge rocks in the hole as

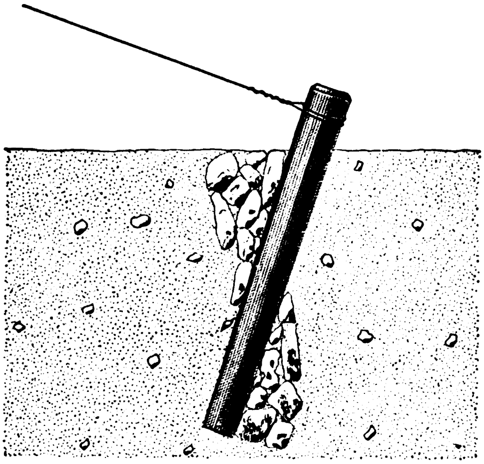


FIG. 25.

shown, dirt being firmly tamped about them, as in pole setting. Side guys running from anchors should be fastened to the pole just below the second cross-arm from the top.

49. Anchor Log and Rod.—Another common

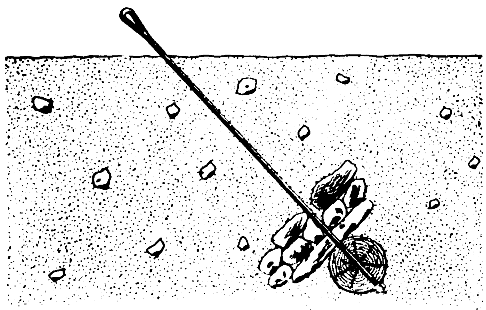


FIG. 26.

method of anchoring the guy wire is by means of the **anchor log** placed as shown in Fig. 26. The anchor log

may be made of the same material as the pole, and, as in the case of the guy stub, may be formed from a portion of a pole. Railroad ties, where obtainable, are often used for this purpose. It should be from 4½ to 8 feet long, and not less than 30 inches in circumference. The anchor rod should be of good wrought iron not less than ⅝ inch in diameter, and from 6 to 8 feet long. It should be threaded on its lower end for a heavy galvanized-iron nut, and should be further provided with a galvanized-iron washer ⅜ inch in thickness and 4 inches square. At the top of the rod, there should be a welded eye, the opening being 1½ inches across at the widest place. The guy rod should pass directly through the center of the anchor log, as shown, and should extend about 6 inches above the surface of the ground. In burying the anchor log, it is well to pile heavy rocks above it in a direction to meet the strain of the guy wire, 5 or 6 feet being, in ordinary cases, a sufficient depth at which to place the anchor log.

50. An excellent anchor may be made from two pieces of timber 1½ inches thick by 16 inches square, placed together so that the grain in one piece is at right angles to the grain in the other. The anchor rod passes through the center of both, and the nut is screwed on. The whole, buried 4½ to 5 feet, will, if properly tamped, hold very heavy corners. In quicksand or live gravel, they should be 20 inches square. An older style of anchor (a 4-foot log) requires the moving of about two-thirds more earth than does this style, and does not answer the purpose any better.

51. Guying to Trees.—Where it becomes necessary to anchor to the base of a tree, heavy wooden blocks should be placed, as shown in Fig. 27, at intervals about the tree, in order to prevent the tree being strangled by the guy wire. If this is properly done, the tree will not be injured, while a guy wire placed directly about the trunk of a tree will often kill it within a year. The guy wire should not even be wrapped around the tree, but only looped, as shown. In

order to hold the blocks in place until the guy wire is permanently tightened and settled, an extra piece of wire may be wrapped around the blocks and fastened tight, but it should not be left on permanently. Too much care cannot be taken to protect shade trees in towns and cities. Consideration such as this should always be borne in mind, for

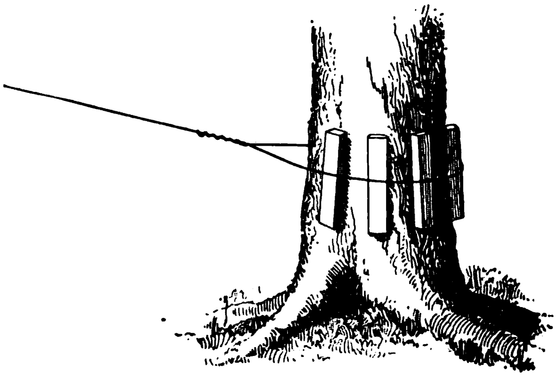


FIG. 27.

right-of-way and guy-wire privileges are very hard to obtain, and a few instances where real damage is produced by their use will render the obtaining of subsequent privileges doubly hard. If it can be avoided, it is best not to use trees at all for anchors. The least swaying of a tree where a guy wire is anchored will soon loosen the pole.

52. Guy Wires.—It is best, and especially for heavy construction, to use a stranded wire rope manufactured especially for guy wires and similar purposes. These ropes are commonly composed of 7 strands of steel wire, the external diameter of the rope varying from $\frac{3}{32}$ to $\frac{1}{2}$ inch, the most common sizes for guying being $\frac{1}{4}$ inch and $\frac{3}{8}$ inch.

The best way to fasten a stranded guy-wire cable, and the way in which it should generally be done, is by means of wrought-iron clamps, as shown in Fig. 28. They are made especially for this purpose. Where the guy rope is to be attached to an eye, as, for instance, in the top of an anchor rod, a thimble *a*, such as that shown in Fig. 28, is

used to form an eye in the rope, this being made to interlink with that of the anchor rod. Where, however, the guy wire is to be secured to the pole or to a guy stub, the thimble *a* is not used, but the wire rope is passed twice around the pole

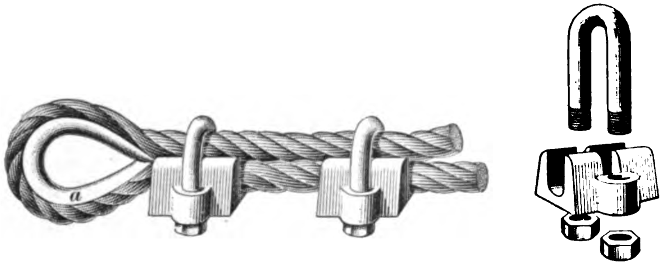


FIG. 28.

as before, and then secured by means of the clamps. Guy wires fastened with clamps can be removed when necessary with no waste of material and much quicker than when twisted together, in the old way, with pliers.

Fig. 28 shows a two-bolt clamp. Some recommend that only the stronger three-bolt standard clamp be used.

53. Sometimes two strands of No. 9 iron wire twisted together will make a very satisfactory guy rope. In many cases, even a single strand of No. 8 or No. 6 is used. In tying the guy wire about the pole or guy stub, it is customary to pass it twice around the pole or stub and then to secure it by twisting the end around itself, as shown in Fig. 29. To prevent the guy wire from slipping away from its position on the pole or guy stub, it is recommended to secure each coil tightly in place with from three to six galvanized-steel staples. These staples should be 2½ inches long and may be made from No. 6 B. W. G. galvanized-steel wire. Where

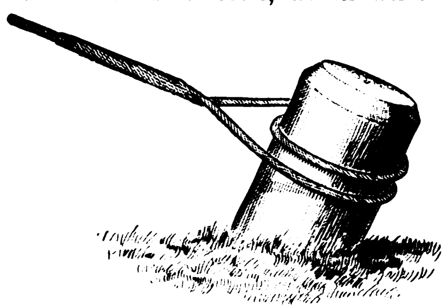


FIG. 29.

steel rope is used, the strands should be untwisted before the tie is made and then wound around the main rope in parallel layers, as shown in the figure.

54. Where to Use Guys.—According to an article in the "Telephone Magazine," May, 1900, the following general suggestions should be followed in guying pole lines:

On straight lines carrying one cross-arm, a head guy and a side guy should be placed at least once in every mile. On lines carrying two cross-arms and more than 10 wires, double head guys and double side guys should be placed at least once in every mile. On lines carrying three cross-arms and more than 30 wires, double head guys and double side guys should be placed every half mile. On lines carrying four cross-arms and more than 40 wires, double head guys and double side guys should be placed every quarter of a mile, and additional side guys should be used wherever it is considered necessary. The pole at the beginning of each curve should be head guyed and side guyed, and also such other poles on the curve as may be deemed necessary. An additional pole should be set within 75 feet of a terminal pole. The terminal pole should be head guyed in both directions and the additional pole head guyed to the terminal pole, if necessary. Head guys should be placed on at least three poles before turning a corner.

55. Anchor Poles. — Where an overhead line ends, it is necessary to thoroughly anchor the last pole in order to counteract the strain brought upon it by the line wires, which in this case will be all in one direction. These strains are frequently very great, so much so that it is sometimes a very difficult problem to provide means to adequately stand them. In some cases, structural-iron poles are built especially for the purpose, these being cross-braced by means of iron latticework and thoroughly set, deep in the ground, in a large bed of concrete. This method, however, is very expensive, poles of this type costing from $150 to $800, according to the conditions to be met. A cheaper pole, and one

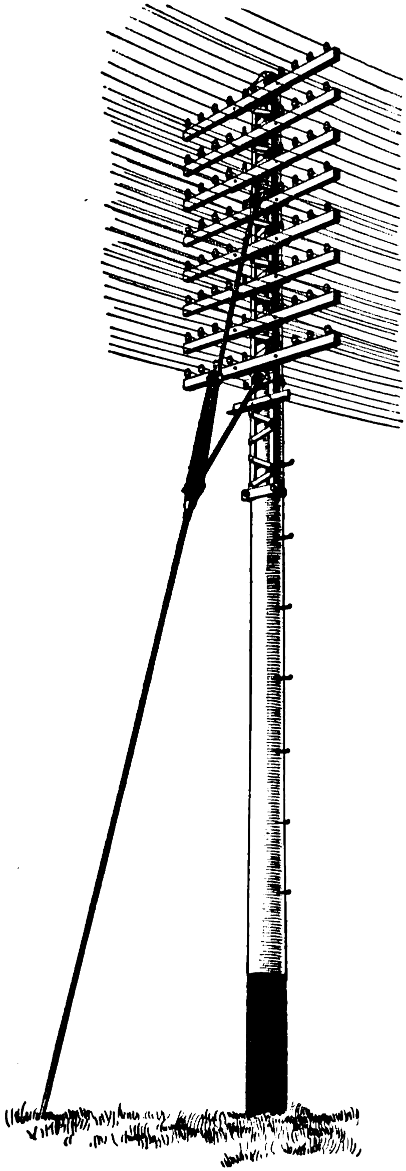


FIG. 30.

that, although much more expensive than the ordinary one, is far less expensive than the structural-iron pole, is a composite pole such as is shown in Fig. 30. This consists of a very heavy wooden pole braced at the top by means of an iron lattice-work upon which the cross-arms are mounted and to which the heavy iron guy rods are fastened, as shown.

A pole of this kind may be designed for meeting almost any strains that can be placed upon it. The particular pole shown was of Norway pine, 70 feet long, 16 inches in diameter at the top and 22 inches at the butt, and set 10 feet below the surface. It was designed to carry 100 wires and 4 cables, all being dead-ended at this point. The lattice-work at the top was built of two 3″ × 7″ steel angle irons connected together by diagonal lattice pieces. At intervals of 16 inches, 3″ × 4″ angle irons were set, upon which the cross-arms were mounted. This lattice is secured to the

pole by means of U-shaped bands to which the two branches of the guy rod are attached. The manner of setting this pole in the ground is shown in Fig. 31. A heavy oak platform

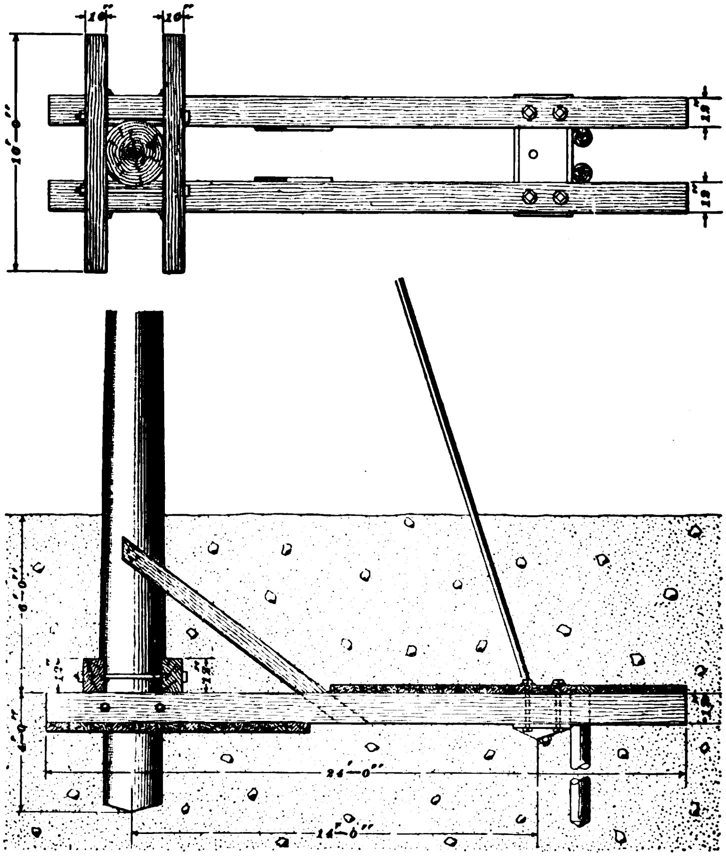


FIG. 31.

is built around the base of the pole, as shown, and afterwards covered with earth or stone. The object of the latticework is to relieve the pole of all bending strain. The pole itself serves only to receive the downward component of the forces acting upon it, while the tension in the line wires and cables is taken entirely by the heavy wrought-iron

guy rod. Where poles of this description are used, it is of great importance that adequate measures shall be taken to prevent it from rotting, and, therefore, it is well to thoroughly coat the butt and the entire underground woodwork with tar.

The more expensive forms of anchor pole, such as have been described, are usually necessary only in cities. Where the lines are not too heavy and where sufficient room may be had for planting a guy anchor, the method shown in Fig. 32 is used. The end pole is made very heavy and is set

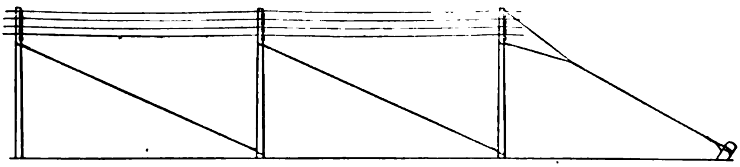


FIG. 32.

deep in the ground and heavily guyed by a **Y** guy to a guy stub or any other available anchor. Each of the next five or six poles are then head guyed in a direction to resist the strain, thus all bearing a share of the excessive strain due to the wires.

56. Extra Strong Line.—In certain sections of the country, where severe sleet storms break down the poles and wires, causing great interruption to the telegraph service and heavy expense for repairs, the following construction has been suggested by Mr. K. McKenzie in a paper read before the Association of Railway Telegraph Superintendents:

Two poles should be set where now one is used. The poles should be set 6 feet apart at the bottom, brought together at the top, and bolted firmly together with a bolt ½ inch in diameter, with the nut on the end screwed up tight. The cross-arms should be fastened to both poles with ½-inch bolts with a nut on the end. One bolt in each cross-arm should be sufficient and no braces would be required. The poles should be further strengthened by braces bolted on diagonally to both poles. On heavy curves, the outside pole should have a guy down to an anchor of

the same kind of wood as the pole, so their lives would be the same. The reason for guying the poles on curves to anchors is to prevent the poles from pulling out of the ground, as they frequently do when braced. When two poles are used, they need not be as heavy as when one pole is used. For instance, a single pole 7 inches at the top may be replaced by two poles 5½ inches at the top.

RECONSTRUCTION.

57. The following information on reconstructing telegraph lines is abstracted from a paper read before the Association of Railroad Telegraph Superintendents in 1899, by Mr. C. H. Bristol:

If it can be done, it is well to set all poles and anchors before handling the wires, as it gives the poles time to become settled before climbing them, and also insures the presence of the foreman with all the men. If the party is divided, the foreman cannot watch both the setting of the poles and the handling of the wires. Where possible to do so, poles should be located so as to give room enough between them and the fence to carry a reel.

58. Pulling Up Poles.—Moving or resetting poles with a number of wires on them can be accomplished without removing the wires by using a roller 8 to 10 inches in diameter (made of a piece of old pole), a chain of ½- or ⅝-inch round links, and a couple of pulling-bars. The chain is fastened around the pole and passed around the roller, which is used as a horizontal capstan. Then, with the bars inserted in holes previously made in the roller, turn the latter, having one man to hold the slack in the chain as it comes to him from the roller. The roller should lie close to the pole and is raised off the ground by placing it on two old cross-arms, or any pieces of timber that will keep it clear so that it can be readily turned by the bars. In this way, a large pole can be lifted with very little digging around it and it is much cheaper than taking the poles down, or attempting to pull

them up with bars. It also avoids the damage to poles that the pulling-bar causes if the poles are large or carry many wires. This is also a good plan when resetting a line of poles, as all the old stumps can be pulled out and the hole thus utilized at much less expense than digging a new hole.

59. The **handling of wires** on reconstruction has undergone many changes in late years. It is not now considered necessary to restring or pull the slack out of all wires when transferred from old to new poles; as a matter of fact, it is much better for the wires that it should not be done. It has been proved that wires too tightly drawn are a detriment rather than an advantage, and where they are no longer pulled tight, there are many less breaks and joints. The expense of handling wires on reconstruction is said to be reduced one-half where this plan is adopted.

60. **Joints** in the iron wire are now made in reconstruction work by using a third piece of wire; this third piece adds much strength to the joint and often prevents breaks caused by soldering. It should extend out on the main wire at each end of the joint at least two turns beyond the main wire. Joints made in this way will stand one-half more strain than those made of the two ends only. Iron wire joints should always be soldered. When simply repairing a line, the lineman, with very few exceptions, will never solder a joint that he makes, although it should certainly be done.

61. Moving Wires Without Interrupting the Service.—When right of way permits, it is a good plan to locate a new line 10 feet away from the old one, as it facilitates the transfer of wires from the old to the new poles, and gives sufficient room to avoid a great amount of trouble with the wires, which is a matter of much importance in these days of busy wires, in both commercial and train service.

There are many lines where railway right of way is narrow, and two lines of poles must necessarily stand close together and often cross each other. In such cases. it is

much better to use a cable, temporarily, and cut the line wires "dead." Thus, they can be worked faster and the time gained will offset the labor of handling the cable. In many instances, it is impracticable to handle wires and operate them at the same time.

62. Linemen.—The lineman should be so stationed that he can get out on the line with as little delay as possible. He should inspect all his wires at least once a week and should carefully examine each office at least once a month, and make a report on the latter to the telegraph superintendent. Brush, tree limbs, and foliage should be kept entirely clear of the wires. The lineman should be thoroughly impressed with the idea that the insulation must always be kept in good condition.

The superintendent of telegraph, or his assistant, should make frequent irregular trips over the lines and note their condition. The best of linemen usually need supervision, and if they know that the line is inspected at irregular periods, they will be more careful to have the wires in good condition at all times.

63. Telephones for Linemen.—Since linemen, as a rule, do not understand the Morse code, it has always been very difficult to hold communication between them and the telegraph stations when they are at work on deranged lines, and especially when the trouble is remote from the nearest station; therefore, some other method of communication is often greatly needed.

If the line is not in use, a compact telephone set, such as can readily be obtained, and is often used by telephone linemen, is very useful. The station and lineman's telephones are simply connected between the line and the ground, or between two line wires. If the line is in use, it is still possible to telephone over it by connecting a condenser of 2 or 3 microfarads capacity between each telephone set and the line. The telephones and condensers may be connected in series across two line wires instead of between one line wire and the ground.

INSULATORS.

64. Insulators in this country are usually made of glass, while in Europe porcelain is more commonly used. When new, porcelain is a better insulator than glass, but it is more expensive, and, under the action of cold, the glazed surface becomes cracked. When this happens, the moisture soaks into the interior structure, and its insulating quality is greatly impaired. Tests, recently made by Mr. F. W. Jones, electrical engineer of the Postal Telegraph Company, have shown that, when newly put up, the insulation resistance of porcelain insulators is from 4 to 8 times better than glass, but that along railroads and in cities smoke forms a thin film upon each material, so that at the end of a few months their insulating properties are nearly alike. On country roads, away from railroad tracks, the porcelain insulators maintain a higher insulation than the glass during rain storms, but in fine weather it is not so high. Porcelain has an advantage over glass in that it is not so brittle and therefore less likely to break when subjected to mechanical shocks, such, for instance, as being hit with stones by schoolboys and with bullets by hunters, who make targets of them. Porcelain does not condense and retain on its surface a thin film of moisture so readily as glass, i. e., it is less hygroscopic. On the other hand, however, glass insulators are not subject, to such an extent as porcelain, to the formation of cocoons and cobwebs under them, the transparency of the glass serving to allow sufficient light to pass through the insulator to render it an undesirable abode for spiders and worms. As cocoons, cobwebs, etc. serve to lower the insulation of the line to a great extent, this is an advantage that in this country it is not well to overlook.

65. As a rule in this country, the defective insulation due to the use of glass insulators is one of the smallest of the difficulties encountered in working telegraph lines. On turnpikes, the working is far more seriously impeded by the contact of tree limbs with the wires during the spring and summer, owing to the impossibility of securing the consent

of farmers to properly trim the trees. Trees may have been trimmed so that their limbs are perfectly clear of the wires in dry weather, yet, when loaded with moisture, the branches are so bent as to interfere with the service more or less until the moisture has been evaporated by the wind and sun.

66. The form of insulator shown in Fig. 10 and in Fig. 33 (*c*) is much used in telegraph and somewhat in

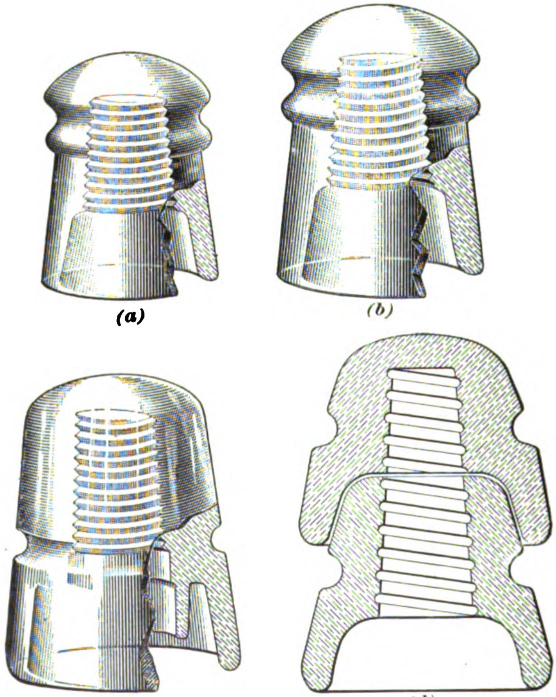


FIG. 33.

telephone work. It weighs 22 ounces and is bell-shaped, with an interior thread and a double petticoat. The object of the double petticoat is to form a long path over which leakage currents from the line must pass before they reach the pin, and to keep the pin as dry as possible. The resistance of insulators follows the same law as the resistance of conductors. The longer the path afforded and the less the

cross-section of the path, the greater is the resistance that the insulator will offer to leakage currents from the line. Hence, the length of the insulating surface, measured from the groove in which the wire rests, down the outside surface, and up the inside surface, to the contact surface between the insulator and pin, should be as great as possible. Furthermore, the diameter of the insulator, both external and internal, should be as small as is consistent with its strength, for the smaller this diameter, the narrower will be the conducting film, and the greater its resistance.

The conducting path is over 20 per cent. longer on the double-petticoat insulator, Fig. 33 (*c*), than on the single-petticoat insulator, Fig. 33 (*b*), although the double-petticoat is a little larger in diameter. Furthermore, since a large part of the conducting surface on the double-petticoat insulator is underneath, it is sheltered and protected from the falling rain. On the other hand, the single-petticoat insulator seems to dry off quicker after the rain is over. All things considered, the double-petticoat insulator seems to be the better for telegraph lines. The double-petticoat and single-petticoat insulators, shown in Fig. 33 (*b*) and (*c*), are the most common forms used on telegraph lines in this country. An excellent double-petticoat porcelain insulator is made in Germany and is extensively used there and in other countries, but not in the United States.

67. Pony and Hibbard Insulators.—A form of insulator shown in Fig. 33 (*a*) and known as the **pony insulator** is much used for telephone lines, where No. 12 B. & S. hard-drawn copper wire is used. While not having such a high resistance as the double-petticoat insulator, still it dries quicker after a rain, and, on the whole, gives good satisfaction for telephone-line work. In Fig. 33 (*d*) is shown the Hibbard transposition insulator used by the Bell companies, where the telephone lines are transposed. There is also a good transposition insulator made in one piece. Transposition insulators are necessarily large and somewhat heavy, generally requiring specially large and heavy pins.

WIRES FOR TELEGRAPH USE.

68. Sizes of Wire.—Before considering the advantages and disadvantages of the various kinds of wire, it will be necessary to discuss the different methods by which the sizes of wire are designated. Unfortunately, various standards of wire gauges have been adopted by different manufacturers, the result being a lack of unity in this direction, which frequently causes confusion.

69. Circular Measure.—The best method of designating the size of a wire is to express its diameter in *mils*, and its cross-sectional area in *circular mils*.

70. A **mil** is a unit of length used in measuring the diameter of wires, and is equal to $\frac{1}{1000}$ inch; that is, 1 mil = .001 inch.

71. A **circular mil** is a unit of area. If the diameter of a wire is given in mils, the square of this diameter gives its cross-sectional area in circular mils. This method of expressing the area of cross-section of a wire is chosen in preference to expressing it in square inches, because a very simple relation exists between the circular mil and the diameter of a wire, so that either is more easily determined from the other than if the area were expressed in square inches.

The area of any circle in square measure is equal to

$$\pi r^2 = \tfrac{1}{4}\pi d^2,$$

where r is the radius and d the diameter of the circle.

If d is expressed in inches, the area $\frac{1}{4}\pi d^2$ will be in square inches. If d is in mils, the area will be in square mils. The area of a circle 1 mil in diameter is $\frac{1}{4}\pi \times 1^2 = \frac{\pi}{4}$ square mil; and, conversely, 1 square mil $= \frac{4}{\pi}$ circular mils. The area of any circle in circular mils will be equal to the area of that circle in square mils multiplied by the number of circular mils in 1 square mil; thus, the area of a circle

d mils in diameter, expressed in circular mils (C. M.), is equal to $A = \frac{\pi d^2}{4} \times \frac{4}{\pi} = d^2$.

From this we see that the area of any circle expressed in circular mils is equal to the square of the diameter expressed in mils, or

$$A \text{ (in C. M.)} = d^2. \qquad (1.)$$

EXAMPLE 1.—What is the area in circular mils of a round wire having a diameter of .46 inch?

SOLUTION.— .46 inch = 460 mils. Since the area in mils is equal to the square of the diameter in mils, we have

$$460 \times 460 = 211,600 \text{ circular mils. Ans.}$$

EXAMPLE 2.—Find the area of a round copper rod having a diameter of $\frac{3}{16}$ inch.

SOLUTION.— $\frac{3}{16}$ inch = 187.5 mils.

$$187.5 \times 187.5 = 35,156.25 \text{ circular mils. Ans.}$$

72. If we know the area of a wire in circular mils, we may obtain the diameter in mils by extracting the square root of its area in circular mils.

EXAMPLE.—What is the diameter of a wire having a cross-sectional area of 1,021.5 circular mils?

SOLUTION.— $\sqrt{1,021.5} = 31.961$ mils = .031961 inch. Ans.

73. As has been stated, various manufacturers have adopted different standards by which they designate the various numbers of their wires. These are usually termed **wire gauges,** and in each gauge a particular number refers to a wire having a certain diameter. The size of wire generally decreases as the gauge number increases, but the law by which this decrease occurs is not the same in the different gauges.

74. Brown & Sharpe, or American, Gauge.— This gauge is usually termed B. & S., and in the United States, copper wire is usually designated according to it. The rule by which the sizes of wire increase as the gauge number diminishes is a very simple one in this gauge, and, considering this simplicity, it is surprising that so few people understand it. If we take any gauge number as a basis of

comparison, then, by adding 3 to the gauge number, we obtain the number of a wire having very nearly ½ the cross-sectional area. To illustrate: One No. 7 wire will have the same cross-sectional area as two No. 10's, as four No. 13's, as eight No. 16's, and so on. Similarly, by subtracting 3 from any gauge number, we obtain the number of a wire having very nearly twice the cross-sectional area. Thus, one No. 1 has twice the area of a No. 4; one No. 10 has twice the area of a No. 13. A little study will show that the ratio between the area of each wire and the next smaller or larger is equal to the cube root of 2, or 1.26; for, in order to obtain the size of a wire of twice the area of a given wire, we must multiply the area of the given wire by the ratio three times, therefore the cube of the ratio must be equal to 2.

75. From the foregoing we may deduce the following rules, remembering that the resistance of a wire varies inversely as its cross-sectional area:

Rule I.—*The ratio between the resistance of any wire in the B. & S. gauge and that of the next higher number is that of 1 to 1.26.*

Rule II.—*The ratio between the resistance of any wire in the B. & S. gauge and that of the next lower number is that of 1.26 to 1.*

76. A wire three sizes smaller than a given wire will have a resistance twice as great, and a wire three sizes larger will have a resistance one-half as great, as that of the given wire.

Example 1.—Find the resistance of 1,000 feet of No. 16 B. & S. gauge copper wire, having given that the resistance of 1,000 feet of No. 10 wire is 1 ohm.

Solution.—No. 16 is six sizes smaller than No. 10, and will therefore have $2 \times 2 = 4$ times the resistance. $4 \times 1 = 4$ ohms. Ans.

Example 2.—The resistance of a No. 12 B. & S. gauge copper wire is 8.37 ohms per mile. What is the resistance (*a*) of a mile of No. 11? (*b*) of a mile of No. 13?

Solution.—(*a*) $8.37 \div 1.26 = 6.64$ ohms. Ans.
(*b*) $8.37 \times 1.26 = 10.54$ ohms. Ans.

TABLE 6.

DIFFERENT STANDARDS FOR WIRE GAUGE IN USE IN THE UNITED STATES.

(*Dimensions of Wires in Decimal Parts of an Inch.*)

Number of Wire Gauge.	American, or Brown & Sharpe. (B. & S.)	Birmingham, or Stubs. (B. W. G.)	Washburn & Moen M'f'g Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	G. W. Prentiss, Holyoke, Mass.	Old English, From Brass Mfrs' List.	British Standard. (S. W. G.)	Number of Wire Gauge.
000000			.4600					000000
00000			.4300	.4500				00000
0000	.460000	.454	.3930	.4000				0000
000	.409640	.425	.3620	.3600	.3586			000
00	.364800	.380	.3310	.3300	.3282			00
0	.324860	.340	.3070	.3050	.2994			0
1	.289300	.300	.2830	.2850	.2777			1
2	.257630	.284	.2630	.2650	.2591			2
3	.229420	.259	.2440	.2450	.2401			3
4	.204310	.238	.2250	.2250	.2230		.2320	4
5	.181940	.220	.2070	.2050	.2047		.2120	5
6	.162020	.203	.1920	.1900	.1885		.1920	6
7	.144280	.180	.1770	.1750	.1758		.1760	7
8	.128490	.165	.1620	.1600	.1605		.1600	8
9	.114430	.148	.1480	.1450	.1471		.1440	9
10	.101890	.134	.1350	.1300	.1351		.1280	10
11	.090742	.120	.1200	.1175	.1205		.1160	11
12	.080808	.109	.1050	.1050	.1065		.1040	12
13	.071961	.095	.0920	.0925	.0928		.0920	13
14	.064084	.083	.0800	.0800	.0816	.08300	.0800	14
15	.057068	.072	.0720	.0700	.0726	.07200	.0720	15
16	.050820	.065	.0630	.0610	.0627	.06500	.0640	16
17	.045257	.058	.0540	.0525	.0546	.05800	.0560	17
18	.040303	.049	.0470	.0450	.0478	.04900	.0480	18
19	.035890	.042	.0410	.0400	.0411	.04000	.0400	19
20	.031961	.035	.0350	.0350	.0351	.03500	.0360	20
21	.028462	.032	.0320	.0310	.0321	.03150	.0320	21
22	.025347	.028	.0280	.0280	.0290	.02950	.0280	22
23	.022571	.025	.0250	.0250	.0261	.02700	.0240	23
24	.020100	.022	.0230	.0225	.0231	.02500	.0220	24
25	.017900	.020	.0200	.0200	.0212	.02300	.0200	25
26	.015940	.018	.0180	.0180	.0194	.02050	.0180	26
27	.014195	.016	.0170	.0170	.0182	.01875	.0164	27
28	.012641	.014	.0160	.0160	.0170	.01650	.0148	28
29	.011257	.013	.0150	.0150	.0163	.01550	.0136	29
30	.010025	.012	.0140	.0140	.0156	.01375	.0124	30
31	.008928	.010	.0135	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0130	.0120	.0136	.01125	.0108	32
33	.007080	.008	.0110	.0110	.0130	.01025	.0100	33
34	.006305	.007	.0100	.0100	.0118	.00950	.0092	34
35	.005615	.005	.0095	.0095	.0109	.00900	.0084	35
36	.005000	.004	.0090	.0090	.0100	.00750	.0076	36
37	.004453		.0085	.0085	.0095	.00650	.0068	37
38	.003965		.0080	.0080	.0090	.00575	.0060	38
39	.003531		.0075	.0075	.0083	.00500	.0052	39
40	.003145		.0070	.0070	.0078	.00450	.0048	40
41							.0044	41
42							.0040	42

EXAMPLE 3.—The resistance of a No. 00 B. & S. gauge copper conductor is .411 ohm per mile. What is the resistance of a similar conductor of No. 3 gauge?

SOLUTION.—The third size smaller than No. 00 is No. 2. The resistance of No. 2 per mile is, therefore, $2 \times .411 = .822$ ohm. The resistance of No. 3 is 1.26 times that of No. 2, or $.822 \times 1.26 = 1.036$ ohms. Ans.

77. It is a very convenient fact to remember that the diameter of a No. 10 wire in the B. & S. gauge is very close to $\frac{1}{10}$ of an inch (.10189), and that its resistance per thousand feet is practically 1 ohm (1.0199). For rough values, one can, by remembering these facts, compute the resistance in cross-sectional area of any other size in the B. & S. gauge without using the table. For accurate calculations, however, it is always better to consult a table giving the various properties of different sizes.

78. Other Wire Gauges.—Besides the Brown & Sharpe gauge, the following have been or are used to a considerable extent: Birmingham, or Stubs', wire gauge, abbreviated to B. W. G.; Washburn & Moen Manufacturing Company's gauge; Trenton Iron Company's gauge; G. W. Prentiss' gauge; British Standard wire gauge, abbreviated S. W. G., and the old English gauge. Table 6 shows the diameters of the wires of the different gauge numbers according to each of these standards.

CONDUCTIVITY.

79. The **specific resistance of a conductor** is the resistance between the opposite faces of a cube 1 centimeter square of the given substance at a temperature of 0° C., or 32° F. Table 7 gives the resistances of the more common metals in microhms, or millionths of an ohm, per cubic centimeter, at a temperature of 0° C.

80. The **specific conductivity of a conductor** is the reciprocal of its specific resistance.

TABLE 7

SPECIFIC RESISTANCE OF CONDUCTORS IN INTERNATIONAL OHMS.

Conductor.	Specific Resistance. Microhms per Cubic Centimeter at 0° C.	Resistance of 1 Mil-Foot.		Temperature Coefficient per Degree Centigrade.	Percentage Conductivity.
		0° Cent. 32° Fahr.	24° Cent. 75° Fahr.		
Copper, annealed	1.594	9.59	10.507	.00388	100.00
Copper, hard drawn	1.629				97.80
Silver, annealed	1.500	9.40	10.160	.00380	106.00
Silver, hard drawn	1.629				
"E. B. B." iron	9.750	58.60	65.300	.00463	16.20
"B. B." iron			78.500		13.50
Steel (wire)			90.800		11.60
Aluminum	2.889	17.75	19.400	.00390	54.50
Lead	19.630	115.50	129.000	.0050(?)	8.20
Mercury	94.070	600.00	613.000	.00089	1.73
German silver	20.760	126.00	127.200	.00040	8.30
Gold, annealed	2.053				
Platinum, annealed	9.031				
Zinc, pressed	5.610				
Nickel, annealed	12.440				
Antimony, pressed	35.400				
Bismuth, pressed	130.800				
Tin, pressed	13.170				

81. The **percentage conductivity of a conductor** is the ratio that its specific conductivity bears to that of some standard conductor, usually pure copper, the conductivity of the latter being taken as 100

82. The **percentage conductivity of a wire** is the ratio the conductivity of that wire bears to the conductivity of a *pure copper* wire at the same temperature and of the same length and weight, the conductivity of the latter being taken as 100. The percentage conductivity is frequently

used in specifications as to the quality of copper wire, it being a frequent requirement that the wire shall have a conductivity equal to 98 per cent. that of pure copper.

83. The Mile-Ohm.—A convenient standard for expressing the conducting quality of wires of a given metal, regardless of the size of the wires, is what is commonly termed the **mile-ohm,** or, more properly, the **weight per mile-ohm.** When the weight per mile-ohm of a certain quality of metal is referred to, the weight of a circular wire 1 mile long and of such a size as to have a resistance of 1 ohm is meant. Obviously, the better the conducting quality of the metal, the smaller will be the weight per mile-ohm, for a wire a mile long having a resistance of 1 ohm will be of smaller diameter if the metal is a good conductor than if it is a poor conductor.

It is not uncommon to say that the weight per mile-ohm of a certain grade of copper wire is, say, 888 pounds at a temperature of 60°, or that the weight per mile-ohm of a certain grade of iron wire is 6,500 pounds. These expressions mean, in the first case, that a wire made of this grade of copper, 1 mile long, having a resistance of 1 ohm, would weigh 888 pounds, and in the second case, that the wire made of that grade of iron, 1 mile long, and having a resistance of 1 ohm, would weigh 6,500 pounds.

84. The weight per mile-ohm of a metal forms a convenient basis for determining the percentage conductivity; for, since the weight of a given wire varies as its cross-section, and since the conductivity varies directly as the cross-section, it follows that the conductivity of two wires will be inversely proportional to their respective weights per mile-ohm. Thus, if we know that the weight per mile-ohm of pure copper at 60° F. is 871 pounds, while the weight per mile-ohm of a sample is 888 pounds, then the percentage conductivity may be found from the following proportion, remembering that the conductivity of pure copper is 100:

$$x : 100 :: 871 : 888,$$

or
$$x = \frac{871}{888} \times 100 = 98.08,$$

where x is the percentage conductivity.

85. If we know the resistance per mile of a given wire, and also the weight per mile-ohm of that metal, then we may determine the weight of the wire per mile by dividing the weight per mile-ohm by the resistance per mile. On the other hand, if the weight per mile is known, the resistance per mile may be ascertained by dividing the weight per mile-ohm by the weight per mile. Thus, an iron wire weighing 204 pounds per mile, made from metal having a weight per mile-ohm equal to 6,500 pounds, will have a resistance equal to

$$\frac{6,500}{204} = 31.86 \text{ ohms}.$$

EXAMPLE 1.—If the weight per mile-ohm of a pure copper wire is 871.17 pounds at 60° F., and the weight per mile-ohm of an iron wire is 4,600 pounds, what is the percentage conductivity of the iron wire, pure copper being taken as a standard?

SOLUTION.—Calling x the percentage conductivity of the iron wire, we have

$$x : 100 :: 871.17 : 4,600;$$

that is,
$$x = \frac{871.17 \times 100}{4,600} = 18.93. \quad \text{Ans.}$$

EXAMPLE 2.—A piece of copper wire 1,000 feet long weighs 31.43 pounds and has a resistance of 1.0199 ohms at a temperature of 60°. What is its percentage conductivity, having given that the weight per mile-ohm of pure copper at 60° is 871.177 pounds?

SOLUTION.—Weight per mile of sample is

$$\frac{31.43 \times 5,280}{1,000} = 165.95 \text{ pounds.}$$

The resistance per mile of sample is

$$\frac{1.0199 \times 5,280}{1,000} = 5.385.$$

The weight per mile-ohm of the sample is equal to the weight per mile times the resistance per mile, or

$$165.95 \times 5.385 = 893.64 \text{ pounds.}$$

The percentage conductivity of the sample is then equal to

$$\frac{871.177 \times 100}{893.64} = 97.48. \quad \text{Ans.}$$

COPPER WIRE.

86. The best wire for telegraph lines is hard-drawn copper, and it is replacing iron wire. However, considerable galvanized-iron wire is still being used. Reference to Table 7 will show that copper has the lowest specific resistance, and, therefore, the greatest specific conductivity, of any metal except silver. This feature alone would tend to make copper the most valuable of metals for electric-transmission purposes, excepting silver, which is but slightly better, and which is unavailable on account of its high cost.

87. Pure annealed copper has a specific gravity of 8.89 at 60° F.; 1 cubic inch of it weighs .32 pound, and its melting point is about 2,100° F. As first manufactured, copper wire did not possess enough tensile strength to well adapt it for line wire, and for that reason and because of its greater expense, it was used but little for that purpose. The process of hard-drawing copper wire has, however, greatly increased its tensile strength without seriously injuring its conductivity.

The weight per mile of a copper wire is given by the formula

$$W = \frac{d^2}{62.5}, \qquad (2.)$$

where d is the diameter in mils and W the weight in pounds per mile.

The resistance per mile in ohms of any pure copper wire at 75° F. is given by the formula

$$R = \frac{56,970}{d^2}, \qquad (3.)$$

where d is the diameter in mils and R the resistance per mile in ohms.

EXAMPLE 1.—What is the weight per mile of a copper wire 80.808 mils in diameter?

SOLUTION.—Weight $= \frac{(80.808)^2}{62.5} = 104.48$ pounds per mile. Ans.

EXAMPLE 2.—What is the resistance per mile (at 75° F.) of a copper wire 102 mils in diameter?

SOLUTION.—Resistance per mile $= \frac{56,970}{(102)^2} = 5.476$ ohms per mile. Ans.

88. Matthiessen's Standard. — Tables giving the resistance of the various sizes of copper wire are usually based on the grade of wire used by Doctor Matthiessen in determining the resistance of copper. The conductivity of the wire used by Matthiessen was at one time the highest known, but copper wire has since been produced having a somewhat higher conductivity. Matthiessen found that a piece of soft copper wire 1 foot long, and having a uniform diameter of .001 of an inch, had a resistance of 9.612 legal ohms at a temperature of 0° C. Such a piece of wire is termed a mil-foot, meaning that its diameter is 1 mil and its length 1 foot. Inasmuch as there are three different standard ohms, the British Association, or B. A., ohm, the legal ohm, and the international ohm, it is well to give the values of Matthiessen's standard in all of them. Table 8 is taken from the report of the Standard Wiring Table Committee of the American Institute of Electrical Engineers, and gives the resistances, at 0° C., not only of the mil-foot, but of the meter-gram, the meter-millimeter, and the cubic centimeter.

TABLE 8.

MATTHIESSEN'S STANDARD.

Dimensions of Standard.	Resistance at 0° C.		
	B. A. Ohms.	Legal Ohms.	International Ohms.
Meter-gram soft copper.......	.143650000	.142060000	.141730000
Meter-millimeter soft copper..	.020570000	.020350000	.020300000
Cubic centimeter soft copper..	.000001616	.000001598	.000001594
Mil-foot soft copper...........	9.720000000	9.612000000	9.590000000

89. Tables 9 and 10 give the resistances and weights for all sizes of copper wire, according to the B. & S. and the B. W. gauges, respectively. These tables are based upon Matthiessen's standard.

TABLE 9.

Gauge No.—B. & S.	Diameter in Mils, or $\frac{1}{1000}$ Inch.	Area in Circular Mils. C. M. = d^2.	Area in Square Inches. Area = $\frac{d^2}{1,000,000} \times .7854$.	Weights—Specific Gravity, 8.89.				Resistance at 68° F., in International Ohms, Based Upon Matthiessen's Standard.				
				Pounds per 1,000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound, Annealed.	Ohms per 1,000 Feet.		Ohms per Mile.		Feet per Ohm, Annealed.
	d	d^2						Pure Annealed.	Hard Drawn.	Pure Annealed.	Hard Drawn.	
0000	460.000	211,600.00	.1661900000	640.50000	3,381.400	1.561	.00007639	.04893	.050036	.25835	.26419	20,440.000
000	409.640	167,805.00	.1317900000	508.00000	2,682.200	1.969	.00012150	.06170	.063094	.32577	.33314	16,210.000
00	364.800	133,079.40	.1045200000	402.80000	2,126.800	2.482	.00019310	.07780	.079558	.41079	.42007	12,850.000
0	324.865	105,534.50	.0828870000	319.50000	1,686.900	3.130	.00030710	.09811	.100330	.51802	.52973	10,190.000
1	289.300	83,694.20	.0657320000	253.30000	1,337.200	3.947	.00048830	.12370	.126490	.65314	.66790	8,083.000
2	257.630	66,373.00	.0521280000	200.90000	1,060.600	4.977	.00077650	.15600	.159530	.82368	.84239	6,410.000
3	229.420	52,634.00	.0413390000	159.30000	841.090	6.276	.00123500	.19670	.201140	1.03860	1.06210	5,084.000
4	204.310	41,742.00	.0327840000	126.40000	667.390	7.914	.00196300	.24800	.253610	1.30940	1.33920	4,031.000
5	181.940	33,102.00	.0259990000	100.20000	529.060	9.980	.00312200	.31280	.319870	1.65160	1.68890	3,197.000
6	162.020	26,250.50	.0206180000	79.46000	419.550	12.580	.00496300	.39440	.403320	2.08250	2.12950	2,535.000
7	144.280	20,816.00	.0163510000	63.02000	332.750	15.870	.00789200	.49730	.508540	2.62580	2.68500	2,011.000
8	128.490	16,509.00	.0129670000	49.98000	263.890	20.010	.01255000	.62710	.641270	3.31110	3.38590	1,595.000
9	114.430	13,094.00	.0102830000	39.63000	209.240	25.230	.01995000	.79080	.808760	4.17530	4.27690	1,265.000
10	101.890	10,381.00	.0081548000	31.43000	165.950	31.820	.03173000	.99720	1.019900	5.26570	5.38480	1,003.000
11	90.742	8,234.00	.0064656000	24.93000	131.630	40.120	.05045000	1.25700	1.285400	6.63690	6.78690	795.300
12	80.808	6,529.90	.0051287000	19.77000	104.390	50.590	.08022000	1.58600	1.621800	8.37410	8.56330	630.700

13	71.961	5,178.40	.0040672000	15.68000	82.791	63.790	.12760000	1.99900	2.044300	10.55500	10.79400	500.100
14	64.084	4,106.80	.0032254000	12.43000	76.191	80.440	.20280000	2.52100	2.577900	13.31100	13.61200	396.600
15	57.068	3,256.70	.0025579000	9.85800	52.050	101.400	.32250000	3.17900	3.250800	16.78500	17.16500	314.500
16	50.820	2,582.90	.0020285000	7.81800	41.277	127.900	.51280000	4.00900	4.099600	21.16800	21.64600	249.400
17	45.257	2,048.20	.0016087000	6.20000	32.736	161.300	.81530000	5.05500	5.169200	26.69100	27.29400	197.800
18	40.303	1,624.30	.0012757000	4.91700	25.960	203.400	1.29600000	6.37400	6.518300	33.65500	34.41600	156.900
19	35.890	1,288.10	.0010117000	3.89900	20.595	256.500	2.06100000	8.03800	8.219600	42.44100	43.40000	124.400
20	31.961	1,021.50	.0008023100	3.09200	16.324	323.400	3.27800000	10.14000	10.372000	53.53900	54.74900	98.660
21	28.462	810.10	.0006362600	2.45200	12.946	407.800	5.21200000	12.78000		67.47900		78.240
22	25.347	642.40	.0005045700	1.94500	10.268	514.200	8.28700000	16.12000		85.11400		62.050
23	22.571	509.45	.0004001500	1.54200	8.142	648.400	13.18000000	20.32000		107.29000		49.210
24	20.100	404.01	.0003173300	1.22300	6.457	817.600	20.95000000	25.63000		135.53000		39.020
25	17.900	320.40	.0002516600	.96990	5.121	1,031.000	33.32000000	32.31000		170.59000		30.950
26	15.940	254.10	.0001995800	.76920	4.061	1,300.000	52.97000000	40.75000		215.16000		24.540
27	14.195	201.50	.0001582700	.61000	3.221	1,639.000	84.23000000	51.38000		271.29000		19.460
28	12.641	159.79	.0001255100	.48370	2.554	2,067.000	133.90000000	64.79000		242.09000		15.430
29	11.257	126.72	.0000995360	.38360	2.025	2,607.000	213.00000000	81.70000		431.37000		12.240
30	10.025	100.50	.0000789360	.30420	1.606	3,287.000	338.60000000	103.00000		543.84000		9.707
31	8.928	79.70	.0000625990	.24130	1.274	4,145.000	538.40000000	129.90000		685.87000		7.698
32	7.950	63.21	.0000496430	.19130	1.010	5,227.000	856.20000000	163.80000		864.87000		6.105
33	7.080	50.13	.0000393680	.15170	.801	6,591.000	1,361.00000000	206.60000		1,090.80000		4.841
34	6.305	39.75	.0000312210	.12030	.635	8,311.000	2,165.00000000	260.50000		1,375.50000		3.839
35	5.615	31.52	.0000247590	.09543	.504	10,480.000	3,441.00000000	328.40000		1,734.00000		3.045
36	5.000	25.00	.0000196350	.07568	.400	13,210.000	5,473.00000000	414.20000		2,187.00000		2.414
37	4.453	19.83	.0000155740	.06001	.317	16,660.000	8,702.00000000	522.20000		2,757.30000		1.915
38	3.965	15.72	.0000123450	.04759	.251	21,010.000	13,870.00000000	658.50000		3,476.80000		1.519
39	3.531	12.47	.0000097923	.03774	.199	26,500.000	22,000.00000000	830.40000		4,384.50000		1.204
40	3.145	9.89	.0000077634	.02993	.158	33,410.000	34,980.00000000	1,047.00000		5,528.20000		.955

TABLE 10.

COPPER WIRE—BIRMINGHAM WIRE GAUGE.

Gauge No. (B. W. G.)	Diameters in Mils, or $\frac{1}{1000}$ Inch.	Area in Circular mils. C. M. = d^2.	Weights.		Resistances in International Ohms, Based Upon Matthiessen's Standard at 68° F.	
			1,000 Feet.	Mile.	Ohms per 1,000 Feet.	Ohms per Pound.
0000	454	206,116	624.000	3,294.000	.05023	.00008051
000	425	180,625	547.000	2,887.000	.05732	.00010480
00	380	144,400	437.000	2,308.000	.07170	.00016400
0	340	115,600	350.000	1,847.000	.08957	.00025600
1	300	90,000	272.000	1,438.000	.11500	.00042230
2	284	80,656	244.000	1,289.000	.12840	.00052580
3	259	67,081	203.000	1,072.000	.15430	.00076010
4	238	56,644	171.000	905.000	.18280	.00106600
5	220	48,400	146.000	773.000	.21390	.00146000
6	203	41,209	125.000	659.000	.25130	.00201400
7	180	32,400	98.000	518.000	.31960	.00325800
8	165	27,225	82.000	435.000	.38030	.00461500
9	148	21,904	66.000	350.000	.47270	.00712900
10	134	17,956	54.000	287.000	.57660	.01061000
11	120	14,400	44.000	230 000	.71900	.01650000
12	109	11,881	36.000	190.000	.87150	.02423000
13	95	9,025	27.300	144.000	1.14700	.04199000
14	83	6,889	20.800	110.000	1.50300	.07207000
15	72	5,184	15.700	83.000	1.99700	.12730000
16	65	4,225	12.800	68.000	2.45100	.19160000
17	58	3,364	10.200	54.000	3.07800	.30230000
18	49	2,401	7.300	38.400	4.31200	.59330000
19	42	1,764	5.300	28.200	5.87000	1.09900000
20	35	1,225	3.700	19.600	8.45200	2.27900000
21	32	1,024	3.100	16.400	10.11000	3.26200000
22	28	784	2.400	12.500	13.21000	5.56500000
23	25	625	1.900	10.000	16.57000	8.75600000
24	22	484	1.500	7.700	21.39000	14.60000000
25	20	400	1.200	6.400	25.88000	21.38000000
26	18	324	.980	5.200	31.96000	32.58000000
27	16	256	.770	4.100	40.45000	52.19000000
28	14	196	.590	3.100	52.83000	89.04000000
29	13	169	.510	2.700	61.27000	119.80000000
30	12	144	.440	2.300	71.90000	165.00000000
31	10	100	.300	1.600	103.50000	342.00000000
32	9	81	.250	1.300	127.80000	521.30000000
33	8	64	.190	1.020	161.80000	835.10000000
34	7	49	.150	.780	211.30000	1,425.00000000
35	5	25	.076	.400	414.20000	5,473.00000000
36	4	16	.048	.256	647.10000	13,360.00000000

90. Temperature Coefficient.—The temperature coefficient for pure copper is .0021 for a change of 1° F. This figure is exact enough for a correction to 60° or 75° F., that is, for all ranges of temperature that are likely to occur in the testing room; but for ranges below 50° F., or above 100° F., it is better to consult a table. Table 11 gives the constants by which the resistance of a copper conductor (at the observed temperature) must be multiplied to correct its resistance to 75° F.

TABLE 11.

Temperature. Degrees F.	Factor.	Temperature. Degrees F.	Factor.	Temperature. Degrees F.	Factor.	Temperature. Degrees F.	Factor.
100	.9484	82	.9853	64	1.0236	46	1.0634
99	.9504	81	.9874	63	1.0258	45	1.0657
98	.9524	80	.9895	62	1.0280	44	1.0679
97	.9544	79	.9916	61	1.0301	43	1.0702
96	.9564	78	.9937	60	1.0323	42	1.0725
95	.9585	77	.9958	59	1.0345	41	1.0748
94	.9605	76	.9979	58	1.0367	40	1.0771
93	.9626	75	1.0000	57	1.0389	39	1.0793
92	.9646	74	1.0021	56	1.0411	38	1.0816
91	.9666	73	1.0042	55	1.0433	37	1.0839
90	.9687	72	1.0064	54	1.0455	36	1.0862
89	.9708	71	1.0085	53	1.0478	35	1.0885
88	.9728	70	1.0106	52	1.0500	34	1.0908
87	.9749	69	1.0128	51	1.0522	33	1.0932
86	.9769	68	1.0149	50	1.0544	32	1.0954
85	.9790	67	1.0160	49	1.0567		
84	.9811	66	1.0193	48	1.0589		
83	.9832	65	1.0214	47	1.0612		

EXAMPLE.—The observed resistance of a copper wire is 12.746 ohms at 88° F. What is its resistance at 75° F. ?

SOLUTION.—For 88° F. we find, from Table 11, that the multiplying factor is .9728 ; therefore, 12.746 × .9728 = 12.399 ohms. Ans.

91. Strength of Copper Wire.—Good hard-drawn copper wire will support at least three times its own weight in pounds per mile. Thus, a No. 10 B & S. gauge copper wire weighing 166 pounds per mile will have a breaking strength of 3 × 166 = 498. In making specifications for copper line wire, it is customary to require that it shall have a breaking strength equal to at least 3 times its weight per mile.

TABLE 12.

TENSILE STRENGTH OF COPPER WIRE.

Numbers. B. & S. Gauge.	Breaking Weight in Pounds.		Numbers. B. & S. Gauge.	Breaking Weight in Pounds.	
	Hard-Drawn.	Annealed.		Hard-Drawn.	Annealed.
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

Table 12 gives the tensile strength of the various sizes in the B. & S. gauge of both hard-drawn and annealed copper wire. The breaking strengths of all but the largest sizes in this table were calculated upon the basis that soft wire has a tensile strength of 34,000 pounds per square inch and that the hard-drawn wire has a tensile strength of 60,000 pounds per square inch. The tensile strength per square inch is taken at 50,000 pounds for 0000, 000, and 00, 55,000 pounds for 0, and 57,000 pounds for 1.

92. Mechanical Properties.—In purchasing copper wire in large quantities, certain requirements are made as to the strength and other mechanical properties of the wire. The strength of the various sizes of copper wire should be in accordance with Table 12. All wire should be fully up to the gauge standard and truly cylindrical. The inspector should test the size and roundness of the wire by measuring each end of each coil, and also several intermediate points. A variation of not more than 1½ mils on either side of the specified gauge number should be allowed, and there should not be a variation of more than 1 mil upon opposite diameters at the same point. A sample slightly over 12 inches long should be tested for torsion. This test may be made as follows: The wire is gripped by two vises exactly 12 inches apart. One of the vises should then be slowly revolved, and the number of twists before the rupture of the wire takes place should be counted.

Some companies require that hard-drawn copper wire shall conform to the specifications given in Table 13, which is taken from Roebling's handbook.

The sizes given in the table are the ones in general use for line wires.

93. Durability of Copper Wire.—Aside from its superior conductivity, copper wire possesses another great advantage over iron wire in that it is practically indestructible under ordinary climatic conditions. When the wire is first put up, a thin oxide, or chloride, rapidly forms upon its surface, after which no change whatever takes place.

TABLE 13.

HARD-DRAWN COPPER WIRE.

Number and Gauge.	Diameters in Mils.			Weights per Mile.			Breaking Weights.			Weights of Coils.		Conductivity.		Twists in 6 Inches.	Per Cent. Elongation in 5 Feet.
	Required.	Maximum.	Minimum.	Required.	Maximum.	Minimum.	Actual Required.	Actual Minimum.	Per Square Inch.	Maximum.	Minimum.	Required.	Minimum.		
8 B. W. G.	165.0	166.0	164.0	436.4	441.7	431.1	1,328	1,301	62,100	218	152	97	96	30	1.14
12 S. W. G.	104.0	104.9	103.1	173.4	176.4	170.4	549	538	64,600	219	151	97	96	40	1.00
10 B. & S.	101.9	102.8	101.0	165.0	168.0	162.0	540	519	64,800	218	152	97	96	40	.99
12 B. & S.	80.0	81.2	79.3	102.6	105.7	100.8	334	327	66,500	72	52	97	96	44	.94
14 B. & S.	64.0	65.0	63.0	65.0	67.5	63.0	220	212	68,200			97	96	47	.91

Except in very unusual conditions, where the atmosphere is filled with particularly destructive gases, copper wire will suffer no chemical change even when exposed to the weather for an indefinite time.

IRON WIRE.

94. Iron wire is largely used for telegraph and telephone lines, although it is rapidly being replaced by copper. It weighs 483 pounds per cubic foot and has a specific gravity of 7.73. A cubic inch of iron wire weighs about .28 pound.

95. Grades of Iron Wire.—The various grades of iron wire on the market are termed "Extra Best Best," "Best Best," and "Best." A steel wire is also used which is cheaper and of higher resistance than iron. It has an advantage, however, of possessing greater tensile strength. It should not be used except on short lines, or in special cases where it is desirable to have great tensile strength.

96. The terms designating the grades are used almost indiscriminately, but among conscientious manufacturers they have approximately the following weights per mile-ohm:

TABLE 14

IRON AND STEEL WIRE.

Name of Wire.	Weight per Mile-Ohm.	
	Roebling's Sons Co.	Washburn & Moen.
Extra Best Best	4,700	5,000
Best Best	5,500	6,200
Best	6,000	
Steel	6,500	6,500

Extra Best Best (E. B. B.) is the highest grade iron wire obtainable. As may be seen from the value of the mile-ohm, it stands the highest in conductivity, and besides this, is very uniform in quality, being both tough and pliable.

Best Best (B. B.) is less uniform and tough than the Extra Best Best, but is a fairly good grade of wire. It is often sold, however, by the less reliable manufacturers, as the finest grade.

Best (B.) is a term applied to the poorest grades of wire. It is harder than the better grades, is much more brittle, and has a lower conductivity.

Steel wire is lower in conductivity than any of the grades of iron wire, but possesses a distinct advantage in point of tensile strength. For a short line where long spans are necessary, this wire is sometimes used in preference to iron wire, as its lack of conductivity may not be a great objection in a short line, while its tensile strength may be a decided advantage.

97. Roebling gives the following formulas from which the resistance per mile may be calculated for E. B. B. and B. B. grades of galvanized-iron wire:

$$R \text{ for E. B. B.} = \frac{338,000}{d^2}, \qquad (4.)$$

$$R \text{ for B. B.} = \frac{396,000}{d^2}, \qquad (5.)$$

in which d is the diameter of the wire in mils.

For the resistance of galvanized-steel wire, Roebling gives the following formula:

$$R = \frac{467,000}{d^2}, \qquad (6.)$$

in which d is the diameter in mils.

The constants from which the resistances of galvanized iron and steel wires are calculated vary considerably. Washburn & Moen give for the constants in formulas **4**,

5, and **6,** for their wire, the values 355,000, 440,000, and 462,000, respectively.

For a good quality of iron wire, 360,000 may be used as an average value for the constant.

98. The weight per mile of galvanized iron and steel wire may be calculated from the following formulas:

$$W \text{ for galvanized iron} = d^2 \times .0139, \qquad \textbf{(7.)}$$

$$W \text{ for galvanized steel} = d^2 \times .0140, \qquad \textbf{(8.)}$$

where d is the diameter in mils.

Washburn & Moen give .01408 for E. B. B., B. B., and steel, for the value of the constant in formulas **7** and **8.**

99. Galvanizing.—Iron, as is well known, is very susceptible to corrosion, due to moisture and other elements in the atmosphere, and in order to protect iron wires used in outdoor work, they are covered with a thin film of zinc. This process is called **galvanizing.** In order to render the surface of the iron wire perfectly clean, it is drawn through a vat of hydrochloric acid while hot, and immediately afterwards through a vat of molten zinc, the latter being kept at a uniform temperature of 740° F. by a furnace underneath the containing vessel.

The zinc coating, upon being exposed to the atmosphere, becomes oxidized, and as oxide of zinc is not soluble in water, it forms a protection against moisture. However, when the zinc is exposed to the action of sulphur or chlorine from salt spray or the acid gases in smoke, it is converted into zinc chloride or sulphate, which readily dissolves in water. Under especially adverse conditions, it is impossible to make iron wire last more than a few years, and in some cases a few months, and it is therefore desirable to use copper wire in such cases, as this is practically indestructible.

100. Test of Galvanizing.—In view of the fact that the film of zinc is often so thin or so uneven as not to be effective in producing the desired results, it is always an important matter to test the galvanizing before accepting

any large quantity of wire. For this purpose, several samples of the wire should be taken at random and immersed in a saturated solution of copper sulphate for 1 minute. They should then be wiped dry and clean, and the operation repeated four times. If at the end of the fourth immersion

TABLE 15.

IRON WIRE—BIRMINGHAM WIRE GAUGE.

Number B. W. G.	Diameter in Mils = *d*.	Area in Circular Mils = d^2.	Weight in Pounds.		Breaking Strengths in Pounds.		Resistance per Mile (International Ohms) at 68° F.		
			1,000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	6.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120.40	139.00
18	49	2,401	6.3	33	99	189	140.80	164 80	194.80

there is no appearance of a copper deposit on the wire, the wire remaining *black*, as after the first immersion, the sample is well galvanized. If, however, a deposit of copper does appear on the wire, it is a sign that the zinc has been entirely removed, by combining with the sulphuric acid of

the solution to form zinc sulphate. In this case the wire should be rejected, as it shows that the zinc coating is not thick enough. This is the test required by the Western Union Telegraph Company.

101. Table 15 gives the sizes and principal properties of three grades of galvanized-iron wire. The sizes are according to the Birmingham Wire Gauge, which is the one most commonly used for iron wire.

102. Table 16 contains the results of tests of certain samples of wire of American manufacture. The column headed "Percentage Conductivity" gives the percentages that the conductivities of the various samples bear to the conductivity of pure copper. "Percentage of Elongation" means the percentage of the length a wire will elongate before breaking. The column headed "Relative Breaking

TABLE 16.

Sample Mark and B. W. Gauge.	Mechanical.					Electrical.	
	Weight per Mile, in Pounds.	Percentage of Elongation.	Number of Twists That 6 Inches Will Stand.	Actual Breaking Stress, in Pounds.	Relative Breaking Stress.	Percentage Conductivity.	Resistance per Mile in Ohms, at 60° F.
E. B. B. 12	190.83	11.50	15.00	417.50	11,552.20	14.40	30.50
E. B. B. 8	381.66	17.70	26.50	937.50	12,930.50	17.30	12.67
E. B. B. 11	222.64	17.20	21.50	577.50	13,639.40	15.60	24.20
161 9½	282.80	10.00	26.50	770.00	14,375.90	21.90	16.10
E. B. B. 10	254.44	17.70	28.50	697.50	14,478.10	17.80	18.42
146 9½	287.50	16.00	29.00	832.50	15,288.86	21.90	16.10
E. B. B. 6	508.88	11.40	21.50	1,587.50	16,462.40	17.70	9.21
E. B. B. 9	318.05	19.30	17.50	1,007.50	16,725.10	16.90	15.54
Nashua 8	381.66	15.10	26.50	1,535.00	21,183.00	14.70	15.00
M. S. plain 6	528.00	10.40	19.50	2,137.50	21,375.00	13.50	11.78
443 8	378.10	10.00	31.00	1,635.00	22,301.40	16.50	16.10
A. H. 9½	293.50	16.00	27.50	1,257.50	22,635.00	15.10	22.70

Stress" gives the number of feet of its own length that each sample would be able to sustain.

By referring to Tables 15 and 16, it will be seen that the wires that bear the greatest tensile strain have the poorest conductivity.

103. Specifications.—Iron wire for use on telegraph and telephone lines should conform to the following specifications of the Western Union Telegraph Company:

1. The wire must be soft and pliable, and capable of elongating 15 per cent.. without breaking, after being galvanized.

2. Great tensile strength is not required, but the wire must not break under a less strain than 2½ times its weight, in pounds, per mile.

3. Tests for ductility should be made as follows: The piece of wire will be gripped by 2 vises, 6 inches apart, and twisted. The full number of twists must be distinctly visible upon the 6-inch piece between the vises, and the number of twists must not be less than 15.

4. The weight per mile for the different gauge wires must be: for No. 4 B. W. G., 730 pounds; No. 6, 540 pounds; No. 8, 380 pounds; No. 9, 320 pounds; No. 10, 250 pounds; or as near these figures as practicable.

5. The electrical resistance of the wire in ohms per mile, at a temperature of 68° F., must not exceed the quotient arising from dividing the constant number 4,800 by the weight of the wire, in pounds, per mile. The coefficient .003 will be allowed for each degree (F.) in reducing to standard temperature.

6. The wire must be well galvanized, and capable of standing the tests given in Art. **100.**

MERITS OF COPPER AND IRON WIRES.

104. Iron wire possesses an advantage over copper wire in respect to its first cost, it being much cheaper; but in nearly all other respects, copper is very much superior. In

tensile strength there is little to choose between them, hard-drawn copper being strong enough for all except the most trying conditions.

On a pole line consisting mainly of hard-drawn copper wires, some authorities on line construction advise the use of one or more No. 6 B. W. G. galvanized-iron wires to increase the strength of the system. In durability, copper is far superior; for no matter how well the galvanization of iron wire is done, the zinc coating will eventually allow the corrosion of the iron itself, after which the destruction of the wire is a matter of but a short time. The greatest points in favor of copper, however, are its electrical properties. It has a conductivity six times better than the best grades of iron wire, and over seven times better than the poorer grades.

105. We have seen that the distance over which telegraphic transmission can be accomplished depends, in some manner, on the product of the ohmic resistance of the line and the electrostatic capacity. If either one or both of these properties are increased, transmission will be correspondingly poorer. If an iron wire of the same size as a copper wire is used, the electrostatic capacity of the circuit will be practically the same, but the resistance will be six or seven times higher, and, therefore, the product of electrostatic capacity and resistance will be from six to seven times higher. Manifestly, this is a drawback to the use of iron. If we use an iron wire having the same conductivity as a given copper wire, the iron wire must possess six or seven times as great a cross-sectional area as the copper, and in this case the electrostatic capacity would be much higher, thus increasing the product of the capacity and resistance.

ALUMINUM WIRE.

106. The adaptability of aluminum as a line conductor for telegraph and telephone currents is exciting more and more interest as the price of aluminum is lowered, on account

of the improvements in its methods of production. The following table gives some figures regarding the relative merits of aluminum and copper:

TABLE 17.

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM.

	Aluminum.	Copper.
Conductivity (for equal sizes)	.54 to .63	1
Weight (for equal sizes)	.33	1
Weight (for equal length and resistance)	.48	1
Price—Al., 29c.; Cop., 16c. (bare line wire)	1.81	1
Price—(Equal resistance and length, bare line wire)	.868	1
Temperature coefficient per degree F.	.002138	.002155
Resistance of mil-foot (20° C.)	18.73	10.5
Specific gravity	2.5 to 2.68	8.89 to 8.93
Tensile strength (hard-drawn) per square inch	40,000	60,000
Coefficient of expansion per degree F.	.0000231	.0000093

107. Table 17 shows that copper has a decided advantage in regard to resistance for equal sizes, but aluminum has a great advantage in the matter of weight, an aluminum wire being less than one-third as heavy as a copper wire of the same size. An aluminum wire possesses less than one-half the weight of a copper wire having the same length and resistance, although, of course, in this case the aluminum wire would be considerably larger than the copper. Pound for pound, aluminum at 29 cents per pound is almost twice as expensive as copper at 16 cents, but for two wires of equal resistance and length, the aluminum wire will be over 13 per cent. cheaper than the copper. For equal resistances, the aluminum wire will have a considerable advantage in point of strength as well as of cost.

108. City Electrician E. B. Ellicott, of Chicago, made the following comparative tests on copper and aluminum wires before erecting them, for a durability test, parallel

with railway tracks, where they would be subject to the fumes and smoke of locomotives:

Kind of Wire.	Twists in 6 Inches.	Breaking Weight in Pounds.	Elongation in 5 Feet. Inches.	Weight per Mile in Pounds.
No. 10 hard-drawn copper wire..	55	515	$3\frac{1}{16}$	173
No. 10 aluminum..............	27	275	$1\frac{1}{8}$	$51\frac{1}{2}$

It is interesting to note that, although the copper wire gave greater elongation and number of twists, the breaking weight of the aluminum wire was more than half that of the copper wire of the same size, while the actual weight of the wire was less than one-third.

109. The grades of aluminum wire in Table 18 are those manufactured by the Pittsburg Reduction Company, and Table 19, giving the resistance of pure aluminum wire, is taken from a pamphlet issued by that company.

110. Tying and Joining.—In tying aluminum line wires to the insulators, it is best to use an annealed aluminum wire made for this purpose; for, when tied with too hard a wire, the line wires will become indented, and, consequently, will break under a less strain than if the cross-section had been unimpaired. Aluminum cannot be soldered readily like copper and iron. Furthermore, the soldering of aluminum line wires is not recommended. Those sizes that are used for telegraph and telephone lines can be easily joined by twisting their ends together, as are copper and iron wires.

Aluminum sleeve joints, either McIntire tubes or rolled-up sheet sleeves, can now be obtained from the same manufacturers that make similar sleeves for joining copper wire. Joints of this kind are recommended because they are easily

TABLE 18.

RESISTANCE, TENSILE STRENGTH, AND WEIGHT OF ALUMINUM LINE WIRE.

Grade.	Conductivity. Pure Copper = 100.	Comparative Section of Equal Conductivity. Copper = 100.	Comparative Weight of Same Lengths of Equal Conductivity. Copper = 100.
A 0	62	156.4	47.
A 75	58	167.0	50.2
A 2	54	180.0	54.

No. in B. & S. Gauge.	Diameter in Mils. d.	Circular Mils. d^2.	Area in Square Inches. $\frac{d^2 \times .7854}{1,000,000}$	Grade A 0.		Grade A 75.		Grade A 2.		Pounds per Mile. Sp. Gr. 2.68. Water, 62.355 lb. per Cu. Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given. Grade A 75.
				Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.	Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.	Resistance per 1,000 Feet at 75° F.	Tensile Strength, Pounds per Square Inch.		
4	204.31	41,742.0	.0327840	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	33,102.0	.0259980	.5058	27,500	.5408	34,000	.5818	42,000	159.30	266.4
6	162.02	26,250.5	.0206170	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	20,816.0	.0163490	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	16,509.0	.0129660	1.6340	30,000	1.1050	37,000	1.1870	48,000	79.46	133.2
9	114.43	13,094.0	.0102840	1.2780	32,000	1.3670	39,000	1.4680	50,000	62.99	105.4
10	101.89	10,381.0	.0081532	1.6130	33,000	1.7240	40,000	1.8520	51,000	48.71	83.6
11	90.74	8,234.0	.0064670	2.0330	35,000	2.1730	41,000	2.3350	53,000	39.63	66.3
12	80.81	6,529.9	.0051286	2.5650	39,000	2.7410	42,000	3.0840	55,000	31.43	52.6
13	71.96	5,178.4	.0040671	3.2330		3.4560		3.7120		24.83	
14	64.08	4,106.8	.0031469	4.1790		4.4670		4.7980		19.76	

TABLE 19.

TABLE OF RESISTANCES OF PURE ALUMINUM WIRE.*

Pure aluminum weighs 167.111 pounds per cubic foot. The conductivity of pure aluminum is 60% of the conductivity of pure copper.

Am. Gauge, B. & S. No.	Resistance at 75° F.			
	R Ohms 1,000 Feet.	Ohms per Mile.	Feet per Ohm.	Ohms per Pound.
0000	.08177	.43172	12,229.8000	.00042714
000	.10310	.54440	9,699.0000	.00067022
00	.13001	.68645	7,692.0000	.00108116
0	.16385	.86515	6,245.4000	.00167390
1	.20672	1.09150	4,637.3500	.00272720
2	.26077	1.37637	3,836.2200	.00434410
3	.32872	1.73570	3,036.1200	.00690570
4	.41448	2.18850	2,412.6000	.01097730
5	.52268	2.75970	1,913.2200	.01745600
6	.65910	3.48020	1,517.2200	.02775800
7	.83118	4.38850	1,203.1200	.04413800
8	1.06802	5.53550	964.1800	.07017900
9	1.32135	6.97670	756.7800	.11156100
10	1.66667	8.80000	600.0000	.17467000
11	2.10120	11.09470	475.9080	.28211000
12	2.64970	13.99000	377.4120	.44856000
13	3.34120	17.64200	299.2980	.71478000
14	4.31800	22.80000	231.5820	1.16225000
15	5.19170	27.46200	192.6120	1.76000000
16	6.69850	35.36800	149.2860	2.86670000
17	8.44720	44.60200	118.3800	4.55880000
18	10.65180	56.24200	93.8820	7.24900000
19	13.81480	72.94200	72.3840	12.19160000
20	16.93800	89.43000	59.0406	18.32800000
21	21.35800	112.76700	46.8222	29.14200000
22	26.92000	142.13800	37.1466	46.31600000
23	33.96200	179.32000	29.4522	73.68600000
24	42.82500	226.12000	23.3508	117.17000000
25	54.00000	285.12000	18.5184	186.28000000
26	68.11300	359.65000	14.6814	296.32000000
27	85.86500	453.37000	11.6460	485.56000000
28	108.27700	571.70000	9.2358	749.02000000
29	136.53500	720.90000	7.3242	1,190.97000000
30	172.17000	908.98000	5.8087	1,893.90000000
31	212.12000	1,119.98000	4.7144	2,941.50000000
32	273.97000	1,445.45000	3.6528	4,788.90000000
33	345.13000	1,822.30000	2.8974	7,610.70000000
34	435.38000	2,298.80000	2.2969	12,109.40000000
35	548.92000	2,898.20000	1.8218	19,251.00000000
36	692.07000	3,654.20000	1.4449	30,600.00000000
37	872.93000	4,609.20000	1.1456	48,661.00000000
38	1,100.62000	5,811.20000	.9086	76,658.00000000
39	1,387.47000	7,325.80000	.7207	121,881.00000000
40	1,749.50000	9,236.80000	.5716	193,835.00000000

*Calculated on the basis of Dr. Matthiessen's standard, viz.: 1 mile of pure copper wire of 1/16 inch diameter equals 13.59 ohms at 15.5° C. or 59.9° F.

and quickly made, and are said to possess both the mechanical strength and the conductivity of the line wire itself.

111. Mr. C. T. Child states that the conductivity of aluminum is 63 per cent. that of copper, referring to commercial samples. This would make the diameters of wires for equal conductivity as follows: copper 10, aluminum 12.64. Two wires of equal conductivity would require 1 pound of aluminum and 2.08 pounds of copper.

Based on the weights for equal conductivity (copper 100, aluminum 48), there is an equivalent price of aluminum at which conductors of equal efficiency made from the two metals will be equal in cost. These relative prices are here given in cents per pound.

Price of Copper, per Pound. Cents.	Equivalent Price of Aluminum, per Pound. Cents.	Price of Copper, per Pound. Cents.	Equivalent Price of Aluminum, per Pound. Cents.
12	25.00	17	35.35
13	27.10	18	37.35
14	29.15	19	39.40
15	31.20	20	41.50
16	33.30		

If two wires of equal length and equal resistance, one of copper and the other of aluminum, be covered with the same thickness of insulating material, the amount required by the aluminum will be 17½ per cent. more than that required by the copper. The weight of the insulated aluminum, if the ordinary rubber or other good insulating material be used, will still be considerably less than that of the insulated copper wire.

The tensile strength of commercial soft-drawn and hard-drawn aluminum wire is given by Mr. Child as 26,000 and 40,000 pounds per square inch, respectively. Owing to the larger amount of working that the smaller sizes receive, the

TABLE 20.

FACTORS FOR THE DIFFERENT CONDUCTIVITIES OF ALUMINUM.

Conductivity of Aluminum.	63	62	61	60	59	58	57	56	55	54
Relative cross-section.................. (Copper equals 100)	154.0	156.5	159.0	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Weight of aluminum (weight of copper of equal length and equal resistance equals 100)....................................	46.25	47.00	47.77	48.55	49.38	50.24	51.11	52.02	52.97	53.95
Tensile Strength—Factor by which to multiply tensile strength per square inch of aluminum to obtain tensile strength per square inch required in a copper wire of equal resistance in order to secure same breaking strength......................	154.0	156.5	159.0	161.7	164.4	167.3	170.2	173.2	176.3	179.7
Price—Factor by which to multiply copper price per pound to obtain equivalent price of aluminum; also factor by which to divide aluminum price per pound to obtain equivalent price of copper........	2.160	2.13	2.10	2.060	2.030	1.990	1.960	1.920	1.890	1.850
Price—Factor by which to divide copper price per pound to obtain equivalent price of aluminum; also factor by which to multiply aluminum price to obtain equivalent price of copper.........................	.4625	.47	.4777	.4855	.4938	.5024	.5111	.5202	.5297	.5395

tensile strength for No. 12 and smaller wires is 45,000 pounds per square inch; and it is still greater when they are alloyed with 1 per cent. of other metals. Since the aluminum wire for the same conductivity will have a larger cross-section than copper, then for equivalent wires aluminum is the stronger.

112. Table 20 gives some convenient factors for different conductivities of aluminum as compared with 97 per cent. conductivity copper wire having the same resistance.

113. Both aluminum and copper are practically indestructible under ordinary atmospheric exposure, and there would probably be but little choice between them in this regard. In bare-wire construction, however, the fact that aluminum is somewhat more bulky for a given resistance would be of little disadvantage from a mechanical standpoint, except for its greater resistance to the wind, while it would possess an advantage in regard to strength, cost, and weight. From an electrical standpoint, however, there is one disadvantage due to the greater size of aluminum wire. Its greater surface for a given conductivity renders its electrical capacity with respect to the earth, or with respect to other conductors, much higher, and thus the product of the electrostatic capacity and the resistance would be greater than for a copper wire of the same resistance.

WIRE MADE OF TWO OR MORE MATERIALS.

114. Phono-Electric Wire.—This is a composition or alloy wire that has recently been placed on the market by the Bridgeport Brass Company. They claim that it is absolutely homogeneous, both in mechanical and molecular structure, and that it does not depend on a hardened skin for its strength. Furthermore, they say that phono-electric wire has a breaking strain, for the various sizes of wire, from 40 to 45 per cent. greater than that of hard-drawn copper, and that its properties are absolutely permanent. The company gives the following comparative tests:

TABLE 21.

Kind of Wire.	B. & S. Gauge.	Tensile Strength. Pounds per Square Inch.	Elastic Limit. Pounds per Square Inch.
Hard-drawn copper	0	52,000	41,775
Phono-electric.....	0	73,500	57,860
Hard-drawn copper	0	54,000	39,645
Phono-electric.....	0	76,500	55,195

From these tests, phono-electric wire seems to have a high elastic limit, which should enable it to endure severe strains without taking a permanent stretch, and thereby weakening the wire for future emergencies.

The company also says that tests have shown that phono-electric wire is exceedingly tough. While a 6-inch piece of No. 8 hard-drawn copper wire broke at 30 turns, a phono-electric wire of the same size and length stood the strain of 50 complete turns. In a smaller size wire, the difference was still greater. The 6-inch piece of No. 14 hard-drawn copper wire stood the strain of 47 turns, while the phono-electric wire of the same size and length did not break until 120 turns had been made. Its conductivity is 50 per cent. that of pure copper. All things being considered, it is much superior to iron, but not to hard-drawn copper, for line wires; it is now being used by a few companies for that purpose.

115. Bimetallic Wire.—This wire, made by Roebling's Sons Company, consists of a steel center with a cover of copper. Its conductivity is about 65 per cent. that of pure copper. The percentage of copper and steel may vary a trifle, hence the strength and weight will also vary. According to a table that this company gives, the bimetallic wire (taking No. 9 B. & S.) has a breaking strength about 40 per cent. greater than that of hard-drawn copper. This wire has been used by some telephone companies.

116. Silicon- and Aluminum-Bronze Wires.—The high tensile strength of bronze wires and their freedom from corrosion render them especially suitable for guy wires. They resist corrosion fully as well as hard-drawn copper. The tensile strength of some silicon-bronze wires is as high as 80,000 pounds per square inch, and they are capable of standing 80 twists in a length of 6 inches before breaking. An aluminum-bronze wire showed a strength of 110,000 pounds per square inch, but its ductility was less than that of the silicon-bronze wire.

Their low conductivity, not much over 35 per cent. that of pure copper, and much lower for some of the alloys, excludes them from use for line wires.

Although bronze wires cost about six times as much as either iron or steel, the saving in the cost for repairs and renewals will make up more or less for their high first cost. It is probably on account of this cost that they are used but very little, if at all.

STRINGING OF WIRES.

117. Paying Out.—Where but a single wire is to be strung upon poles, the method usually adopted is to secure

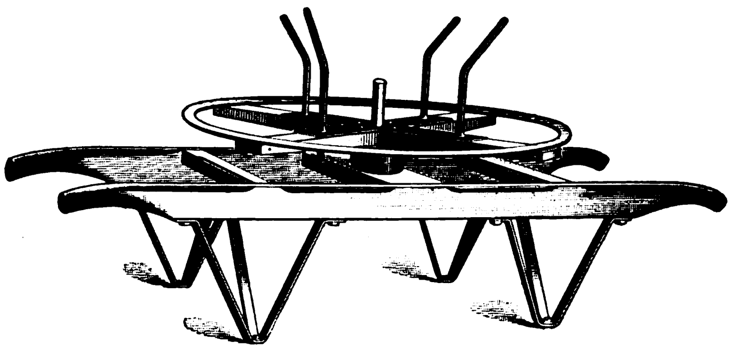


FIG. 31.

one end to the cross-arm of the pole at the beginning of the stretch and to unreel the wire from a *pay-out reel* carried

along the base of the poles. The wire is drawn up to each cross-arm, and after being pulled up to the proper tension, is tied to the insulators, as will be described later. For paying out the wire, many different forms of reels may be procured. A form mounted on a hand barrow is shown in Fig. 34, and is one of the most convenient types of reel. The coil of wire is held in place by the four vertical pins on the reel itself, and as the barrow is carried along by two men, the wire is paid out without any danger of kinking. When it is desired to pay out several wires at once, as described later, a number of reels of the same general form as that of Fig. 34 are mounted upon a wagon or cart, which is then drawn along the pole line, paying out a separate wire from each reel.

When, however, more than a few wires are to be strung, what is termed a **running board** is used. This consists of a piece of oak board about as long as a cross-arm and having holes for the attachment of wires spaced about the same distance apart as the pins on a cross-arm. A rope is attached to the center of the running board, by which it may be drawn over the cross-arms, pulling the wires after it.

When the running board is used, a strong rope is first laid over all the cross-arms of the stretch to be strung. The pay-out reels are mounted at the beginning of the stretch, and the wires from them are attached directly to the running board, to the center of which is also attached the rope. By means of a team of horses at the other end of the stretch, the running board is then drawn along, being lifted over the pole tops by men stationed on each pole. In this way 10 wires may be strung at once. When the wires for the lower cross-arms are to be strung, the running board is usually made to carry 5 wires instead of 10, so as to serve for one end of the cross-arm only. Sometimes, however, two of these are used at once, one on each side of the pole, a separate rope being used for each.

After the wires are properly laid upon the cross-arm, one end of each is made fast and then each wire is pulled up to the proper tension.

118. Tension of Wires. — Several methods are in vogue for obtaining the proper tension in the line wire. The wire is clamped by means of some form of wire clamp, or *come-along*, as they are usually termed, of which there are many forms on the market. It is then pulled up either by hand or by means of a block and tackle, the tension being judged either by the amount of sag in the wires or by a line dynamometer, or spring balance, which shows by an indicator the number of pounds of tension in the wire.

119. In Fig. 35 is shown a form of **come-along** that has met with much favor. It has the advantage of having smooth, straight parallel jaws, thus obtaining a firm grip on the wire without the liability of kinking or nicking it. These clamps are made of steel forgings riveted together, as shown. The member *A* is pivoted to the jaw *B* by the rivet *b*, and

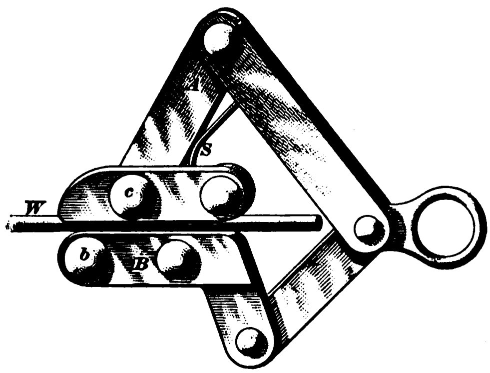


FIG. 35.

to the other jaw by the rivet *c*, so that when the wire *W* is placed between the jaws and tension applied on the eyelet of the come-along, the jaws are forced together, thus gripping the wire and at the same time maintaining the pull in the direction of the wire. The spring *S* serves to open the jaws automatically, thus releasing the wire as soon as the tension is removed.

Considerable care must be taken not to nick or kink

hard-drawn copper wire. When a kink does occur, it should be cut out and the wire joined.

120. Table 22, taken from Roebling's handbook on wire, gives the amount of sag in inches at the center of the span for different lengths of span at various temperatures. This applies to both iron and copper wire.

TABLE 22.

SAG IN LINE WIRES.

Temperature in Degrees Fahrenheit.	Span in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
– 30	1	2	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{1}{2}$	8
– 10	$1\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{3}{4}$	5	9
10	$1\frac{1}{2}$	$2\frac{5}{8}$	$3\frac{1}{2}$	$4\frac{3}{8}$	$5\frac{3}{4}$	$10\frac{1}{4}$
30	$1\frac{3}{4}$	3	4	$5\frac{1}{8}$	$6\frac{3}{4}$	12
60	$2\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{2}$	7	9	$15\frac{3}{8}$
80	$3\frac{1}{8}$	$5\frac{3}{8}$	7	$8\frac{5}{8}$	$11\frac{1}{4}$	$18\frac{3}{4}$
100	$4\frac{1}{3}$	7	9	11	14	$22\frac{1}{4}$

Obviously, the temperature at the time of stringing plays an important part in the determination of the proper tension, for if strung too tight in hot weather, the wires, in contracting in colder weather, will be likely to snap. Therefore, it is necessary to allow a much greater sag in hot weather than in cold. For spans from 400 to 600 feet in length, the sag should be about $\frac{1}{40}$ the length of the span, while for spans of from 600 to 1,000 feet in length, the sag should be about $\frac{1}{30}$ the span.

As the coefficient of expansion of aluminum is greater than that of copper (see Table 17), it is necessary, in stringing

aluminum wires at ordinary temperatures, to allow a little greater sag than for copper wire, otherwise the aluminum wire may break when cold weather comes.

121. Iron-Wire Tie.—There are several methods of tying line wires to insulators. The most common iron-wire tie is shown in Fig. 36. This view shows both plan and side view of the insulator and tie. The tie-wire for an ordinary line insulator is usually made from 14 to 16 inches in length and of the same size as the line wire, or slightly smaller. The line wire is laid in the groove of the insulator, after which the two ends of the tie-wire, after passing half around the insulator, are wrapped in a close spiral about the line wire. Some advocate to start wrapping one end of the tie-wire over and the other end under the line wire.

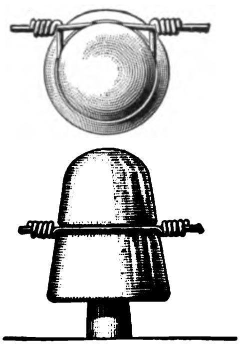


FIG. 36.

122. Helvin Tie.—The **Helvin tie,** which has been used quite successfully with hard-drawn copper wire, is shown in Fig. 37. The tie-wire is wound around the insulator and given a twist about itself, and the ends are then wound around the line wire. It is superior, especially for hard-drawn copper wire, to the preceding tie, which has been commonly used with iron wires. Where hard-drawn copper line wires are fastened to insulators, the tie-wire itself should be soft copper.

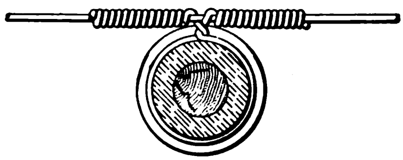


FIG. 37.

123. Another tie, and one that is now being largely used in telephone work, and which is probably the best for hard-drawn copper wire, is shown in Fig. 38. In this, the line wire is laid in the groove of the insulator, and the tie-wire is laid in the groove and passed once entirely around the

insulator. One end of the tie-wire is then brought *down over* the line wire, while the other end is brought *up under* it in an opposite direction, the two ends being wound around the line wire, as shown in the figure.

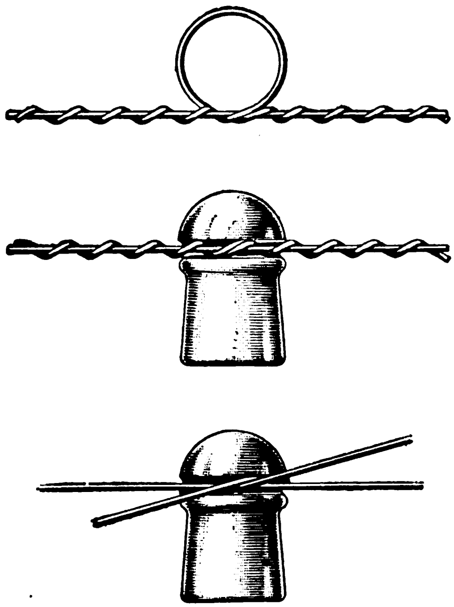


FIG. 38.

124. Dead-Ended.—Where a line is terminated at an insulator, or **dead-ended,** as it is called, it is looped around the insulator, as shown in Fig. 39, and the end given about 8 close turns around the wire. The wire should be only looped and not wrapped around the insulator, and the twists should begin at a point about 2½ inches from the insulator. If another wire is to be joined to the line at this point, leave projecting enough of the end with which to make the joint, otherwise cut the end off close to the line wire. This is much better than making the joint with the stretched part of the wire. McIntire and rolled-up, sheet-metal sleeves, such as will be described presently for making joints in line wires, are often used in making a dead end.

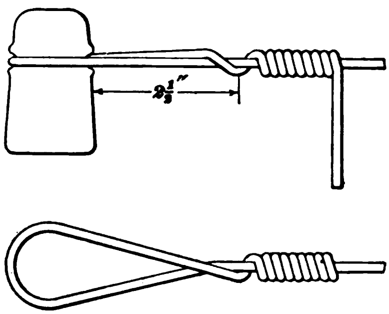


FIG. 39.

125. Position of Line Wire on Insulator.—On straightaway work, the line wire should always lie on the side of the insulator next to the pole, excepting the two inner wires, which are placed on the side away from the pole. On curves, however, all the line wires should always lie on the side away from the center of the curve, in order that the strain, due to the bend in the wire, may be taken by the insulator instead of by the tie-wire.

126. Splicing.—Until recent years, wires were usually connected in this country by means of the American wire joint, shown in Fig. 40. In order to make this joint, the wires are first placed side by side, and then each end is wound about the other. The joint should then be soldered, to insure the maintenance of perfect electrical contact. In soldering this joint, it is well to apply solder only at its

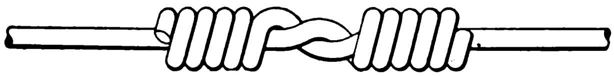


FIG. 40.

center, for the reason that the heat necessary to cause the solder to flow takes a certain amount of temper from the wire, and, therefore, is very apt to weaken it. By weakening the center portion only, two strands of the wire are available to stand the strain, and therefore a rupture is not as likely to occur as if the ends of the splice were heated, for then the strain would be borne by a single strand only.

127. On terminal poles, copper and iron wires should never lie together in the same groove of the insulator, but should be tied around separate grooves on a double-grooved insulator, or else each wire should end on separate insulators. The joint in either case should be thoroughly soldered.

128. Soldering.—The best way to solder joints is by the use of a dip pot and pouring ladle. By this method, there is less danger of weakening the wire by overheating it than when a gasoline torch is used, or when the joint is dipped into a pot of melted solder.

129. McIntire Sleeve Joint.—Another joint, which is rapidly coming into general use, and which should entirely supersede the American joint, especially for hard-drawn copper and aluminum wires, is the **McIntire sleeve joint.** A variety of sizes of copper, aluminum, and even iron sleeves can now be obtained for this purpose. Since no soldering is required, there is no danger of injuring the strength of the line wire by heating it. The ends of the

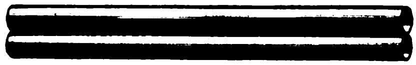


FIG 41.

wire are slipped into a double sleeve of the same material as the wire, as shown in Fig. 41, and the two are then twisted through several turns, making the joint like that shown in Fig. 42. These joints give excellent service, always keeping good electrical contact without the use of solder. In applying them, three complete turns or twists should always

FIG. 42.

be given. On a telegraph line from Montreal to Vancouver, using hard-drawn copper wire, weighing 300 pounds per mile, the McIntire sleeve joints were soldered at the ends. By tests it was found that the breaking strength of the joint was increased by soldering it from 500 to 900 pounds. This line, using over 3,000 miles of wire, was put up in 1898.

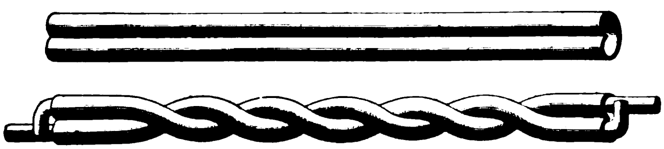


FIG. 43.

130. Rolled Sleeve Joint.—Instead of the two separate tubes, of which the McIntire sleeve is made, an oval-shaped sleeve, made out of one piece of rolled-up sheet

metal, is now considerably used for both hard-drawn copper and aluminum. Such a sleeve and a completed joint is shown in Fig. 43.

131. Tokay Joint.—Still another method of joining hard-drawn copper line wires, sometimes called the **Tokay sleeve joint,** has given entire satisfaction for the two years that it has been used by at least one of the Bell telephone companies. It is made in the following manner: The two wires to be joined are slipped into a single round sleeve, snugly fitting the wire, and about 3¾ inches long, until the ends of the wires butt together at the middle of the sleeve. Then, by means of a special compressing tool, the sleeve and wire are compressed or flattened in about five separate places on each end of the sleeve joint. This prevents the wires from pulling out of the sleeve. It is, perhaps, not so strong as the McIntire sleeve joint, and the conductivity of the joint is doubtless less, but it is claimed that the line wire will break before the sleeve will allow the wires to pull out. It makes a neater joint than the McIntire, hardly being noticeable from the ground. Furthermore, in mending a break, or joining cut wires, it does not require an extra piece of wire and two sleeve joints, one sleeve joint being all that is required.

132. Tie Wrenches.—Iron, copper, and aluminum wires should be joined by means of steel **wrenches** instead of pliers. They can be better tied or joined and with less damage to the wire in this way. Twisting clamps or

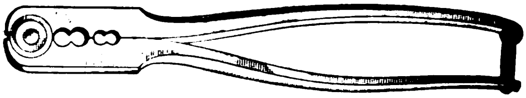


FIG. 44.

wrenches are also used when joints are made with McIntire connectors. One of these twisting clamps is shown in Fig. 44. One size wrench will make joints in wires Nos. 8 to 16;

another in wires Nos. 4, 5, and 6. For the ordinary American joints, such as shown in Fig. 40, the wrenches are similar to the one illustrated here, except that there is one oval-shaped hole instead of the two nearly complete circular holes shown in this figure.

133. Climbing.—Two forms of climbers, shown in Figs. 45 and 46, are in common use. These are termed, respectively, "Western" and "Eastern" climbers, and each style has its own advocates. In the Western climbers, the rod which is strapped to the leg is on the opposite side from the spur, and therefore is secured to the outside of the leg. In the Eastern pattern, the rod is on the same side as the spur, and is therefore secured to the inside of the leg.

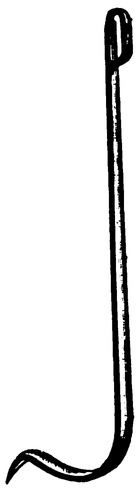


FIG. 45.

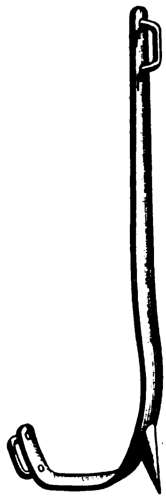


FIG. 46.

Climbing is an art which can be attained only by practice, and the best way to learn it is to practice on the lower portion of a pole, without attempting to ascend to the top at first. The main points to be remembered in climbing are to secure a hold with the spur by a direct downward thrust of the leg, instead of with a side thrust toward the pole, as is the tendency with an amateur; also, the body should be held out at arm's length from the pole, the pole being clasped in the palms of the hand, instead of being hugged close to the body. It is more difficult to descend than to ascend, and therefore the beginner should be cautious about climbing too high at first.

134. Size of Line Wire.—No definite rules can be given for the size of wire to use on overhead lines. The following sizes are those in use:

No. 10 B. & S. hard-drawn copper and No. 4 B. W. G. galvanized-iron wires are now used on important quadruplex circuits. Formerly, No. 6 B. W. G. galvanized-iron wire was used for this purpose.

No. 6 B. W. G. galvanized-iron wire is used for important circuits between cities.

No. 8 B. W. G. galvanized-iron wire, or No. 12 B. & S. hard-drawn copper wire, is much used for circuits of 400 miles, or less, in length. No. 9 B. W. G. galvanized-iron wire was formerly used for this purpose.

No. 9 B. W. G. galvanized-iron wire was, until recently, the size most generally used in the United States. It is now used on short circuits where No. 8 is not considered necessary.

Nos. 10 and 11 B. W. G. galvanized-iron wires are used for still shorter circuits and for railway-telegraph, police, fire-alarm, and private lines. No. 12 B. W. G. galvanized-iron wire is also used for these purposes and for telephone lines.

Nos. 13 and 14 B. W. G. steel wires are used for short private lines, for telephone lines, and where strength is especially necessary.

No. 8 B. & S. copper wire should be used for permanent terminal-office ground wires.

135. Wires Entering a Building.—Great care should be used in running wires into buildings. They should enter in a dry place, and, whenever possible, under a projecting roof. Where such a roof is not available, a cover should be made by supporting a 12-inch board on brackets. This board should be of sufficient length to cover all the wires; it should have a slope sufficient to freely carry off all water, and should have its inner edge beveled, that it may fit closely to the side of the building. The wires should enter the building through porcelain or rubber tubes of sufficient length to pass entirely through the wall. They should be supported in such a manner as to run upwards toward the hole through which they enter, or else they should be bent

down enough to form a loop just before entering the tubes. In this way, water will be prevented from running down the wires and into the wall.

At railway stations the wires should be brought into the telegraph office as near to the switchboard as possible, and in such a manner that they can always be seen and inspected. Where there are six or more wires entering an office, a cable should be used.

136. Inside Wiring.—Inside of a building, the wires should be supported on porcelain knobs or porcelain cleats. Wood cleats may be used, but are not so good. The wires, unless a cable is used, should, if possible, be kept at least 4 inches apart, and as far from the ground, pipes, metal work, etc. as possible. The wires should never be fastened down with staples.

TELEGRAPH CABLES.

137. Where it is necessary to run a greater number of wires than can be accommodated by the bare-wire construction already described, cables become necessary. For both indoor and outdoor work, the use of a cable makes it possible to easily run a large number of wires where the same number by the ordinary construction would be out of the question. Moreover, for the problem of underground and underwater work, where it is impossible to use bare-wire construction, the cable forms the only solution.

RUBBER-COVERED CABLES.

138. Cables composed of rubber-covered wire, without a lead cover, are frequently used for overhead telegraph circuits, although the paper-insulated cable is much more desirable. A good rubber-covered cable manufactured in this country is made as follows: The wires are of copper No. 14, 16, or 18 B. & S. gauge, having a conductivity of 98 per cent. that of pure copper. The wire, having been

thoroughly tinned, is given a double coating of rubber insulation and then taped. After the requisite number of con-

TABLE 23.

AERIAL CABLES WITH RUBBER-COVERED WIRES.

Number of Conductors.	14 B. & S. Insulated to 6/32".		16 B. & S. Insulated to 5/32".		18 B. & S. Insulated to 4/32".	
	Outside Diameters. Inches.	Weight per 1,000 Feet. Pounds.	Outside Diameters. Inches.	Weight per 1,000 Feet Pounds.	Outside Diameters. Inches.	Weight per 1,000 Feet. Pounds.
2	3/8	102	3/8	92	3/8	82
3	1/2	149	7/16	126	13/32	104
4	9/16	183	1/2	155	7/16	127
5	11/16	226	5/8	193	1/2	151
6	3/4	260	11/16	222	9/16	175
7	13/16	297	3/4	251	5/8	200
10	15/16	401	7/8	335	11/16	256
12	1	465	15/16	393	3/4	296
15	1 1/8	563	1	468	13/16	355
18	1 3/16	651	1 1/16	541	7/8	413
20	1 1/4	714	1 1/8	593	29/32	452
25	1 3/8	863	1 3/16	708	15/16	541
30	1 7/16	1,008	1 1/4	824	1	633
35	1 1/2	1,147	1 5/16	938	1 1/16	723
40	1 9/16	1,268	1 3/8	1,053	1 1/8	813
45	1 5/8	1,431	1 1/2	1,182	1 3/16	903
50	1 3/4	1,577	1 5/8	1,311	1 1/4	994

ductors are bunched, the cable is double-taped and covered with tarred jute, over which is placed a heavy braid of

cotton saturated with weather-proof compound, which serves not only to protect the rubber from the action of the air, but to protect the entire cable from mechanical injury. The manufacturer claims that these rubber-covered wire cables are waterproof and can be used under water where there is no danger of mechanical injury. The sizes and weights of cables made in this manner are given in Table 23, which is taken from Roebling's handbook.

139. Tape-covered cable, especially if put up on a slant, should have the joint in the tape on the under side of the cable to prevent water or moisture from working into the cable. The cable should be retaped when the outside cover begins to disintegrate or fray out. For, if left until the covering of tape begins to separate, the insulation over the individual conductors will crack and the cable will soon be damaged beyond repair. See Art. **165** for making joints in rubber insulated cables.

140. The insulation resistance of wires in this cable will, if the cable is in good condition and the proper materials are used, vary from 300 to 500 megohms per mile, at a temperature of 60° F., after the cable has been immersed in water for 24 hours. This cable is, therefore, well adapted for underwater work where it is not subject to mechanical injury. For use in mines, or where it is necessary to pass a large number of wires on poles through the foliage of trees, this cable should give good results. One objection to cables of this kind is the high electrostatic capacity of the conductors. Rubber is an excellent insulator, but has a very high specific inductive capacity, thus greatly increasing the electrostatic capacity of the wires which it serves to insulate.

While high electrostatic capacity is undesirable in a telegraph cable, it is not so serious an objection as in a telephone cable. On the other hand, a low resistance is more desirable in telegraph than in telephone cables, consequently telegraph-cable conductors are seldom smaller than No. 14 or No. 16 B. & S.

PAPER CABLES.

141. Methods of Reducing Capacity.—To reduce the electrostatic capacity of the conductors of a cable, three methods are available: *First*, the wires may be placed farther apart; *second*, the wires may be made smaller; and *third*, an insulating medium having a low specific inductive capacity may be used.

To place the wires farther apart would be to defeat the principal object for which the cable is employed—that is, compactness. The sizes of the wire may be reduced to a certain limit, but beyond that limit the mechanical strength of the conductor and its ohmic resistance forbid us to go. As a result of this reduction in the size of wires, Nos. 19 to 22 B. & S. gauge are commonly used in dry-core telephone cables. In following the third method of reducing the electrostatic capacity, various materials having a lower specific inductive capacity than rubber have been tried, and have been found to give far better results so far as the electrostatic capacity is concerned, and, in fact, in all other respects, when proper care was exercised in their manufacture and maintenance.

142. Saturated-Core Cables.—Underground or overhead cables for telegraph purposes are now usually insulated with paper or cotton fiber and saturated with an insulating compound. Paper is preferable to cotton. The composition of the insulating compound is a trade secret, known only by the companies that manufacture the cables. These cables are commonly termed **saturated-core cables**, in order to distinguish them from the dry-core paper cables used for telephone systems.

The advantage of a saturated-core cable over a dry-core is that if the lead is injured, only a small portion of the cable (sometimes only a few inches) will be lost, and the injury may be located and repaired before much damage is done. Sometimes the conductors in a telegraph cable are made of No. 16 or 18 B. & S. gauge, but generally of No. 14 B. & S. gauge, and each wire is insulated to a thickness of $\frac{5}{32}$ inch.

The conductors are laid up in layers, each layer being wound in a contrary direction to the preceding one. The bunch of insulated conductors should be covered with the same thickness of insulation as is used on each wire, and the whole encased in a lead sheath $\frac{1}{8}$ inch thick.

Fig. 47 shows a saturated paper-core telegraph cable made by the National Conduit and Cable Company. This company makes a large variety of paper-insulated cables—dry-core cables for telephone purposes, and saturated-core cables

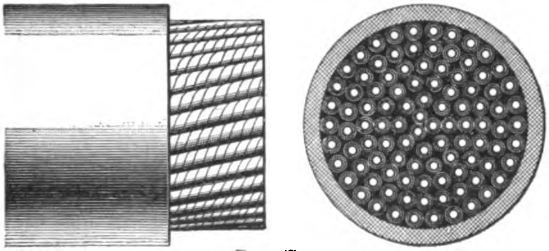


FIG. 47.

for telegraph, electric-light, and power purposes. These paper-insulated cables have proved very satisfactory and successful wherever used. The cable illustrated in this figure contains 100 conductors of No. 14 B. & S. copper wire, each conductor being covered with a paper insulation that has been treated with an insulating compound. The lead sheath is $\frac{1}{8}$ inch thick, and the outside diameter of the cable is $1\frac{5}{8}$ inches. Telegraph cables with this number of conductors are usually somewhat larger in diameter.

SPECIFICATIONS FOR LEAD-COVERED TELEGRAPH CABLES.

143. Following are the **specifications** of the Postal Telegraph-Cable Company and the Western Union Telegraph Company for lead-covered underground telegraph cables.

144. Postal Telegraph-Cable Company.—For about......feet of underground lead-covered cable, containing......copper conductors, also for about......feet

containing......copper conductors. Each conductor to be No. 14 B. & S. gauge (.064 mil in diameter).

Copper of at least 98 per cent. purity, per Matthiessen's standard, to be insulated with cotton fiber to a diameter of $\frac{6}{32}$ inch, or with paper to a diameter of $\frac{5}{32}$ inch, saturated with insulating compound and each conductor (with all other conductors grounded) to have an insulation resistance, when laid, of at least 300 megohms per mile from end to end, at 75° F., to be determined in the customary manner by the electrical engineers of both of the parties hereto, within 30 days after it is laid.

The Postal Telegraph-Cable Company will require the contractor to furnish a table of the coefficients of the dielectric's resistance, showing its decrease above and its increase below 75° F. within the limits of variation of temperature to which the cable may be subjected, and the minimum of 300 megohms per mile will be modified accordingly.

The lead covering not to be less than $\frac{1}{8}$ inch thick, and to contain not less than 3 per cent. of tin. The cable to be of the highest standard of excellence, to be determined by comparison with the best grades of similar cable. The contractors to turn the cable over to this company, laid in the duct, free from all mechanical injury, with proper splices, and the Western Electric style of terminal heads, acceptable to this company. If a cable according to the above specifications cannot be laid in the subway provided, on account of the duct being too small, the Postal Telegraph-Cable Company is to be notified prior to the manufacture of the cable.

The contractor to give the usual guarantee to furnish a cable that will remain in good electrical condition for 5 years after it is laid; and to agree to repair, or to reimburse the Postal Telegraph-Cable Company for any expenditures incurred in repairing defects that may appear during that period, not caused by mechanical or other extraneous injury.

145. Western Union Telegraph Company.—......feet of cable containing......conductors, each conductor composed of No. 16 B. W. G., 98 per cent. pure

TABLE 24.

LEAD-COVERED TELEGRAPH CABLES.

Number of Conductors.	14 B. & S. Insulated to $\frac{3}{32}$".		16 B. & S. Insulated to $\frac{5}{32}$".		18 B. & S. Insulated to $\frac{4}{32}$".	
	Outside Diameters. Inches.	Weight per 1,000 Feet. Pounds.	Outside Diameters. Inches.	Weight per 1,000 Feet. Pounds.	Outside Diameters. Inches.	Weight per 1,000 Feet. Pounds.
1	$\frac{3}{8}$	308	$\frac{3}{8}$	299	$\frac{3}{8}$	291
2	$\frac{7}{16}$	438	$\frac{7}{16}$	421	$\frac{13}{32}$	356
3	$\frac{1}{2}$	573	$\frac{1}{2}$	546	$\frac{7}{16}$	421
4	$\frac{5}{8}$	810	$\frac{9}{16}$	670	$\frac{15}{32}$	486
5	$\frac{3}{4}$	972	$\frac{5}{8}$	793	$\frac{1}{2}$	551
6	$\frac{13}{16}$	1,132	$\frac{11}{16}$	946	$\frac{17}{32}$	616
7	$\frac{7}{8}$	1,295	$\frac{3}{4}$	965	$\frac{9}{16}$	681
10	$\frac{15}{16}$	1,512	$\frac{13}{16}$	1,155	$\frac{5}{8}$	820
12	$1\frac{1}{16}$	1,873	$\frac{7}{8}$	1,327	$\frac{3}{4}$	978
15	$1\frac{3}{16}$	2,263	$\frac{15}{16}$	1,518	$\frac{13}{16}$	1,148
18	$1\frac{1}{4}$	2,523	$1\frac{1}{16}$	1,880	$\frac{7}{8}$	1,318
20	$1\frac{5}{16}$	2,756	$1\frac{1}{8}$	2,076	$\frac{15}{16}$	1,477
25	$1\frac{7}{16}$	3,250	$1\frac{5}{16}$	2,496	1	1,690
30	$1\frac{9}{16}$	3,515	$1\frac{3}{8}$	2,768	$1\frac{1}{16}$	1,903
35	$1\frac{11}{16}$	3,910	$1\frac{7}{16}$	3,040	$1\frac{3}{16}$	2,116
40	$1\frac{3}{4}$	4,175	$1\frac{1}{2}$	3,312	$1\frac{1}{4}$	2,330
45	$1\frac{13}{16}$	4,441	$1\frac{9}{16}$	3,533	$1\frac{9}{32}$	2,471
50	$1\frac{15}{16}$	4,835	$1\frac{5}{8}$	3,755	$1\frac{5}{16}$	2,628
55	2	5,100	$1\frac{11}{16}$	3,978	$1\frac{3}{8}$	2,866
60	$2\frac{1}{16}$	5,365	$1\frac{3}{4}$	4,200	$1\frac{7}{16}$	3,104
65	$2\frac{1}{8}$	5,631	$1\frac{13}{16}$	4,422	$1\frac{15}{32}$	3,245
70	$2\frac{3}{16}$	5,897	$1\frac{7}{8}$	4,644	$1\frac{1}{2}$	3,402
80	$2\frac{5}{16}$	6,408	2	5,087	$1\frac{5}{8}$	3,798
90	$2\frac{7}{16}$	6,916	$2\frac{1}{16}$	5,402	$1\frac{11}{16}$	4,027
100	$2\frac{9}{16}$	7,375	$2\frac{1}{8}$	5,720	$1\frac{3}{4}$	4,275

copper wire insulated to $\frac{5}{32}$ inch with paper saturated with insulating compound. Cable core to be wrapped with saturated paper of the same thickness as the insulation on the wires. The lead covering to be $\frac{1}{8}$ inch thick, alloyed with 3 per cent. of tin.

146. Table 24, taken from Roebling's handbook, gives the outside diameters and weights per 1,000 feet of telegraph cables that are insulated with cotton fiber or rubber, and covered with a lead sheath. Where saturated paper insulation is used, both the weights and sizes for most cables will be slightly less.

147. The usual sizes of telegraph saturated paper-insulated cables are 10, 25, 50, 75, 100, 150, and 200 conductors. The diameters over the lead sheath are approximately as given in Table 25.

TABLE 25.

TELEGRAPH CABLES.

Number of Conductors.	Outside Diameters. Inches.
10	$\frac{3}{4}$
25	$1\frac{1}{8}$
50	$1\frac{5}{8}$
75	$1\frac{7}{8}$
100	$2\frac{1}{8}$
150	$2\frac{3}{8}$
200	$2\frac{5}{8}$

148. Dry-Core Cables.—The telephone cables now most commonly used in this country are made by insulating the various wires with a loose wrapping of very porous dry paper, after which the wires are twisted in pairs and bunched into a cable. A sheath of lead is then placed over

the cable, in order to exclude all moisture and also to prevent mechanical injury. The loose wrapping of the paper and its porous nature insure the inclusion of a great amount of dry air in the cable, which, as we have seen, possesses the lowest electrostatic capacity of any known substance, hydrogen excepted. Two or three feet at each end of the dry-core cable is always saturated or sealed up tight, to exclude moisture, with paraffin; or, better, with some of the special compounds that are made and used by the cable manufacturers. Immediately after testing in the factory, the lead sheath at each end is hermetically sealed by a plumber's joint.

149. The electrostatic capacity of the wires in a cable built in this manner is often as low as .06 microfarad per mile, and it is customary, in making specifications for telephone cables using No. 19 B. & S. gauge wire, to specify that the electrostatic capacity of each wire shall be lower than .08 microfarad per mile. All cables of this description are made in twisted pairs, the conductors being twisted together so as to give one turn in about 6 inches.

The dry-core cable represents the highest development in the line of telephone cables. The high insulation obtained by the dry air and paper, the low electrostatic capacity, and the compactness of the cable as a whole render it admirably adapted for both underground and aerial work.

150. Objections to Dry-Core Cables.—There is one objection against the dry-core cable, and whether or not this is a serious objection depends on the manner of manufacture and the subsequent care of the cable. A puncture in the sheath allows the entrance of moisture, which, due to capillary attraction, will soon penetrate the entire length of the cable, thus totally ruining the insulation. When moisture first enters, immediate steps must be taken to expel it and to repair the fault, and, if this is not done in an intelligent and prompt manner, the cable will soon be worthless. This point shows the necessity for making frequent insulation tests on cables of the dry-core type, so that if moisture

enters, its presence may be detected before it has time to do serious damage.

151. Lead Sheaths for Cables.—Sometimes the sheaths for cables are made ot pure lead, but specifications usually call for a mixture of 3 per cent. of tin with the lead. The reason for this is that where cables are used for underground work, the lead is more likely to be attacked by chemical action than is the mixture of lead and tin. Considerable difference of opinion exists as to the advisability of making the mixture of lead and tin, some manufacturers claiming that it is impossible to obtain an even mixture of the two, and that the sheath will not be homogeneous, and will therefore contain spots that are more or less brittle, owing to the excess of tin.

The Standard Underground Cable Company, of Pittsburg, Pennsylvania, make the sheath of pure lead and afterwards give it an outside coating of tin, claiming that the tin is then in a position to do the most good in preventing chemical action without in any way interfering with the quality of the sheath itself.

152. Outside Braiding of Cables.—The lead sheath of cables is frequently covered with a braiding of cotton saturated with weather-proof compound. While this undoubtedly protects the sheath from abrasion in both overhead and underground work, it is subject to several disadvantages. Among these is the fact that it renders the location of punctures or injuries in the cable sheath more difficult to locate. After some years, the braiding rots off and hangs in shreds from the aerial cables, thus presenting an unsightly appearance. In underground cables, the braiding is likely to become disengaged, and thus bind the cable in the duct in which it lies, thus rendering its subsequent drawing out a very difficult matter. The general opinion now held by many engineers seems to be that, except under certain conditions, the outside braiding on a lead-covered cable is a disadvantage, and, therefore, that its extra expense is worse than useless.

SPLICING AND REPAIRING LAND CABLES.

153. The **splicing** together of two dry-core telegraph cables is a matter involving considerable care and skill. It should never be left in the hands of irresponsible persons. If the cable is already on poles, it will be necessary to erect a platform, if one is not already provided, on the pole where the splice is to be made; or, if in the middle of a span, a traveling platform suspended beneath the cable from the messenger wire upon which the cable is supported must be used, provided, of course, arrangements cannot be made to make the splice on the ground.

154. Testing for Moisture.—Careful tests should be made to determine whether or not moisture has entered the insulation of the cable from the exposed end. If the cable is new, its end will be sealed and probably will be free from moisture, but if the splice is necessary on account of having to cut away an injured portion of the cable, there are many chances that moisture will be present in the insulation. A short piece of cable should be cut off and dipped in very hot insulating compound. The rising of bubbles through the liquid is a sure sign of moisture, but if no bubbles arise, then it is safe to say that the cable is dry. If moisture is found in small quantities, it may sometimes be expelled by heating the cable sheaths with a torch for a considerable distance back of where the splices are to be made and gradually working toward the end. Great care must be taken, however, in doing this, not to melt the lead and thus destroy the sheath. The cable should not be spliced until all moisture is expelled, and if this cannot be done by ordinary methods, then a section of it should be cut away, and the end so exposed again tested for moisture.

155. Before beginning work on the splice itself, careful tests should be made for grounded or open wires in a cable, for to connect a good wire in one section of the cable to a defective wire in another section means the loss of both the good and the bad wire.

156. Slack in Cable.—The two cables on which the splice is to be made are drawn together until their ends overlap from 2 to 4 feet, according to the nature of the conditions. When splices have to be made in manholes where the cables are made to either bend around the side of the hole or to lie loosely on its floor, the cable ends are made to overlap as much as 4 feet, in order to give sufficient slack when the splicing is done. When cables are suspended from poles, however, no slack is needed, as the sag is not increased at the point of splicing, so that the ends are made to overlap only enough to allow of the performance of the work in the proper manner.

157. Chipping Knife.—The lead sheath is cut away from both cable ends for a short distance, and the conductors and their paper insulation exposed. It is very important, in order that the conductors may not be injured, that the sheath should be removed in the proper manner. The tool used for this work is called a **chipping knife,** and is shown in Fig. 48. It will be seen to be a heavy broad-backed blade *a* having a stout edge *c* and a handle *d*. It is made of tool steel. In Figs. 49 and 50 is shown the proper method of removing the lead sheath. In Fig. 49, at a point about 2 feet from the cable end, a

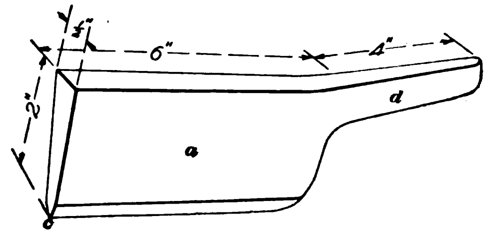


FIG. 48

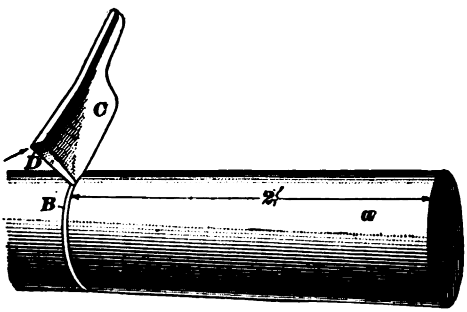


FIG. 49.

circular groove is cut at *B* in the sheath *a*. In doing this the chipping knife *C* is held in the position shown, while blows are struck with a hammer on the head *D*, in the direction indicated by the arrow, so as to give it a tangential motion. In this way the sheath is cut, without the knife being allowed to cut down into the conductors. This groove having been cut, a longitudinal incision is made from it to the cable end. The method of holding the knife for this work is shown in Fig. 50. As before, the blows are struck at the point *f*, and the knife is thus given a backward and tangential motion combined, which rips off the sheath, as shown at *c*, without the possibility of injuring the conductors.

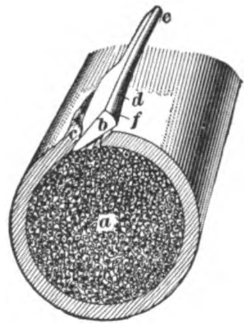


FIG. 50.

158. When all is ready, cut away the lead sheath from the end of each section in the manner explained in the last paragraph for a distance of 6 inches on a 10-conductor cable and for a distance of 11 inches on a 200-conductor cable, and corresponding distances for other sizes. Then slip a

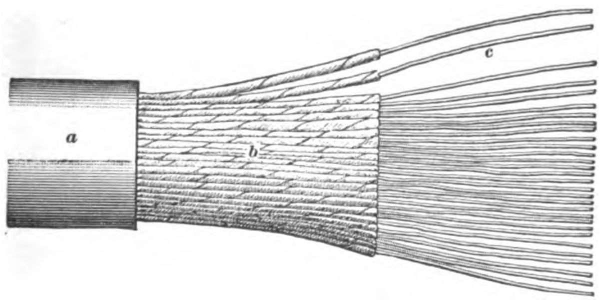


FIG. 51.

piece of lead pipe about 1¼ inches larger in diameter than the outside diameter of the cable over one end of the cable and back several feet, out of the way of the workmen. The condition of the cable after the ends of the conductors

have been stripped of their insulation to a point 4 inches from the end would then be represented by Fig. 51.

159. Lead Sleeves.—The length and diameter of the **lead sleeve** will, of course, depend on the size of the cable. For a 10-conductor cable, the lead sleeve should be about 10 inches long and about 2 inches outside diameter, and for a 200-conductor cable, it should be from 18 to 20 inches long and about 4 inches outside diameter, and corresponding lengths and diameters for intermediate sizes. When the joint is finally completed, the sleeve should overlap the lead sheath on the end of each cable at least ½ inch, though 4 inches is preferable; thus making the sleeve from 1 to 8 inches longer than the distance between the ends of the two cable sheaths after the splice has been made. The lead of the sleeve should be at least as thick as the lead cover of the cable. The ends of a sleeve should be dressed or hammered down to fit snugly upon the lead cover of the cable.

160. Joining the Conductors.—The joining of the ends of the wires is done in two ways: either the ends are brought together and simply twisted, as shown at *c*, Fig. 52 (*a*), or they are joined as shown in Fig. 40, in which the end

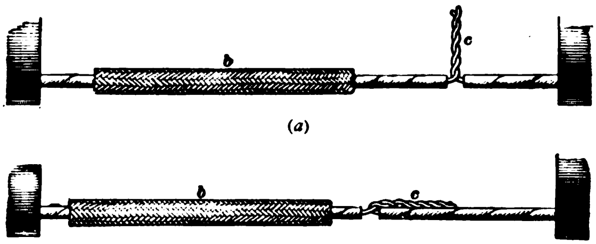


FIG. 52.

of the first wire is wrapped around the second wire and the end of the second wire is, in turn, wrapped around the first, but in the reverse direction. The joint shown in Fig. 52 (*a*) is called a "common joint"; the other, shown in Fig. 40, is called a "Western Union" or American joint. In splicing

lead-covered paper cables, the common joint is always used, but in splicing braid-covered cables, the Western Union splice only is permissible. On the whole, the Western Union splice is the better, as it has a much greater tensile strength.

161. Now slip a cotton or paper sleeve, about 6 inches long, over every other wire in the end of one cable, and over every other wire in the end of the other cable. Cotton sleeves are now being used in preference to the paper sleeves that were formerly used. The wires are then joined by merely twisting them tightly together, making a common joint that is then bent away from the cotton sleeve, as shown at *c*, Fig. 52 (*b*). It is not customary today to solder the joint. If the joint is soldered, use the grease of a tallow candle as a flux and take care not to spill solder over any of the other wires.

After making the joints, the sleeves should be slid over them, leaving the finished splice as shown in Fig. 53. The

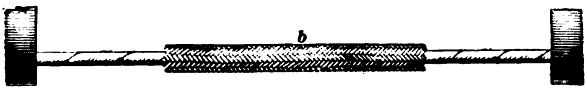


FIG. 53.

joints should be staggered as much as possible throughout the entire length of a splice, in order that an undue bulge may not occur at any one section of the cable. When all the wires are spliced and smoothed down, the appearance of the cable will be somewhat as represented by Fig. 54.

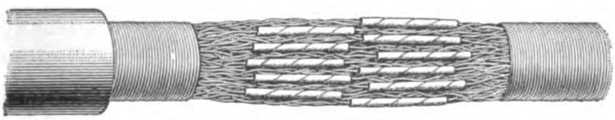


FIG. 54.

162. Boiling Out.—The next process is termed **boiling out,** and on it depends in a great measure the success of the splice. A large bowl of hot insulating compound and a convenient ladle should be provided. The bowl should be

placed directly under the splice, and as close to it as possible, and the hot insulating compound should be poured, by means of the ladle, over the splice, and allowed to drip back into the bowl. This process should be repeated until no bubbles appear in the hot liquid, the presence of bubbles always indicating that a certain amount of moisture is left in the cable. After the splice is boiled out, it should be served with a plain strip of white cotton and again boiled out with insulating compound. The lead sleeve should then be slipped over the splice while still hot, and the surface of the lead of the sheath and of the sleeve having been thoroughly cleaned, the sleeve should be secured to the sheath at each end by a plumber's wiped joint. In the making of this joint, the services of a good plumber will be required, and the work should not be left until the joint is perfectly made, thus furnishing as good a protection to the conductors within as the sheath of the cable itself.

163. Filling Sleeve Joints.—Where saturated-core cables are used, the sleeve is generally filled by pouring hot insulating compound through two holes cut in the lead sleeve for this purpose. These holes are made about one-third the distance from the ends and the hot insulation is poured into them alternately until the sleeve is filled. Sufficient time should be given the compound to permeate the cable and drive off any moisture that may be present. The expulsion of all moisture is important. Should there be any indication of moisture in the cable when the insulating compound is being poured into the sleeve, one end should be elevated, in order that, as the compound is being poured into one hole, it will run out at the other, carrying with it all moisture. The amount of overflow should at least equal that required to fill the sleeve. This overflow may be caught in a vessel and used for other joints. When the sleeve has been completely filled, the holes are closed by having sheet-lead caps carefully soldered over them.

164. The finished joint is shown in Fig. 55. After making a splice, the conductors should be tested out for

crosses and continuity. The end of a cable should never be opened during rainy or foggy weather, as enough moisture will enter the cable to cause considerable injury. If caught in a shower while making a splice, great care must be taken

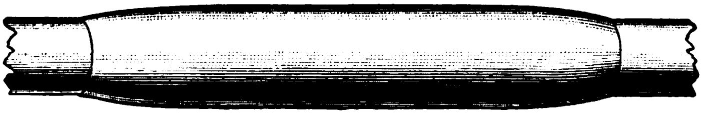


FIG. 55.

to protect the cable ends from moisture by thoroughly soaking them in hot insulating compound and wrapping them with canvas. If the end of a cable must be left for a considerable time, the sheath should be sealed with a lead cap by a plumber's wiped joint.

165. Insulating a Joint On a Rubber Cable.—On rubber-insulated cables the copper conductors are joined as described in connection with cables insulated with fiber or paper. The wire splice is then covered by a thin layer of pure unvulcanized rubber tape, $\frac{1}{64}$ to $\frac{1}{32}$ inch in thickness, wrapped spirally around the splice, and this layer is covered with tapes until the insulation is as thick as on the main conductor. The tapes contain less and less rubber until the outer layer is reached, which is usually a first-class adhesive cotton or linen tape. When the cables are lead-covered, the rubber tapes do not require vulcanization, as the lead cover is air-tight; but on aerial or other non-leaded cables, the rubber should be carefully vulcanized by means of heat, applied by a spirit lamp or other suitable device, and then covered with linen or cotton tape, as a mechanical protection. The vulcanizing of non-leaded rubber cables is a very important feature, and should be entrusted only to a skilled expert if satisfactory results are to be obtained and the cable is to last any length of time.

166. Rubber cables are also spliced in the following manner, although it does not make as thorough and lasting a joint as the method previously given: The wires in the

rubber cables having been spliced, each joint is wrapped with a piece of approved waterproof tape of sufficient length to make three layers. After this has been done, the wires at the splice are wrapped with several layers of heavy tarred tape, of sufficient length to render this section of the same thickness as the cable. This wrapping should cover the braid on the cable for a distance of 3 inches from the points where it is cut. In the last two years there has been a tendency shown to solder the joints in the wires, but it has not become the universal practice.

167. Branch Cable Joints.—In making **T**, **Y**, and four-way joints it is customary to use split sleeves. A split **T** sleeve is shown in Fig. 56. The split sleeve is slipped over the joint and secured by a plumber's wiped joint to the lead sheaths of the cable ends. The edges of the sleeve that are to be wiped or soldered together are trimmed so that they touch only on the inside and widen gradually toward the outside, as at *a* in Fig. 57. The space *a* is filled with solder, thus making a good tight joint. When centered over the splice, each end should overlap the lead sheath of the cable ends at least ½ inch, though a distance of 4 inches is preferred. Split sleeves for joints can be obtained from cable manufacturers, but unsplit ones may be purchased at plumbers' supply stores, in which case it is necessary to split them. The separate branches of a **T**, **Y**, or four-way joint should be from 13 to 16 inches long for a 150-conductor cable.

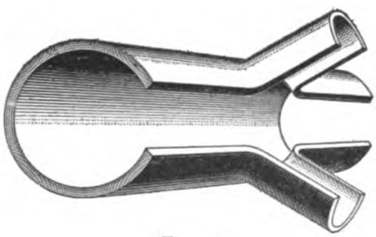


FIG. 56.

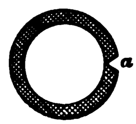


FIG. 57.

Should it be impossible to obtain **T**, **Y**, or four-way sleeves, substitutes may be improvised by using ordinary straight sleeves or lead pipe. This is a more expensive way to make a joint, but, nevertheless, it is often done.

CABLE TERMINALS.

168. Where a cable ends in an office or upon a pole, means must be provided for connecting the wires in the cable to the wires leading from it; and especially in cable

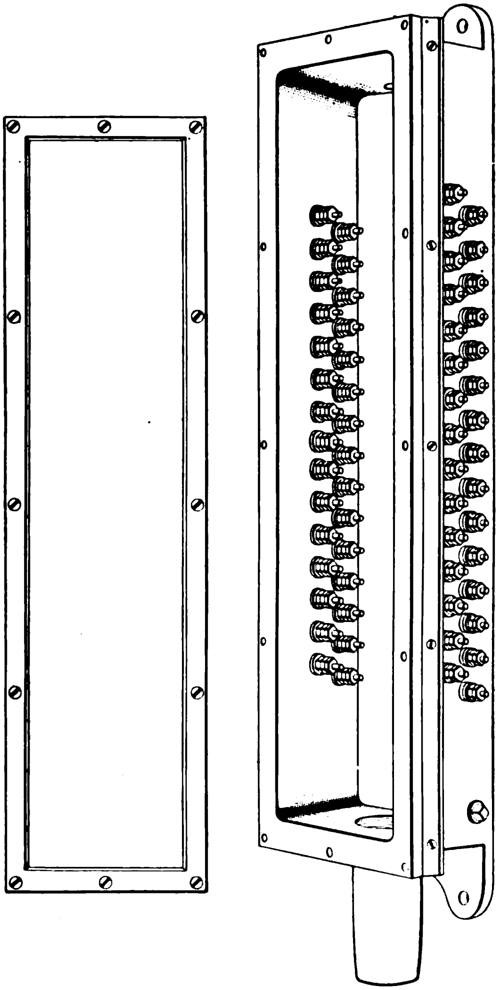


Fig. 58.

terminals located out of doors, is it necessary to provide means for excluding all moisture.

169. Box Terminals.—Various forms of cable terminals are found upon the market. These usually consist of a cast-iron or hard-rubber box, capable of being hermetically sealed to the cable sheath and having within a set of terminals to which the wires of the cable may be fastened. After all the connections within the box have been made, the cover is put in place and secured, a rubber gasket, shown only in Fig. 59, serving to make the joint tight. When the cover is secured in place, the outside wires may be connected to the terminals that project through the sides of the cable head.

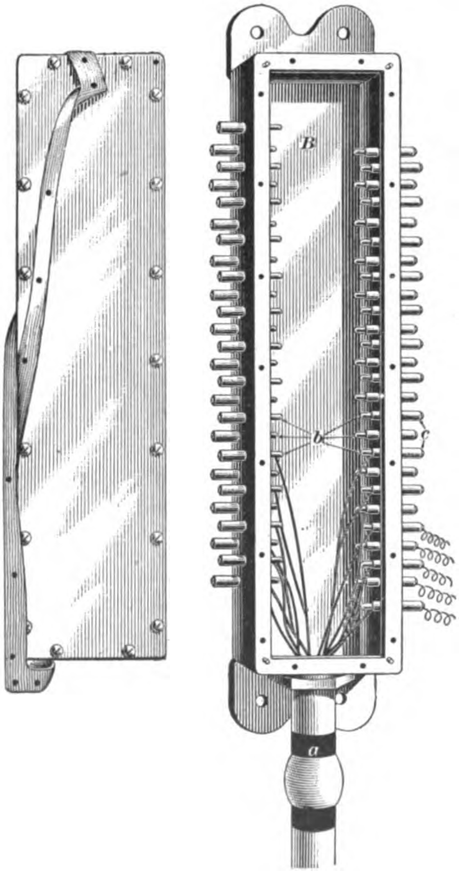


Fig. 59.

170. Probably the form of cable head most generally used is the one shown in Fig. 58. This is a rectangular cast-iron box into which the cable is brought from below, the lead sheath being secured to the sleeve of the cable head projecting downwards by a plumber's wiped joint. The cable conductors are securely fastened under washers and nuts on the inside of the head to terminals that project through insulating bushings to the

outside of the head, where the outside wires are in turn fastened in like manner.

171. Another form of cable head, used more for telephone than for telegraph cables, is shown in Fig. 59. A brass sleeve *a*, secured to the bottom of the cast-iron box *B*, affords ready means for securing the cable sheath to the box in a water-tight and air-tight manner. The various conductors from a cable are led up within the box and fastened to the individual terminals *b*, which pass through the insulating bushings *c* to the outside of the box. In a cable head of this style, it is necessary to solder the wires to the terminals.

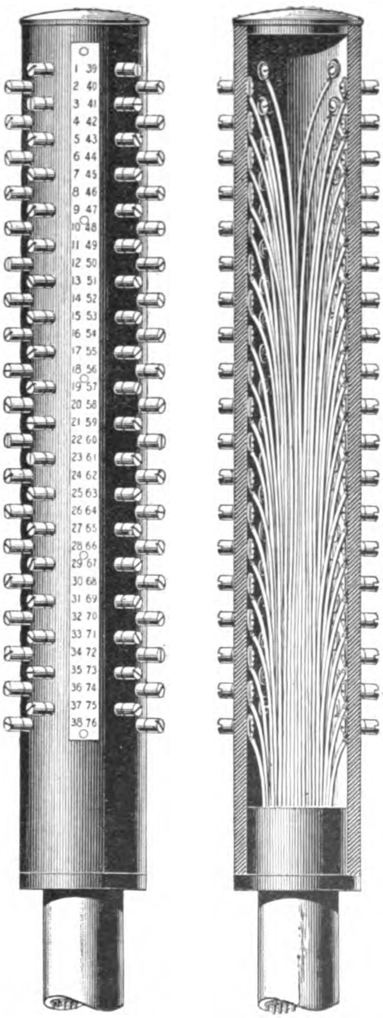


Fig. 60.

172. Tubular Terminal Head.—The **tubular terminal heads,** made of hard rubber, are rapidly coming into general use. One is shown, both open and closed, in Fig. 60. The ends of the inside wires are secured under washers and screws, and the ends of the outside wires by strong binding posts, to terminals that extend through the sides of the head. Telegraph-cable

heads are generally filled with hot insulating compound after all the inside wires and the head itself are secured in position.

173. Lightning Arresters.—Lightning arresters and fuses should be placed in the pole box near the cable

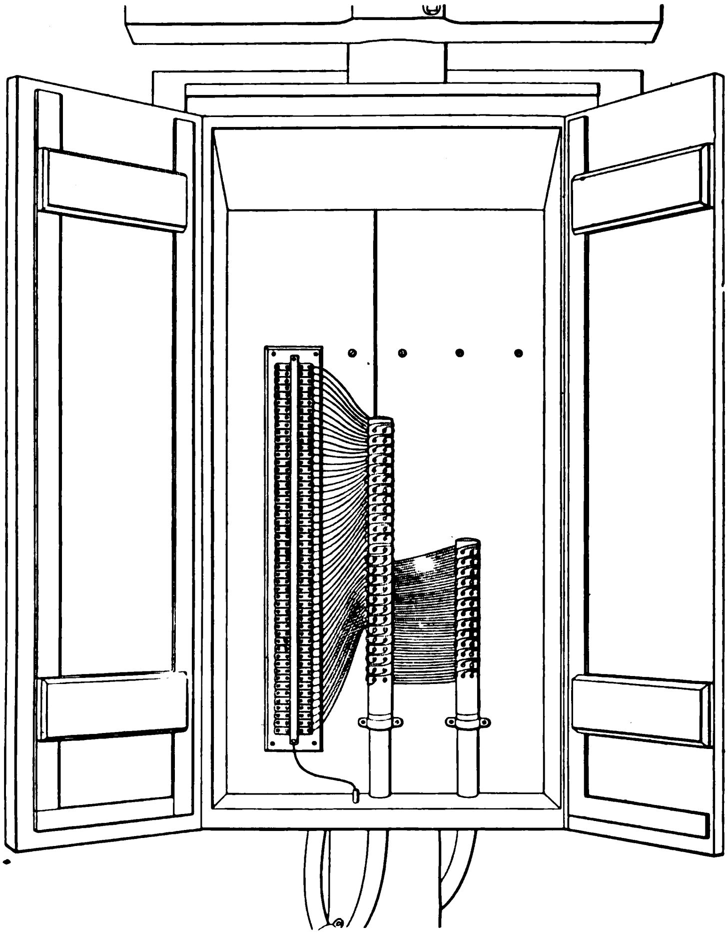


FIG. 61.

head, in order to prevent injuries to the cable from lightning or by the passage through it of heavy currents, such as might

be caused by crosses with power or lighting wires. These protecting devices may be procured in a variety of forms. Cable heads with the arresters attached directly to them are not very desirable.

A pole box with two tubular cable heads and lightning arresters is shown in Fig. 61. Pole boxes are intended to be waterproof, but sometimes they are not, and, hence, special care should be taken to make the cable heads moisture-proof.

174. Pothead Terminals.—Terminals known as **potheads** are sometimes used for telegraph cables on poles, but are rarely used in telegraph offices. Though but little used on telegraph cables, the knowledge of how to make a pothead terminal may be useful some time, and warrants our giving here the necessary instructions. When properly made, pothead terminals are thoroughly reliable, and have the additional advantage of being extremely cheap. In order to terminate a cable in this manner, the cable end is secured in an upright position, with the ends of the wires projecting about 10 or 12 inches, in the case of a 100-wire cable, beyond the end of the sheath. A sleeve of pure lead, $\frac{1}{8}$ inch thick and having an internal diameter slightly greater than the external diameter of the cable sheath, is then slipped down over the cable and out of the way.

Pieces of good rubber-covered wire long enough to reach wherever desired are spliced to the wires in the cable. A good wire for this is No. 14 or 16 B. & S. gauge okonite. It need not have an outside braid. Each splice should be covered with a cotton or paper sleeve, and all splices should be kept within a space of about 8 inches from the end of the cable sheath. The wires as they leave the cable should then be bound with several layers of heavy cotton twine or wicking in such manner as to prevent the insulating compound that will be subseqently poured in from entering the cable. This latter remark applies more particularly to the dry-core paper cables. All the rubber-covered wires should then be taped together with okonite tape in such a manner that

about one-half of the tape will be below the surface of the compound when poured in. The spliced wires should then be opened up as much as possible, so as to allow room for the insulating compound to fill the spaces between them.

175. A thin brass tube about 20 inches long and about ½ inch in diameter should then be bound with twine alongside of the wires, with its lower end about even with the end of the cable sheath. After this, the lead sleeve should be drawn up over the splices until it laps over the cable sheath only about 1½ or 2 inches. It should then be securely wiped to the sheath by a plumber's joint. The lead sleeve should then be warmed with a torch until it can barely be touched with comfort with the hand, and some sealing compound, previously heated to about 350° F., should then be poured slowly through a funnel into the top of the brass tube. This should continue until the insulating mixture is within ½ inch of the top. The funnel may then be removed and the compound allowed to settle and cool. The next day, and from day to day thereafter for about a week, the tube should be filled with hot compound to make up for the settlement. After it has ceased to settle, the top of the lead sleeve may be dressed into contact with the okonite tape wrapping, thus giving a rather finished appearance to the work. It is well to place a cross-mark on the outside of the lead sheath at the point where the brass tube ends on the top, so that it may readily be found when needed.

The reason for using the brass tube instead of pouring the insulated compound directly in the top of the lead sleeve is that by so doing the mixture is forced to the bottom of the joint, from which it proceeds slowly upwards, thus expelling all the air. The insulating compound may be purchased from various cable manufacturers and wire dealers, and in ordering it care should always be taken to specify the purpose for which it is to be used. A good way to test whether or not the compound is too hot is to dip a piece of okonite wire into it, holding it there for about 2 minutes; if, upon withdrawal, the insulation upon the wire is softened so as to

readily peel off, the fluid is too hot. If, however, the insulation remains firm, the mixture is not too hot.

176. The **spider** is a term used by linemen to designate the wires that connect the cable-terminal posts to the line wires. Where the pins and posts are numbered alike, as it is best to do, the spider wires are generally lashed together, for there will be no need to disturb them later. For spider wires use rubber-covered and braided copper wire. The spider can be most conveniently made up in the shop by laying out the same number of arms and in the same position as they are on the pole. Starting from each pin, leave the wires long enough to reach up into the cable box. Lash them together and tag the two ends of each wire alike, thus requiring no testing when they are connected on the pole.

OVERHEAD CABLE LINES.

SUSPENSION OF CABLES.

177. Messenger Wire.—Overhead cables are supported from a steel wire or rope stretched between the poles. These are termed **messenger,** or **carrier, wires,** and usually consist of several strands of steel wire twisted together to form a cable. Table 26 gives the weight per 100 feet and the estimated breaking strength of the various sizes of messenger wire from $\frac{3}{32}$ inch to $\frac{1}{2}$ inch in diameter.

For supporting heavier cables, containing 100 wires or more, nothing less than a $\frac{1}{2}$-inch stranded rope should be used. For small cables, the $\frac{3}{8}$-inch or even $\frac{1}{4}$-inch messenger wires will prove sufficient, provided the length of the spans is not excessive. The messenger wire may be supported directly from the pole by means of wrought-iron brackets, of which one type is shown in Fig. 62; or where a number of cables are to be run on the same poles, cross-arms for the cables may be made by bolting a piece of 3-inch angle iron directly to the pole. This may be of any

TABLE 26.

Diameter. Inches.	Weight per 100 Feet. Pounds.	Estimated Breaking Strength. Pounds.
$\frac{1}{2}$	51	8,320
$\frac{15}{32}$	48	7,500
$\frac{7}{16}$	37	6,000
$\frac{3}{8}$	30	4,700
$\frac{5}{16}$	21	3,300
$\frac{9}{32}$	18	2,600
$\frac{17}{64}$	15	2,250
$\frac{1}{4}$	$11\frac{1}{2}$	1,750
$\frac{7}{32}$	$8\frac{3}{4}$	1,300
$\frac{3}{16}$	$6\frac{1}{2}$	1,000
$\frac{5}{32}$	$4\frac{1}{2}$	700
$\frac{9}{64}$	$3\frac{1}{2}$	525
$\frac{1}{8}$	$2\frac{1}{4}$	375
$\frac{3}{32}$	2	320

length required, and should project on each side of the pole to a sufficient distance to give room for the desired number of cables. The messenger wire may be supported beneath the angle-iron cross-arm by means of hooks, or it may be passed directly through the cross-arm, slots being cut to the hole in such manner as to allow the messenger wire to be readily slipped in and at the same time to prevent it from accidentally escaping. The messenger wire should be drawn up tightly by means of a block and tackle, and firmly anchored at its ends and at frequent intermediate points, so as to prevent any great length of it going down should a fracture occur at any point.

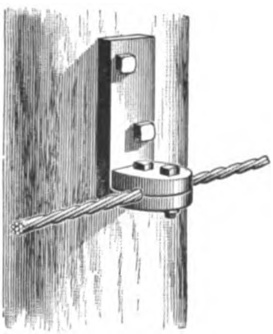


Fig. 62.

178. Sag of Messenger Wire.—The amount of sag that should be allowed when the cable is up is about 1 per cent. of the length of the span. That is, in a span of 100 feet, the sag at the center should be 1 foot; in a 150-foot span, 1.5 feet, and so on. In order not to exceed this, the messenger wire should not dip more than 2 or 4 inches before the cable is put up. As the strain on the messenger wire should not exceed 3,000 pounds, it is best to set the poles only 100 or 125 feet apart; then, as the wire and poles will give a little, the final strain will not exceed 2,000 pounds, even with rather heavy cables.

179. Table 27, taken from Roebling's handbook, will give the size of stranded iron-wire cable that should be used to support telegraph cables of various weights, per 1,000 feet, for spans of various lengths. In calculating the supporting

TABLE 27.

SUPPORTING CAPACITY OF ORDINARY GALVANIZED IRON-WIRE STRANDED CABLE.

Diameter of Stranded Cable. Inches.	Span in Feet.								
	100	110	120	125	130	140	150	175	200
	Weight in Pounds of 1,000 Feet of Telegraph Cable That the Strands Will Support.								
$\frac{1}{2}$	2,818	2,516	2,263	2,152	2,050	1,867	1,709	1,391	1,154
$\frac{15}{32}$	2,520	2,247	2,020	1,920	1,827	1,663	1,520	1,234	1,130
$\frac{7}{16}$	2,030	1,812	1,630	1,550	1,476	1,344	1,230	1,001	900
$\frac{3}{8}$	1,580	1,409	1,266	1,204	1,146	1,043	953	774	640
$\frac{5}{16}$	1,110	899	890	846	805	733	670	544	450
$\frac{9}{32}$	860	765	680	652	620	563	513	414	340
$\frac{1}{4}$	585	521	468	445	423	385	352	285	235
$\frac{7}{32}$	433	385	346	329	313	284	260	210	172
$\frac{3}{16}$	337	300	270	257	245	223	204	165	137

capacity of the iron-wire cable, a dip of 1 per cent. of the length of the span and a factor of safety of 2 have been allowed. By a "factor of safety of 2," we mean that the stranded iron cable is assumed to have only ½ the breaking strength given in Table 26. Since the telegraph cables help in a great measure to carry their own weight, the stranded-wire cables will safely carry the loads given for them in the table. The weights of lead-covered and rubber-covered telegraph cables per 1,000 feet, which must be known in order to use this table for determining the size of the messenger wire and the span required for a certain cable, are given in Tables 23 and 24.

180. Fastening the Messenger Wire.—The ends of the messenger wire must be securely fastened around the poles. It should be wrapped around the pole at least twice, and the end securely fastened to the straightaway portion by a clamp similar to the kind shown in Fig. 28. As messenger wires and guys are apt to injuriously compress the pole, it is recommended to put a heavy sheet of galvanized iron around the pole under the wires. In order to hold the messenger wire tight, the end poles must be firmly anchored to the ground. An end guy carried back 3 or 4 poles is not a good plan, because all the poles may give sufficient to not only produce slack in the messenger wire, but also in the line wires as well. An anchor log 12 feet long and 1 foot in diameter, buried 10 feet under the surface, has been known to sustain from 6 to 8 cables, producing a strain on the anchor of at least 30,000 pounds. In this case, 2 anchor rods, 1½ inches in diameter, were used. The anchor may be made still more secure by filling in around the log with cemented concrete.

181. The guy wires should have double the strength of the messenger wire, in order to prevent the least yielding, and should be securely and permanently pulled up and fastened before the messenger wire is strung. The greater the horizontal distance from the pole to the anchor, the less

will be the strain upon the anchor and the guy wire. However, in cities, where it is necessary to consider the convenience of pedestrians, the anchor should not be placed very far from the base of the pole. A good way is to carry the messenger wire back to the next pole beyond the cable pole and there fasten it at a height of about 15 feet from the ground. A guy wire stretched between this point and an anchor placed at a horizontal distance of 10 feet from the pole will not be very objectionable. In anchoring poles, they should be given a slight rake toward the anchor, so that when the messenger wires and cables are up, the final strain will pull it up to a perpendicular position.

182. Pole Brace.—Where it is impossible to place an anchor or to use a guy, the pole may be braced as shown in Fig. 63. The brace *b* is set against the pole high enough to meet the dead-ended messenger wire *d*. The brace should be secured to the pole, so that it cannot possibly drift, by at least 3 lagscrews, and the messenger wire dead-ended below the meeting point, between the pole and the brace. As a further precaution, connect the pole and brace by a stranded or stout wire *c* about 5 feet below the top of the brace. Make sure, by means of lagscrews, staples, or otherwise, that this wire cannot slip on either the pole or the brace. The pole should be set securely in the ground, or there may be a tendency for it to rise.

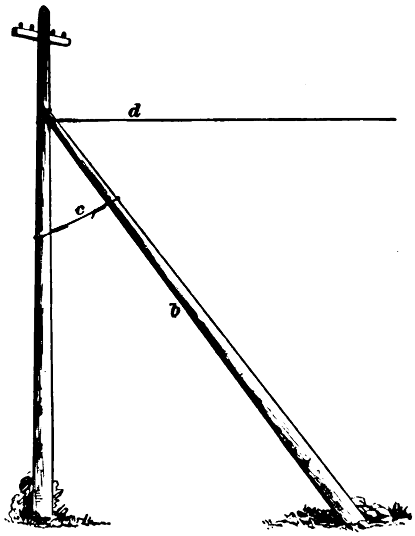


FIG. 63.

183. Handling a Cable.—It will hardly do to roll a cable reel over the ground to the place where it is needed, and it takes a great deal of muscle as well as time to load it on a truck and to unload it again; therefore, the following method, used by a prominent construction company, is one of the most convenient. The cable reel is supported by an arrangement shown in Fig. 64, which consists primarily of a large pair of wheels, a 2-inch round steel axle, and a frame of strap iron 2 in. × ½ in. (*a a*), to which a short wagon tongue has been attached. The strap-iron frame is attached to the axle by means of two **U** bolts *c*, *c*. Four collars *b*, *b*, *b*, *b* with setscrews keep the wheels, which work loosely on the axle, in their proper position.

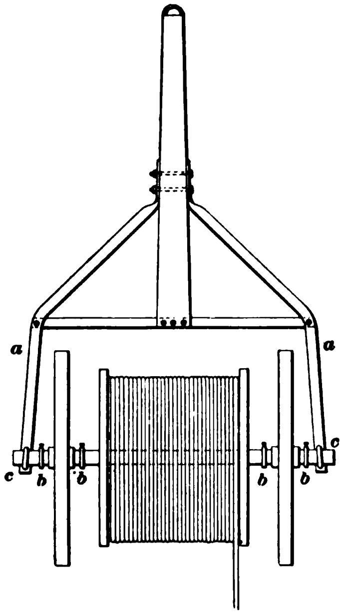


FIG. 64.

To load the reel, loosen up the **U** bolts *c*, *c* on the end of the axle, and the collars *b*, *b*, *b*, *b*, and remove the wheels. Then slip the axle through the cable reel, and run the cable up an incline until it is high enough to allow the wheels to go on again. Put the wheels and collars on the axle, roll it off the incline to the ground, put on the frame, hitch it to a truck, take it to the place where it is needed, and there unhitch it from the truck, block the wheels, and open up the reel.

NOTE.—The preceding articles on the sag and fastening of messenger wires, the pole brace, and the handling of a cable, are condensed from an article on "Aerial Cables" in the "Telephone Magazine" for January, 1900.

184. Cable Hangers.—Lead-covered cables are sometimes supported from the messenger wire by means of **cable**

hangers, secured to the cable usually at intervals of 18 to 24 inches. Although this is not generally considered the best method for supporting cables, it is considerably used and therefore is given here. For small light cables, the hooks need not be placed closer together than 30 inches. There are several different styles on the market, some of which are made of sheet metal and others of malleable iron. In spite of all precautions, a hanger will sometimes catch, in which case the sheet-metal hangers will generally give way, but the solid hanger has often been known to hold on and seriously injure the cable before the signal to stop could be passed along. For this reason, the malleable or solid iron hangers are not recommended.

185. Malleable Iron Hangers.—The hanger shown in Fig. 65 is composed of malleable iron, and is readily clamped upon the cable by a special tool designed for the purpose. This tool and the method of using it in clamping

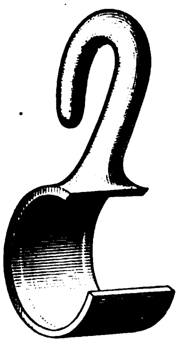


FIG. 65.

FIG. 66.

a hanger to a cable is shown in Fig. 66. The broad band of the hanger is slipped over the cable at the desired point, and the tongs are then applied, as shown, thus squeezing the band of the hanger around the cable until the gap is entirely closed.

It is well, although not strictly necessary, to provide a piece of thin sheet lead about 1½ inches wide and long enough to almost encircle the cable, and to clamp this on under the

hanger. This serves as an additional protection to the cable sheath, which is especially desirable where the sheath is extra light.

186. Hold-Fast Cable Clip.—The *hold-fast cable clip*, illustrated in Fig. 67, is quickly and easily applied by hand. The metal strap is simply drawn around the cable and passed through the hanger; the part with the hooks is then turned up, as shown in the illustration, which action takes up the slack, binds the strap tightly about the cable, and prevents the latter from slipping. All parts are made of galvanized steel, so that they will not rust. This clip can be removed and used again. It is made by J. S. Barron & Co.

FIG. 67.

187. Cable Stringing.—When the messenger wire is in place and pulled up to the proper tension, a *leading-up*

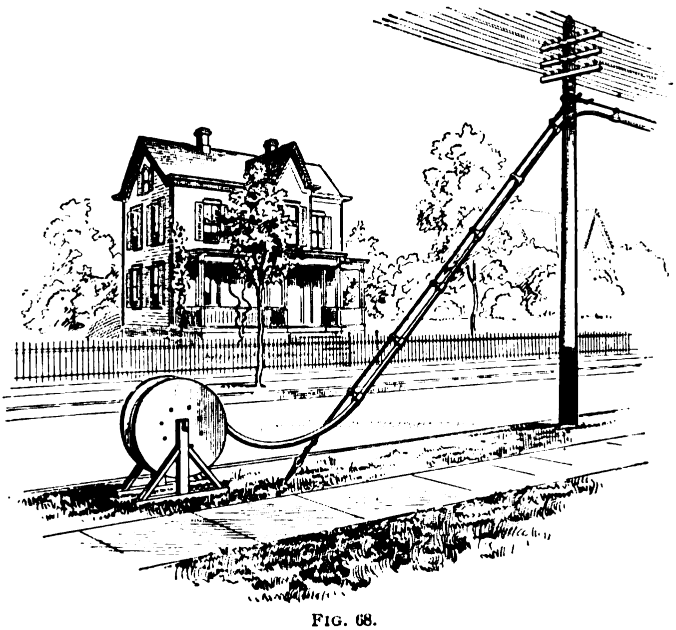


FIG. 68.

wire of the same material as the messenger wire should be secured to the end of the messenger wire and to a stake or other suitable anchor in the ground, at a distance of 75 or 100 feet from the last pole in the stretch. An anchored guy wire, where there happens to be one, can sometimes be used for this purpose. The reel upon which the cable is wound should then be placed a few feet beyond the lower end of the leading-up wire, as shown in Fig. 68, and in such manner that the cable will unwind from the top side of the reel rather than from the bottom.

188. For drawing along the cable, a rope is first suspended directly under the cross-arms on the poles for the entire length of the stretch to be strung. A ½-inch hemp rope may be used, but a ¼-inch steel-stranded cable will prove more convenient. One end of this rope is attached to the end of the cable, while the other is secured to a capstan or windlass at the distant end of the stretch. If no capstan can be obtained, a set of large pulley blocks and a long rope with a horse hitched to it may be used. The cable should not be pulled faster than 10 to 15 feet a minute when hangers are used, for they cannot be attached if the cable travels at a faster rate. To help the rope around a corner, two snatch blocks should be used.

189. Fastening Rope to Cable.—For fastening a rope to a cable, Mr. A. E. Dobbs, in the "Telephone Magazine," gives the following methods: The end of the rope is frayed out, braided around the cable, the end lashed down with marline twine, and the fastening finished by a series of

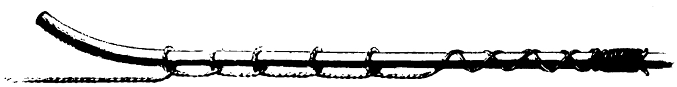


FIG. 69.

half-stitches, as shown in Fig. 69. This method generally holds, but, if the pull is a long and hard one, as it is apt to be if an attempt is made to string up 1,000 feet of cable, the lead may creep and break or even pull off altogether.

In order to prevent this, the plan shown in Fig. 70 is sometimes used. The end of the cable is bent back and one or more hitches taken at the bend. This method puts the

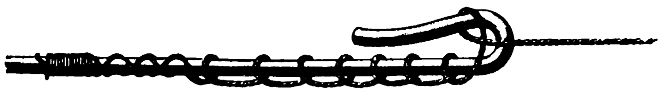


FIG. 70.

strain on the wires inside the cable. It is, of course, taken for granted that 3 or 4 feet of the lead at the end of the cable will be thrown away.

Another method, sometimes used on aerial, and very often on underground, cables, is shown in Fig. 71. This consists of a concave clamp made to fit over the end of the

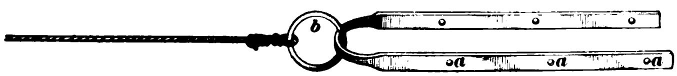


FIG. 71.

cable. Through the holes *a*, *a*, *a*, rivets or screws are driven into the cable in order to hold the clamp in place. The cable is pulled along by means of a rope fastened to the ring *b*.

190. One man is needed to turn the reel and mark the cable where the hangers are to be put on. As the cable leaves the reel, another man attaches the hangers, the cable being drawn slowly enough to allow him to properly do this. Another man hooks the hangers upon the leading-up wire as the cable begins its ascent. A man stationed on each pole lifts the hangers around the support or cross-arm as the cable proceeds.

It is not necessary to attach every hanger to the messenger wire during the process of drawing up, and in order to save labor on the part of the men and facilitate the work, it is well to attach only every fourth or fifth hanger. This method may be followed until the forward end of the cable reaches the last span in the stretch, when a signal should

be given for the man on each pole to hook every hanger upon the messenger wire as it passes. By this means the entire cable will be hooked up when it reaches its destination.

Some claim that aerial telegraph cables can be put up quicker and cheaper by the use of snatch or pulley blocks than by sliding the cable along carrier wires as by the method just given. Thus the passing of the cable hangers around the pole fastenings of the carrier wire is avoided.

191. An improvement on the method just given of drawing up cables is frequently followed where a large amount of cable is to be erected. This method is used extensively by the Standard Underground Cable Company, by whom it was developed. The hangers are attached to the cable in the usual way, but these are not hooked over the messenger wire during the process of drawing up. Instead of this, the cable rests in carriers, shown in Fig. 72, each consisting of a grooved wheel *A*, pivoted to a supporting stirrup *C*. The grooved wheel rests on the messenger wire, while the cable carrying the hangers is supported in the stirrup beneath. These carriers are applied at intervals of from 10 to 15 feet, and serve to support the cable while it is being drawn over the messenger wire. In order to make it unnecessary to remove the carriers from the messenger wire as they pass a cross-arm or support, switches or side tracks are clamped on the messenger wire at each cross-arm. These serve to engage the wheel of the carriers and guide them down under the cross-arm and again up on the other side and back on to the messenger wire. These switches are so made as to be readily bolted to the messenger wire. When the cable is all pulled up except the last section, men stationed at each pole place the hangers on the wires and remove the carriers as they pass, so that when the last section is pulled into position, all hangers are in place. The switches, or side tracks, are then removed, leaving the cable permanently suspended.

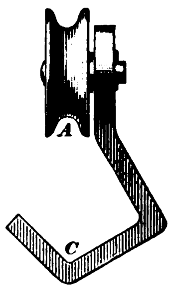


FIG. 72.

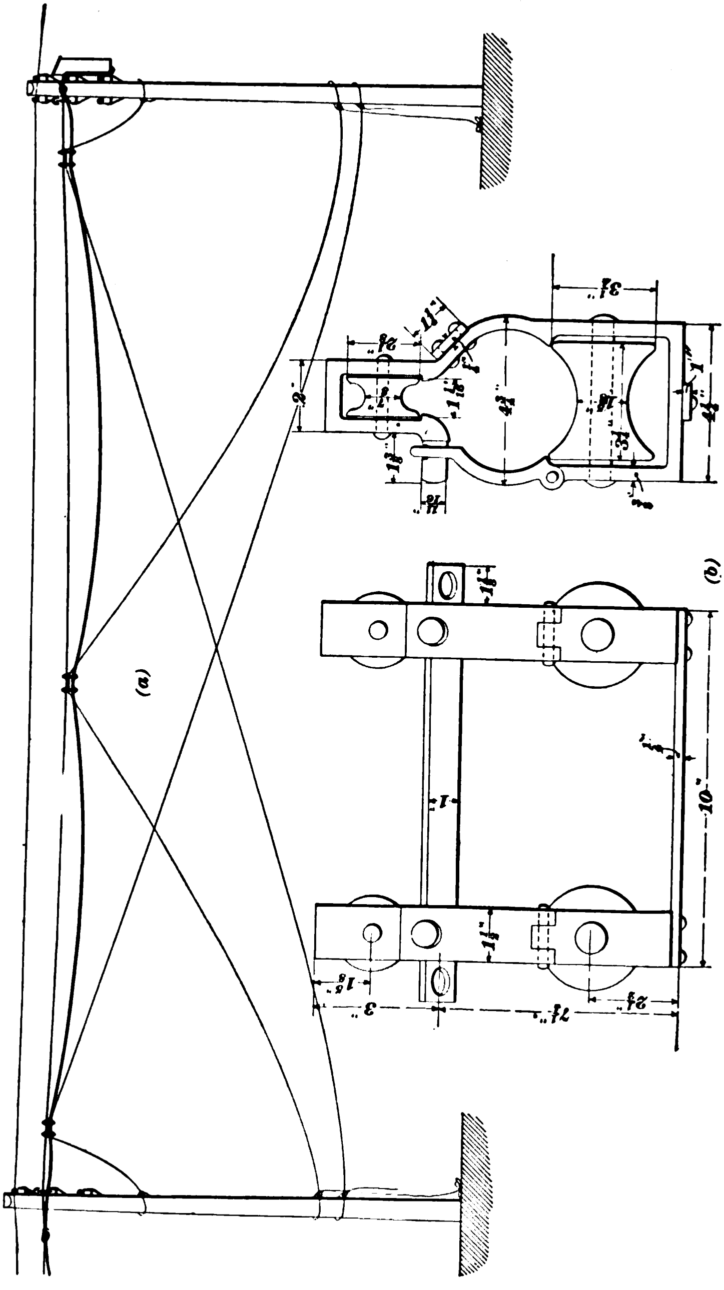


FIG. 73.

192. The method given below for stringing and holding up an aerial cable is superior to the preceding ones. In this, a special cable carrier (shown in Fig. 73), consisting of four grooved wheels and a wrought-iron framework, is used. Two small wheels, fastened in line with each other, in order that they can either run along or rest upon the messenger wire, support both the carrier itself and the cable. Two larger wheels, with grooves larger than the diameter of the largest cable, are in line with each other and directly under the former two. As the cable is drawn along over the two large wheels, the latter revolve. All four wheels are in the same plane and are fixed in position, but revolve freely. These carriers are readily slipped over the wires, but when the two side bars are closed, the cable cannot fall from the carrier nor the carrier from the messenger wire. One carrier is placed on each side of and near to each pole, and one or more between, depending on the length of the span and the weight of the cable. They are held in position by two ropes fastened to the poles, often near to the ground, one on each side of the carrier, so that the carriers will not move when the cable is drawn through them. By placing one on each side of a corner pole, the cable can be pulled around the corner without difficulty. After the cable has been strung and fastened to the messenger wire, the carriers can be drawn to the nearest pole and removed.

193. Chinnock Cable Winder.—Probably the best way to support the cable from the messenger wire is by wrapping the cable and messenger wire with strong marline rope or twine, as shown in Fig. 74. The cable is drawn up to the supporting wire and wrapped to it with the marline by means of the **Chinnock cable winder,** commonly called the "spinning-jenny." The device as shown in Fig. 74 consists of a bobbin, made in two halves with a hole through the center large enough to allow the cable and supporting wire to pass through it. (*a*) is a sectional and (*b*) an end view of the winder. The inside of the bobbin is nicely lined with copper, to make it smooth and wear well.

To use the device, place the two halves over the cable and supporting wire, fasten them together by the hooks or other means provided, and wrap on enough marline to support the cable between two poles. Fasten one end of the marline at one pole. Then, by pulling the bobbin along by means of a rope *d* attached to the projecting hook *c*, the bobbin draws the cable up close to the wire, pushes before it the slack of the cable, and the marline twine twists itself spirally around the cable and supporting wire. When it reaches a support, the bobbin must be removed, replaced on the other side of the support, and again wound with marline. Sometimes two wrappings of marline are used, in order to make the cable more secure, requiring the process above described to be repeated between supports.

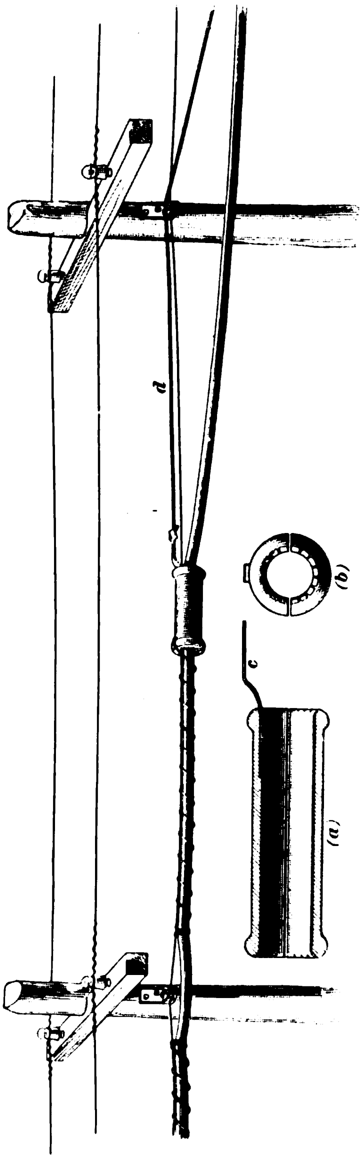


FIG. 74.

The spinning of cables holds them up better than the method of hooking them to the carrier wire. The marline when worn out can easily be removed and new marline spun on by men working on the poles,

without the use of ladders or a carriage of some sort that will carry a man along the messenger wire, which are necessary when hooks have to be replaced. Supporting the cable by wrapping it and the messenger wire together with marline twine is, all things considered, much preferable to hanging it up by means of cable hangers.

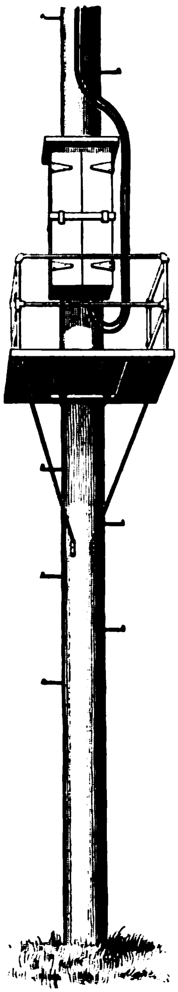


FIG. 75.

194. Cables should be ordered from the factory in certain specified lengths, and these lengths should be so proportioned that the joints will come at the poles and not in the middle of the spans. It is always well to allow a few feet of slack in each section of cable, in order to allow room in the future for making necessary splices as repairs are needed.

195. Pole Balconies.—Where an aerial cable line ends for the purpose of connecting with an underground line or with bare overhead wires, or where an underground cable terminates for the purpose of connecting with overhead lines of bare wire, suitable cable terminals, such as already described, should be provided on the pole and enclosed in a waterproof box. In order to facilitate the work of making connections and the subsequent testing out of lines, a balcony should be built below the box containing the terminals. A pole thus equipped is shown in Fig. 75.

UNDERGROUND CABLE LINES.

CONDUITS.

196. Underground construction work is becoming of more and more importance, for the increasing number of uses to which electricity is put renders the number of

circuits in city streets so numerous as to be a constant menace to both life and property when placed overhead. Besides this, their appearance is, to say the least, unsightly, which is in itself a sufficient reason for the city authorities to demand their being placed underground. Another strong argument in favor of placing wires underground is that they are not liable to injury from storms or fires, and that the cost of maintenance of the plant, when once properly installed, is less than if the wires were placed overhead.

197. It is almost universal practice in this country to place underground cables in conduits. In many places in Europe, the cables are laid directly in trenches, which are afterwards filled up, thus leaving the cable permanently buried. This practice is followed but little in this country, it having several disadvantages, chief among which are the difficulty of access to the cable for the purpose of repairing faults, the liability of the cable to injury from chemical action due to moisture and other elements in the soil, and the liability to mechanical injury from the pickaxes of workmen.

198. Open-Box Conduit.—The first conduit used in this country consisted of a wooden box or trough, made from 1½-inch rough lumber and large enough to contain all the cables needed. After digging the trench, the bottom is approximately leveled to grade, after which the trough, open at the top, is laid, the various sections being butt-ended and held in alinement by a short strip of board nailed along one side and lapping over the joint for a distance of about a foot on each side. After the conduit is laid, the reel containing the cable is mounted on wheels and drawn alongside the trench, the cable being unreeled and carefully laid in the bottom of the box as it proceeds. When all the cables have been laid, the box is filled with hot pitch, melted in any convenient manner, preferably in a wagon similar to that used for the same purpose in asphalting streets. The cover of the box is then nailed on and the trench refilled. The highest points in the conduit should be left open for some

days, so as to provide means for pouring in additional pitch to make up for the room left by settling.

199. Cables laid in this manner have given very good satisfaction, and the method is, to say the least, an inexpensive one. It is, however, subject to one very serious difficulty, and that is due to the inability to make subsequent extensions. It is almost impossible to predict, at the beginning of the work, the number of circuits that will be required in a given line of cable; and, moreover, to install as great a number as may be needed in the future involves a greater expense than most companies desire to bear at the outset. Forms of conduit have, therefore, come into general use that allow an extension of the cable system to meet the subsequent growth of the exchange.

200. Flexible Conduit Systems.—The conduits may be of either wood, clay, or iron, and are usually provided with a number of ducts extending as nearly as possible in straight lines between manholes, in such manner as to allow the cable to be drawn in or out, as desired, with but very little trouble. Systems of this kind may be classified under the heading of *flexible conduit systems*, the term referring to the possibility of making changes in the arrangements and numbers of cables rather than to the possibility of actually bending the conduits themselves.

201. Creosoted Wood Conduit.—A form of conduit largely employed, and one having the advantage of being very cheap to install, is one composed of sections of wooden tube, the fiber of the wood being impregnated with creosote, in order to prevent its decay. This form of conduit is commonly known as *pump-log conduit*, on account of the resemblance of the wooden sections to the ordinary form of wooden pump logs. A section of this conduit is shown in Fig. 76,

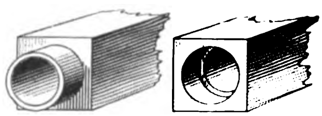


FIG. 76.

the ends being doweled in order to preserve the proper alinement in joining. These sections are usually 8 feet in length, and have circular holes through their centers from 1½ to 3 inches in diameter, according to the size of cable to be drawn in. The external cross-section is square and 4½ inches on the side, in the case of a tube having a 3-inch internal diameter. Such a conduit as this, if properly impregnated with creosote, will probably have a life of from 15 to 20 years, and perhaps much longer, this point being one concerning which there is considerable argument, and which probably time alone will decide.

202. In laying a pump-log conduit, a trench is usually dug several inches wider than the number of ducts to be laid side by side require, and after properly grading the bottom of the trench, a 2-inch creosoted plank is laid throughout its length for a foundation. The conduits are then laid in as many layers as are required, the ends being merely butted together without further precaution for securing perfect joints. In laying the tubes, however, the joints between the different layers should be broken as much as possible, in order to give greater strength to the structure. The sides of the trench are filled in and thoroughly tamped as the work progresses, and after the required number of ducts are in place, another 2-inch creosoted plank is placed above them, after which the trench is filled in and the pavement relaid. In digging the trench for this form of duct, it is well to make it of such a depth that the top plank will not be less than 2 feet from the surface of the street.

203. Cement-Lined Pipe Conduit.—This conduit, made by the National Conduit and Cable Company, is now largely used for underground wires. The sections shown in Fig. 77 are usually 8 feet long and are made as follows: A tube is made of thin wrought iron, No. 26 B. W. G., .018 inch thick, and securely held by rivets 2 inches apart. The tube is then lined with a wall of Rosendale cement ⅝ inch thick, the inner surface of which is polished while

drying, so as to form a perfectly smooth tube. This comes in three sizes, each having a length of 8 feet and internal diameters of 2, 2½, and 3 inches, the latter being the

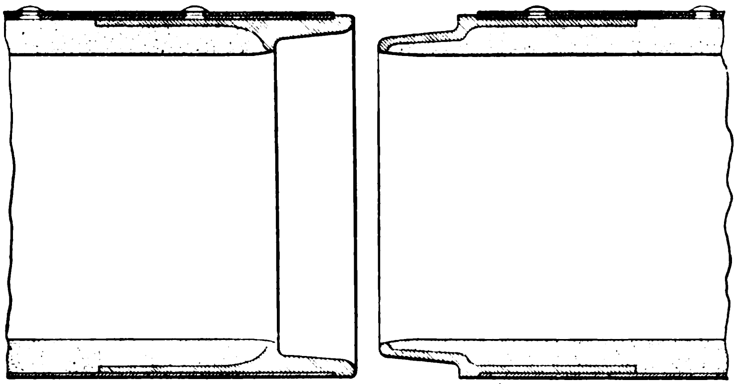


FIG. 77.

standard size. Each end is provided with a cast-iron beveled socket joint, by the use of which perfect alinement may be obtained by merely butting the ends together. These beveled socket joints also allow of slight bends being made in the line of conduit as it is being laid.

204. This conduit is laid in a trench, the bottom of which is first properly graded and then filled with a layer of from 4 to 6 inches of concrete composed of broken stone, sand, and cement. The tubes are then laid in layers, until the required number is in place, thoroughly embedded in good cement mortar, and the sides of the hole filled in with concrete as the tubes are laid. On top of the entire structure is placed a layer of from 4 to 6 inches of concrete, after which the trench is entirely filled with earth. The trench should be of such depth that the top of the upper layer of concrete will be at least 2 feet below the surface of the ground.

In laying this conduit, special attention should be given to carefully covering the joints with cement mortar, as in this way the conduit may be rendered perfectly water-tight. It is usual to allow about 1 inch of space between the layers

of ducts and to make each layer break joints with the preceding one, in order that the whole structure may possess considerable lateral strength. It is frequently advantageous to build in the sides of the trench a wall of rough boards, in order to prevent caving in of the sides and also to confine the cement mortar while setting. A view of a partially completed conduit line constructed with cement-lined pipes is

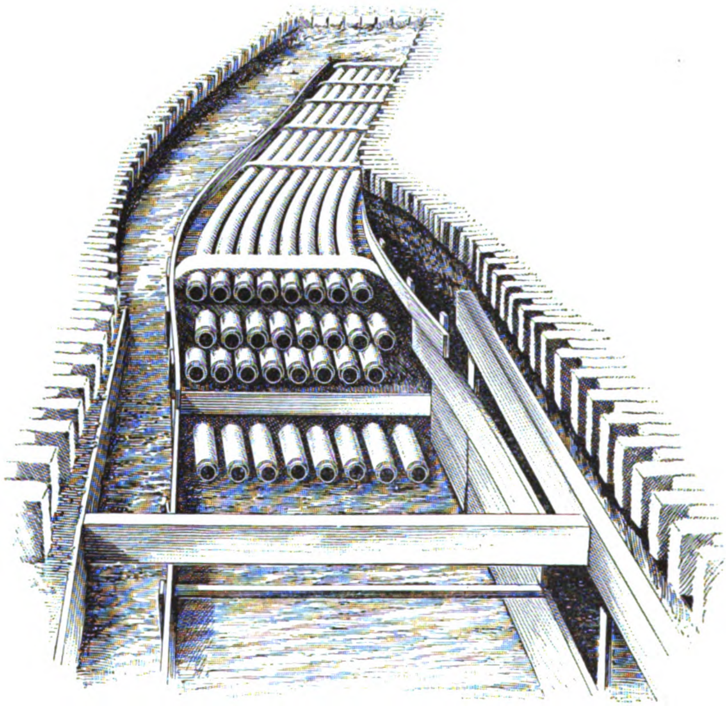


FIG. 78.

shown in Fig. 78. This line consists of four layers of 8 ducts each, making 32 ducts in all. This shows also how curves may be made in the line when necessary. Such curves should always be made with caution, and it is much better, if possible, to continue the line of conduit in a straight line between the manholes.

205. Cement-Arch Conduit.—This is a conduit recently devised by Mr. C. H. Sewall, of Chicago, and seems to be meeting with much success in practice. This conduit is formed in arches made of cement molded over a network of wire cloth. The cross-section of one of these arches is shown in Fig. 79, the dimensions there given being those of the standard size of conduit. The wire cloth, which gives toughness to the structure, is woven from No. 20 B. W. G. iron wire, with a mesh $\frac{3}{8}$ inch square. The cement is made of a mixture of equal parts of Portland cement and sand. The lengths of the section are usually 6 feet, although short sections may be procured, as well as curved sections, where it is necessary to make bends in the line of conduit. This conduit is laid on a previously prepared cement floor, the joints between the sections being covered with an arch of wire gauze lined with cotton cloth, as shown in Fig. 80.

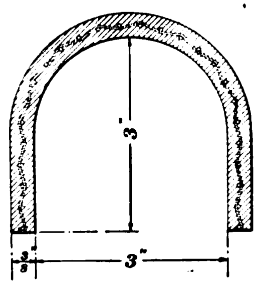


FIG. 79.

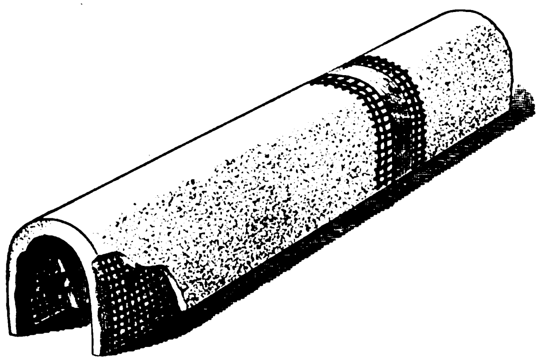


FIG. 80.

In laying this conduit, a trench is dug in the usual manner and the bottom filled with a layer of concrete about 4 inches in thickness. This concrete floor is troweled smooth and to an even grade from one manhole to another. The arches are then dipped in water and laid upon this floor, a templet

being used to secure the proper alinement. As soon as the first tier of arches is in position, it is immediately covered with concrete, which is then troweled smooth, forming a second floor, upon which the second tier is laid. This work

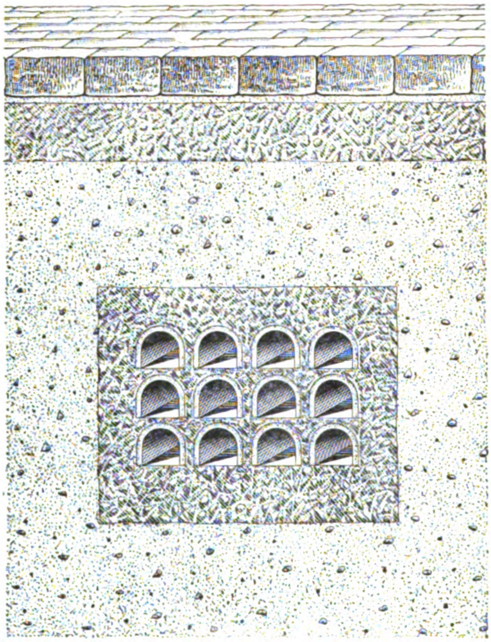


FIG. 81.

may be very rapidly done, as it is not necessary to wait for the complete setting of the concrete before the second and successive layers are laid. A cross-sectional view of a 12-duct line of this conduit is shown in Fig. 81.

206. Vitrified-Clay, or Terra-Cotta, Conduit.—A form of conduit that is probably used in good construction work to a greater extent than any other is made of vitrified clay. This material has the advantage of being absolutely proof against all chemical action, and unless destroyed by mechanical means will last for ages. Besides this, its insulating properties are high, and it is comparatively cheap and easily laid.

When clay conduits were first used, it was customary to form various sections with two or more ducts, one of the most common form being the 4-duct type, two sections of which are shown in cross-section in Fig. 82. These are made with 2, 3, 4, 6, and 9 ducts, all in 8-foot lengths. In another form, each section had two ducts only, these ducts being large enough to accommodate several cables. In this form, however, much trouble has been experienced, due to the fact that when several cables are laid in a single duct, it often becomes impossible to withdraw them, owing to the fact that they are much more likely to become wedged than in the forms where one cable only occupies a single duct. It is not good practice to put more than one cable in the same duct. With multiple-duct clay conduits, dowel pins are generally used at the joints to connect two sections, thus helping materially in preserving the alinement.

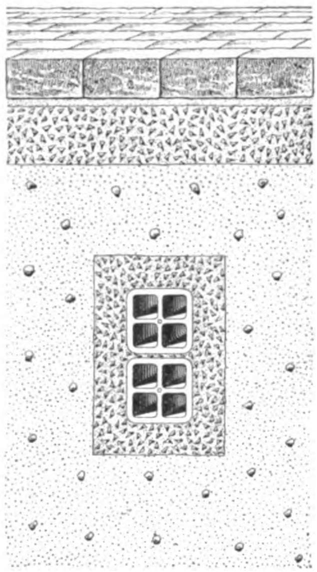


FIG. 82.

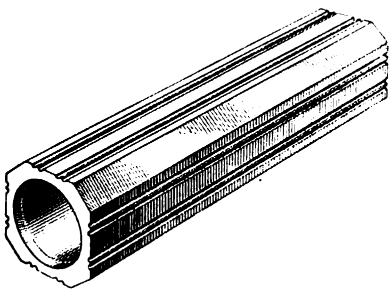


FIG. 83.

207. The form of clay conduits now most commonly used is shown in Fig. 83, this being usually made in lengths of 18 inches, having an internal diameter of from 3 to 3¼ inches, and being 4¾ inches square outside. This duct has a great advantage over the multiple-duct sections, due to the greater ease of handling, and also to

the fact that it is much less liable to become warped or crooked in the process of burning during its manufacture than the larger and more complicated forms. Like the cement-lined pipe, it is laid on a bed of concrete, cemented together with mortar, and entirely surrounded by concrete. In laying, a *mandrel*, like that shown in Fig. 84, which is of

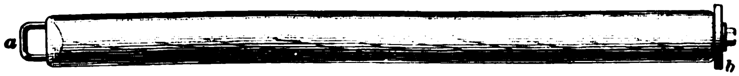


FIG. 84.

wood, 3 inches in diameter and about 30 inches long, is used. At one end is provided an eye *a*, which may be engaged by a hook in order to draw it through the conduit, while at the other end is secured a rubber gasket *b*, having a diameter slightly larger than that of the interior of the duct. One

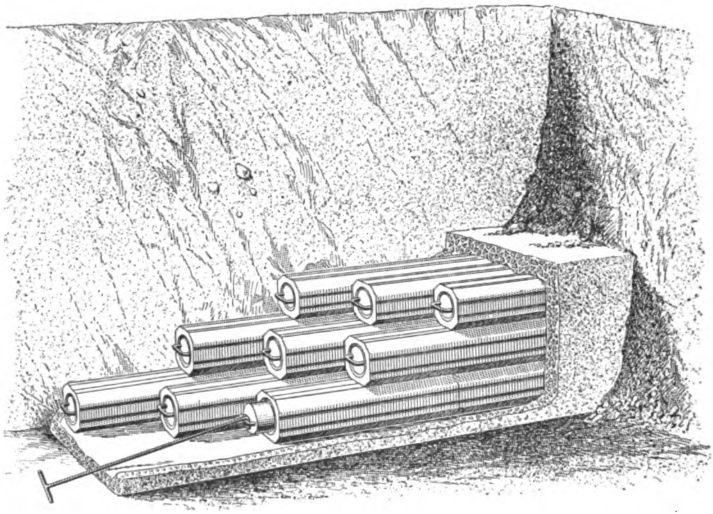


FIG. 85.

of these mandrels is placed in each duct when the work of laying is begun. As the work progresses, the mandrel is drawn along through the duct by the workmen by means of an iron hook at the end of a rod about 3 feet long, the method of doing this being shown in Fig. 85. By this

means, the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt which may have dropped into the duct is also removed. The cylindrical part of the mandrel insures good alinement of the ducts, thus securing a perfect tube from manhole to manhole.

208. Fig. 85 illustrates the method of laying this conduit, and shows how the joints should be broken in the various layers so as to insure a maximum lateral strength to the structure.

All conduits should be laid to such grades that there will be no low points or traps in the conduit which will not drain into the manholes.

209. Concrete and Mortar for Conduit Work.—In nearly all modern types of conduit, except the creosoted wood, the use of concrete and mortar is required. Concrete forms the foundation for the structure, and is also used in filling in the sides and top of the trench, thus enclosing the entire structure of ducts in a continuous mass of this material. The concrete for this purpose should be made as follows:

Good cement........................	1 part.
Clean sand..........................	2 parts.
Broken stone or screened gravel.....	5 parts.

The stone should not be larger than will pass through a ring $\frac{3}{4}$ inch in diameter.

The cement and sand should be first thoroughly mixed, after which a sufficient quantity of water should be added to form a soft mortar. The broken stone or gravel, in the proportion specified, should then be added, and the whole mass thoroughly mixed to a uniform consistency. Mortar is used for binding together the various sections of the ducts in much the same manner as in laying brick, and also to render the joints between the sections of a duct watertight. A good mortar for conduit work may be mixed as follows:

Good cement........................	1 part.
Sand................................	2 parts.

The cement and sand should be thoroughly mixed together while dry, after which water should be added to give the mixture the proper consistency for working.

MANHOLES.

210. Manholes form a very important part in cable systems, and require careful design to properly adapt them to the particular conditions to be met. They are usually placed about 400 feet apart, and, if possible, at the intersection of streets. They should be located with a view to making the line of conduit between them as nearly straight as possible. The size of the manhole will depend on the number of ducts that are to be led to it, as well as the number of men that will be required to work in it at one time. Manholes 6 feet square and from 5 to 6 feet high will usually be required for large systems, while for smaller systems, or the outlying portions of large ones, they may be made as small as 4 feet in length in the direction of the conduit, 3 feet wide, and 3 or 4 feet high.

211. Construction of Manholes.—Manholes may be constructed of either cement or hard-burned brick laid in Portland-cement mortar, the latter probably being preferable. The foundation should consist of a layer of cement, the concrete at least 6 inches thick, mixed according to the proportion given in Art. **209.** The walls, if of brick, should be laid in cement mortar, mixed according to the formula for mortar given in Art. **209,** and should also be thoroughly plastered on the outside with the same mortar. They should never be less than 8 inches thick, and preferably 9 to 13 inches. When adjacent to a trolley line, the walls should not be less than 13 inches thick, and should frequently be made about 16 inches thick where large manholes are being constructed in busy streets. As the brickwork is laid up, the iron brackets for supporting the cables around the sides should be built in. The roof should be of either arched brick or structural iron, supporting some form of

cast-iron manhole cover, of which there are several types on the market.

It is rapidly coming to be considered better practice to thoroughly ventilate conduit systems than to attempt to

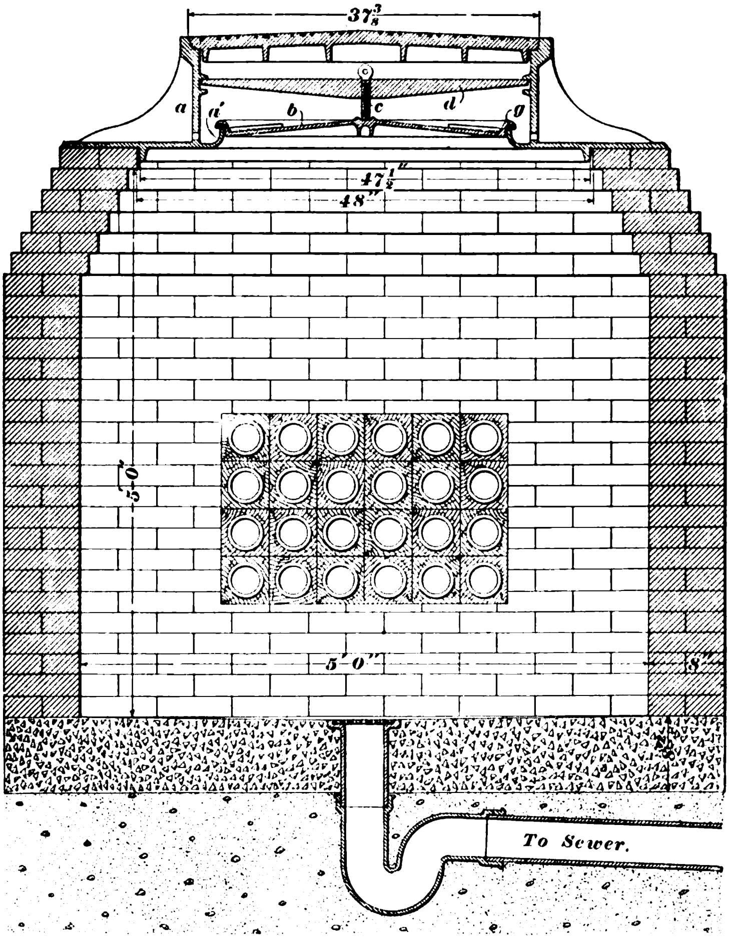


FIG. 86.

make them gas-tight and water-tight. It seems almost impossible to prevent the accumulation in conduits of dangerous and explosive gases, and this being the case, it is

necessary to provide means for both drainage and ventilation. If the subway system is subject to illuminating and sewer gases, it is advisable to seal all the ducts where they enter the manholes with pure clay, plaster of Paris, or other suitable material that will not attack the cables, thus preventing the free circulation of gas from one manhole to another. Where the gases, as is sometimes the case, are so plentiful in the manhole as to render it unsafe for a workman to enter it, the gas is driven out by an ordinary hand blower.

212. In Fig. 86 is shown a manhole built of brick, with a cast-iron cover, designed to exclude all moisture. The dimensions of the manhole are clearly shown, the brickwork being corbeled in at the top, to support the manhole cover and frame. In this, the particular form of cover shown consists of a heavy frame *a* of cast iron, having an inner and an outer cover. The inner cover *b* rests upon an upturned flange *a'* of the frame, the connection between the two being made water-tight by a rubber gasket *g*. This cover is forced down upon the gasket by means of the screw *c* passing through a heavy rod or crosspiece *d* secured between flanges in the framework *a*. The outer cover is of cast iron, and made heavy enough to retain its place by gravity alone. The bottom of the manhole should be connected by a 6-inch clay tile pipe with the nearest sewer, this drain pipe being provided with a ¾ **S** iron trap to prevent the entrance of sewer gas into the manhole. The conduits should be given an even slope, either from one manhole to another or from a central point in each direction to the manholes at each end of that section.

213. It is usually not necessary to provide water-tight covers for manholes when a connection is provided from the bottom of the manhole to the sewer. The connection with the sewer should remove all water from the manholes, while the use of a perforated cover greatly aids in ventilation. In many forms of manhole covers, a deep pan is suspended beneath the cover, which serves to catch all moisture

and dirt falling through the holes in the cover without interfering with the ventilation. Where no drain pipe is provided for the manhole, however, the water-tight cover is an absolute necessity. Conduit systems should either be as near gas-tight and water-tight as possible or else well drained and ventilated. In systems not gas-tight and not sufficiently ventilated, gases collect in the conduits and manholes and frequently explode, often doing considerable damage, and even resulting in loss of life.

214. The frame and covers of the manhole should rest upon the four walls, if possible, and where the manhole is too large for the casting to reach over, **I** beams and arches should be used, the arches not being wider than 2½ feet. The manhole frame and cover, in large cities, where the traffic is heavy, should not weigh less than 1,300 pounds.

What is known as the noiseless cover is considered by some as the best form, not only owing to its being noiseless, but because the asphaltum with which the cover is filled acts as a cushion and saves the iron from the blow or impact given by the heavy passing vehicles.

INTRODUCING CABLES INTO CONDUITS.

215. Preparing the Duct.—Assuming that the line of conduit, or subway, as it is frequently called, and also that the manholes are built, the first step before introducing the cables is to make sure that the ducts are all clear. This is usually provided for in the laying of the conduit, especially if the mandrel, shown in Fig. 84, has been used. The particles of dirt, however, may readily be removed by washing out the duct with a hose carrying a heavy pressure of water. In cases where this is not done, it is well to draw through the duct a mandrel carrying a gasket of leather or rubber, which will in its progress push all foreign matter before it.

216. Rodding.—The process called **rodding** is used in order to introduce a wire or rope into the duct for the purpose of drawing in the cable. This process consists of

pushing a number of jointed rods into a duct from one manhole until the first rod reaches the other manhole. The rods are joined together by screw connections or by bayonet joints, as they are pushed in. When the chain of rods reaches between the two manholes, a rope or wire is attached to one end and pulled through, the rods being disjointed one by one as they reach the second manhole.

The introduction of a wire into the duct may often be greatly facilitated by using, instead of the rods, a steel wire about ¼ inch in diameter and provided with a ball about 1 inch in diameter at its end. This wire may be pushed through a smooth duct without trouble for distances up to 500 feet. If an obstruction is found during the rodding that cannot be removed by means of the rods or by water, the distance to the obstruction can readily be measured upon the withdrawal of the rod. This distance can then be measured off along the ground over the subway, thus locating the spot where the obstruction occurs. The conduit should then be opened, the difficulty removed, and the structure repaired. This difficulty, however, should never be met where proper care is taken in laying the conduit.

217. Drawing In.—The process of **drawing in** the cable is illustrated in Fig. 87. The cable reel should be mounted on horses, so as to be free to revolve in such manner that the cable will unwind from its top. The end of the heavy rope leading through the duct should then be attached to the cable either by grips made especially for the purpose or by binding it with iron wire for a distance of 18 inches or 2 feet from the end. Fig. 87 (*b*) represents a section of a cable grip of iron pipe made to fit the cable snugly. It is fastened to the cable, as shown, by common wood screws, and the piece *d* to which the *drawing-in rope* is fastened is screwed into the end of the iron pipe. Another form of cable grip was illustrated in Fig. 71.

The drawing-in rope may be secured to the cable as follows: Punch two holes by means of a spike through the center of the cable from side to side, the first about 3 inches

from the end and the second about 3 inches from the first; then form a link to connect the cable and the drawing-in rope by passing a No. 10 or No. 12 steel wire several times through the eye of the rope and the holes in the cable; fasten the ends of the wire so that they will not slip. This is a simple and cheap method, and the means for making it are easily procured.

Whenever a hole is made in the end of the cable for fastening the drawing-in rope, the end should be cut off when the cable has been drawn in, to remove all moisture, and then sealed if a joint is not to be made at once. The other end

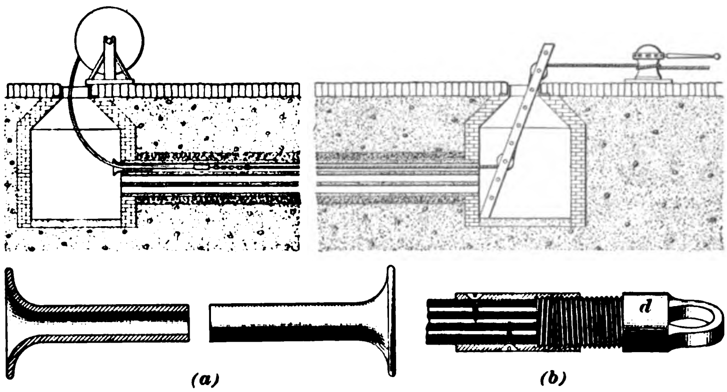


FIG. 87.

of the rope is passed over the grooved rollers, arranged on heavy planks mounted in the distant manhole, as shown, and should then be secured to a capstan or some form of windlass, by which a slow and steady pull may be exerted upon it. A man should be stationed in the manhole at which the cable enters, in order to properly guide the cable into the duct, to prevent it from being kinked or unduly strained. It is well to use a special funnel-shaped guide, made of wood or lead, at the entrance of the duct, in order to further insure the cable against injury by the corners of the duct. This guide is shown in Fig. 87 (*a*). It is sawed longitudinally into two sections, as shown in the left part of Fig. 87 (*a*), where the cable is to continue on through a

manhole, and where it would, therefore, be impossible to remove the cylindrical protector if it were not sawed in two parts.

218. Arrangement of Cables in Manholes.—After the cables are drawn in, they are spliced, proper care being taken, of course, to connect no good wires to bad ones. Sufficient slack should be left within the manhole to allow the cable to pass along the sides instead of directly across them, so as to allow plenty of room for the workmen and also to allow a certain amount of slack in case it is needed in making future repairs. It is a good plan to place a piece of sheet lead, heavy felt, or leather under each cable at the point where it emerges from the duct. This greatly reduces the liability to injury of the sheath at that point, due to the weight of the cable in the manhole. If the manhole is large, it is desirable that suitable support shall be arranged on its sides for the systematic support and arrangement of the cables. Sometimes racks are provided upon which cast-iron hooks are placed, this arrangement giving excellent satisfaction.

219. Distribution From Manholes.—It is usually the practice to run the cables that are to serve a certain district to a manhole located as near as possible to the center of that district, and to distribute from that point by means of overhead construction, although sometimes underground distribution to the points the wires are to serve is required. In this latter case, the service wires are usually led from the manholes in the form of small lead-covered cables enclosing one or more wires, the service cables being led through iron pipes, if possible, to the basement of the building where the connection is to be made.

In passing from an underground to an overhead system, a cable pole is arranged in close proximity to the manhole. A 3-inch iron pipe is then led from the manhole and by a gradual bend upwards along the side of the pole to a point high enough to insure the protection of the cable from injury by passers-by. The cable terminates in a terminal placed

in a box, as already described in connection with Fig. 75, and connection is made with the overhead circuits.

220. A construction similar to this is shown in Fig. 88, where means are provided for leading a cable from a *hand-hole* or distributing box to the cable pole. Handholes, such as shown in this figure, are often used where a distribution center occurs between two manholes, and where it is not necessary to provide for access to all the cables. In this case, only those ducts that are to carry cables for this

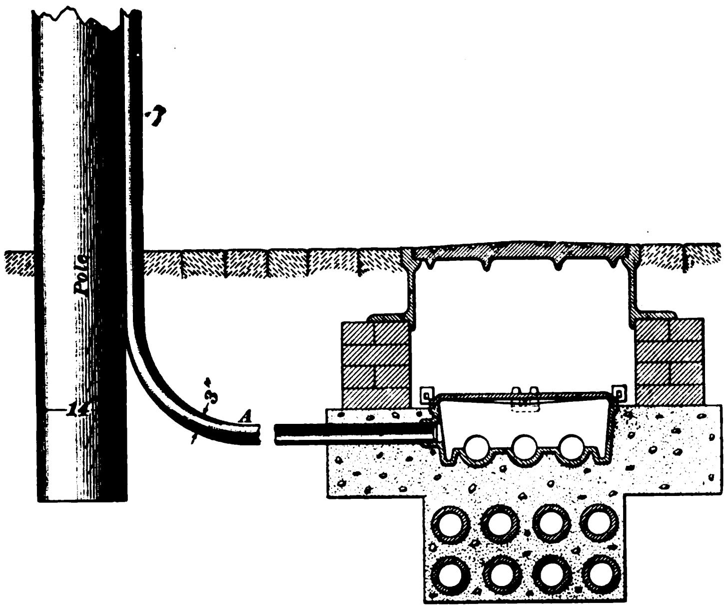


FIG. 88.

particular section are brought into the handhole, and for this purpose are laid on top of the subway, the through cables being carried in the ducts below, as shown. One or more 3-inch iron pipes *A* lead from the handhole to the pole, to which they are secured by means of wrought-iron straps. The construction of the handhole is shown quite clearly in this figure, this particular one being adapted for use with cement-lined conduit. It is a matter of great importance

in this kind of work that the handhole should be free from moisture, for which purpose double water-tight covers are used. The ends of the pipe leading up the pole should be thoroughly sealed, in order to prevent moisture from trickling down the outside of the cable and entering the handhole in this manner. These pipes may be left open for ventilating purposes, in which case the service box should be drained.

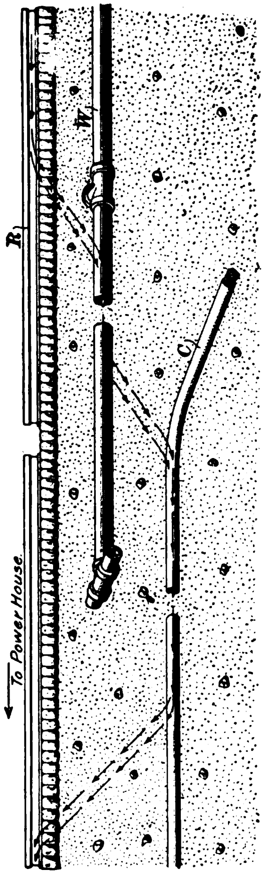


FIG. 89.

ELECTROLYSIS.

221. Earth Currents.—Currents due to electric-railway or other systems carrying large currents and using earth returns are likely, in choosing their path back to the power station, to select the sheaths of underground cables, or of any other metallic bodies that offer paths of comparatively low resistance. This phenomenon in general may be illustrated by Fig. 89. In this, the return current at the remote end of the trolley line enters the earth, we will say, from the rails *R* and meeting with a line of water pipe *W*, which forms a route to the power house, selects this conductor as the return circuit. After a time this line of pipe may come in proximity to the line of telephone cables *C*, whose lead sheaths form a still better return path. The current will then follow this new-found conductor to some point where a more direct route is again found, and the current will emerge from the cable sheaths and enter the new conductor.

222. Danger Points.—Except in a few cases, the current in flowing from one kind of a conductor to another will be compelled to pass through the earth, and it is at the points where the current emerges from the conductor and enters the earth that electrolytic action occurs, to the probable destruction of the conductor. Thus, in Fig. 89, the *danger point* on the cable sheath *C* would be that at which the current left the sheath in order to pass back to the earth and rails, no damage being likely to occur at the point where the current enters the sheath.

223. The use of conduits of highly insulating material, such as vitrified clay, goes a great way toward preventing the effects of electrolysis, but it is found necessary to use other means of protection for the cables. Especially is this true in all forms of conduit where no attempt is made to insulate the cable sheaths from the surrounding earth.

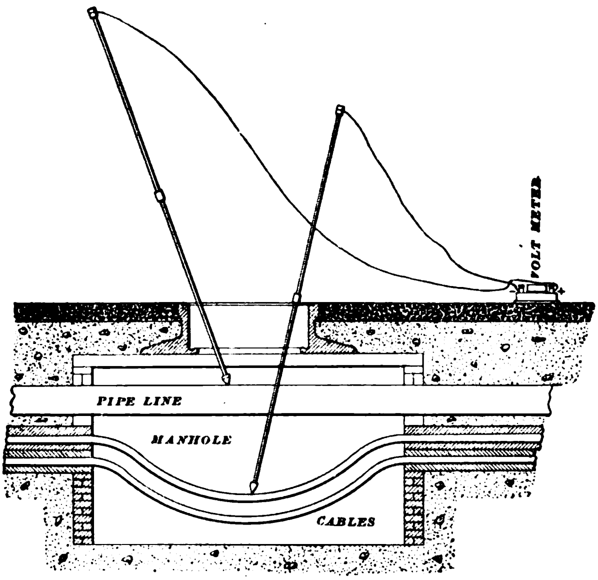


FIG. 90.

224. Locating Danger Points. — The method of procedure in each case, in order to locate the danger points on

a cable, is usually to measure the difference of potential between the cable sheath and the surrounding conductors, such as water pipes or the rails of electric railways, at frequent intervals along the cable line. A convenient method of taking these measurements is shown in Fig. 90. Two brass rods of ⅜-inch stock, about 10 feet long, should be provided. They should each be made in two parts, so as to be easily taken apart and put together again, and one should have a conical steel tip for making contact with the earth and other conductors, while the other should be provided with a wedge-shaped tip sufficiently sharpened to make a good contact with the cable and yet not so sharp as to injure it.

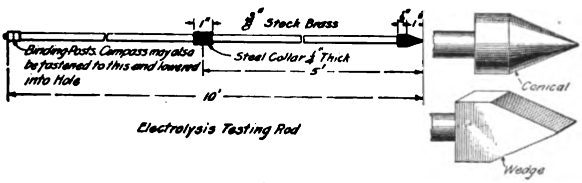


FIG. 91.

The construction of these rods is shown in Fig. 91. Upon opening the manhole, the rod should be connected with the voltmeter by means of wires of suitable length, and the rod

TABLE 28.

Location of Manholes.	Reading from Cable. To Earth. Volts.	To Water. Volts.	To Gas. Volts.	To Duct. Volts.	To Track. Volts.
1st Ave. and A St.	– 0.2	– 1.2	– 1.0	– 0.10	– 4.0
1st Ave., bet. A and B Sts.	– 0.3	– 1.2	– 1.0	– 0.10	– 4.2
1st Ave. and B St.	– 0.3	– 1.2	– 1.0	– 0.05	– 4.3
1st Ave. and C St.	– 0.3	– 0.9	+ 0.2	– 0.05	– 3.8
1st Ave. and D St.	– 0.4	– 1.0	+ 0.4	– 0.05	– 3.2
1st Ave., bet. D and E Sts.	– 0.4	– 1.0	+ 0.3	– 0.05	– 3.0

with the wedge-shaped tip should be touched to the cable, while the other one is successively touched to the earth, the duct, whatever pipes there may be in the hole, and to whatever other grounded conductors there may be in the vicinity.

Readings of the voltmeter should be taken at frequent intervals along the cable line and the results recorded in some such form as that shown in Table 28.

225. By means of such a table, made out for the entire length of the cable line, the danger points may readily be picked out. As long as the cable sheath is negative to all the surrounding conductors, it is in no danger from electrolysis, for this indicates that the current is flowing from the surrounding conductors to the sheath. If, however, a point is found where the cable sheath is positive to the surrounding conductors, we know that the current is then flowing from the cable to the other conductors through the ground at that point. The maximum positive point on the cable should be determined, and a heavy copper bond should be run from this point to the water pipe or other conductor to which the readings indicate the current to be flowing.

The record given in the table would show that the maximum danger point in this case was at 1st Avenue and D Street, and a bond would therefore be required from the cable at that point to the gas pipe.

226. Method of Bonding Cable Sheaths.—With most companies, a standard method has been adopted for bonding the cable sheaths. Bonds are placed between all the cables of an underground line in every manhole through which they pass. The wire used is No. 8 B. & S. gauge, bare copper, tinned. Fig. 92 illustrates the method adopted for soldering the bonds to the lead sheaths.

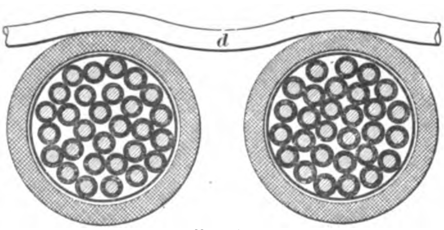


FIG. 92.

The surfaces of all the sheaths are scraped clean of mud, with which they are nearly always covered. In doing this work, an old file will be found useful, but great care must be taken not to cut away too much of the sheath. The end of the *bond wire d* is then heated in a portable furnace and placed on the bright surface of the sheath and solder applied. A soldering iron is then used to heat the sheath to the required temperature. The surface of the next sheath is then cleaned in turn, and the bond wire bent down and soldered to it.

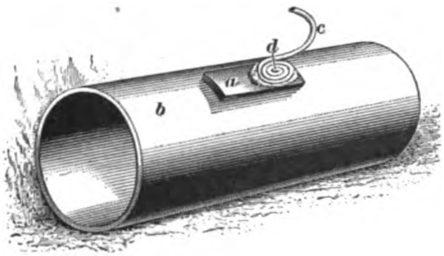


FIG. 93.

227. If the bond wire is to lead to a gas pipe, it may be soldered as in Fig. 93, in which *a* is a piece of sheet copper, which is soldered to the surface of the pipe *b*, which has been previously brightened and tinned. The bond wire *c* is then coiled as at *d* and soldered to the copper plate.

228. It is impossible to solder to a water pipe on account of the water rapidly conducting the heat away from the pipe itself. Where it is necessary to bond to a

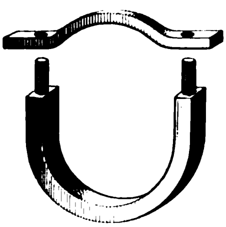


FIG. 94.

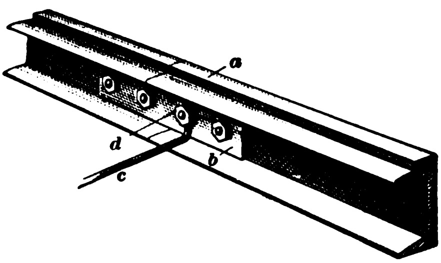


FIG. 95.

water pipe, a yoke, shown in Fig. 94, may be made of strap iron and securely clamped in place upon the water pipe, the surface of which has been previously brightened. The

whole should then be given a heavy coating of asphaltum, to prevent corrosion.

The method of bonding to a rail is shown in Fig. 95, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.

SUBAQUEOUS CABLE LINES.

CONSTRUCTION.

229. It is frequently necessary to extend telegraph lines under water, either in crossing rivers, bays, or lakes, or in extending lines from the main land to neighboring islands. For short lengths of cable across rivers or bays having smooth bottoms and slow currents, cables of the ordinary lead-covered type, having rubber or gutta-percha insulation, are sometimes used, no special armor for the mechanical protection of the cable being necessary. It is well in such cases to order an extra heavy lead sheath, and also to cover the lead sheath with a heavy braiding of fibrous material saturated with waterproof compound.

In order to meet more severe conditions, special armored cables of the best rubber- or gutta-percha-covered wire are required, the whole bunch being embedded in rubber insulation or a heavy wrapping of jute, which is afterwards served

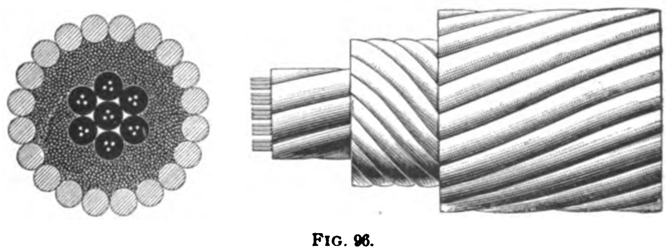


FIG. 96.

with an armor composed of iron wire of about No. 10 B. & S. gauge, affording a continuous mechanical protection for the wires and insulation within. This construction is shown in Fig. 96.

230. For long under-water cables, where it is necessary to reduce the electrostatic capacity of the conductors to as great an extent as possible, a special paper insulation is sometimes used between the conductors. The Felten-Guilleaume Company manufactures an excellent type of cable for this purpose. In Fig. 97 is shown a cross-section of a 4-wire cable. The four conductors *a*, *a* and *b*, *b* are insulated from each other by a cross-shaped paper diaphragm *c*. The group is then wrapped by a spiral paper tube *d*. This tube is then covered with a lead sheath *e*, after which a double coating *f* of gutta-percha insulation is applied. The iron armor consists of spiral wrappings of iron wire *w*, of the peculiar cross-section shown, this cross-section being adapted to cause an interlocking between the adjacent wires in such manner as to form an arch that will resist a large amount of compressive strain, besides giving the cable the requisite tensile strength. Over the iron armor is placed a heavy braiding of fibrous material saturated with waterproof compound. Cables built on this general plan are now being used successfully for telephonic transmission across the English Channel.

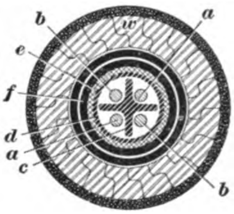


FIG. 97.

LAYING SUBAQUEOUS CABLES.

231. The means to be adopted for laying cables under water must be decided upon for each particular case. Of course, in laying comparatively long lines, the same methods that are followed in the laying of submarine telegraph cables should be adopted, the cable being coiled in tanks on a steamer and paid out over the stern by special apparatus as the vessel proceeds. In laying a cable across a comparatively narrow river, the reel on which the cable is wound should be mounted in the bow of the boat, so as to unreel over the stern of the boat, the cable passing from the under side of the reel. One end of the cable is secured

to the shore at or near the point where it is to terminate permanently, after which the boat proceeds across the river, paying out the cable as it goes. Men should be stationed at the reel in order to regulate the tension of the cable as it unwinds, thus preventing too much slack. After reaching the opposite shore, the end is secured and permanent connections with the overhead or underground circuits are made. The shore ends of the cable, extending as far out into the deep water as possible, should be buried, in order to protect it from mechanical injury.

232. A method of propelling a boat across a river in a very nearly straight line, which may often be successfully used, is as follows: A rope is first stretched across the river between the points near where the cable is to terminate. This rope may engage running blocks on the bow and stern of the boat, thus serving to guide it across the river. The boat may be propelled by pulling it along the rope by hand, or, where the water is not too deep, by poling it.

SUBMARINE CABLES.

233. The laying of the first transatlantic cable was begun in 1857, but an accident prevented more than 300 miles being laid that year. During the next year, however, a cable was successfully laid and about 400 cablegrams transmitted before it ceased to work, September 1, 1858. The next attempt was made in 1865, and after two more failures a cable was finally ready for the use of the public August 26, 1866. Now there are at least 13 cables across the Atlantic Ocean, and new ones are being laid from time to time, and before many years there will probably be one across the Pacific Ocean, connecting the United States, Hawaii, and the Philippine Islands.

234. Insulating Material for Submarine Cables. Gutta percha, vulcanized India rubber and even pure India rubber are used to cover or insulate the copper cores of

submarine cables. The former is the best for deep-sea cables where the pressure is great, and in shallow water where the temperature is not very low. Pressure increases the insulating qualities of gutta percha, rendering it more non-porous, while the opposite is the case with rubber. Moreover, the resistance of gutta percha is more reliable in warm, shallow water. However, for an underground cable where the temperature is liable to be high, due to neighboring steam pipes or other causes, neither gutta percha nor rubber insulation would be at all suitable, because the high temperature softens them. Both gutta percha and rubber compounds improve as the temperature decreases, and at low temperatures, where the pressure is not too great, both are suitable for cables and practically imperishable. Where the pressure is very great, as at the bottom of the ocean, gutta percha alone is suitable. Hooper's vulcanized rubber, being more homogeneous, close-grained, and non-porous, is more like gutta percha than is pure rubber. Gutta percha is practically the only insulating material used today in deep-sea and long submarine cables.

235. The work of manufacturing and laying submarine cables is done by a few large companies, two firms in England having made nearly all the long cables now in use. As the manufacture, laying, and testing of submarine cables is a business in itself, only a brief description of the modern cable is given here.

236. A **submarine cable** consists of a core, which comprises the conductor, made of copper wire, and its insulating covering of gutta percha, over which is placed a tanned jute yarn covering, to protect the gutta percha from the steel-wire sheathing. As a protection against the Teredo bug, some cables have the gutta percha covered with a layer of white canvas tape and then with brass tape. This method has successfully protected a cable that was laid in 1879 in the Straits of Malacca and in Java. Over the gutta percha and jute yarn is wrapped the steel-wire sheathing, and this, in turn, is enclosed in jute yarn and a bituminous compound.

The different coverings of an intermediate cable are shown in Fig. 98, the specimen being cut at intervals to show each covering in succession.

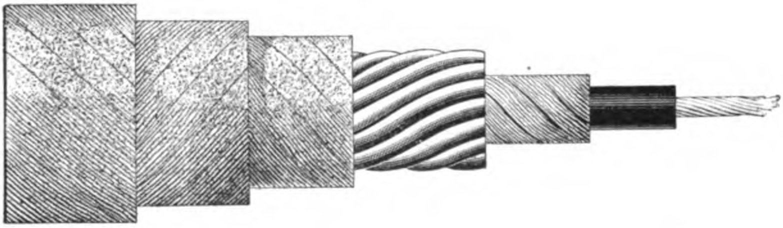


FIG. 98.

There are as many as seven different types of sheathing, increasing in strength and protective power as the shallow water is reached. Four types are shown in Fig. 99, in which (*a*) is the deep-sea type, with a sheathing of many small steel wires. This type weighs about 1½ to 2 tons per knot. In the intermediate types (*b*) and (*c*), the sheathing wires become gradually larger, and finally in the shore-end type (*d*), the deep-sea sheathed cable (*a*) is again sheathed with strands, each made of three steel wires. It will be noticed, however, that the core of copper wires and the gutta percha are the same size throughout.

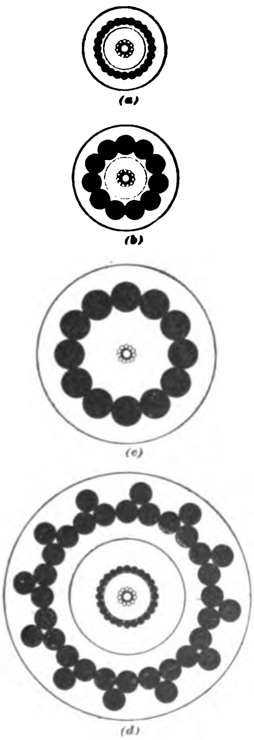


FIG. 99.

An intermediate cable, for use in a depth of from 500 to 1,000 fathoms,* would weigh about 3 tons per knot, a heavier intermediate cable, for use in from 50 to 100 fathoms, about 6½ tons, and a shore-end cable about 10½ tons.

* A fathom is equal to 6 feet and a knot to 6,080 feet.

237. Dimensions of Submarine Cables. — The dimensions of several submarine cables are as follows: A cable manufactured and laid across the Atlantic Ocean in 1894 by the Telegraph Construction and Maintenance Company for the Anglo-American Telegraph Company has a conductor formed of a central wire surrounded by 12 smaller wires. It has a resistance of 1.682 ohms per knot, and the dielectric has an electrostatic capacity of .42 microfarad per knot. The $K R$ constant is low, being .706 per knot, and allows a speed of 47 words (of five letters) per minute on ordinary traffic. The copper core weighs 650 pounds, and the gutta percha 400 pounds, per knot. The cable is 1,847 knots long, and was manufactured and laid in five months.

The $K R$ of this cable was given in *Telegraphy*, Part 2, under the subject of "Speed of Signaling," as 2.47. This is a little greater than will be obtained by using the values given here; that is, 2.47 is a little greater than $\frac{(1,847)^2 \times .706}{1,000,000}$. This slight difference is doubtless due to the connecting lines or instruments at both ends. The factor 1,000,000 is used to reduce microfarads to farads.

Another cable was manufactured and laid in 1894 by Messrs. Siemens Brothers and Company for the Commercial Cable Company. This cable is 2,161 knots long and weighs 5,460 tons. It contains 495 tons of copper, or 510 pounds per knot; 315 tons of gutta percha, or 325 pounds per knot; 575 tons of jute; 3,000 tons of steel; and 1,075 tons of compound. The $K R$ is 4.671, and it has a speed of 40 words per minute.

The Canso-Waterville Atlantic Cable, of the Commercial Cable Company, has a total resistance of 6,997 ohms, an electrostatic capacity of 876 microfarads, and a length of 2,345.72 knots.

TELEGRAPHY.

(PART 4.)

TELEGRAPH REPEATERS.

1. A **telegraph repeater** consists of an arrangement of instruments and apparatus whereby signals coming over one line are repeated or sent forwards on another line by a separate battery. A common relay is really a repeater, for it causes the sounder in the local circuit to repeat the signals that pass through the relay coils. Thus, if the relay is placed midway between two end offices, and if the line on one side is connected to the relay coils and the line on the other side to the local contact points of the relay, it becomes a one-way repeater; that is, it will repeat in one direction. The simplest form of a repeater would consist of two relays, one for repeating in one direction and the other for repeating in the other direction.

2. Need of Repeaters.—As the length of a line increases, the working efficiency, which depends on the relation of insulation resistance to conductor resistance, decreases until it becomes so small that satisfactory signals cannot be transmitted no matter how much the battery power may be increased. Even if the insulation could be made sufficiently perfect, the line resistance would finally, as its length increased, become so great that it would require an electromotive force so high in order to force the necessary

current through the circuit that it would be neither safe, practical, nor economical. An electromotive force above 300 volts requires very good insulation of the line wire and also tends to develop a ground or leak at every weak point. Poorly insulated lines that may work fairly well with a low electromotive force may act as if permanently grounded at some intermediate station if too high an electromotive force is employed. Furthermore, if the resistance of the line could be kept small and the insulation sufficiently high, and an electromotive force of sufficient strength could be used, even then the electrostatic capacity of a long line would be so high that it would seriously diminish the speed of signaling. For, the time required for the current to become strong enough to affect the distant relay increases as the electrostatic capacity K increases, and if the resistance R also increases, as it usually does, with the length of the line, then the time increases as the product KR increases. This has been fully explained in preceding pages. On account of this retarding influence of the electrostatic capacity of the line and the inductance of the relay coils, both of which tend to delay the rise and fall of the current, the duration of contact at the distant relay is less than that at the sending key, thus causing a shortening of the signals and, hence, a reduction in the number of good signals that can be transmitted in one minute.

3. Firm or Heavy Sending Required.—On a very long line, very deliberate and firm, and, therefore, slower sending is required in order to get good signals on account of this retardation. In such a case, the whole line, neglecting the leakage to earth at the insulators, has to be charged and discharged through the end offices. Now, if this long line be divided into sections, each section charges and discharges independently of the others, and the sections being shorter than the whole line, it is evident that they will all be charged and discharged quicker than if connected in one continuous line. On a very long circuit with several repeaters, there would be a shortening of the signals at the far

end due to the fact that, as each circuit is closed, a short delay occurs in the transmission of a signal, because each armature has to move over a short distance from the rear to the front stop before the circuit is complete. This shortens the dots and dashes in proportion to the number of contacts to be closed, and thus the dots are sometimes wholly lost. Therefore, in operating a circuit containing one or more repeaters, the dots and the dashes should be made firm and longer, or as operators term it, the "sending should be heavy." The more repeaters there are in a circuit, the heavier should be the sending.

As a matter of fact and experience, the loss in speed due to this latter cause is not so great as is the gain in speed due to the quicker charging and discharging of the shorter sections into which the long line has been divided. Thus a long line can actually be worked faster and much more satisfactorily with repeaters than without, especially in wet weather, when the working efficiency decreases.

4. Distance Between Repeaters.—Moreover, it is possible to work long lines in this way, with wires of a reasonable size, fair insulation, and electromotive forces not unreasonably high, that could not be worked as one continuous line. In this country, with large and comparatively low resistance wires, it is not customary to operate, directly, a circuit over 600 miles in length. On well-insulated lines of good conductivity, and especially through dry regions, circuits are sometimes worked much longer distances without repeaters.

The line from San Francisco to New Orleans, a distance of 2,484 miles, is now being worked with only one repeating station, which is at El Paso. This repeating station is even cut out occasionally and the line worked direct. The long stretch of country through Arizona, New Mexico, and Western Texas is unusually well adapted to long-distance telegraphy, the atmosphere being dry and rare. The atmospheric conditions along the California coast and in the swamps of Louisiana and Eastern Texas, through

which the remaining portion of the line runs, are not favorable for long-distance telegraphy, but this has been overcome by using copper line wire and by taking good care of the insulators.

Another long line, that from Montreal to Vancouver, a distance of 2,898 miles, was to be worked, according to last reports, with two equally distant repeating stations. It is quite likely that during part of the year only one repeater will be required. The line will be worked duplex, and, later, if business increases sufficiently, it will be quadruplexed. The entire line consists of hard-drawn copper wire, weighing 300 pounds per mile.

5. Long Circuits Worked by Use of Repeaters.—By the use of repeaters it is possible to work to very great distances. A line from London to Teheran, a distance of 3,800 miles, is worked directly by the aid of five automatic repeaters. In this country, on April 25, 1899, the Associated Press combined its circuits, and formed a line 6,000 miles in length. The matter transmitted from New York for several hours was received in all the leading cities, requiring the services of 41 operators in all.

BUTTON REPEATERS.

6. Repeaters, requiring that a button, or switch, be turned manually by an attendant, in order to change from repeating in one direction to repeating in the opposite direction, are usually called **button repeaters,** and, occasionally, **manual repeaters.** With such repeaters an operator must listen to what is passing and be ready at any moment to turn over the button, or switch, in order to reverse the direction in which messages may be sent and so allow the operator at the receiving end to send, and *vice versa.* A button repeater, since it requires the constant attendance of an operator, is generally employed for temporary purposes only.

THE WOOD BUTTON REPEATER.

7. The arrangement of the Wood button repeater is shown in Fig. 1. *M* is a switch so arranged that the lever *k*, which is pivoted at the center, is always in contact with one or both of the brass pieces *c* and *d*; o, o_1, o_2, and o_3 are binding posts, each joined to the respective brass pieces *a*, *b*, *d*, and *c*; *g* is a ground switch connecting the lever *k* of the switch *M* with the ground at *G*; *W* is the western and *E*

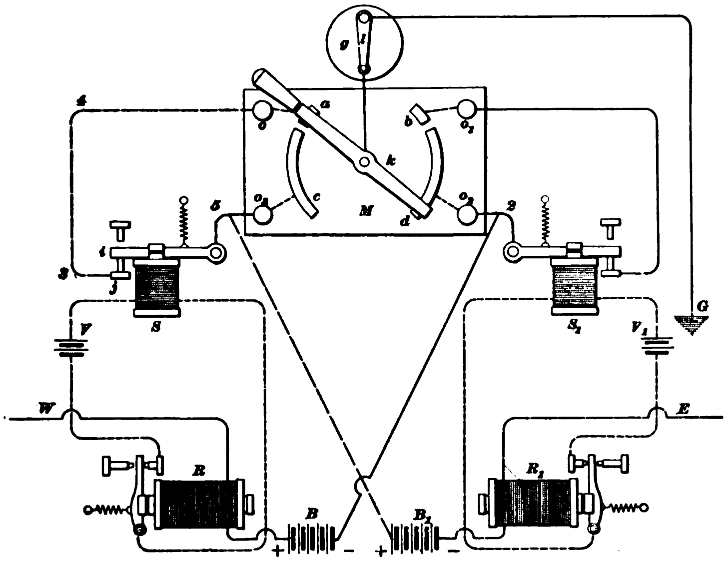


FIG. 1.

the eastern main line; *R* and R_1 are the western and eastern relays; *S* and S_1 the western and eastern repeating sounders, and *B* and B_1 the western and eastern main-line batteries. *B* and B_1 *must be arranged in series*, the plus pole of one being connected to the minus pole of the other, for this arrangement allows the line to be connected straight across, as will be explained later. *V* and V_1 are local batteries.

8. Operation.—If the ground switch *g* is closed and the lever *k* is placed so as to connect *d* with *a*, the western circuit will repeat into the eastern. If the western key is closed, a current proceeds from the plus pole of battery *B*, goes through the relay *R*, then to the western station, where the line is grounded, back through the earth to *G*, through lever *l* to lever *k*, to *d*, o_2, *2*, and to the minus pole of battery *B*. By this current, relay *R* is caused to close its local circuit, which causes sounder *S* to close the circuit of battery B_1. This circuit may be traced as follows: From the plus pole of battery B_1 through *5*, *i*, *j*, *3*, *4*, *o*, *a*, lever *k*, through lever *l* to the earth at *G*, then through the earth to the eastern station and back through the eastern relay R_1 to the negative pole of B_1. The sounder *S* repeats the message and the relay R_1 operates the sounder S_1. No circuit is closed, however, by the armature of the sounder S_1, as there is a break between *b* and *k*. It, therefore, acts merely as a reading sounder.

If the lever *k* be placed so as to connect *c* with *b* while switch *g* is closed, the eastern circuit will repeat into the western, and the circuits may be traced as before, beginning, however, with eastern line and battery B_1. The single ground at *G* will serve for both eastern and western circuits.

If the lever *k* connects *c* and *d* and switch *g* is opened, the eastern and western circuits are connected straight across. This circuit is as follows: From the plus pole of battery *B*, through relay *R* to the western station, through the earth to the eastern station, then to relay R_1, and to the minus pole of battery B_1. Batteries *B* and B_1 are connected as one battery in series through $5–o_3–c–k–d–o_2–2$.

If *k* connects *c* and *d*, and switch *g* is closed, two independent circuits are formed, namely, $B–R–W–G–l–k–d–o_2–2–B$ and $B_1–5–o_3–c–k–l–G–E–R_1–B_1$.

9. In this arrangement, if the two sounders do not work in unison, the lever *k* must be instantly turned by the operator in attendance, so that the person receiving may be able to break and become the sender.

MODIFIED WOOD BUTTON REPEATER.

10. A modified form of the Wood button repeater that is also used is shown in Fig. 2. No provision is made in this arrangement for connecting the circuits straight across. This is not necessary in a repeater, because such connections can be made directly at the switchboard, including an ordinary relay in the circuit if desirable.

When the switch *M* is turned to the left, the switch blade connects *c* with *d* and the eastern circuit will repeat into the western. In this position the east line cannot be opened at the repeater station by any action of the sounder S_1.

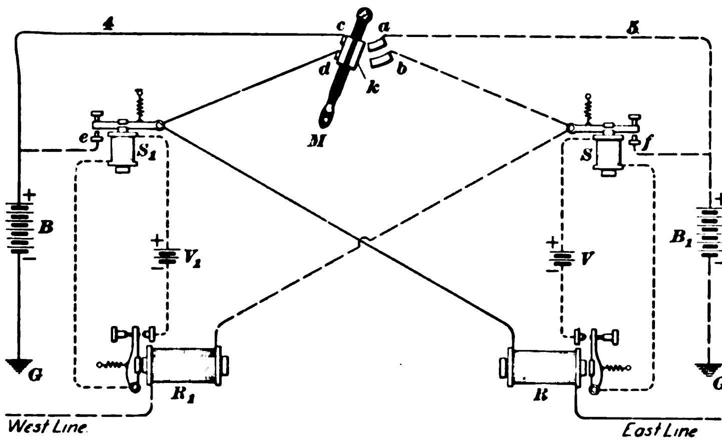


FIG. 2.

When the switch *M* is turned to the right, the switch blade *k* connects *a* with *b* and the western circuit will repeat into the eastern. In this position it is impossible for the operator at the western office to open the western circuit at the repeater station.

When the switch *M* is in the center position, the blade connects *c* with *d* and *a* with *b* and two independent circuits are formed; namely, *G*–*B*–*4*–*c*–*d*–*R*–east line to eastern office and back through the ground to *G*, and G_1–B_1–*5*–*a*–*b*–R_1–west line to western office and back through the ground to G_1.

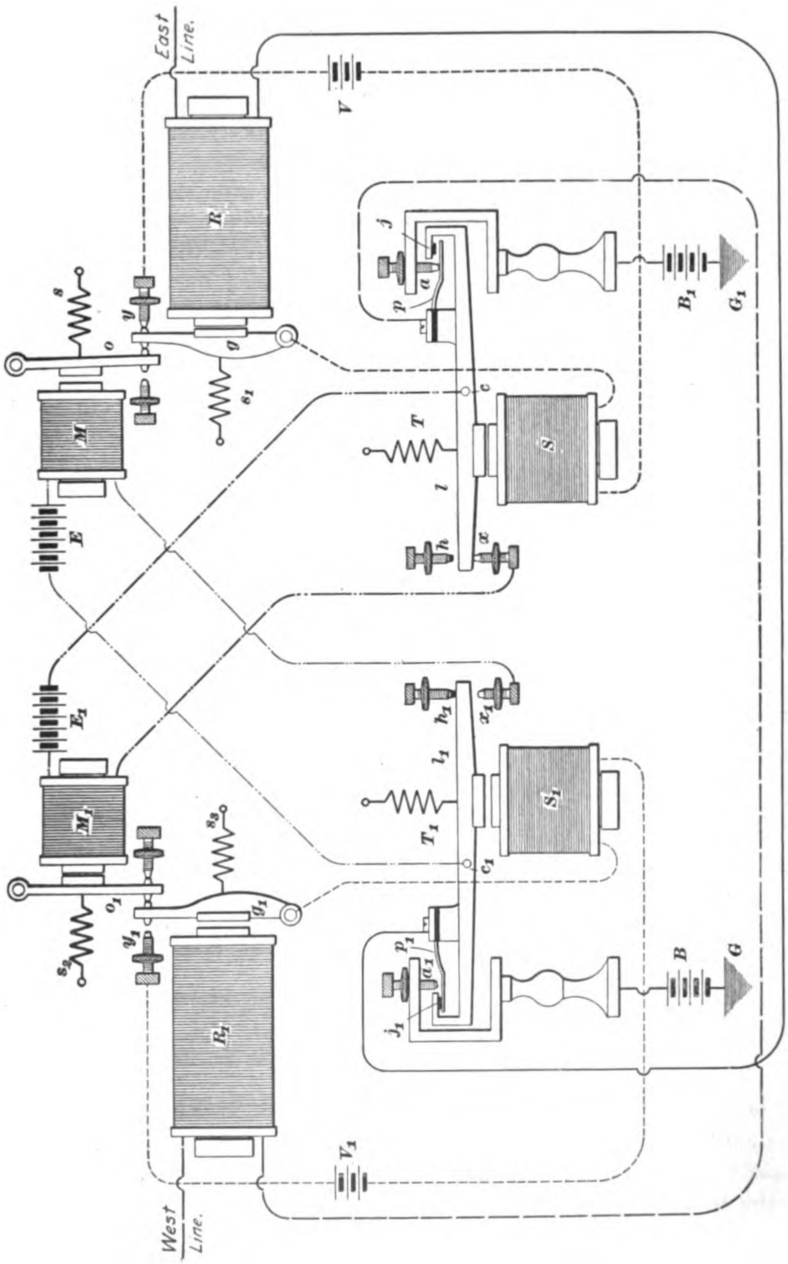


FIG. 3.

The operation of this repeater, outside of the changes in the connections that can be made by means of the switch M, is precisely the same as in the Wood repeater previously described, so that an explanation of its operation in the act of repeating seems to be unnecessary.

AUTOMATIC REPEATERS.

11. An **automatic repeater** is one that will *automatically repeat* in *either direction* without the necessity of turning a switch. An operator, however, is always needed to adjust the armatures of the relays and sounders, and to care for the batteries, but, of course, his time may be largely devoted to other duties.

MILLIKEN REPEATER.

12. The **Milliken repeater,** although one of the earliest automatic repeaters used in telegraphy, is still regarded in the United States as the standard repeater; it is shown in Fig. 3. R and R_1 are main-line relays mounted on metal standards that hold them rigidly in place with respect to the extra magnets M and M_1. The levers of the relays and extra magnets are pivoted, as shown in the figure; the springs s and s_2 are so much stronger than s_1 and s_3 that the levers g and g_1 are pressed against the contacts y and y_1 when there is no current in either R or M, nor in R_1 or M_1, respectively. The telegraph instruments T and T_1 are called *transmitters*. When current flows through the electromagnet S, the armature lever l is attracted, causing the insulated spring, or *tongue* p, as it is called, to come into contact with the stop a slightly before the other end of the lever l touches x. When the current stops flowing through the coil of the transmitter, the lever is released, as shown at T_1, causing the contact at x_1 to be broken slightly before the contact is broken at a_1. The bent-over ends of the levers of the transmitters may or may not be tipped with

insulating pieces j and j_1. B and B_1 are main-line batteries, V and V_1 local batteries, and E and E_1, so-called extra local batteries.

13. Normally, all circuits are closed. The western main-line circuit may be traced from the western office through R_1–p–a–B_1–G_1 and the ground back to the western office. The eastern main-line circuit is from the eastern office through R–p_1–a_1–B–G and through the ground back to the eastern office. The local circuit of R_1 includes V_1–y_1–g_1–S_1, and the local circuit of R includes V–y–g–S. The extra local circuits, including the magnets M and M_1, are, respectively, M–x_1–l_1–c_1–E and M_1–x–l–c–E_1.

14. Operation.—Suppose that all circuits are in their normal condition, that is, closed. If, now, the western key is opened, the relay R_1 will lose its magnetism, but the magnet M_1 retains its magnetism; hence, the armature g_1 is released by the relay magnet and is not held by the spring s_2; therefore, it breaks the local circuit between g_1 and y_1, causing the lever l_1 of the transmitter T_1 to first break at x_1 the extra local circuit containing M, and then to break the eastern main-line circuit between p_1 and a_1. Thus M is first demagnetized and the spring s presses the lever o against the lever g, so that when a moment later R is also demagnetized by the opening of the circuit between a_1 and p_1, the lever g is still held against y, since the spring s is adjusted to overcome the pull of the spring s_1. Thus, the opening of the circuit containing the electromagnet S of the transmitter T is prevented. The opening of this circuit, when the western circuit is repeating into the eastern circuit, would be fatal to the successful operation of the repeater. Therefore, when the western key is opened, the eastern circuit is opened without opening the western circuit at the repeating station. In the figure, the instruments are shown in their proper position when the western key is open.

15. The chief function of an automatic repeater is to automatically prevent the opening or breaking of the sending

circuit at the repeater station. For instance, the transmitter that controls the western circuit must not open the western circuit at the repeating station when the western circuit is repeating into the eastern circuit. The *opposite transmitter*, a term frequently used, may be defined as being the one controlled by the relay in the circuit that is being repeated into. For instance, when the western circuit is repeating into the eastern circuit, the transmitter T is the opposite transmitter, because it is controlled by the relay R in the opposite circuit, and this transmitter T must remain closed while the western is repeating into the eastern circuit.

16. When the western key is again closed, the circuits are closed between g_1 and y_1, between p_1 and a_1, and between l_1 and x_1 in the order named. Thus a signal is sent into the eastern line by the closing of the eastern circuit between p_1 and a_1 and, therefore, the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

The attendant, if necessary, can read the signals from the sound made by the lever l, or l_1. If it is desirable to know just how the signals are being transmitted through the main-line circuits, a relay controlling a local sounder may be cut into either main-line circuit by inserting a double wedge, to the two sides of which the relay is connected, into either line jack at the switchboard.

17. Side-Line Repeater.—A side-line repeater is one that has been arranged to repeat from a through main line into a line branching off from the repeating station. The Milliken repeater can readily be used for this purpose. Suppose, for instance, that there was a through line from New York to Buffalo, and that it was desirable to send the same message to Syracuse by means of a Milliken repeater at Elmira. Suppose, further, that the eastern line in Fig. 3 is the one coming from New York. The battery B in this line may or may not be removed, but the line, instead of being grounded at G, would extend to Buffalo, where it would be grounded after passing through a relay and battery. The

side line circuit would run from the ground G_1 through B_1–a–p–R_1 at Elmira through the west line in this figure to Syracuse. Thus the message passing over the main line from New York to Buffalo would be repeated into the side line running from Elmira to Syracuse. Furthermore, any one of the three operators located at New York, Buffalo, or Syracuse could send while the other two received.

18. The Milliken repeater is considered one of the best repeaters made, and its operation is entirely satisfactory. It requires, however, more local batteries than almost any other repeater, is not so easy to keep properly adjusted, and the extra local batteries must be kept in exceptionally good condition.

19. Repeater Relay and Extra Magnet.—In Fig. 4 is shown the repeater relay and extra magnet commonly listed and sold as the **Milliken-Hicks repeater.** The relay R is adjusted in exactly the same manner as an ordinary relay

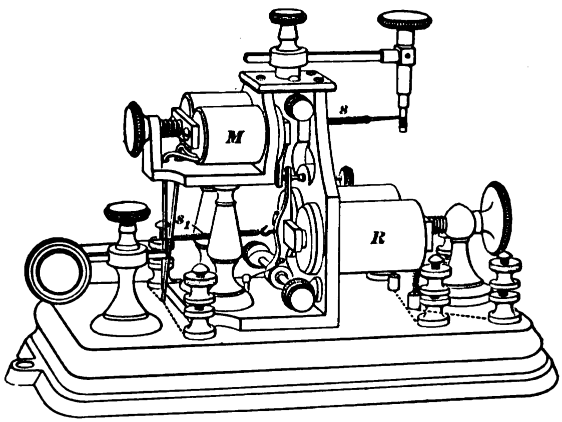


FIG. 4.

and the extra magnet M will seldom need readjustment if the extra local batteries are kept in good condition. The spring s must be slightly stronger than the spring s_1 and the armature of the magnet M must have no more movement than is necessary to allow the circuit to be opened.

contact points, only movement enough to break the circuit, and the spring should be adjusted to have a very moderate tension, only a little more than enough to raise the lever when released by the magnet. The lever should have a play of about $\frac{1}{32}$ inch.

It often happens that the signals will pass through the repeater all right and yet be positively unreadable at the distant office, causing considerable misunderstanding between the operators at one end and at the repeater station. This is due to an improper adjustment of the transmitter contact points, due to the fact that the tongue *p* does not break contact, as it should, at the instant when the other end of the lever is exactly midway in its travel between the lower and upper stops. This incorrect adjustment causes the tongue to cling too long to one point and not long enough to the other. The signals will be too light, that is, too short, if the duration of contact between the tongue *p* and lever *l*, as the tongue end of the lever moves up, is too long, due to *a* being too high; and the signals will be too sluggish, heavy, or long if the duration of contact between *p* and *a*, as the tongue end of the lever moves down, is too long, due to *a* being too low. Therefore, *a* should be adjusted to break just as the lever passes through the horizontal position and is midway in its travel; causing the *duration of contact between p and a and between p and l to be equal.* These remarks will apply to the adjustment of all forms of transmitters wherever used, unless something to the contrary is mentioned.

22. Milliken Repeater Operated by Dynamos. In Fig. 6 is shown the actual connections of the Milliken repeater when the main and local circuits are all supplied with current from dynamos. In this case, one machine D_1 supplies the four local circuits and another *D* the two main-line circuits. The lamps *L*, *L*, etc. are of suitable resistance to allow the necessary current to flow in each circuit. The two main-line circuits from the repeater go to wedges *b i* and $b_1 i_1$ at the loop switch, then by "flying" loops to

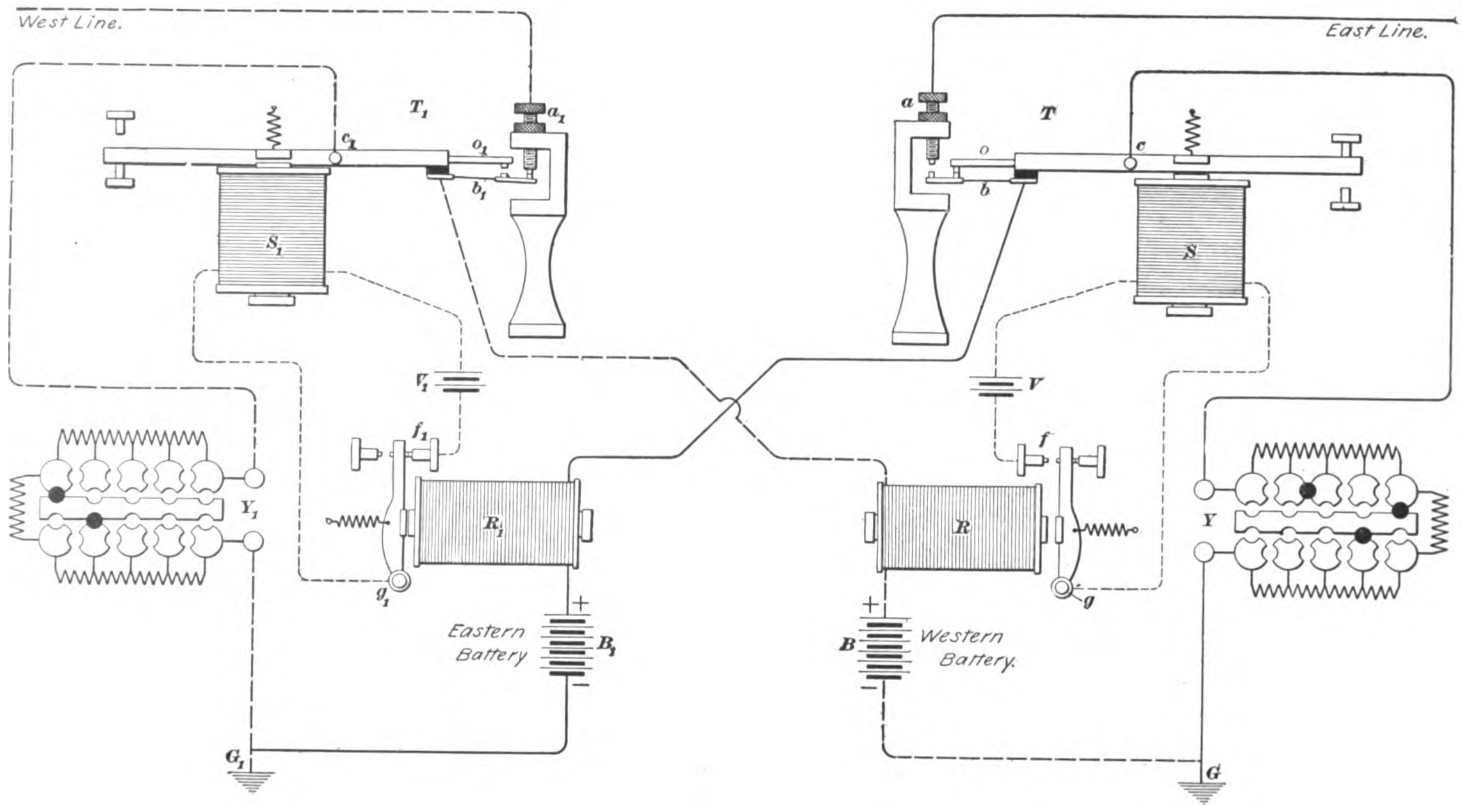

West Line.
East Line.
T1
a1
c1
o1
b1
S1
V1
f1
g1
R1
Y1
G1
Eastern
Battery
B1
T
a
c
o
b
S
V
f
g
R
Y
G
Western
Battery.
B
+
−

FIG. 7.

wedges df and $d_1 f_1$ at the main switch; one side of each circuit then goes to a line, the other side through vertical straps m and m_1, pin plugs, disks n and n_1, lamps L, L, dynamo D, and, finally, to ground G. Keys k and k_1 are included in the main-line circuits in order to enable the attendant at the repeater office to communicate with either of the two distant operators. The six circuits may be traced out as follows: West line to d_1–b_1–R_1–k_1–p–a–i_1–f_1–m_1–n_1–L–D–G back through the ground to the western office and line; east line to d–b–R–k–p_1–a_1–i–f–m–n–L–D–G back through the ground to the eastern office and line; the extra local circuits D_1–V_1–o–x_1–l_1–c_1–M–L–V–D_1, and D_1–V_1–q–L–M_1–c–l–x–V–D_1; and the local circuits D_1–V_1–j–L–y_1–g_1–S_1–V–D_1, and D_1–V_1–u–S–g–y–L–V–D_1.

The operation of this repeater, when supplied with current from dynamos, as shown in the figure, is exactly the same as has already been explained in connection with Fig. 3, where primary batteries were used; and, consequently, the student should readily understand this one without further explanation. All circuits are shown in their normal, or closed, position, and a newer type of transmitter is represented in this figure.

TOYE REPEATER.

23. The **Toye repeater,** which is quite extensively used in the United States, and especially in Canada, is very simple indeed, as will be seen from the diagram given in Fig. 7. The only apparatus necessary in connection with this repeater that has not already been considered are two adjustable resistance boxes Y and Y_1. These are adjusted, as indicated, by means of brass pegs that may be inserted in holes between brass disks in order to cut out one or more of the resistance coils. The resistance in Y must be kept about equal to the resistance of the eastern circuit from the point a to the ground at the eastern office, and the resistance in Y_1 must be kept about equal to the resistance of the western circuit from a_1 to the ground at the western office. R and R_1

are ordinary relays, and T and T_1 are standard transmitters. B and B_1 are the main-line batteries and V and V_1 the local batteries. The connections are so clearly shown that it seems unnecessary to enumerate the various circuits. The principle of this repeater consists in holding the sending circuit closed at the repeater *by substituting in the place of the receiving line at the instant the latter is opened, a resistance equal to the receiving-line circuit*, thus keeping the relay and transmitter that control the sending line closed.

24. Operation. — Suppose all circuits to be closed. Then, a_1 presses against. tongue b_1 and holds the circuit open between b_1 and o_1; and, similarly, a makes contact with the tongue b and keeps b and o separated. When the western operator opens his key, there will be no current from the western office through a_1–b_1–R–B–G. This will allow R to demagnetize and open the local circuit V–S–g–f at f, and, in turn, allow the transmitter T to open the eastern circuit at a; but just the instant before the tongue b separates from a it touches o, and, thus, the current, which previously flowed from B_1 through R_1–b–a to east line and through the ground to G_1 and back to B_1, now flows from B_1 through R_1–b–o–c–Y–G to ground to G_1 and back to B_1. These two circuits being of equal resistance and the rheostat circuit Y being instantly substituted for the eastern circuit by the opening of the transmitter T, the relay R_1 is not only not demagnetized, but the strength of the current remains the same, and, consequently, the *local circuit of the relay R_1 is kept closed and the western circuit is therefore not opened* at a_1. When the western key is closed, current again flows through R, and then through S, and all circuits are again closed, which is their normal state. Thus the western circuit repeats into the eastern. To repeat from the eastern into the western circuit, the foregoing actions are reversed.

25. The special advantages of this repeater are its extreme simplicity and the fact that it requires comparatively few pieces of only standard apparatus, namely,

standard transmitters, relays, and rheostats. However, this repeater is very severe on the main batteries, for they are kept closed all the time. Furthermore, each rheostat must be kept adjusted so that its resistance is about equal to that of the main-line circuit which it replaces, otherwise the difference in the magnetic strength of the relay, due to shifting the battery circuit from the line to the rheostat, may throw the relay out of adjustment and so open one of the circuits at the transmitter that the relay controls.

This means that for efficient service, every change in the weather or resistance of the wire will require an alternation in the value of the rheostat in addition to the usual care of the relay itself, a feat not easily accomplished in extreme weather or on a wire from which there is very much leakage.

26. The Toye repeater is adjusted by varying the resistance in the rheostat until the magnetic pull of the relay is the same whether its circuit is closed at the opposite transmitter through the line or the rheostat. The Toye repeater, without modifications, is not suitable for a side-line repeater, nor is it as satisfactory for all-around work as the Milliken, the Neilson, or the Weiny-Phillips, and perhaps some other modern types. Where a number of short lines have approximately the same resistance, such as the duplex loops, or legs, in the larger cities, the Toye repeater, slightly altered and called the *defective loop repeater*, gives excellent service as a side-line repeater.

27. Bunnell Transmitter.—A form of transmitter made by Bunnell & Co. that may be used in the Toye and other repeaters, and in some multiplex systems, is shown in Fig. 8. The tongue *b* is fastened to a piece of insulating material *i* that is in turn secured to the lever *c*. When the magnet releases the

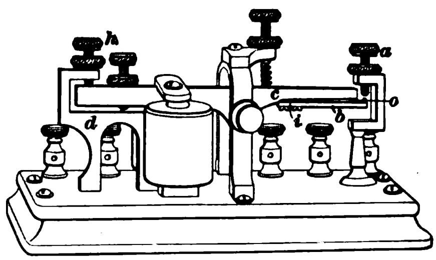
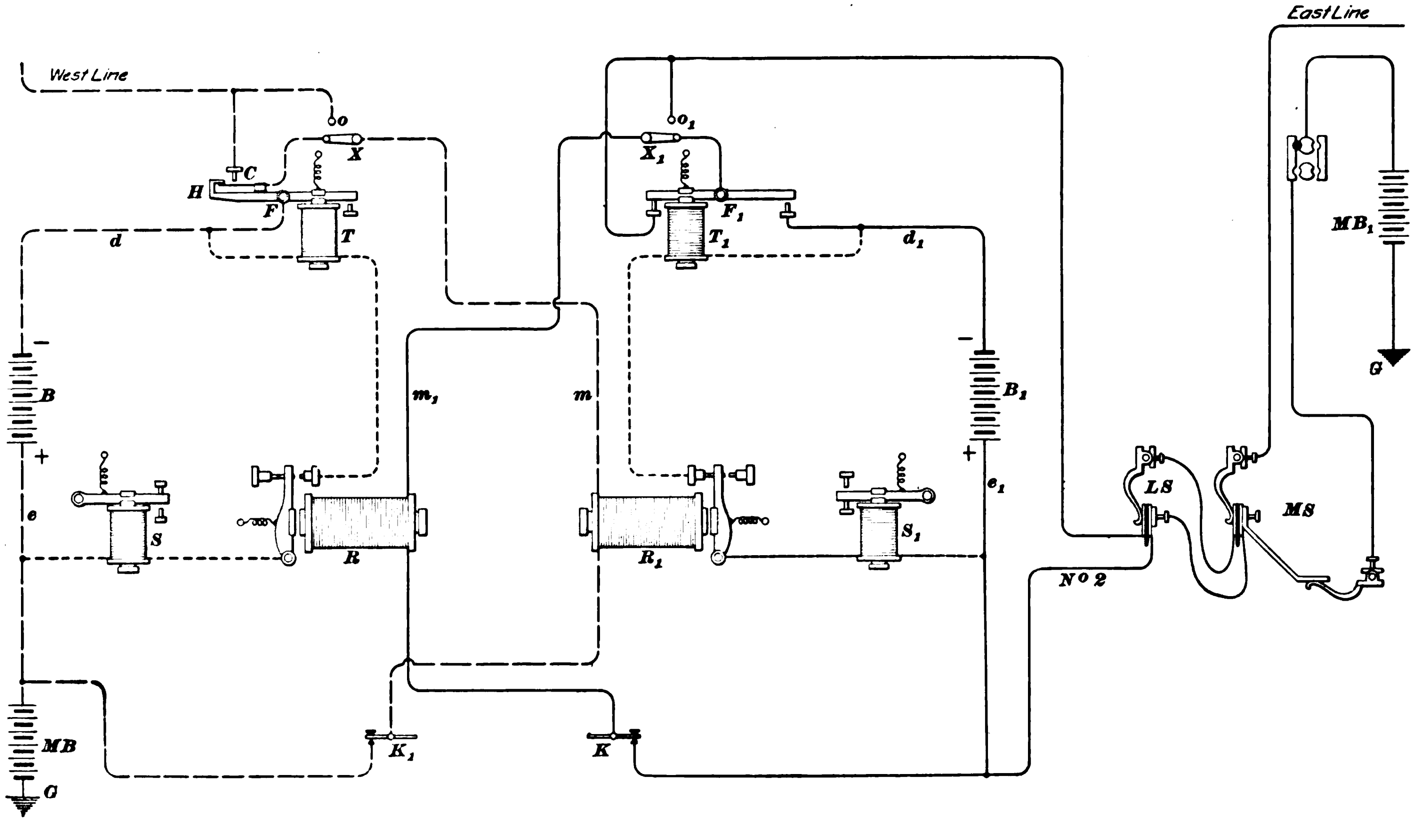


FIG. 8.



West Line
East Line
o
X
C
H
F
T
d
B
e
S
R
m
K
MB
G
o
X
F
T
d
m
R
B
e
S
K
LS
MS
N o 2
MB
G

FIG. 9.

armature, a metal contact point on the end of the lever *c* comes in contact with the tongue *b* and presses the latter away from the contact screw *a*. When the armature is attracted by the magnet, the tongue *b* touches the screw *a* just before the contact point on the tip of the lever separates from the tongue *b*. It is, therefore, a continuity-preserving transmitter because one circuit is closed before the other is opened. *a*, *b*, and *c* are connected to separate binding posts on the base of the instrument.

If this transmitter is used in the *Atkinson* repeater, which will be described presently, it is only necessary to insulate the tip of the screw *h* so it cannot make a metallic contact with the lever *c*, and, also, to connect *d*, which corresponds to *d* in the diagram for the Atkinson repeater (see Fig. 16), to a separate binding post upon the base.

MODIFICATION OF THE TOYE REPEATER.

28. The repeater illustrated in Fig. 9 was explained in "The Telegraph Age" of July 16, 1900, by Mr. R. J. Hewett. Although the rheostat, the distinctive feature of the Toye, is eliminated, still it is called a modification of that repeater. All that is necessary to fit out a full set of repeaters are two common relays R and R_1, two transmitters, or two pole changers, or one transmitter and one pole changer T and T_1, two 2-point table switches X and X_1, two keys K and K_1, and two auxiliary batteries B and B_1 of about 7 cells each. Two sounders S and S_1 had better be used as reading sounders, for their use will allow the transmitters to be adjusted closely, so as to reduce their mechanical lag to a minimum.

"Pole changers may be used instead of transmitters. This is shown on the right of the diagram. The stroke of the pole changer T_1 should, however, be shorter than when it is used in regular quadruplex service, so as to reduce the no-current interval, which occurs when the lever F_1 of the pole changer is moving from one position to

another, to a minimum; and, since the no-current interval is, in this case, not accompanied by a reversal of current, as in regular quadruplex service, there is no excessive sparking and no difficulty in maintaining a close adjustment. It, therefore, makes a very close breaking repeater, being equally as close as the Neilson repeater."

The keys K and K_1 enable the attendant at the repeater office to communicate with either of the two distant operators. The switches X and X_1 are in the proper position in the diagram for the use of the apparatus as a repeater. When these switches rest on the contact buttons o and o_1, the relays, sounders, and keys constitute two independent office sets. The eastern circuit is shown connected through the loop switch $L S$ and the main switchboard $M S$, one wire being connected to the east line and the other wire through the main-line battery $M B_1$ to the ground G. The western circuit would be connected through a loop, main switch, west line, and battery in the same manner. The switchboard loop must always connect to the main line in such a way as to have the polarity of the auxiliary battery B_1 agree with the polarity of the main battery $M B_1$, otherwise there will be a reversal of the current through the relay R when the transmitter or pole changer T_1 opens, and this would cause a kick, or break, in the signals. The kick would result in a vibration of the lever of the relay R. When this occurs, it is only necessary to reverse the wedge at the switchboard to correct the trouble.

29. As a makeshift, ordinary box relays may be used in place of the transmitter or pole changer. For this purpose, the insulated back contact is supplied with a platinum point, and a third binding post is provided for it. The reading sounder is then omitted, as it cannot be worked in circuit with the high-resistance box relay.

30. Operation.—Suppose the eastern operator opens his key; then the relay R opens its local circuit, allowing the sounder S and transmitter T to release their armatures and the hook end H of the transmitter T descends

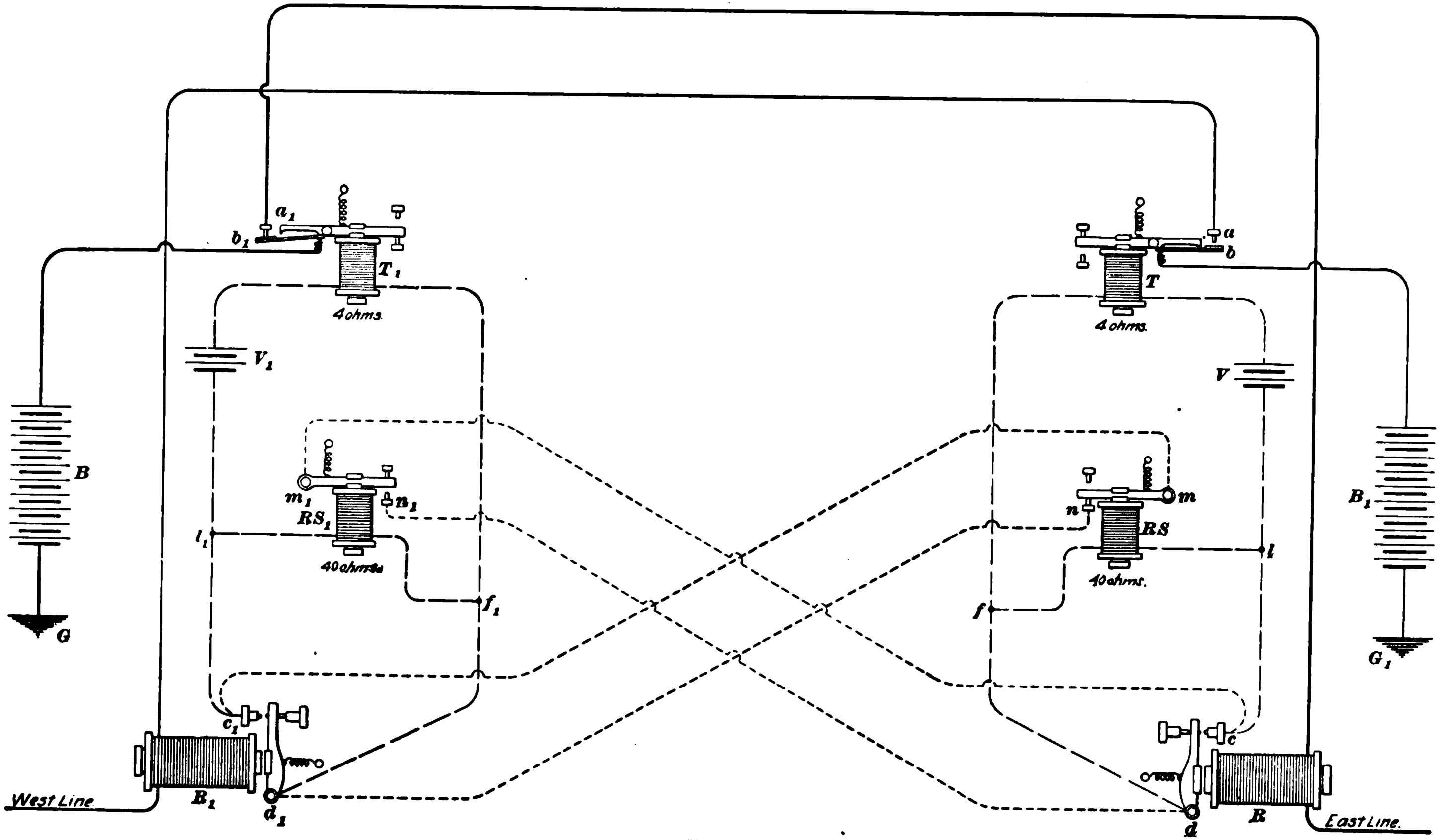
and carries with it the spring tongue, thus breaking contact with the stop C and opening the west line. At the same time that the west line is opened at this contact stop C, the spring tongue makes connection with the hook H, as previously explained, and this connects the auxiliary battery B in a closed circuit containing the relay R_1, key K_1, wire e, battery B, wire d, transmitter lever F, hook H, spring tongue, switch X, and wire m. The relay R_1 is thus held closed, and, consequently, T_1 will be held closed and inactive, and thus prevent breaking back into the sending side.

31. When the circuits are idle, the auxiliary batteries supply current to their transmitters and sounders in the usual way, but when the circuits are working, the auxiliary battery on the sending side will supply current to the relay on the receiving side and hold it closed whenever the receiving side is opened at the transmitter. The auxiliary battery is thus on closed circuit all the time, either on its transmitter and sounder circuit or on the opposite relay. This is all right for gravity cells, because it is better to have them closed too much rather than too little of the time. Having them closed the entire time, however, means considerable consumption of battery material.

NEILSON REPEATER.

32. The **Neilson,** or **Neilson shunt repeater,** as it is also called, has given entire satisfaction in Canada. It has an advantage over some other repeaters in that it only requires one local battery for two magnets. It may also be used as a side-line repeater.

In Fig. 10, in which is given the diagram of connections for the Neilson repeater, R and R_1 are ordinary relays; RS and RS_1, repeating sounders, each of 40 ohms resistance; B and B_1, the main-line batteries; V and V_1, the local batteries; and T and T_1 are either ordinary transmitters or repeating sounders, each of 4 ohms resistance.



a1
b1
T1
4 ohms.
V1
B
m1
n1
RS1
l1
40 ohms.
f1
G
c1
West Line
B1
d1
a
b
T
4 ohms.
V
m
n
RS
l
40 ohms.
f
B1
G1
c
d
R
East Line.

FIG. 10.

33. When current flows in the two main-line circuits, the armatures of the relays R and R_1 hold the local circuits closed at c and c_1 and, consequently, currents flow through the two local circuits V–T–f–d–c–l–V and V_1–T_1–f_1–d_1–c_1–l_1–V_1. These currents energize the transmitters T and T_1, and keep the two main-line circuits closed at the contact points of the transmitters, the eastern circuit being closed at b_1 and the western at b. In this condition the magnet coils of the repeating sounders RS and RS_1 are short-circuited or shunted by the relay armatures, which have practically no resistance when compared to the 40 ohms in the repeating sounders, and, therefore, practically no current flows through the repeating sounders. Consequently, the contact points n and n_1 at the repeating sounders are normally open. In this condition of the local circuits, the transmitters get $\frac{2}{4+4} = \frac{1}{4}$ ampere, assuming each cell to have an electromotive force of 1 volt and an internal resistance of 2 ohms.

Suppose the circuit through the relay R is opened; then its armature opens the circuit at c, thus removing the short circuit around RS and leaving the transmitter T and the repeating sounder RS in series. The current from V will now flow in the circuit V–T–f–RS–l–V. The current in this circuit is $\frac{2}{40+4+4} = \frac{1}{24}$ ampere, which is not enough to keep the transmitter T closed, but is sufficient to close the 40-ohm repeating sounder RS because it has so many more turns of wire in its coils than there are in the 4-ohm transmitter coils.

If, with T open and RS closed, the repeating sounder RS_1 on the other side should by any means close, RS would be again short-circuited, although this time through f–d–n_1–m_1–c–l, instead of through f–d–c–l, as before. Still the result would be the same; RS would open and enough current would flow through the transmitter T to close it. This must not occur; that is, RS_1 must not close nor RS open while the eastern key is open; and, furthermore, RS_1 must never close while the eastern circuit is repeating into the western.

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34. Operation.—The two main circuits will normally be closed, causing the two transmitters to be closed and the two repeating sounders to be open. Suppose the eastern key is opened. There now being no current through the relay *R*, it will release its armature and thus open the short circuit around *R S* at *c*. This will leave the repeating sounder *R S* in series with the transmitter *T*, causing *R S* to close and *T* to open at the same moment. The opening of *T* opens the western circuit at *a*, allowing R_1 to demagnetize, and to open its local circuit at c_1. Furthermore, as soon as *T* opened, the repeating sounder *R S* closed, thereby closing the short circuit f_1–d_1–*n*–*m*–c_1–l_1 around *R* S_1, thus preventing the closing of *R* S_1 or the opening of T_1, and so preventing the opening of the east line at b_1. Thus, when the eastern key is opened, the east-line circuit is not opened at the repeater. When the eastern key is closed, current will flow from the positive pole of *B* through b_1–a_1–*R* to east line, to the eastern office, the ground, and back through the ground to *G* and to the negative pole of the battery *B*. This will energize *R* and so close the local circuit at *c*, allowing ¼ ampere to flow through the circuit *V*–*T*–*f*–*d*–*c*–*l*–*V* and causing *T* to close the west-line circuit at *a*. The repeating sounder *R S*, being short-circuited by the armature of the relay *R*, loses its magnetism and, consequently, opens at *n* the short circuit f_1–d_1–*n*–*m*–c_1–l_1, around *R* S_1, but at the same instant, since R_1 is now magnetized, the other short circuit, f_1–d_1–c_1–l_1, around *R* S_1 is closed at c_1. Thus the current through T_1 remains the same, ¼ ampere, and T_1 is kept closed and *R* S_1 open, that is, demagnetized, no matter whether the east line is open or closed. Consequently, the transmitter T_1 remains closed all the time that the eastern circuit is repeating into the western—the essential feature of a repeater.

To repeat from the western into the eastern circuit, the above operations are reversed. In this repeater, the local batteries are closed all the time and furnishing the maximum current, ¼ ampere, except when the eastern or western key is open in the act of sending a space.

35. Repeating Sounder.—By providing an ordinary sounder with contact points, so that the movement of the lever opens and closes a second circuit entirely distinct from the circuit containing the sounder coils, we have a repeating sounder. Such a repeating sounder, often called the **quadruplex repeating sounder** because it was probably first used in quadruplex systems, is shown in Fig. 11. It is similar to the ordinary sounder made by the Western Electric Company. It has two platinum contact points, one on the top of the post *u* and one on the bottom of the screw *i*. The circuit is opened and closed between these two platinum points. It also has two extra binding posts *e* and *f*. One of these binding posts is connected to the post *u*, which is insulated from all other metal parts of the sounder, and the other is connected through the lever *l* to the screw *i*.

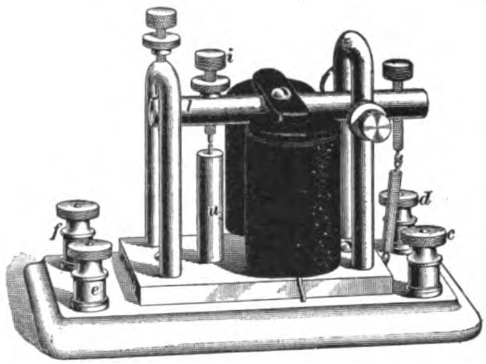


FIG. 11.

36. Spring Contact Repeating Sounder.—Another form of repeating sounder, which resembles the ordinary sounder made by Bunnell & Co., is shown in Fig. 12. It has a flat spring, or tongue, *a* at one end of the lever *c* where the second circuit is opened and closed when the lever vibrates down and up.

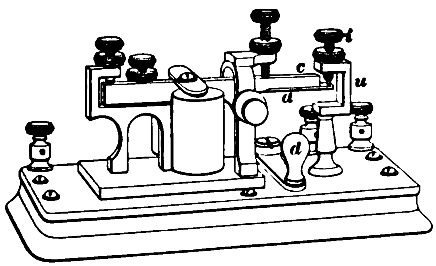


FIG. 12.

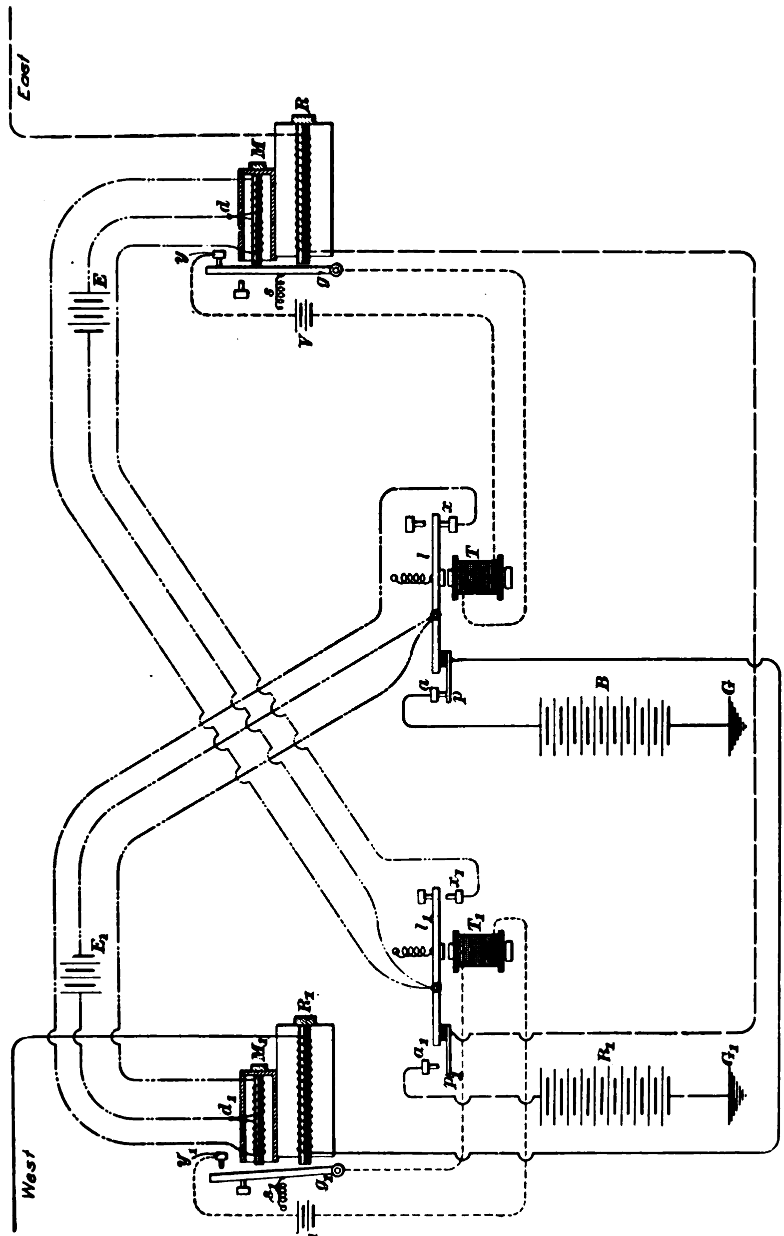


FIG. 13.

The screw *i* and its supporting post *u* are insulated from all other metal parts, except one binding post to which it is connected. The tongue *a* is connected through the lever to which it is fastened to a separate binding post. By means of the switch *d*, the circuit may be permanently opened. The Western Electric Company, also, make a repeating sounder similar to their regular sounder, but with a spring tongue.

WEINY-PHILLIPS REPEATER.

37. The **Weiny-Phillips repeater,** used by the Postal Telegraph-Cable Company, the United Press, Great Western Railway Company, and probably others, is shown in Fig. 13. T and T_1 are transmitters; B and B_1, the main-line batteries; V and V_1, the local batteries that operate the transmitters; E and E_1, extra local batteries in circuit with the extra magnets M and M_1; and R and R_1 are the main-line relays.

By means of the extra magnets and extra local batteries, the continuity of the line that is repeating into the other line is preserved, resembling, somewhat, in this respect, the Milliken repeater, except that the extra magnet does not have a separate armature lever of its own, but acts directly on the lever of the line relay above which it is placed. This extra magnet is made quite different in shape and construction from the ordinary electromagnets used in ordinary relays and sounders. It has but one coil, which is enclosed in a soft-iron cylinder, open at the front and closed at the rear except for a hole at the center through which the iron core may project. In the ordinary relay magnet, the path of the lines of force is through one iron core, the yoke, the other iron core, and the armature back to the first iron core, thus completing their circuit. In this magnet the path of the lines of force is through the iron core, the rear-end iron plate, the sides of the iron cylinder, and the armature back to the iron core, from which they started.

38. Differentially Wound Magnet.—The winding and construction of the extra magnet is the distinctive feature of this repeater. There are two coils of the same number of turns and resistance on the magnet. The end of one coil and the beginning of the next are joined together and connected to a binding post on the base of the instrument. In Fig. 14 is shown an iron core over which two coils are wound in this manner. If a battery is connected between the first, or inside, end of one coil, and the last, or outside, end of the second coil, as shown at (*m*), the current, since it flows through both coils in the same direction around the iron core, will magnetize it as usual in any relay. But if the battery be connected as shown at (*n*), the current

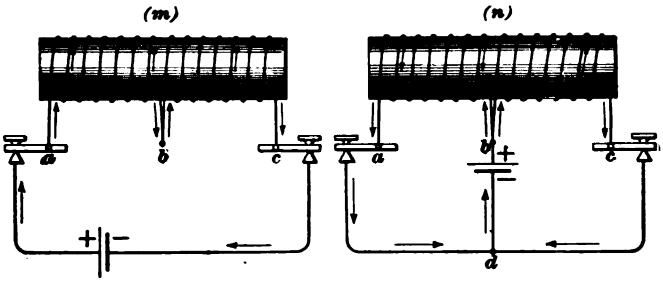


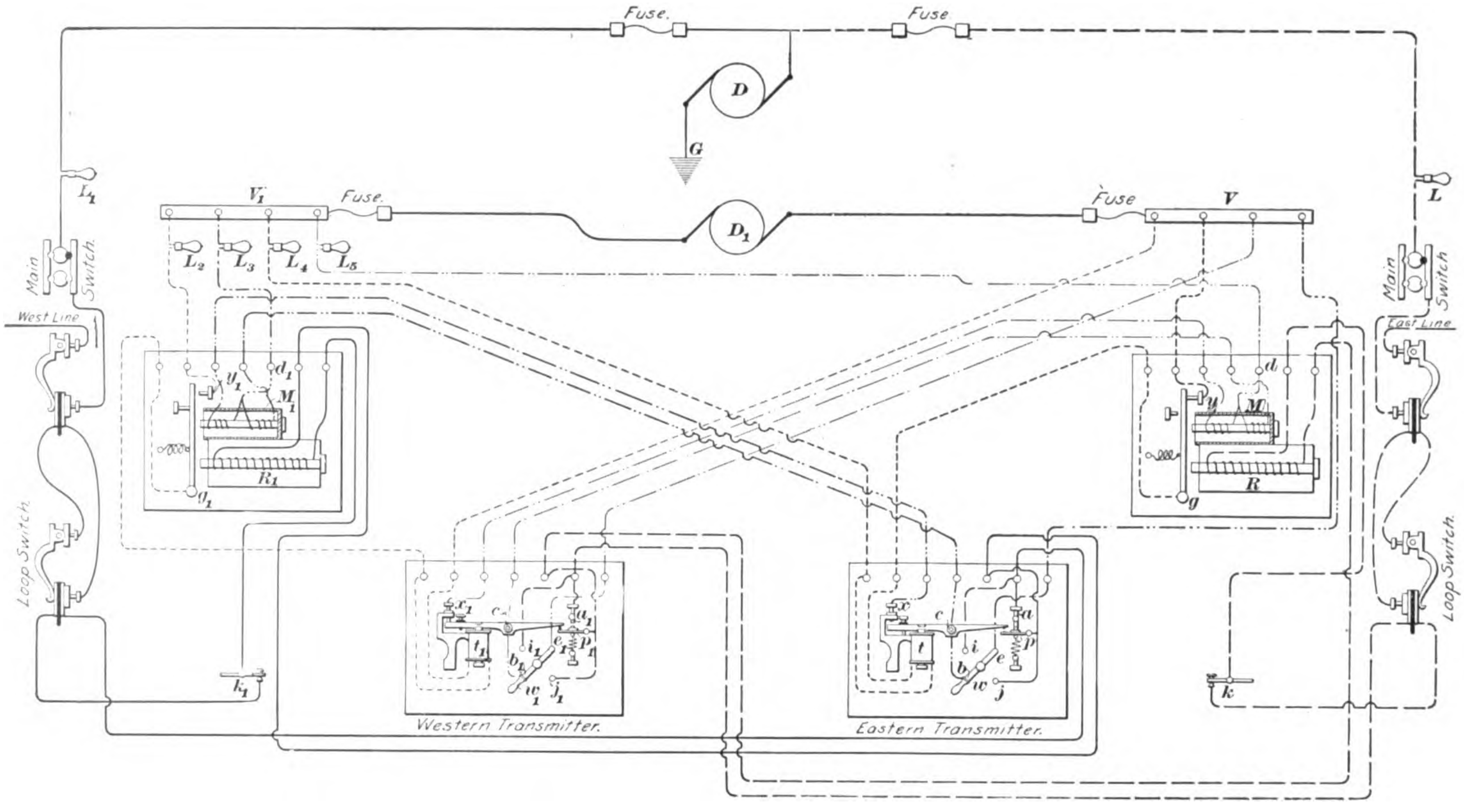
FIG. 14.

from the positive pole of the battery will divide into two parts at *b*, one flowing in the right-hand coil around the iron core in one direction, the other flowing in the left-hand coil, but in the opposite direction around the iron core. Consequently, the magnetizing forces of the two coils oppose each other, and the magnetism created in the iron core will be due to the difference in these two magnetizing forces. If both coils have exactly the same resistance, the current in each will be exactly equal; and, furthermore, if there are also exactly the same number of turns in each coil, then the ampere-turns in each coil will be equal but opposing each other; and, consequently, their resultant magnetizing force, being due to the difference of two equal opposing forces, will be zero and the core will not be magnetized at all.

However, should the key *a* in the diagram (*n*) be opened, the core will be magnetized in a certain direction because the current now circulates only through the right-hand coil, and, therefore, the magnetizing effect of this coil is not opposed, as before, by that of the left-hand coil, whose magnetizing effect is now zero. If *a* is closed and *c* opened, the core will be magnetized as strongly as before, but in an opposite direction. But as long as the armature is made of soft iron and is not polarized (that is, permanently magnetized) by the presence of a permanent magnet, the core will attract it no matter in which direction the core is magnetized. A magnet having two similar coils of the same number of turns and the same resistance, and connected as shown at (*n*), is said to be **differentially wound.** This differential method of winding a magnet has been explained here more fully, perhaps, than is necessary in connection with this repeater, but it should be thoroughly understood because many of the present duplex and quadruplex systems, which will be taken up later, would be impossible without differentially wound magnets.

39. When the transmitter *T*, Fig. 13, is closed, the current from the extra local battery E_1 will flow to d_1, where it divides *equally*, because the two circuits are equal in resistance, one half flowing through the right-hand coil of the magnet M_1 to the lever *l*, where it reunites with the other half that flowed through the left-hand coil on M_1, through *x* to *l*; from which point the whole current returns to the battery. Hence, when the transmitter is closed, as shown at *T*, the magnet M_1 is not magnetized and it exerts no attractive force on the armature lever g_1. When the transmitter opens, as shown at T_1, the left-hand coil of *M* is opened at x_1 and current then flows only through the right-hand coil of *M*. This energizes the magnet and causes it to pull the armature lever *g* against the contact stop *y*, in spite of the spring *s*.

40. Operation.—In the normal condition, all circuits are closed. Suppose the western key is opened, thereby



Fuse.
Fuse
D
G
V1
Fuse.
D1
Fuse
V
L1
L
L2
L3
L4
L5
Main Switch
Main Switch
West Line
East Line
Loop Switch.
Loop Switch.
Western Transmitter.
Eastern Transmitter.
R1
R
M1
M
k1
k

FIG. 15.

depriving the relay R_1 of current. Since current is flowing through both coils on M_1 in opposite directions, M_1 exerts no attractive force on its armature and, therefore, the armature lever g_1 is pulled away from y_1 by the spring s_1, thus opening the local circuit, containing the battery V_1, and demagnetizing the transmitter magnet T_1. This allows the transmitter T_1 to open, at x_1, the circuit through the left-hand coil on M, thereby allowing the right-hand coil on M to energize the magnet. The magnet M will, therefore, hold the armature lever g against the stop y, when, a moment later, the eastern circuit is opened at p_1, and so cuts off all current from R. Thus the opening of the local circuit containing the transmitter magnet T is prevented, thereby ***preserving the continuity of the western circuit*** between p and a and, also, preventing the magnet M_1 from being energized and attracting its armature lever g_1. Therefore the eastern circuit remains open as long as there is no circuit in the western line and relay R_1. As soon as the western key is closed, the relay R_1 will be magnetized, thereby attracting the lever g_1, and closing at y_1 the local circuit through V_1-y_1-g_1-T_1. This in turn closes at p_1 the eastern circuit through R-p_1-a_1-B_1-G_1 through the ground back to the eastern office, and, also, closes at x_1 the extra local circuit containing the left-hand coil on M, thus allowing the lever g to be held in contact with y by R alone. Thus all circuits are again in their normal condition, that is, closed.

The operation of repeating from the eastern into the western circuit is the reverse. Two local circuits may be supplied from the same battery, that is, E_1 and V_1 may be replaced by one battery and E and V by another battery.

41. Arrangement of Weiny-Phillips Repeater With Dynamos.—The connections for this repeater, where dynamos are used instead of primary cells, are shown in Fig. 15. All four local circuits are supplied from one dynamo D_1 and the two main lines from another dynamo D. The little circles represent the binding posts on the base of

the instruments. L_2, L_3, L_4, and L_5 are lamps, or non-inductive resistance coils, of the proper resistance to allow the desired current to flow in their respective circuits.

On the base of each transmitter there is a switch. With these switches w and w_1 in the positions shown in this figure, that is, w connecting b with c and w_1 connecting b_1 with c_1, the apparatus is properly connected to automatically repeat in either direction, the same as shown in Fig. 13, but with dynamos substituted for primary cells. With the switches in the positions shown, the various circuits may be traced as follows: The western circuit is from the west line through the jacks at the main and loop switchboards, through k_1 and R_1 to the eastern transmitter, then through the tongue p, contact stop a, the loop and main switchboards, lamp L_1, dynamo D, and ground plate G, to the western office and west line. The eastern circuit is from the east line through the jacks at the main and loop switchboards to k–R–p_1–a_1 through the loop and main switchboards to L–D–G and back through the ground to the eastern office and east line. The circuit through the magnet t_1 of the western transmitter may be traced from D_1 through V_1–L_3–y_1–g_1–t_1–V–D_1. The circuit through t may be traced from D_1 through V_1–L_4–t–g–y–V–D_1. The extra local circuit through M_1 is from D_1–V_1–L_3–d_1, at which point the current divides into two equal parts, one part going through the right-hand coil on M_1 to c–b–c–V–D_1, the other through the left-hand coil on M_1 to x–c–b–c–V–D_1. The extra local circuit through M is from D_1 through V_1–L_5–d, at which point the current divides into two equal parts, one part going through the right-hand coil on M to c_1–b_1–c_1–V–D_1, the other through the left-hand coil on M to x_1–c_1–b_1–c_1–V–D_1. The repeating operation is exactly the same as that explained in connection with Fig. 13.

42. By shifting the switch w so as to disconnect c from b and to connect i with j, the current is cut off from both coils of the extra magnet M_1, and the western main-line contact points $p\,a$ on the eastern transmitter are short-circuited. This enables the western transmitter to be used as a simple

sounder for the relay R_1 and, moreover, the western line still repeats into the eastern line, but the eastern cannot now repeat into the western circuit. The reverse is the case when w_1 is turned to connect i_1 with j_1 and w is in its present position connecting b with c. When both switches are turned so as to connect i with j and i_1 with j_1, the eastern and western line circuits may be used independently of each other the transmitters acting merely as sounders.

ATKINSON REPEATER.

43. The **Atkinson repeater,** shown in Fig. 16, requires two ordinary relays R and R_1, two repeating sounders RS and RS_1, two transmitters T and T_1, two main-line batteries B and B_1, two local batteries V and V_1, and two extra local batteries E and E_1. After the transmitters have once been adjusted and all screws firmly locked in place, they will need no further attention and the repeater can then be readily kept in proper order by any operator that is able to adjust an ordinary relay and sounder. This repeater has proved quite successful for this reason. The transmitter shown in Fig. 8 may be used in this repeater. In the *normal condition*, the two main-line, the two local, and the two extra local circuits are closed, causing the armature levers of all six magnets to be attracted, and all their local contacts to be closed *except* f and f_1, *which are open.*

44. Operation.—The opening of the eastern key will cause R to release its armature and to open at m the local circuit containing V and T, because f is already *open* and remains so as long as T_1 remains closed. It will be shown that T_1 will not be affected at all by the opening or closing of the eastern key and remains closed as long as the western key is closed. The opening of the local circuit containing T will cause this transmitter to release its armature and to open the extra local circuit at d and to open a moment later the western circuit at a. The opening at d of the extra local

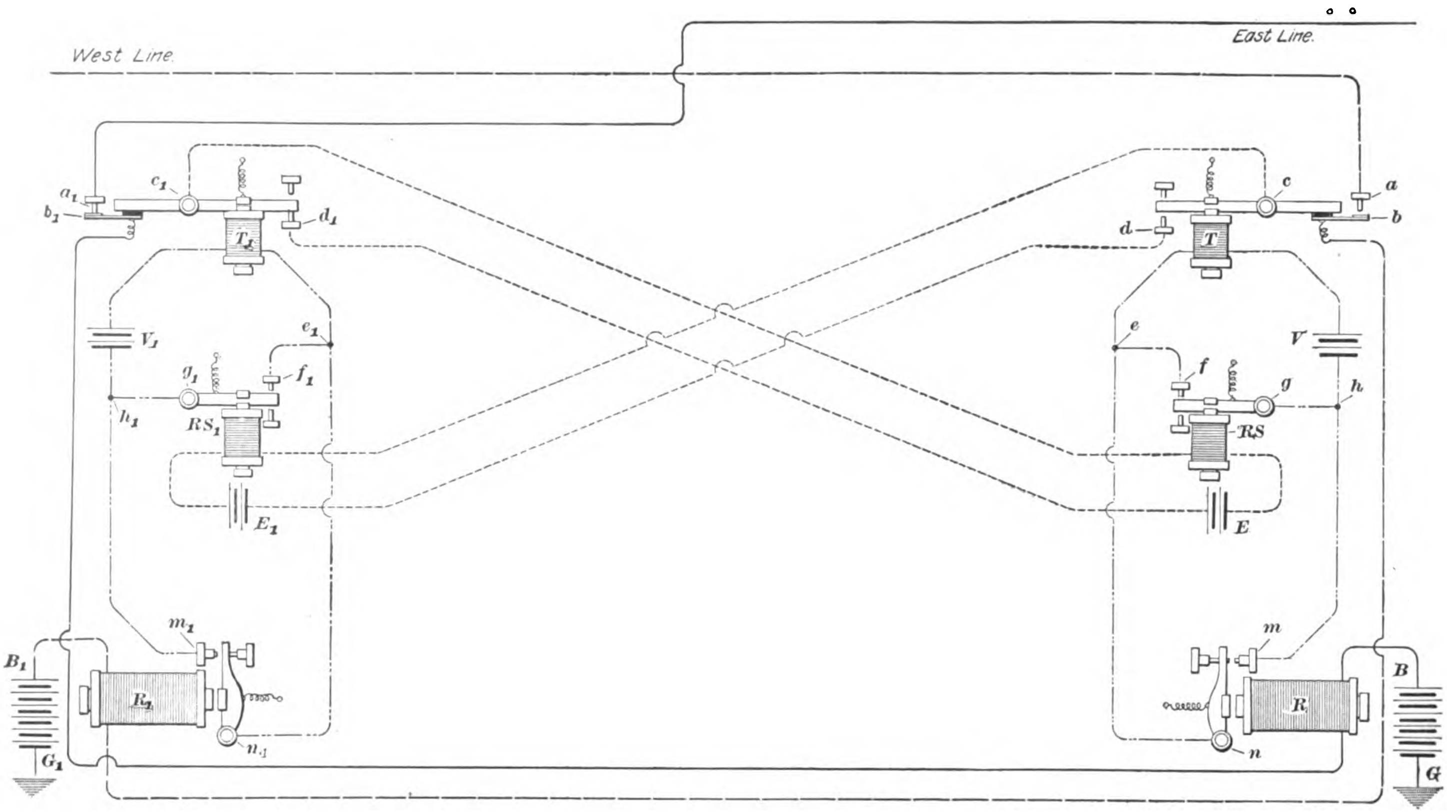

West Line.
East Line.
a
b
c
d
T
a_1
b_1
c_1
d_1
T_1
V
V_1
e
f
g
h
RS
e_1
f_1
g_1
h_1
RS_1
E
E_1
m
n
R
m_1
n_1
R_1
B
G
B_1
G_1

FIG. 16.

circuit containing $R S_1$ and E_1 will close at f_1 the shunt circuit h_1-g_1-f_1-e_1 around the armature m_1-n_1 of the relay R_1 slightly before, or at the same instant that the armature of R_1 opens at m_1, on account of R_1 being demagnetized when the west line is opened at *a*. Thus the western circuit is opened at *a* and the transmitter T_1 is kept closed in spite of the fact that R_1 releases its armature. Furthermore, *R S* is kept closed at d_1, thereby preventing the closing at *f* of the local circuit containing *V* and *T*, which, should it happen, would interfere with the signal. When the eastern key is closed again, *R* will close its local circuit at *m*, causing the transmitter *T* to close the western circuit at *a*, and a moment later, to close at *d* the extra local circuit containing E_1 and $R S_1$. The closing of these two circuits first causes R_1 to close its local circuit at m_1, and then $R S_1$ to open at f_1, thus restoring all the circuits to their normal condition without opening the sending line (in this case the east line) at the repeating station. Therefore, the eastern circuit is not opened at any time at the repeater station while the eastern is repeating into the western circuit. Evidently, the operation described will be reversed when repeating from the western into the eastern circuit.

HORTON REPEATER.

45. The **Horton repeater,** which was introduced in 1896, is said to have been used by the Lehigh Valley Railroad, Philadelphia and Reading Railroad, the National Transit Company, on some of the lines of the Long Distance Telephone Company, North American Telegraph Company, and the Pennsylvania Railroad lines west of Pittsburg.

46. The distinguishing feature of the Horton repeater is the method adopted for preserving the continuity of the sending circuit while repeating into the opposite line. This is accomplished by using the force of gravity, dispensing with extra armatures or springs, the holding force being

obtained by the withdrawal instead of the application of a local current. In Fig. 17, illustrating this repeater, T and T_1 are ordinary repeating transmitters and R and R_1 are main-line relays. The latter have inclined bases and local retracting magnets M and M_1 that are placed directly behind the relay armatures. The retracting magnet acts, when energized, on the armature as a retractile force (in place of the usual spring) to draw it backwards and away from its local contact when the main-line current through the front or relay coils is interrupted. On account of the inclined base,

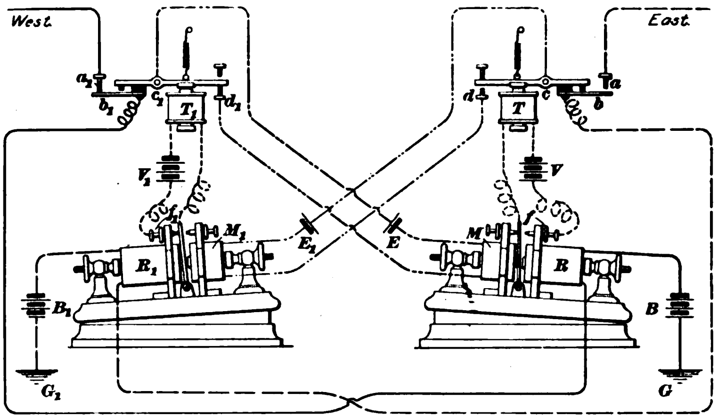


FIG. 17.

the armature will retain its forward position by gravity, and so keep the local circuit through the transmitter closed whenever there is no current in the retracting magnets, regardless of the presence or absence of a current through the relay coils in front. When both the relay and retracting magnets are energized, the pull of the relay on the armature, aided by gravity, is sufficient to keep the armature of the relay R against the front contact f, and thus keep the transmitter T closed. Consequently, the transmitter *T can only be opened when there is current in the retracting magnet M and none in the relay magnet R.*

The retracting magnet may be moved toward or away from the armature as desired, in order to increase or

decrease its attractive force on the armature, in the same manner as an ordinary relay is adjusted. This is the only part of the repeater requiring adjustment after it has once been properly set up, and for this reason it is said to give better results than some other repeaters in the hands of ordinary operators.

47. Operation.—In their normal condition, all circuits are closed. Opening the western key interrupts the current through the relay *R*, the armature of which is thereby drawn away from its local contact *f* by the attraction of the retracting magnet *M*, which remains closed, as will be shown presently, thus permitting the transmitter *T* to open first at *d* the local circuit of the retracting magnet *M*, and then at *a* the eastern circuit. The opening of the local circuit at *d* demagnetizes the retracting magnet M_1. This prevents any movement of the armature of the relay R_1, which continues to be held against its front contact stop f_1 by its own weight, when, an instant later, the east main-line circuit passing through the relay R_1 is opened at *a*. Thus the local circuit containing the magnet of the transmitter T_1 is kept closed, thereby preserving at a_1 the continuity of the western main-line circuit. Thus a closed path is preserved from the western office through a_1–b_1–*R*–*B*–*G* back through the ground to the western office, thereby enabling the western office to again close the relay *R*. When the western office does this by closing his key, *R* attracts its armature, closing at *f* the circuit containing *T*, which, in turn, first closes the east line at *a*, causing R_1 to hold on to its armature when, a moment later, the local circuit containing M_1 is closed at *d*. Now all circuits are again closed, which is their normal condition. Therefore, the western circuit is not opened at any time at the repeater while the western is repeating into the eastern circuit. Evidently the operation described will be reversed when repeating from the eastern into the western circuit.

48. It is claimed for the Horton repeater that it is very efficient and sensitive, permitting the closest possible

adjustment of both relay and transmitter armatures, the play of which may be so shortened up that their motion is scarcely perceptible, which, together with the instantaneous application of the holding force, increases the capacity of the repeater for rapid work. Any marked decrease in the strength of the extra local current can be quickly compensated for by giving the adjustment screw of the retracting magnet a turn so as to bring it closer to the armature. It is further claimed that one cell is sufficient for each extra local battery E and E_1, as against six in each extra local circuit of the Milliken repeater, and that the transmitter can be operated with less battery power on account of the close adjustment possible, thus saving about ten cells of local battery where this repeater is used in place of the Milliken.

Like the Milliken and other repeaters, the Horton repeater may be divided into half sets for use in connection with the duplex or quadruplex systems. This use of repeaters cannot be well explained until after the duplex and quadruplex systems have been considered.

SIDE-LINE AND MULTIPLE REPEATERS.

49. Most of the repeaters described can be readily adapted to repeat from a main line at an intermediate station into a branch or side line. Furthermore, by continuing one main line through a number of repeater sets, the one main line will repeat into all the branch lines, or one transmitter may be made to have as many extra tongues and contact points as there are lines into which it is desirable to repeat. Automatic repeater sets arranged to do this are sometimes known as **three-cornered repeaters.**

Automatic multiple repeaters have also been devised that, in one case, will repeat into eight, and, in another, into an almost unlimited number of circuits. However, standard repeaters, which the telegraph companies have on hand, can be arranged as explained above to do this, and to our knowledge no special multiple repeaters are in general use.

DOUBLE-CURRENT SYSTEM.

50. The Morse open-circuit and closed-circuit systems, explained in *Telegraphy*, Part 1, are sometimes called **single-current systems,** because the current in the line and relays, while a message is being transmitted, flows only in one direction. A dot or a dash is caused by a current flowing through the relay, while a space is caused by the absence of a current. It makes no difference in which direction the current flows through the relay, because a current in either direction will cause the relay to attract its armature.

51. The **double-current system** is one in which reverse currents, or currents in both directions through the line and relays, are employed. A current in one direction through the relays produces dots and dashes, and a current in the opposite direction is necessary in order to produce a space. The double-current system is used on all submarine cables, on polar, quadruplex, Wheatstone automatic, and printing telegraph systems, and more or less on simplex land lines throughout Europe. A **simplex circuit** is one over which only one message is sent at one time.

52. Polarized Relays. — For double-current transmission, *polarized relays* are necessary in place of the ordinary relays employed on single-current systems. A **polarized relay** is one that requires the direction of the current flowing through it to be reversed in order to move the armature from one stop to the other. A current in one direction will keep the local-sounder circuit closed at the front stop of the relay, and a current in the reverse direction is necessary before the local-sounder circuit can be opened at this point. The mere absence of a current will leave the armature of the relay against whichever stop the last current may have moved it. Dots and dashes are made by currents flowing in one definite direction and spaces by currents flowing in the opposite direction. A battery reversing key must be employed in place of the ordinary make-and-break key.

53. The polarized relay and the use of the double currents will be fully explained because of their importance in duplex, quadruplex, and other systems. In telegraphing by means of the Morse single-current system, the opening of the key leaves the line charged. This charge flows to earth through the path of least resistance, requiring on a long line, and especially on submarine cables, an appreciable time for the total charge to reach the earth through the ground connection at the distant end. If the key is so constructed that instead of simply opening the circuit it connects the opposite pole of the same, or a similar battery, to the line, then the charge of opposite polarity rushing from the battery into the line will neutralize more or less of the original charge remaining on the line, thus reducing the latter to a neutral, or unchanged, state much quicker than if all the original charge had to flow to earth before the line would be clear. Thus the line is ready for a new signal in a shorter time than under the single-current system and, consequently, more rapid transmitting is possible.

54. By the use of polarized relays and double currents, 190 words a minute can be transmitted by the Wheatstone automatic system between New York and Chicago, whereas, on the ordinary Morse single-current system, 80 words is about the limit on a line only 350 miles long. However, the greatest advantage of the double-current over the single-current system is probably due to the higher efficiency of the polarized relay over the ordinary relay, especially during wet weather when there is a large amount of leakage from the line.

THEORY OF THE POLARIZED RELAY.

55. Polarity of Soft-Iron Cores.—If a coil of insulated wire is wound around a soft-iron core and is connected to a battery so that the current circulates around the iron core in the direction shown by the arrows in Fig. 18 (*a*), the iron will be magnetized, having a north pole *N* at the

left-hand end and a south pole S at the right-hand end. If the battery be reversed, so that the current flows in the opposite direction, as shown by the arrows in Fig. 18 (*b*), then

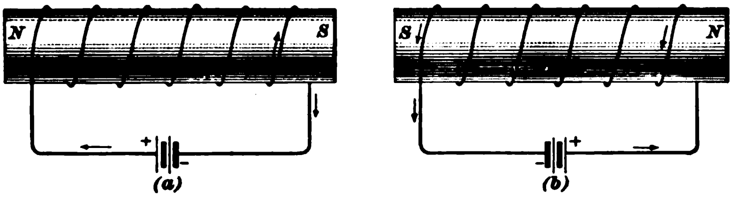


FIG. 18.

the magnetism will be reversed, having now a south pole S at the left-hand end, and a north pole N at the right-hand end.

56. A Permanently Magnetized Armature.—It is a well-known fact that similar magnetic poles repel each other and dissimilar magnetic poles attract each other. Fig. 19 represents a bar of soft iron, bent so as to bring the

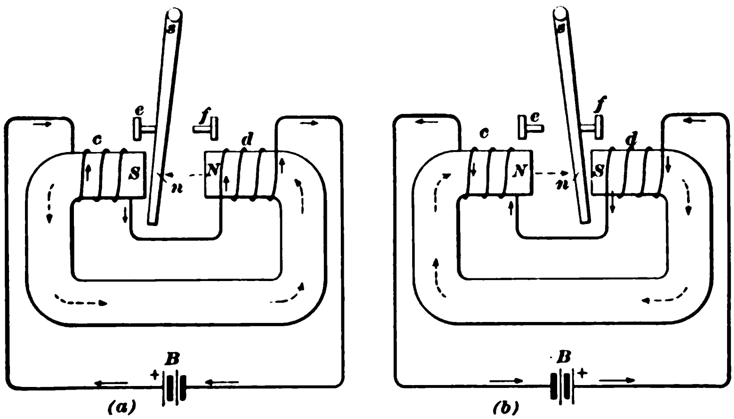


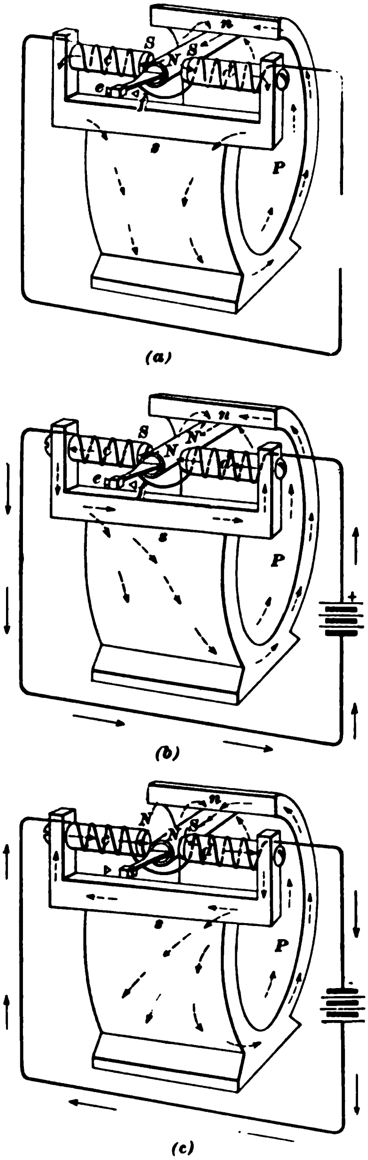
FIG. 19.

two ends opposite each other. Around each end of the iron bar is wound a coil of insulated wire, the two coils being wound in the same direction around the iron and connected in series with one another and with a battery B, as shown.

When a current from the battery circulates in the direction of the arrows shown in Fig. 19 (*a*), the current in each coil will magnetize the iron in the same direction, and thus produce magnetic lines of force in the direction of the dotted arrows, and, consequently, a north pole at *N* and a south pole at *S*. If a permanently magnetized piece of steel be suspended so that its north pole *n* is free to move between the poles of the electromagnet, the south pole *S* of the electromagnet will attract the north pole *n* of the permanent magnet, and the north pole *N* of the electromagnet will repel the north pole *n* of the permanent magnet. Consequently, the north pole *n* of the permanent magnet will move over as near to the south pole *S* as the stop *e* will permit. If the battery and, as a result, the direction of current is reversed in the coils, the lines of force in the soft iron and the polarities of the ends of the soft-iron core will be reversed, as shown in Fig. 19 (*b*). Now the north pole *n* of the permanent magnet, being attracted by the south pole *S* and repelled by the north pole *N* of the electromagnet, will move from the stop *e*, as shown at (*a*), to the stop *f*, as shown at (*b*). If the current be reversed, the permanent magnet will move back to *e*. Thus every time the direction of the current is reversed, the permanent magnet, or **armature,** as it is called, will move from one stop to the other.

57. Permanent Magnet of a Polarized Relay. In order to keep the armature permanently and strongly magnetized, and in order to otherwise increase the efficiency of the instrument, the polarized relay has a strong and rather large permanent magnet. A skeleton view of one form of a polarized relay is shown in Fig. 20. *P* is a curved piece of special magnet steel that has a very strong coercive force and which is, therefore, quite permanent and not easily weakened or demagnetized. In the rear end of this permanent magnet, the armature, or **tongue,** as it is also called, is loosely pivoted, and on the front end of the permanent magnet is placed a piece of iron of about the same

shape as that shown in Fig. 19. This rectangular piece and the tongue are made of the very best quality of magnetically soft iron. On the ends, or cores, of the soft-iron piece are wound the coils *c* and *d*. If the rear end of the permanent magnet is a north pole *n*, and the front end a south pole *s*, then, when there is no current flowing in either coil, the soft-iron parts will be magnetized on account of their contact with the permanent magnet, so as to have north and south poles where indicated by the letters *N* and *S*, respectively.



(a)

(b)

(c)

FIG. 20.

The dotted arrows indicate the direction of the lines of force through the various parts of the magnetic circuit. In (*a*) the lines of force are due entirely to the permanent magnet. If the tongue was exactly half way between the faces of the iron cores, it should, theoretically, remain there because each core would attract it with exactly the same force. But the least deviation in the equality of these two forces, due to the least deviation of the tongue from the exact middle position, will cause the tongue to fly against the stop *e* or *f*, toward whichever

one the pull is the greater. To get the tongue to remain in an intermediate position, where the two forces are exactly in equilibrium, would be about as difficult as it is to stand an ordinary egg on its small end. Practically, it is impossible.

58. Suppose that current flows through the coils *c* and *d*, as shown at (*b*). As in Fig. 19 (*a*), this current through the coils in the direction shown here will tend to make the right-hand end of the core, over which *c* is wound, a south pole *S*, but the permanent magnet, also, tends to make this end a south pole; hence, it becomes a stronger south pole than when there is no current flowing through *c*. This same current tends to make the left-hand end of the core, over which *d* is wound, a north pole, but the permanent magnet tends to make it a south pole; hence, it becomes either a very much weaker south pole, or a north pole *N'*, as here indicated. It is not, however, so strong a north pole as the right-hand end of the opposite core is a south pole. The result of these changes in polarities will be to create a strong attraction between *S* and *N* and a weaker repelling action between *N* and *N'*. Hence, the two cores no longer oppose each other, but both tend to move the tongue in the same direction. If the tongue was originally against the stop *f*, it will now move over against *e* and remain there even after the current is stopped. For the iron will return to its normal magnetic state when the current is stopped, as shown in Fig. 20 (*a*), in which the opposite ends of both cores become south poles again and, therefore, attract the tongue. But the attractive force of each core for the tongue varies inversely as the square of the distance between each core and the tongue; hence, the core that is the nearer to the tongue attracts it with a very much greater force than the more distant core, and the tongue is consequently held firmly against the stop *e*.

If the current be reversed in direction, the magnetic condition will be as represented in Fig. 20 (*c*) and the tongue will move from the stop *e* over against the stop *f*, because *S*

attracts and N' repels N. Thus a reversal of the current will move the tongue from one side to the other.

59. Advantages of Polarized Relays.—A polarized relay is a very efficient instrument. In the first place there is no spring to oppose the motion of the tongue or armature. Then the force that moves the tongue in one direction is exactly equal to the force that moves it in the opposite direction, because the current has the same strength in both directions. If the current in one direction weakens, it also weakens equally in the opposite direction and, hence, no adjustment is required for a variable current. Furthermore, the sending of reverse currents through the line tends to free the line more quickly of electrostatic charges and, consequently, allows more rapid sending. Polarized relays can be made exceedingly quick-acting and efficient.

60. In stormy weather a polarized relay will continue to give satisfactory service long after the ordinary, or neutral, relay becomes useless. This may be explained as follows: In *Principles of Electricity and Magnetism*, under the subject of "Lifting Magnets," it was shown that the pull between an armature and a core is proportional to the square of the number of lines of force per square inch at the pole face. Suppose, for example, that there are 200 lines of force per square inch through the armature, or tongue, of the polarized relay due to the permanent magnet alone. Half of these will go from the armature, when in its middle position, through each core, making a density, say, of 100 lines at the polar surface. Suppose, also, that the normal current produces in each core a density of 200 lines of force per square inch, then the total density in one core will be $100 + 200 = 300$, and in the other $200 - 100 = 100$, and, hence, the force of attraction toward one core may be represented by $300 \times 300 = 90{,}000$, and the repelling force of the other core may be represented by $100 \times 100 = 10{,}000$, giving a resultant pull of 100,000. If in wet weather the effective lines of force produced by the current are reduced to 100, then the

pull toward one side will be represented by $(100 + 100)^2 = 40{,}000$ and the repulsion from the other side by $(100 - 100)^2 = 0$, giving a resultant force toward one side of 40,000. The resultant force has, therefore, diminished from 100,000 to 40,000.

61. In order to get the same normal pull in the neutral as in the polarized relay, let the number of lines of force set up in the neutral relay by the normal current be 223.6. Then, in fair weather, the pull between one core and the armature will be represented by $(223.6)^2$, and between the armature and both cores twice this amount, or $2(223.6)^2 = 100{,}000$. Thus the neutral relay is not as efficient even in fair weather, for in order to get the same pull, it must have enough ampere-turns to develop 223.6 lines per square inch, whereas the polarized relay required only enough to develop 200 lines. If we assume, as before, that in wet weather the effective number of lines of force is reduced to one-half its fair-weather value, that is, to 111.8, then the pull will be represented by $2(111.8)^2 = 25{,}998$.

In the polarized relay the pull is reduced from 100,000 to 40,000, whereas in the neutral relay, the pull is reduced from 100,000 to 25,998. Thus in wet weather the neutral relay exerts a pull of only a little more than one-half that exerted by the polarized relay. The less the effective current, the better does the polarized relay appear in comparison with the neutral relay, for it always has the permanent magnetism to assist the variable magnetism. Furthermore, if the force that moves the tongue in one direction decreases or increases, the force that moves it back again in the opposite direction also decreases or increases, respectively, by exactly the same amount, and, therefore, there is no retractile force to readjust. The tongue may be pulled hard one moment and lightly the next, but it will still move across the gap, and that is all that is required. Thus the detrimental effect of an extra flow of current due to leaks in wet weather is almost eliminated, because no matter how much or how little current is flowing, its direction can be

reversed, and it is on these alterations in the direction of the current that the operation of the polarized relay depends.

62. An objection to the ordinary relay is the fact that the current through the relay will vary in strength due to variation in the line resistance and in the leakage to earth in wet and dry weather; consequently, there is a variable magnetic force working against the constant pull of a spring requiring a frequent readjustment of the spring or of the cores of the magnet or of both. The polarized relay, on the other hand, has no spring for the electromagnet to overcome, and, moreover, the action of the cores on the armatures is a double one, they being attracted and repelled at the same time. No alteration in the adjustment is required (except, perhaps, to counteract earth currents, not leakage currents, which must also be done in using the ordinary relay) to meet varying strengths of line current, and for this reason the polarized relay has considerable advantage over the ordinary relay.

WESTERN UNION POLARIZED RELAY.

63. In Fig. 21 is shown a polarized relay used by the Western Union Telegraph Company. This relay was for many years their standard polarized relay. *M*, the permanent steel magnet, is semicircular in shape and 3½ inches in diameter at the widest part. The two coils *c* and *d* are wound upon soft-iron cores between which the armature, or tongue *e*, made of a soft-iron tube, moves. This armature, which is 2½ inches long, is loosely pivoted at the rear. The supports *p* and *o* for the front and rear contact screws *a* and *b*, respectively, form part of a piece that can be moved a limited distance horizontally inside the cylinder *h* by the screw *k*.

The play of the armature is usually adjusted by the screw *a*, and the armature is *centered* by means of the screw *k*. To

center the armature of a polarized relay is to place it so that it can move an equal distance on each side of a point

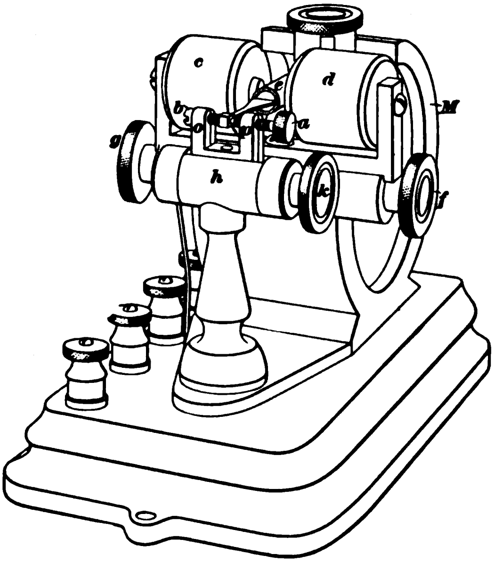


FIG. 21.

exactly midway between the faces of the two soft-iron cores. The cores, over which the coils *c* and *d* are wound, can be moved to and from the armature by the screws *f* and *g*.

NEW STANDARD WESTERN UNION POLARIZED RELAY.

64. The polarized relay shown in Fig. 21 was for many years, as has already been stated, the standard polarized relay of the Western Union Telegraph Company. Now, however, an improved polarized relay, shown in Fig. 22, has become their standard, and is displacing the other. In this connection it may be well to state that in newly designed relays, and other apparatus of the same nature, the moving parts are being made light by the liberal use of aluminum,

and quick-acting by the absence of iron yokes and a better arrangement of the iron parts.

65. In Fig. 22, illustrating this polarized relay, (*x*) shows the instrument complete, with part of one side cut away so that the arrangement of the parts inside can be readily seen; (*y*) is a plan view showing the permanent horseshoe magnet *N A S*, the two coils *h* and *i*, and the four soft-iron pole

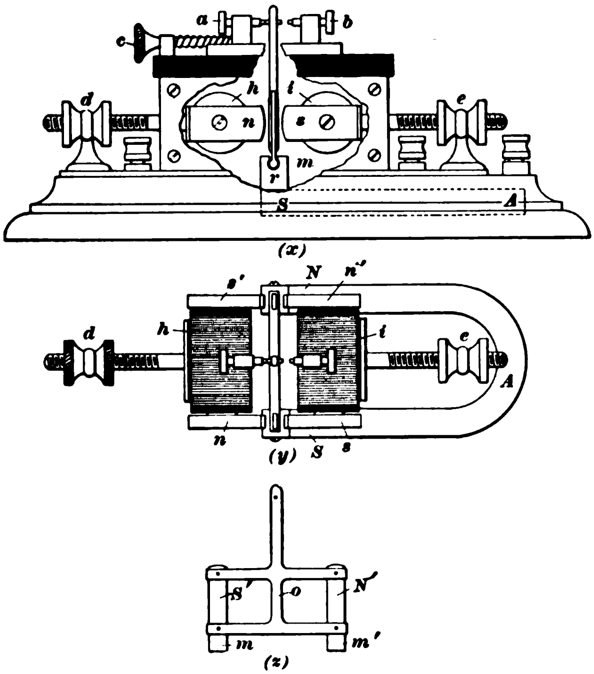


Fig. 22.

pieces *s*, *n*, *s'*, and *n'* that project from the soft-iron cores to which they are fastened. The two soft-iron armatures stand in a vertical position between the pole pieces. The armature frame is shown separately at (*z*). It consists of two soft-iron armatures *S'* and *N'* held together, as shown, by a frame of aluminum *o*.

The permanent magnet *N A S* lies flat in the base of the instrument. Each pole has a short iron extension *r*, in a recess in which the lower ends *m* and *m'* [shown in (*z*)] of the vertical iron armatures *S'* and *N'* rest loosely. The iron armatures are polarized by the permanent magnet. If the permanent magnet has a north pole at *N* and a south pole at *S*, then the armature will be polarized as indicated by the letters *S'* and *N'*, assuming that the end *m* rests in the extension piece *r* fastened to the south pole *S* of the permanent magnet, and m_1 in the extension of the north pole *N*. Each iron armature extends up between two of the core pole pieces, as shown in (*x*). Both armatures are attracted toward the same side by the two pole pieces attached to opposite ends of the *same core* and both are repelled in the same direction by the two pole pieces attached to opposite ends of the *other core*.

When a current circulates in one direction through the coils, the core extensions will have the polarities indicated. When the current is reversed, the polarities of all four core extensions are reversed. Thus twice as many poles are utilized in this instrument as in the older type. Furthermore, the cores are not connected by any yoke, which fact makes the relay respond more quickly to a change in the current.

The cores, coils, and pole pieces may be moved toward or away from the armatures by the screws *d* and *c*. The front and back stop-screws *a* and *b* are mounted on a frame that can be moved as a whole by the screw *c*. As much of the relay as may be convenient is placed in a brass case with a hard-rubber top in order to protect it from dirt and injury. However, there is left just enough of an opening in the side to allow the armatures and the core extensions to be readily seen.

The coils are usually wound differentially in sections; half of each differential winding being wound on each core, and each section containing about 2,850 turns of wire having a resistance of 200 ohms, thus making 400 ohms in each differential winding.

THEORETICAL CONNECTIONS OF DOUBLE-CURRENT SYSTEMS.

66. The use of polarized relays for simplex working is illustrated in Fig. 23. Two terminal and one intermediate offices are shown. *P R* represent polarized relays, and *K*, double-current transmitting keys. The key at each station normally rests on the back stop *c*, and the switch *l* normally connects *c* with *a*. In this position all batteries are cut out of the line circuit, resembling in this respect the Morse open-circuit system. When an operator wishes to send, he moves the lever *l* so as to connect *c* with *b*, as shown at station *E*. With the key resting on the rear stop *c*, negative current flows from *E* to *W* through the line wire, causing each

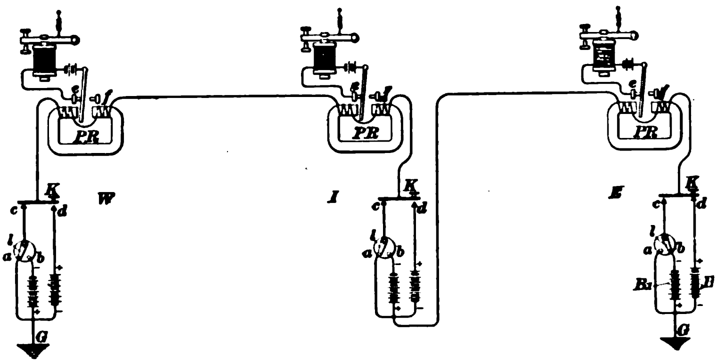


FIG. 23.

polarized relay to hold its armature against the back stop *f*, thus keeping the local-sounder circuits open. When the key is depressed, the negative charge on the line is first neutralized by a positive charge from the battery *B*; then the current rises to its maximum value and a positive current flows from *E* to *W* through the line, causing each polarized relay to move its armature against the front stop *e*. This closes the local-sounder circuits and sooner than would be the case if the single-current system were used. Current will continue to flow in the local-sounder circuits not only until the key breaks away from the front contact *d*, but until it

touches the rear contact *c*. Then a negative current first having neutralized or cleared out the positive charge, flows from *E* to *W* through the line and polarized relays and opens the local circuits.

67. In single-current systems, a current in one direction causes dots and dashes and no current produces the spaces. In double-current systems it is evident that starting a current in one direction starts a dot or dash, and a current in the opposite direction is required to terminate the dot or dash and start a space. The key here shown requires two batteries at each station, but there are keys, which will be shown later, that in one position connect the positive pole of a battery to the line and the negative pole to the earth, and in the other position will reverse the connections of the same battery so that the negative pole of the battery is put to the line and the positive pole to the earth. Such a key requires only one battery.

POLARIZED RELAYS AS REPRESENTED IN DIAGRAMS.

68. In Fig. 24 are shown three additional ways in which polarized relays are represented, and whenever any one of

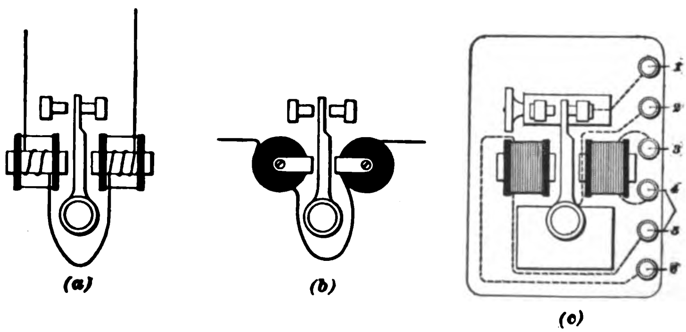


FIG. 24.

these occurs in a diagram hereafter, the student should immediately recognize it as a polarized relay. The way in

which the polarized relay was drawn in Fig. 23 and in (*a*) and (*b*) in Fig. 24 are conventional diagrams; (*c*) is a plan view of the Western Union polarized relay, showing six binding posts. Numbers *1* and *2* are the binding posts to which the local-sounder circuit is connected. Binding posts *3*, *4*, *5*, and *6* are the terminals of the four ends of the two coils. For use as a simple polar relay, *4* and *5* are connected together by a short stout wire and *3* and *6* form the two line terminals of the instrument. The use of the binding posts *4* and *5* will be apparent when the polar duplex and quadruplex systems have been described.

69. Polarized Relay Used as a Single-Current Relay.—A polarized relay may be adjusted so that it will close the local-sounder circuit when the main-line current flows through it in one direction and open the local circuit when the main-line current is interrupted. That is, it may be used in place of an ordinary relay. To use it in this way, the two stops *a* and *b* in Fig. 21 must be so adjusted that the whole play of the armature is on one side of the middle point between the two soft-iron cores. Then, when no current flows, the armature will always be drawn, due to the normal magnetic polarity of the cores produced by the permanent magnet, to the nearer core and the corresponding stop. When the key is closed, the current, in order to send a dot or dash, must circulate in such a direction around the cores as to reverse the normal polarity of the nearer core and increase the strength of the normal polarity of the other core. Then when current flows, the two cores will combine to move the armature toward the middle, but the one stop is so adjusted that the armature cannot pass or *even quite reach* this middle position, and, consequently, as soon as the current stops, the armature flies back toward the nearer pole, and against the corresponding stop. Thus the making and breaking of a current, which must flow in one particular direction with reference to the direction of the winding on the polarized relay, will move the armature and so open and close the local-sounder circuit.

MULTIPLEX TELEGRAPHY.

70. Thus far, methods for transmitting only single messages over a line have been discussed. Such systems are frequently called **simplex** to distinguish them from *multiplex* systems. **Multiplex telegraphy** is the transmission of two or more messages over the same wire at the same time. It is quite obvious that, if instruments can be arranged so that two simultaneous messages can be sent through the same wire, the work of the system is equal to that of two lines. If four messages can be sent simultaneously over the same line, the system is equivalent to a four-wire system. In these two cases a good ground return is assumed. If, then, one line can be made to do the work of four lines, the expense of erection and maintenance of three lines is avoided.

71. The transmission of two telegraphic messages simultaneously in *opposite directions* over the same wire is called the **duplex** system. This system is sometimes called **contraplex telegraphy,** to imply that the messages are being sent in contrary or opposite directions. On a duplex system there is one sending and one receiving operator at each end or office, i. e., four operators in all.

72. The transmission of two telegraphic messages simultaneously in the *same direction* over the same wire is called the **diplex** system. This term is the opposite of contraplex. On a diplex system there are two sending operators at one end and two receiving operators at the other end, or four operators in all.

73. The simultaneous transmission of four independent messages, two in one direction and two in the other, is termed the **quadruplex** system.

On a quadruplex system there are two sending and two receiving operators at each end, eight operators in all.

DUPLEX TELEGRAPHY.

74. There are three systems of duplex telegraphy: the *differential*, *polar*, and *bridge* duplex.

DIFFERENTIAL DUPLEX.

75. The **differential duplex** is also known as the **Stearns duplex.** The essential feature of this system is a differentially wound relay, the principle of which has already been explained. In Fig. 25, the differential relay R has the two outside ends of the coil extended to a distant station through two line wires $g\ h$ and $e\ f$. In one line is connected the relay R_1 and in the other a resistance r equal to the resistance of the relay R_1, both circuits then being grounded

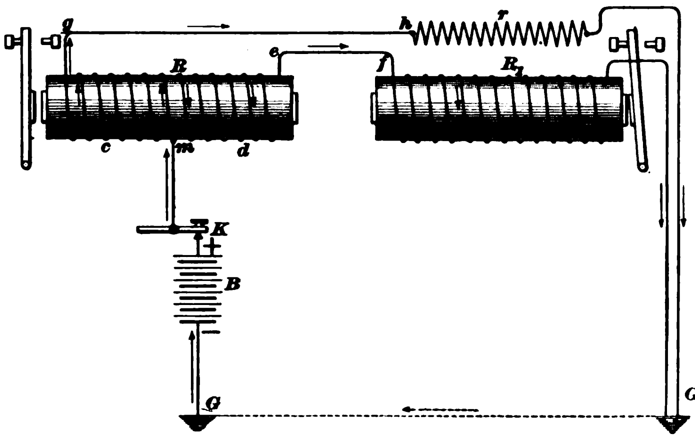


FIG. 25.

at G_1. The winding on the relay R has a connection made at its middle point, so that the two coils c and d, into which the whole winding is divided, have an equal number of turns and an equal resistance. The two line wires $e\ f$ and $g\ h$ have equal resistances and, also, equal electrostatic capacities. Consequently, the resistance and electrostatic capacity from the point m through d–e–f–R_1–G_1 is equal to that through

c–g–h–r–G_1. Therefore, when the key K is closed, the current will divide equally at m, one-half flowing to G_1 through each of the above two circuits, and the relay core R will not be magnetized because two equal currents flow around it in opposite directions. The magnetizing effect of one coil is completely neutralized by that of the other coil. Such a differentially wound non-polarized relay is commonly called a **neutral relay.** Not only will the steady or final current strength in both coils be the same, but since the capacities, as well as the resistances, in the two circuits are equal, the currents in both coils of the neutral relay will rise and fall at exactly the same rate. If the current should reach its maximum value or fall from its maximum value to zero much quicker in one coil than in the other, the armature of the relay would be momentarily affected every time the home key was closed or opened. By the arrangement shown in this figure, however, *the home relay R is not affected by the operation of the home key K.* This is one of the conditions that must be fulfilled in any successful duplex system. At the distant end, the current that flows over the line ef will flow through the relay R_1, and, consequently, that relay will respond every time the key K at the other end is closed, provided, of course, that the current has sufficient strength.

76. Instead of extending the end of the coil c through the line gh and the resistance r to the ground G_1 at the distant end, let it be grounded at G at the home station, as shown in Fig. 26, including between g and G a resistance r equal to the resistance from e through the line ef and the coil d_1 to the ground G_1, and a condenser C having a capacity equal to that of the line ef and so arranged that it will charge and discharge at the same rate as the line. Evidently, the opening and closing of the key K will have no effect on the home relay R, but it will operate the distant relay R_1. The condenser C is a very necessary part of this equipment. For if no condenser is used, the current will rise to its maximum value in one coil of R before it does

in the other, causing a movement, or momentary *kick*, as it is called, of the armature every time the home key is opened or closed. This kick of the armature would cause *false signals* every time the home key was operated and would seriously interfere with incoming signals and render the method useless, except, perhaps, on very short lines.

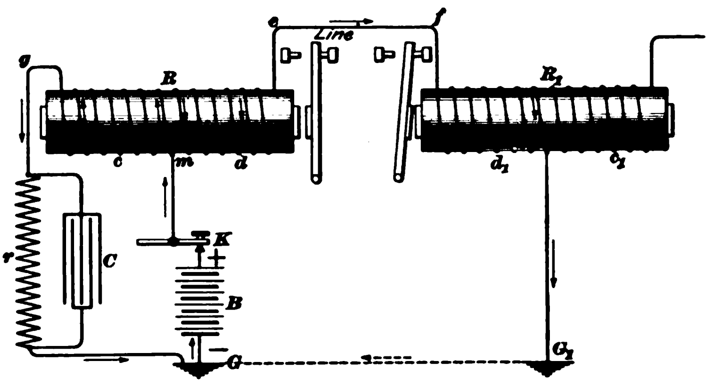


FIG. 26.

The application of the condenser to the artificial line in order to give it a capacity equivalent to that of the line, was first made by Stearns in 1872. Without this discovery of Stearns, who was a pioneer inventor in duplex telegraph work, the duplex and quadruplex systems at present in use would not be practicable.

77. In order to transmit messages in both directions simultaneously, the arrangement of apparatus at each end must be similar, as shown in Fig. 27. The keys have rear and front contacts and, normally, the levers of the keys rest on the rear contacts, which are connected to the ground. Thus the key arrangement resembles that used on the Morse open-circuit system. The resistance and capacity of the circuit from *m* through the coil *c* and $\frac{r}{C}$ to *G* should be equivalent to the resistance and capacity of the circuit

from m through d–e–f–d_1–n–a_1–J_1–G_1. Similarly, the resistance and capacity of the circuit from n through c_1 and $\frac{r_1}{C_1}$ to G. should be equivalent to that of the circuit from n

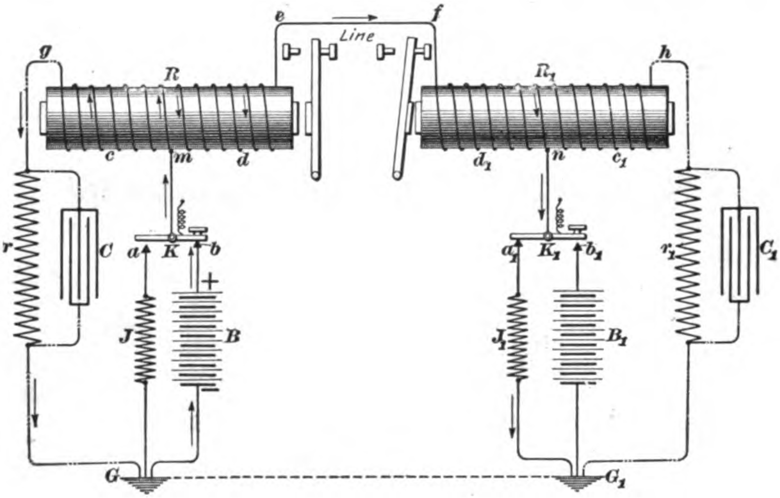


FIG. 27.

through d_1–f–e–d–m–a–J–G. The circuit from g to G, containing r and C, and the circuit from h to G_1, containing r_1 and C_1, are called the *artificial lines;* the coils c and c_1, the *artificial-line coils;* and the coils d and d_1, the *line coils* of the relays.

78. A resistance J equal to the internal resistance of the battery B must be inserted between the ground plate G and the rear contact a of the key. This will give a path of equal resistance from m to the ground G, whether the key K rests on the front or rear contact. J_1 is a similar resistance, equal to the internal resistance of B_1. If such resistances are not used, the home relay, assuming the distant key to be closed, will be more strongly magnetized when the home key is open than when closed, because the current through the line coil d of the home relay will be greater when the

home key K is open than will be the current through the artificial-line coil c when the key K is closed. The unequal magnetization of the relay will produce an inequality in the signals that it is very desirable to avoid.

79. The capacity at C and C_1 should be arranged to resemble the distributed capacity of the line wire. A simple condenser will charge and discharge more quickly than a line wire, in which the capacity is distributed throughout its length. The longer the line and the larger its capacity, the more care must be taken to make the artificial line resemble it. The way in which this is accomplished will be explained in connection with the practical arrangement of the various systems.

VARIOUS POSITIONS OF THE TWO KEYS.

80. When messages are being transmitted simultaneously in both directions, the two keys may be in such positions as to form any one of the following four combinations: both keys may rest on their rear contacts, both on the front contacts, K on the rear and K_1 on the front contact, and *vice versa*. It remains to be shown that no matter which position K occupies, the operation of K_1 will not affect its home relay R_1, but will operate the distant relay R. When this has been shown, it will be evident that, similarly, no matter which position K_1 occupies, the operation of K will not affect its home relay R, but will operate the distant relay R_1.

81. One Key Closed.—Suppose that K_1 rests on the back contact a_1 and that K is pressed against the front contact b, or **closed**, as it is called. Current then flows from the positive pole of B, charging both the line and condenser C, and, when it reaches its maximum value, flows steadily through b to m, where it divides equally, one half flowing through c and r back to the battery B, and the other half flowing through d–e–f–d_1–n–a_1–J_1–G_1 to the ground

plate G, and back to the battery B. There is also a closed circuit from n through c_1 and r_1 to G_1, but the resistance of this path is so very large, compared to that of the path through a_1 and f_1 to G_1, that it need hardly be considered. Moreover, even if there is an appreciable current in the artificial-line coil c_1, it flows in the proper direction in this case through the coil c_1 to help, and not to oppose, the magnetizing influence of the current through the line coil d_1. Thus the closing of the key K will not magnetize, temporarily or permanently, the relay R, because the currents through the two coils c and d are equal and circulate in opposite directions around the iron core of the relay, producing, therefore, no resultant magnetizing force. However, the relay R_1 is magnetized because the currents through the two coils c_1 and d_1 are not equal and opposite in direction, and, furthermore, the current in the coil d_1 is strong enough to cause the armature to be attracted. Hence, the relay R is not magnetized, but R_1 is magnetized when the battery B is connected in the circuit by closing the key K.

82. Both Keys Closed.—If, while the key K is against the front contact b, the key K_1 is closed, then the batteries B and B_1 will be in opposition in the circuit B-b-m-d-c-f-d_1-n-b_1-B_1-G_1-G-B. These two batteries contain the same number of cells and have the same electromotive force; consequently, in the circuit just traced, the current will be zero, since their electromotive forces are opposed to one another. With both keys closed, the currents in the artificial-line circuits, that is, in B-b-m-c-g-r-G-B and in B_1-b_1-n-c_1-h-r_1-G_1-B_1, are due to the electromotive force of only one battery in each circuit; hence, these currents will have their normal strength. Consequently, there is no current in the line coils d and d_1 but there is sufficient current in the artificial-line coils c and c_1 to magnetize both relays R and R_1. Thus, when both keys are closed at the same time, both relays will be closed. Although current from the home battery really closes the home relay, nevertheless it is the distant key that controls the

opening and closing of the home relay. The home key has no control over the home relay.

83. Thus it has been shown that the distant relay R_1 is energized and the home relay R unaffected when only the home key K is closed, and that both relays are energized when both keys are closed, and it is evident that the relay R is energized and R_1 unaffected when only K_1 is closed, and that neither relay is magnetized when both keys are open, because both batteries are then cut off.

84. Let us consider that whenever a current flows from the home key through the two coils on the home relay toward the line and artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through the coils of the home relay toward the key, it is a negative current. Furthermore, let the current that is flowing through one artificial-line circuit due to one battery be considered as having a strength of 1 unit. Then the four possible combinations of key and relay positions and the currents in each coil may be summarized in Table 1.

TABLE 1.

West Key K.	East Key K_1.	Western Office.				Eastern Office.			
		Current in		Difference.	Relay R.	Current in		Difference.	Relay R_1.
		Coil d.	Coil c.			Coil d_1.	Coil c_1.		
Open	Open	0	0	0	Open	0	0	0	Open
Closed	Open	+1	+1	0	Open	−1	0	1	Closed
Open	Closed	−1	0	1	Closed	+1	+1	0	Open
Closed	Closed	0	+1	1	Closed	0	+1	1	Closed

It will be noticed in the above table that whenever the difference between the currents in the two coils of one relay is not zero, the relay is closed and, furthermore, that the

distant relay is open or closed corresponding to whether the home key is open or closed.

85. Cause and Prevention of False Signals.—If, at the same moment, both keys should be in an intermediate position, touching neither the front nor the rear contact, there would be no current in any of the relay coils. Consequently, both relays would open every time this occurred, causing false signals and confusion, if means were not taken to prevent them. When gravity cells are used, false signals may be easily avoided by using a continuity-preserving transmitter that is so constructed that when it closes, contact is made with one stop before the contact with the other stop is broken. A continuity-preserving transmitter that is much used in repeaters and in duplex and quadruplex systems was described and illustrated in Fig. 5. Where dynamos that furnish current at a high potential are used, such a transmitter is not very satisfactory, on account of the injurious sparking that occurs every time the transmitter opens the short circuit it has made around the dynamo.

If a transmitter is used that does not perfectly preserve the continuity of the circuit, the false signals may be avoided by connecting a repeating sounder in a circuit through the *back stop* of the differential relay, and an ordinary sounder in another circuit through the *back stop* of the repeating sounder. This arrangement will give the signals properly, *provided* the interval of no current in the relay, although long enough to allow the armature to break contact with the regular front stop, is still too short to allow the armature to cross the gap and make contact with the back stop. For it is evident that the circuit of the second sounder is not closed until the armature of the repeating sounder touches its own back stop. This arrangement, which was first devised by Edison, is successfully used on the neutral-relay side of some quadruplex systems, in connection with which it will be more fully explained.

86. Method of Indicating Various Circuits.—Whenever it is not especially inconvenient or confusing to

do so, the following system of drawing in the various circuits in the diagrams for the multiplex systems will be employed: The main-line circuit will be drawn in full lines; the artificial-line circuit, in two dots and one dash; the local receiving circuit, in dots; the local sending circuit, in dashes; and the balancing ground-coil circuit in the polar, duplex, and quadruplex systems, in one dot and one dash. This plan will help the student to readily distinguish and trace out the various circuits.

87. Practical Arrangement. — The practical arrangement of the Stearns, or differential, duplex is shown in Fig. 28. The arrangement at the two ends was made slightly different in order to show both in one figure. R and R_1 are the differential relays; S and S_1, the local sounders; T and T_1, continuity-preserving transmitters; and K and K_1, ordinary telegraph keys connected in local circuits with batteries and the magnet coils of the transmitters. By using the ordinary key and a transmitter connected as shown here, operators can send better and faster than they could by using such a key as is shown in Fig. 27. In all multiplex systems where manual transmission is employed, excepting perhaps on cables, an ordinary key connected in a local circuit is used to control some form of a transmitter or pole changer. The circuit containing the transmitter, or pole-changer magnet, and the telegraph key is called the **sending circuit,** the **sending side,** or the **sending leg** when it is extended to a branch office. The resistance of the transmitter magnet is usually about the same as the sounder magnet, and the local transmitter circuits are supplied with current in the same manner as are the sounders.

88. Rh and Rh_1 are rheostats usually containing between 6,000 and 7,000 ohms, adjustable by steps of 100 ohms or less, thus permitting them to be used on lines of No. 6 B. W. G. iron wire that do not exceed about 600 miles in length. For a No. 6 B. W. G. line wire 600 miles long, as much as 9 microfarads may be required in the condenser C. At the Scranton end, an adjustable resistance Cr, called a *retarding coil*,

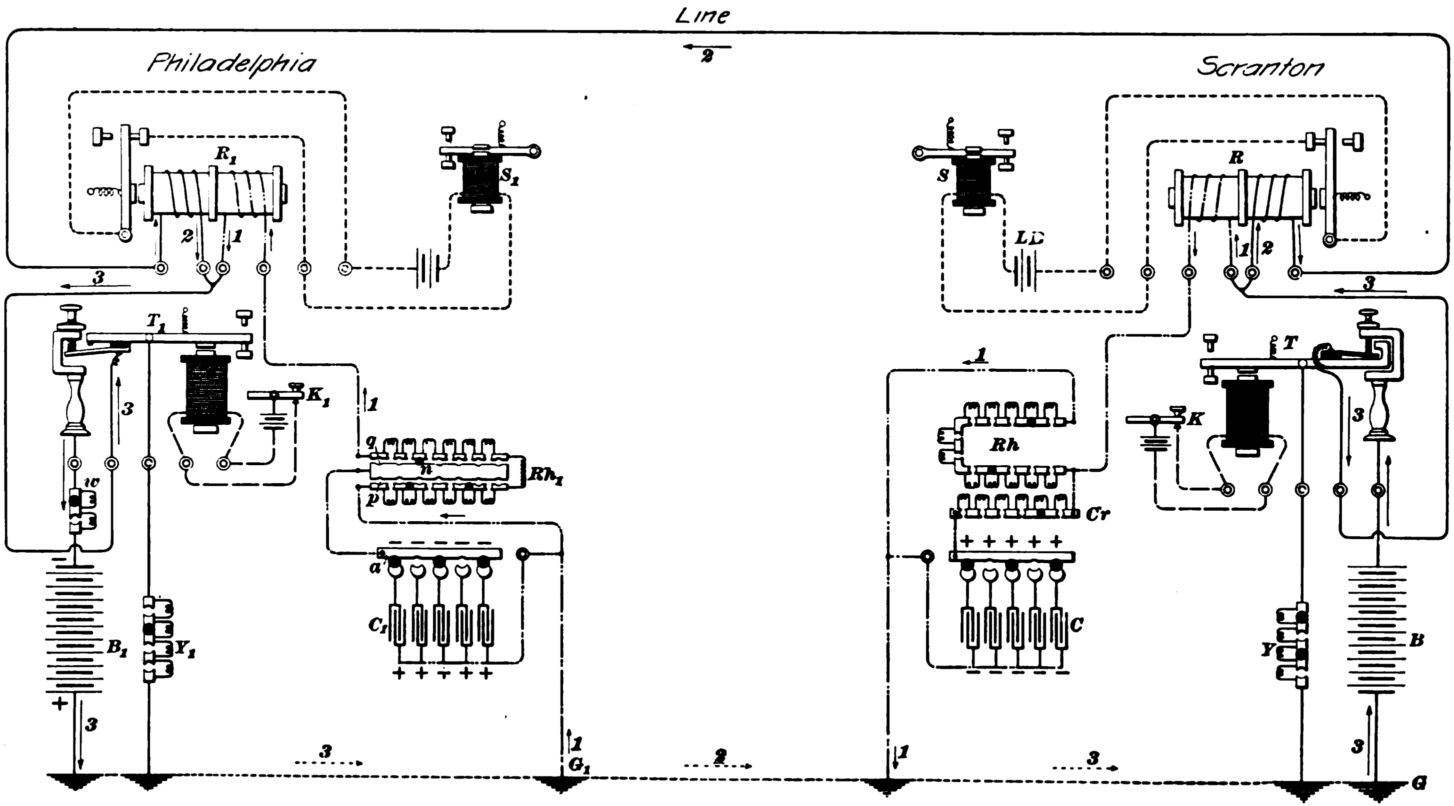

Line
Philadelphia
Scranton
R1
S1
T1
K1
B1
Y1
C1
Rh1
G1
R
S
LD
T
K
Rh
Cr
C
Y
B
G

FIG. 28.

is placed in series with the condenser in order that the artificial line may be made to charge and discharge as slowly as does the line. For, if the condenser discharged before the line, although the total discharge may be exactly the same, there would be a false signal due to the inequality in the rate of discharge of the two circuits. To avoid making this false signal the artificial line must be arranged and adjusted to charge and discharge at exactly the same rate as does the line, neither faster nor slower.

The condenser and resistances are arranged in another way at the Philadelphia end. The adjustable rheostat Rh_1 has a brass center strip *n* to which one terminal of the condenser is joined. A plug may be placed as shown at *n*, so as to connect one terminal of the condenser to any coil in the rheostat.

89. Adjusting Artificial Line.—When a current of electricity is flowing through a wire, the difference of potential between two points that are near together is less than that between the points that are farther apart. Hence, as the charge that a condenser receives depends on the difference of potential at its terminals, the charge that the condenser C_1 will take may be regulated by connecting the terminal *a* of the condenser to different coils of the rheostat Rh_1. In this figure, it is shown connected to a coil through the plug at *n*. The nearer this connection is made to the line, the greater will be the resistance between the terminals of the condenser; and, hence, the greater will be the charge taken by the condenser. The nearer it is made to the ground, the less will be the charge taken by the condenser. If the plug is placed in the hole *q*, the condenser receives the largest charge possible in this arrangement, while if the plug is placed in the hole *p*, the condenser will receive no charge, as both terminals of the condenser are, practically, connected together. Thus, by adjusting the number and position of the plugs along *a* and the position of the plug *n*, and, further, by adjusting the total amount of resistance in Rh_1, this artificial line may be adjusted to

charge and discharge at exactly the same rate as the line and, furthermore, to have the same total resistance and capacity.

90. Spark Coil.—The resistance *Y*, which corresponds to *J* in Fig. 27, is adjusted to equal the internal resistance of the battery *B*, so that the resistance from the tongue of the transmitter to the ground at the same station shall be the same in both the open and closed positions of the transmitter. This is the purpose for which the resistance *Y* is used, but it is usually called the **spark coil** because it also diminishes the intensity or quantity of current in the spark when the short circuit around the battery is broken at the continuity-preserving transmitter *T*. The resistance *w* is necessary when low internal-resistance batteries or dynamos are used in place of the battery B_1, in order to prevent too large a current from flowing and injuring the contact points of the transmitter or the dynamo. In case such a resistance *w* is used, then the resistance Y_1 must be equal to that of *w* plus the internal resistance of the battery B_1. In this arrangement *w* is sometimes called the spark coil and Y_1 the **ground coil.**

91. The diagram is drawn to show the condition of affairs when both keys *K* and K_1 are closed, causing both relays *R* and R_1 and both sounders *S* and S_1 to be closed. The arrows represent the direction and the figures on the arrows the relative magnitude of the currents in the various parts of the circuit.

Practically, it makes no difference which pole of the main-line batteries is connected to the home ground. The positive of one and the negative of the other main-line battery may be connected to the ground, as shown here, or the positive or negative terminals, as shown in Fig. 27, of both batteries may be joined to the ground.

92. Adjustable rheostats are made in various forms. In Fig. 29 is shown the construction and arrangement of the coils in one form of rheostat in which the adjustment

is made by means of brass plugs, or pegs. The coils are wound back upon themselves on wooden spools so they shall have no inductance. When wound in this manner, they are called **non-inductive resistance coils.** If they were wound continuously around the spool in one direction, like an ordinary relay coil, their inductance would often be a very serious and annoying factor. It will be evident that the insertion of the plug *P* in the hole between the brass

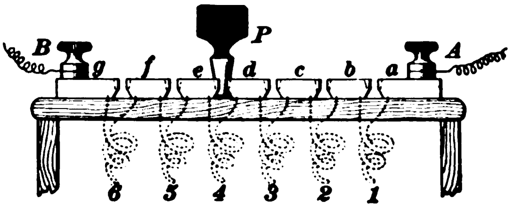


FIG. 29.

blocks *e* and *d* short-circuits the fourth coil, or "cuts it out" as it is frequently expressed. Thus, by the use of enough plugs, any number of coils may be cut out, thereby reducing the resistance as much as may be desired. The blocks are usually mounted on hard rubber and the resistance of each coil in ohms is usually stamped on the cover opposite the hole, or on the adjacent brass block or disk. This figure shows only one row of coils, but larger boxes frequently contain several rows.

93. In Fig. 30 is shown the top of a very convenient form of adjustable rheostat for use in artificial-line circuits.

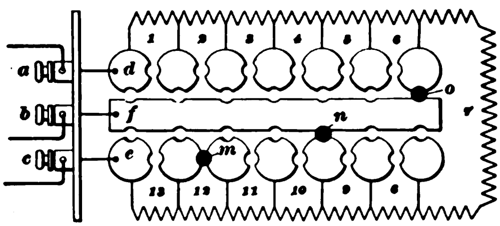


FIG. 30.

Between the two binding posts *a* and *c*, when all plugs are removed, there will be the resistance of the thirteen coils in

series; that is, the sum of all the coils whose values are stamped on the brass disks or on the ebonite cover opposite the holes. If a plug is inserted at *m*, for instance, coil *12* is cut out. If a plug is inserted at *o* and another at *n*, the intervening coils *7*, *8*, and *9* are cut out. Where this box is used on duplex and quadruplex systems, the middle brass strip *f* is connected through the middle binding post *b* to a condenser. By means of a plug, the strip *f* and, hence, one terminal of the condenser may be connected to any coil in the rheostat. In such a case, *f* would usually be connected to one disk and coil by plugging only one hole, the resistance being adjusted by plugging between disks.

94. Adjustable Condenser.—One form of adjustable condenser used in connection with various telegraph systems is shown in Fig. 31. The total capacity is divided into five sections; the capacity of the first section is 4 per cent.

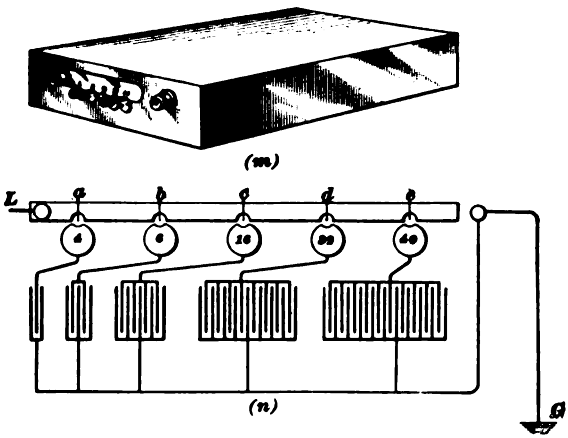


FIG. 31.

of the total capacity. The percentage capacity of each section is plainly marked on the disk to which the section is joined. If the total capacity of the condenser is 2.5 microfarads, then, by placing a plug in the hole *b*, Fig. 31 (*n*), the capacity of the condenser between *L* and the ground *G* will be 8 per cent. of 2.5; that is, .2 microfarad. By placing

plugs in the holes *a*, *c*, and *d*, the capacity will be $4 + 16 + 32 = 52$ per cent. of 2.5, that is, 1.3 microfarads. The condenser can be adjusted by steps of .1 microfarad from .1 up to 2.5 microfarads. The finished appearance of the condenser is shown at (*m*).

95. Differentially Wound Neutral Relays.—Neutral and polarized relays may be differentially wound in several ways. The idea to be kept in mind in winding such relays is to so arrange the two coils that the resistance and the number of turns in each winding shall be exactly equal, and that the effect of equal currents in each coil on the movable part of the relay shall be the same in intensity. The best way would be to wind the coils with two wires,

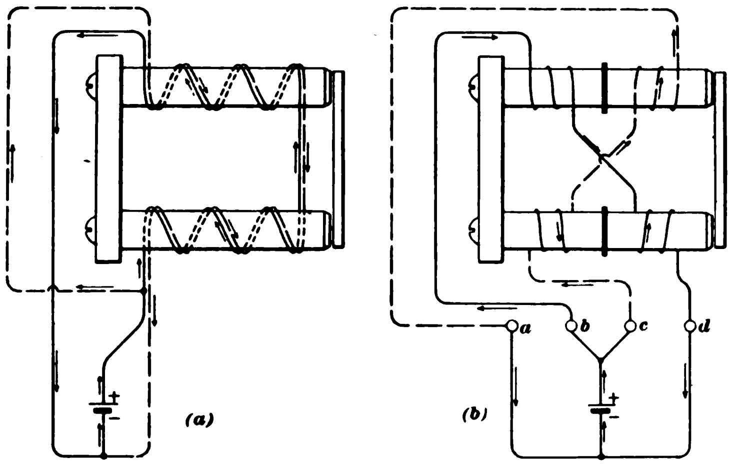


FIG. 32.

side by side, as indicated in Fig. 32 (*a*). Thus the two wires, being insulated from each other, form two coils as near alike in every way as it is possible to get them. The wires composing the two windings on each core being side by side, cause the differential action to be, largely, directly between currents in the windings, rather than between magnetisms produced in the cores by such currents. But this

is not a convenient nor a profitable way to wind them. The other extreme is to wind one coil on each core of the magnet. This is not a good way, because, although the two coils may be very much alike, they do not neutralize each other very well. A compromise that has proved satisfactory consists in winding four separate coils, two on each core, the rear coil on one core, together with the forward coil on the other core, forming one half of the differential winding, and the forward coil on the first core, together with the rear coil on the second core, forming the other half. This method of winding is shown in Fig. 32 (*b*). When the current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to current in the two windings neutralize each other. The ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. Evidently, an excess of current in one winding over that in the other will magnetize the relay. The Stearns differential relay, which is somewhat larger than the ordinary relay, has about 200 ohms in each winding.

BALANCING THE STEARNS, OR DIFFERENTIAL, DUPLEX.

96. Balancing a duplex or quadruplex system includes the adjustment of the various instruments and of the resistance and the capacity of the artificial line to exactly equal that of the main line, so that sending on the home key will not interfere in any way with the signals that are received at the home office from the distant office.

To balance the Stearns, or differential, duplex, ask the distant office to open his key. If Philadelphia, Fig. 28, is the distant office, the line will then be grounded through the transmitter and the rheostat Y_1. Now, turn the retractile spring of your home relay R down and adjust the magnets, as would be done with an ordinary relay, for a weak current, in order to make the relay sensitive to the slightest inequality in the division of the current through its two coils.

Make dots with your own key and vary the resistance in your rheostat *Rh* until your relay no longer responds to your own signals. Then ask the distant office to make dots and readjust your home relay to properly respond to his signals, as would be done with any ordinary relay. If a momentary kick follows each signal, it may be eliminated by varying the capacity of the condenser *C* and the resistance of the rheostat *Cr*. To eliminate the kick at an office where the arrangement is like that shown at the Philadelphia end, the capacity of the condenser is adjusted and the position of the plug *n* varied until the kicks disappear. Leakage from the line wire to the ground is equivalent to a line wire of lower resistance, and when the leakage from the line increases, the resistance in *Rh* will have to be diminished and the condenser may, also, need readjusting.

If the signals from the distant office are stronger when your key is open than when it is closed, there is not enough resistance in the rheostat *Y*, and *vice versa*. The adjustment is not complete until the incoming signals are perfect with the home key held open or closed, or when writing with it.

POLAR DUPLEX.

97. Superiority of Polar Duplex.—In good weather, the differential or single-current duplex gives satisfaction, but its efficiency falls in proportion to the increase in the current that leaks from the line wire down every pole and support to the earth. If this leakage current would disappear when the distant key is open, all would be well; but it does not, and, consequently, the effective, or surplus, current in wet weather becomes too weak to overcome the already high tension of the retractile spring attached to the armature of the relay. The polar duplex overcomes this difficulty to a great extent, and will continue to work satisfactorily long after rain storms have rendered the single-current systems useless.

98. Differential Polarized Relay.—The essential feature of the polar duplex is the differentially wound polarized relay. Fig. 33 represents a polarized, or **polar,** relay, as it is also called, with the two coils connected in three different ways with the same battery. In (*x*) the current circulates only in the coil *c*. The direction of the current and the resultant direction of the lines of force and the polarity of the poles are clearly indicated. Although there is no current in the coil *d*, still the lines of force created in the core by the current in the coil *c* will return to their original starting point through the path offering the least resistance to them, and this path of least resistance is through

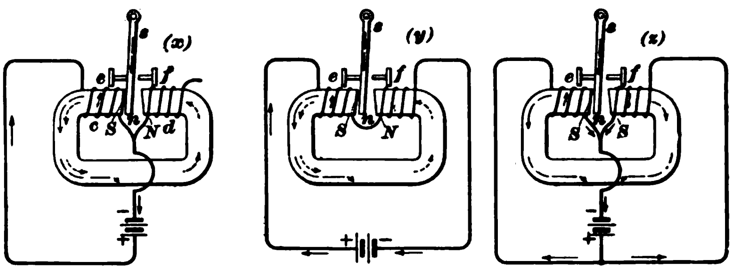


FIG. 33.

the soft iron, as shown by the dotted arrows, and not through the steel magnet, which has been omitted in this figure for the sake of simplicity. Thus the necessity of using the best quality of soft iron for this part of the relay is evident. On account of the lines of force produced by the permanent magnet, shown by means of arrows drawn with dashes, which make a north pole at *n* on the tongue, and those produced by the current in the coil *c*, shown by dotted arrows, there will be a strong south pole at *S*, and a weaker north pole at *N*. This will cause the armature to rest against the stop *e*. If the battery be reversed, the tongue will be drawn against the stop *f*.

In (*v*) the same battery is connected so that the current flows through both coils, but the strength of the current

will only be about one-half what it was in (x), because the two coils will have twice the resistance of one.

The currents circulate through the two coils around the iron in the same direction, tending, therefore, to help and not to oppose each other in magnetizing the soft-iron core. Therefore, the intensity and direction of the magnetism produced in (y) will be the same as that in (x) and the armature will be held against the stop *e*.

In (z) the two coils are connected differentially, so that the current from the battery divides into two equal portions, one portion flowing through each coil, but in opposite directions, around the iron. Consequently, the coils tend to magnetize the iron with equal forces in opposite directions, the result being that they neutralize each other and produce no magnetism; but the permanent steel magnet polarizes the soft-iron parts the same as if there was no current in either coil. Hence, both cores equally attract the armature and it remains against whichever stop it happened to be previously. If the battery, in this case, be reversed, the two coils will still oppose and neutralize each other. Consequently, with the coils connected as shown in (z), they have no influence at all on the tongue, no matter what may be the strength or the direction of the current through the two coils.

99. Method of Winding a Differential Polar Relay.—The differential polar relay is wound with two coils on each core in the manner explained, and for the same reasons that were given in the article on "Differentially Wound Neutral Relays." A diagrammatic view of a differentially wound polar relay is given in Fig. 34. The ends of the coils are brought out to the binding posts *a*, *b*, *c*, and *d*. When current circulates in the coils in the direction shown by the arrows, the magnetizing forces due to the current in the two windings neutralize each other and an excess of current in one winding over that in the other will magnetize the relay.

Each of the four coils has about 2,400 turns of wire and a resistance of 200 ohms. Thus the line winding, or *line coil*,

as it is called, although it consists of two coils, has a resistance of 400 ohms, and the artificial-line winding, which also consists of two coils, has, likewise, a resistance

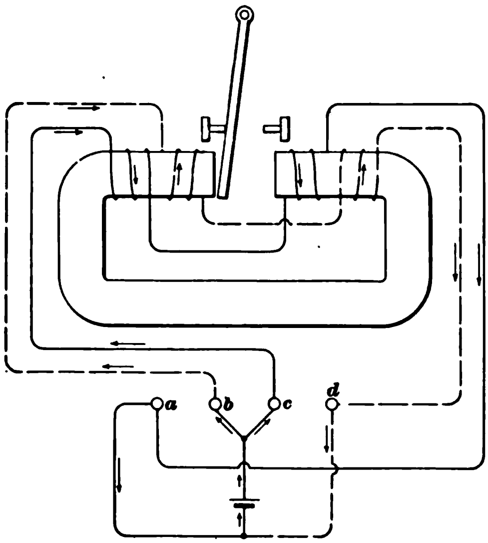


FIG. 34.

of 400 ohms. Polarized relays on duplex circuits require about 25 milliamperes, while on quadruplex circuits the minimum current required to work them varies from 15 to 18 milliamperes.

100. Theoretical Connections of Polar Duplex. The theoretical connections of the polar duplex are shown in Fig. 35. PR and PR_1 are the differentially wound polar relays, and K and K_1 are the battery reversing keys. The resistances Rh and Cr and the condenser C represent the artificial line at the left-hand station; Rh_1 and C_1 represent the artificial line at the right-hand station. All four main-line batteries, two at each end, contain the same number of cells, the negative poles of D and D_1 being connected to the rear contacts a and a_1, and the positive poles of B and B_1 to the front contacts b and b_1 of the keys K

and K_1, respectively. Since K_1 is shown closed, the circuit containing the local battery LB_1 should also have been shown closed between the armature and the stop e_1.

The levers of the keys K and K_1 normally rest on the rear contacts a and a_1, and, since the negative poles of two equal batteries, one at each end, are, in this open position of the two keys, connected to the line, there will be no current flowing in the line or in the line coils d and d_1. However, there will be current in the two artificial-line coils c and c_1, and the direction in which the current flows around the soft-iron cores will be such as to hold the armatures of both polarized relays against their back stops f and f_1. The current in either artificial-line coil due to the home battery may be represented as having a strength of 1 unit.

OPERATION.

101. Key *K* Closed.—If the western operator commences to send by pressing his key K, the positive pole of B will be connected to the relay and line, in place of the negative pole of D. This will reverse the direction of the current through the artificial-line coil c, but its strength will remain the same, namely, 1 unit. The current in the line coils d and d_1 and in the line will now have a strength of 2 units, because the resistance is the same as that of the artificial-line circuit, but the electromotive force is twice as great, because the two batteries B and D_1 are now connected in series in the line circuit, instead of opposing each other as did D and D_1 in the normal position of both keys. Hence, in the polarized relay PR, a current of 1 unit flows through the artificial-line coil c and a current of 2 units through the line coil d; but the direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing through the line coil d in the direction shown by the arrow at that coil. This will produce a north pole at the left-hand end of the core on which the coil d is wound and a south pole at the

right-hand end of the core on which c is wound and, consequently, the tongue, assuming it to have a *south* pole between the two cores, will remain against the back stop f. Thus it has been shown that the closing of the key K does not affect the home relay as long as K_1 remains on the rear contact a_1.

At the east end, the current in the artificial-line coil c_1 has not changed in strength or direction. It has a strength of

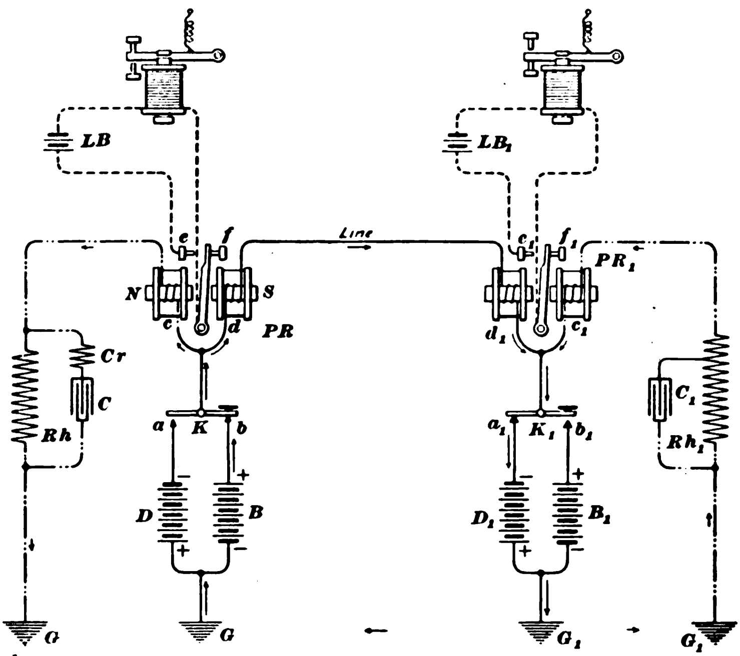


FIG. 35.

1 unit. In the line coil d_1, however, there is now a current of 2 units. The direction of the currents in the two coils, as indicated by the arrows, is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit through the line coil d_1 in the direction shown by the arrow in that coil. This will produce a south pole at the right-hand end of the core on which the coil d_1 is wound and a north pole at the left-hand end of the core on

which the coil c_1 is wound. Consequently, the tongue, assuming it to have a *north* pole between the two cores, *will move against the front stop* e_1, although not so shown in the figure, and close the local-sounder circuit at the eastern office. Thus it has been shown that the closing of the key K when the key K_1 is open operates the polar relay PR_1 at the distant office, but does not affect the home relay. If the tongue of PR_1 is polarized the same as the tongue of PR, as is usually the case, it would only be necessary, in order to make the relay work properly, to connect the line to the coil c_1 and the artificial line to the coil d_1.

102. Both Keys Closed.—If the key K_1 is closed while the key K is also closed, the relay PR will be closed, but the relay PR_1 will not be affected and its armature will continue to remain against the front stop e_1 until the key K is released. For when both keys are closed and rest on their front contacts, the two batteries B and B_1 are connected in opposition in the line circuit. Consequently, no current flows in either of the line coils d or d_1. The current in the artificial-line coil c_1 is reversed and will produce a north pole at the left-hand end of the core on which it is wound, and a south pole at the right-hand end of the core on which the coil d_1 is wound. But this polarity is the same as before and, therefore, the tongue of the polar relay PR_1 remains against the front stop e_1, being unaffected by the change in the currents caused by closing the home key K_1, although the latter has reversed the polarity of the home batteries.

At the western office the current in the artificial-line coil c has not changed in strength or direction, but there is now no current in the line coil d. The direction of the current is such that it reverses the polarity of the cores, producing a north pole at the right-hand end of the core on which c is wound and a south pole at the left-hand end of the core on which d is wound. Consequently, the tongue of the relay PR moves against the front stop e and closes the local-sounder circuit. Thus the closing of the key K_1 when the key K

is closed, closes the polar relay PR at the distant office, but does not affect the home relay PR_1.

103. Key K_1 Closed.—If the western key K is now released, K_1 remaining closed, the two batteries D and B_1 will be in series in the line circuit, the current in the line coils of both relays will have a strength of 2 units, and the current through the artificial-line coil c will be reversed in direction, but will have the same strength as before, namely, 1 unit. The direction of the currents in the coils c and d is such that their magnetizing forces oppose each other, and the result is equivalent to a current of 1 unit flowing through the line coil d. This produces a south pole at the left-hand end of the core on which the coil d is wound and a north pole at the right-hand end of the core on which c is wound. Consequently, the polarity is such that the tongue of the relay PR, which has south polarity, remains against the front stop e when the key K at the western office is released. Thus, the opening of the key K has not affected the home relay PR. At the eastern station the effect of a current of 2 units flowing from the battery B_1 through the coil d_1 to the line, and a current of 1 unit from the same battery flowing through the coil c_1 to the artificial line, is equivalent to a current of 1 unit flowing from the battery B_1 through the line coil d_1. This produces a north pole at the right-hand end of the core on which d_1 is wound and a south pole at the left-hand end of the core on which c_1 is wound; thus causing the tongue of the relay, which has north polarity, to move from the front stop e_1 to the rear stop f_1. Thus, the opening of the key K while the key K_1 is closed, produces no effect upon the home relay PR, but does open the distant relay PR_1.

104. It has, therefore, been shown, no matter what may be the position of the distant key, that the operation of the home key does not affect the home relay but that it does properly operate the distant relay.

105. Let us consider, as we did in connection with the differential duplex, that whenever a current flows from the

home key through either coil on the home relay, toward the line or artificial line, respectively, it is a positive current; and, conversely, that whenever the current flows from the line or artificial line through either coil of the home relay, toward the key, it is a negative current. Furthermore, let the current that flows through one artificial-line circuit due to one battery be considered as having a strength of 1 unit. The student should remember that we assume the portion of the tongue between the cores of the relay PR to be a south pole and the portion of the tongue between the cores of the relay PR_1 to be a north pole. Then the four possible combinations of key-and-relay positions and the currents in each coil may be summarized in Table 2.

TABLE 2.

West Key K.	East Key K_1.	Western Office. Current in Coil d.	Western Office. Current in Coil c.	Difference.	Relay PR.	Eastern Office. Current in Coil d_1.	Eastern Office. Current in Coil c_1.	Difference.	Relay PR_1.
Open	Open	0	−1	+1	Open	0	−1	+1	Open
Closed	Open	+2	+1	+1	Open	−2	−1	−1	Closed
Open	Closed	−2	−1	−1	Closed	+2	+1	+1	Open
Closed	Closed	0	+1	−1	Closed	0	+1	−1	Closed

It will be noticed in the above table that whenever the current in the line coil minus the current in the artificial-line coil of the same relay is +1, the relay is open; and that whenever it is −1, the relay is closed. Furthermore, it will be noticed that the distant relay is open or closed according to whether the home key is open or closed.

106. Keys in Intermediate Positions.—It may be well to consider what happens to the relay during the short interval between the opening of the circuit at one contact of the key and the closing of the circuit again at the other

contact of the same key. Suppose the key K_1 rests on the rear stop a_1, and that the key K, in moving from the rear to the front contact, remains in an intermediate position, touching neither a nor b. In this position D_1 is the only battery in the circuit. It supplies a current of 1 unit to the coil c_1. The artificial line Rh at the western office, the coils c and d, the line, and the coil d_1 are in series with the battery D_1. The resistance of this circuit is double that of the line and the two line coils d and d_1, and, consequently, the current in this circuit will have a strength of ½ unit. The current of a strength of ½ unit in coil d_1 will oppose the current of 1 unit in c_1; but the magnetism due to a negative current of ½ unit in coil c_1 tends to hold the tongue of the relay PR_1 against the back stop f, where it is already. Thus the relay PR_1 will not be affected until the key K touches the front stop b. A current of ½ unit flows in the same direction through both coils c and d, so that their magnetizing forces help each other, and furthermore this current is in the same direction through c as the current of unit strength that flowed only in c when K rested on the rear contact a; hence there is produced a resultant magnetism of the same polarity and strength as when the key K rested on the rear stop a. Consequently, the home relay is not affected, and the tongue remains stationary against the rear stop f.

Suppose that both keys are in an intermediate position at the same instant. Evidently all four batteries are cut off and there is no current in any part of the system. But, now, the magnetism produced in the soft iron by the permanent steel magnet will hold the tongues on whichever side they may be, thus preventing any false signals.

POLE CHANGERS.

107. A very essential instrument in the polar duplex and quadruplex systems is the **pole changer.** This is a device for reversing the battery and, consequently, for

reversing the direction of the current in the circuit. It shifts the line from one pole of a battery to the opposite pole, and, simultaneously, does the same with the wire connected to the ground. Where dynamos are used, it shifts the line from one pole of one dynamo to a pole of opposite polarity on another dynamo. Poles of opposite polarity of the two dynamos are permanently grounded. Thus the operation of a pole changer changes the direction of the current in some part, at least, of the circuit.

A device that will reverse the direction of the current in the circuit without opening the circuit is called a **continuity-preserving,** or **circuit-preserving,** pole changer. Such a pole changer is preferable to one that opens the circuit when shifting the line from one pole of the battery to the opposite pole. While continuity-preserving pole changers are generally used where gravity cells are employed for main-line batteries, they are not practicable, and are not used where dynamos have replaced gravity batteries.

108. Continuity-Preserving Pole Changer.—The principle of the continuity-preserving pole changer is shown in Fig. 36. The battery *B* is connected to two movable spring contact strips *a* and *d*. The line wire is connected to the lever of the key *K*, and the fixed piece *b*, to the ground. In the normal, or open, position of the key, as shown in (*x*), the positive pole of the battery is connected through the strip *a* and contact *c* to the key lever and to the line; the negative pole of the battery is connected through the strip *d* and the fixed contact piece *b* to the ground *G*. In this position of the key, the direction of the current through the circuit is shown by the arrows. If the key is depressed, or closed, as shown in (*y*), the direction of the current in the *line* and in the ground circuit, as shown by the arrows, is the *reverse* of that shown in (*x*). The key, in passing from one extreme position to the other, momentarily short-circuits the battery. For the spring strips *d* and *a* may be made flexible enough and so adjusted that, as the key in (*x*) is pressed down and *c* moves up,

c first touches *d*, then *a* touches *b*, then *c* parts from *a* and finally pushes *d* away from *b*, giving the position of the contacts shown in (*y*). The reverse happens when the key moves in the opposite direction. Thus, the piece *c* momentarily short-circuits the battery and preserves an uninterrupted path from the line to the ground. This short-circuiting does not injure a gravity battery, on account of its rather high internal resistance. It may be a little hard on

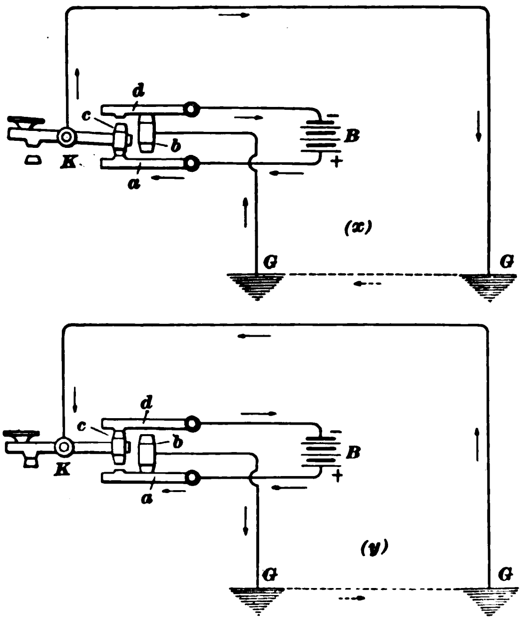


FIG. 36.

the contacts, due to the arc that is formed when the short circuit is opened, but it is not so serious as to render the method impracticable. The desirable feature of this pole changer lies in the fact that the battery is reversed with the least possible interference with the line current. In practice, the lever of the key is never manipulated directly by hand, but by means of an electromagnet, as will be shown presently.

109. B. & O. Pole Changer.—In Fig. 37 are shown the two positions of a pole changer known as the **B. & O.** (Baltimore and Ohio Railroad) **pole changer.** The contact screw *b* is placed behind the lever *f* and never touches it. When the key *k* is closed, the magnet *M* draws down the lever *PC* of the pole changer, causing the piece *e* to push *d*

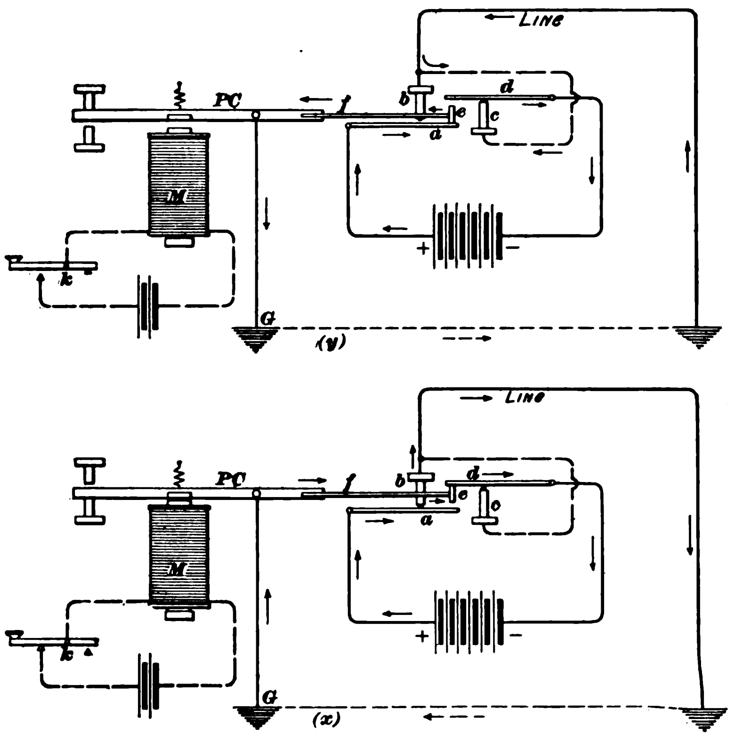


FIG. 37.

away from the contact screw *c*, and allowing *a* to rest against the contact screw *b*, thus giving the position of the contacts shown in (*x*). The springs *d* and *a* may be made long and flexible enough and so arranged that, as the lever *f* moves up, the spring *a* first touches the screw *b*, then *e* touches *d*, then *e* parts from *a*, and, finally, *e* pushes *d* away from *c*. The

arrows show the direction of the current. When the key *k* is open, the position of the contacts and the direction of the current is shown in (*y*). This is a so-called continuity-preserving pole changer. It momentarily short-circuits the battery because *e* touches *d* before it leaves *a*.

110. This pole changer, as made by Bunnell & Co., is shown in Fig. 38. The contact levers *a* and *d* have bearing upon them adjustable springs *m* and *n*. The stop-screws *b* and *c* are also adjustable. These screws and contacts are

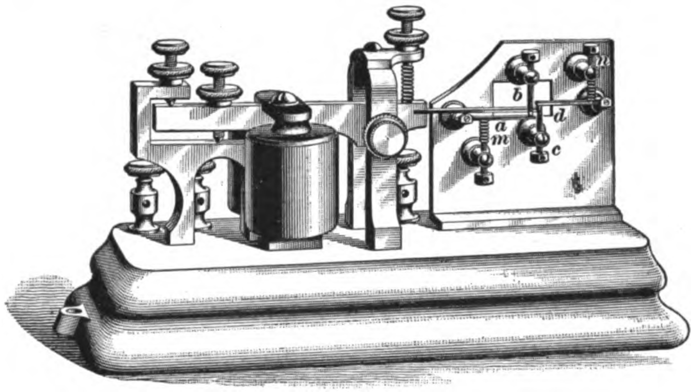


FIG. 38.

not enclosed and are easy of access for the purpose of adjusting and cleaning. The rest of the instrument resembles an ordinary sounder.

111. Western Union Gravity-Battery Pole Changer.—The so-called clock-face pole changer used by the Western Union Telegraph Company, where gravity main-line batteries are employed, is shown in Fig. 39. The contacts are all enclosed in a case having a glass front, so that as much dirt and dust may be kept from them as is possible. The glass front enables one to observe the operation and condition of the contact points.

The principle of this pole changer may be understood by referring to Fig. 40. The centerpiece *e* is fastened to the

end of an armature lever and moves up and down. When down, as shown in (x), the positive pole of the battery B is connected through the strip a and the stop b to the line; the negative pole, through the strip d and the movable contact e to the ground G. The arrows show the direction of the current flowing in the various parts of the circuit. The reverse position is shown in (y). This is a continuity-preserving pole changer. It momentarily short-circuits the battery in the intermediate position and preserves a closed circuit at all times between the line and the ground G; for

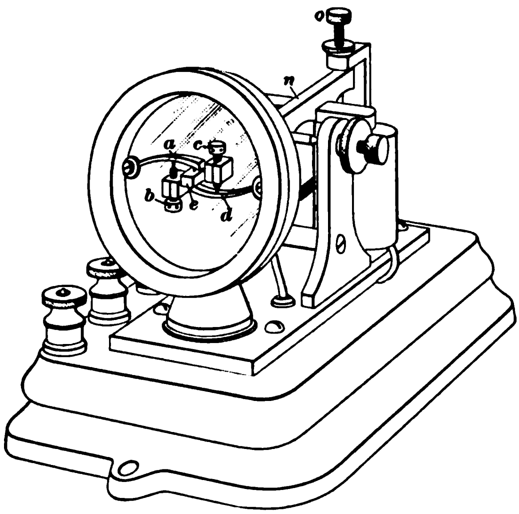


FIG. 39.

as e moves upwards, the spring d first touches the stop c, then e touches the spring a, then e pushes the spring a away from b, and, finally, e parts from the spring d. The movable piece e is in contact with both springs a and d only momentarily; in fact, all these changes follow one another very rapidly and the battery is short-circuited for only an instant. When e moves downwards, the contacts are made and broken in a similar manner. The parts shown in both Figs. 39 and 40 are similarly lettered. In Fig. 39, n is the armature

lever, on the front end of which is fixed the movable contact *e*. The stops *b* and *c* are in contact with the case and connected

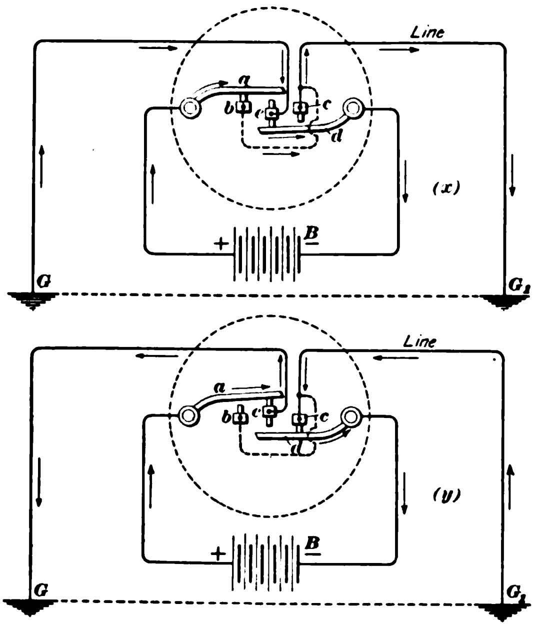


FIG. 40.

to one binding post on the base. The springs *a* and *d* and the lever *n* are all insulated and connected to separate binding posts.

112. Dynamo Pole Changers.—The continuity-preserving pole changer is not suitable for use with dynamos. Where dynamos are used, the same machine supplies all circuits requiring the same polarity and voltage. Hence, where more than one line is supplied from the same machine, it is not practicable to reverse the direction of the current in one line without also reversing it in the other lines. This can readily be done with gravity batteries, because a separate battery is used in each line circuit. Where dynamos are used for duplex and quadruplex systems to supply

positive and negative currents, a separate machine is required for each polarity, and one pole of each machine is permanently grounded.

With dynamos it has been found advisable to use a pole changer that does not short-circuit the machines, but which opens the circuit connected to one pole of one dynamo slightly before it connects the circuit with the opposite pole of the other dynamo. If a continuity-preserving pole changer were used, it would at every reversal, where 350-volt machines are employed, short-circuit 700 volts and cause the formation of bad arcs at the contact points. This would soon put the contact points in very bad condition.

113. Walking-Beam Pole Changer.—To avoid the difficulties referred to in the preceding article, the so-called **walking-beam** type of pole changer, shown in Fig. 41, is used in connection with dynamos. The line is connected to the lever, or beam, *a b* of the pole changer. The positive pole of one dynamo *C* is connected to the contact stop *e* under the *a* end of the beam, or lever; and the negative pole of the second dynamo *D* is connected to the contact stop *f* under the *b* end of the beam. The positive pole of the dynamo *D* and the negative pole of the dynamo *C* are permanently grounded at *G*. Thus, when the key *K* is closed, the positive pole of dynamo *C* is connected to the line through the lever, and when the key is open, the negative pole of *D* is connected to the line. The beam *a b* in moving from one position to the other, momentarily opens the line circuit when in its intermediate position, as is shown in this figure, but the dynamos are never short-circuited.

In circuit with each machine is a non-inductive resistance *l*, either an incandescent lamp or a non-inductively wound coil of German-silver wire. This resistance serves two purposes. It reduces sparking at the contact points, because it limits the strength of the extra current when the pole changer opens the circuit. It prevents injury to the dynamo due to overheating in case there is a short circuit. For

quadruplex circuits, the resistance of this lamp is usually about 600 ohms.

114. Theoretically, there should be no difference in the efficiency of a duplex or quadruplex circuit whether supplied from dynamos or gravity cells in strictly first-class condition.

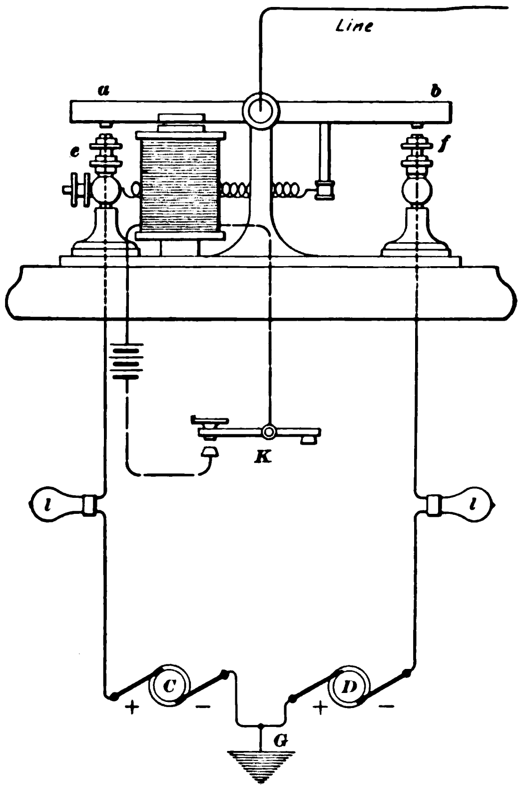


FIG. 41.

The arrangement with gravity batteries possesses the advantage of permitting the employment of the superior continuity-preserving pole changer, which is less liable to interfere with the signals on the neutral relay in the quadruplex system than is the dynamo walking-beam pole changer. On

the other hand, the dynamo is more economical and so much more reliable than a gravity battery that the dynamo arrangement gives the most satisfactory results, all things being considered.

115. Table Switch.—A form of switch that is extensively used on the tables, or desks, in connection with duplex and quadruplex systems is shown in Fig. 42. Along the top is a row of seven screws, or binding posts, to which all wires running to the switch are fastened. Along the bottom is a row of six contact buttons. The buttons *1*, *3*, *4*, and *5* are connected under the switch to the binding posts, as shown by the dotted lines. The buttons *2* and *6* are idle buttons; that is, they have no wires connected to them. The switch arm *A* may rest on button *1* or button *2*, *B* on *3* or *4*, and *C* on *5* or *6*. This makes a very convenient switch and one whose use will be apparent when diagrams for the dynamo duplex and quadruplex systems are given.

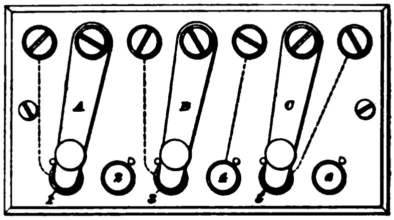


FIG. 42.

116. Polar Duplex Operated by Gravity Battery.—The practical arrangement of the polar duplex at an office where gravity cells are used is shown in Fig. 43. All the apparatus and connections have already been explained except the use of the switch *H* and the resistance *Gc*, called the *ground coil*. This resistance need not necessarily be adjustable; it may be simply a coil having a fixed resistance. The resistance from *r* through the ground coil *Gc* to G_1 should be equal to that of the circuit from *p* through the pole-changer contacts and main battery *B* to the ground *G*. When the duplex set is in operation, the switch *H* rests on *p*; but in order to balance the set, it is desirable to cut off the pole changer and the battery *B*, but to keep the resistance of the circuit the same. This is accomplished by turning the switch *H* to *r*. The resistance

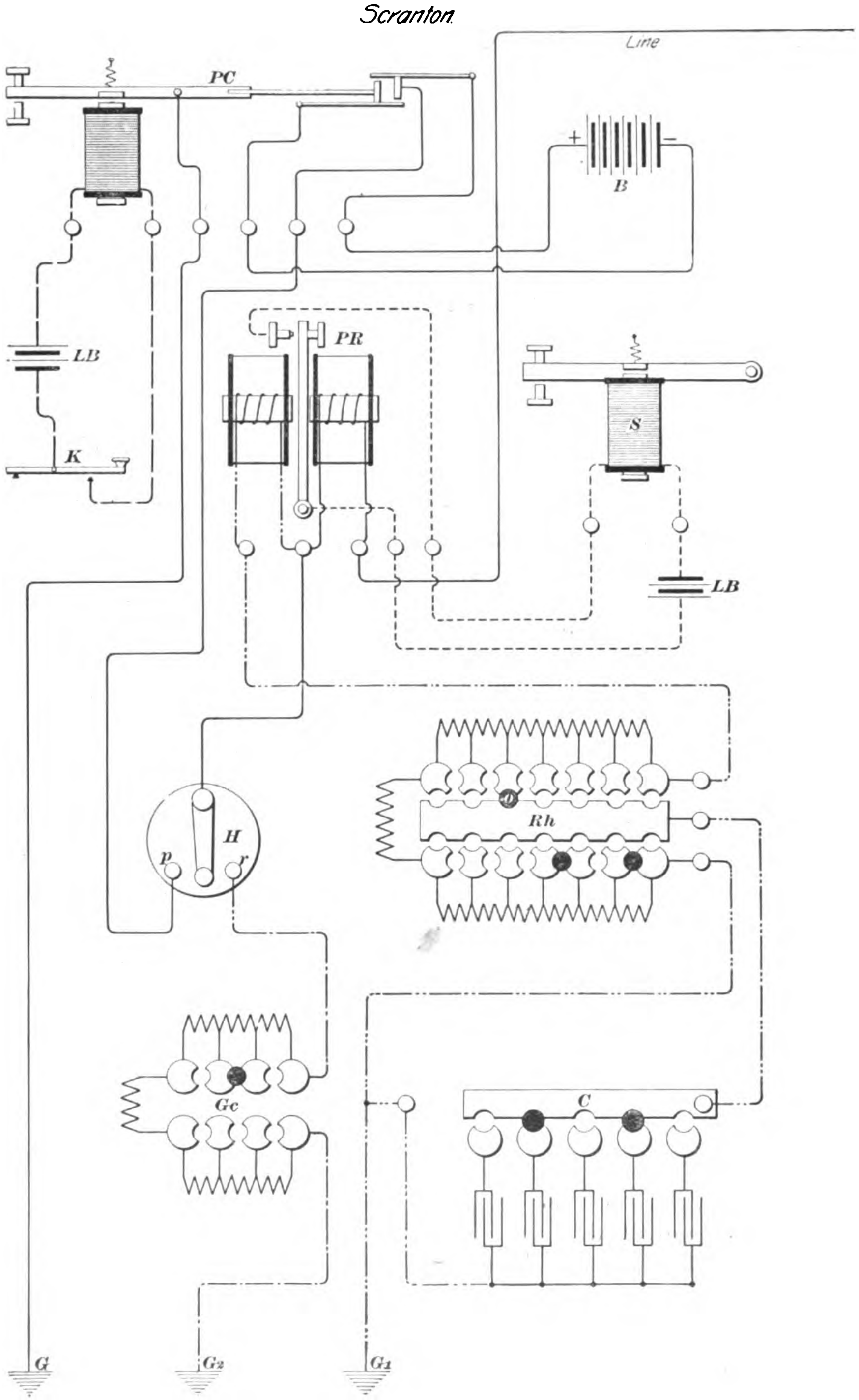


FIG. 43.

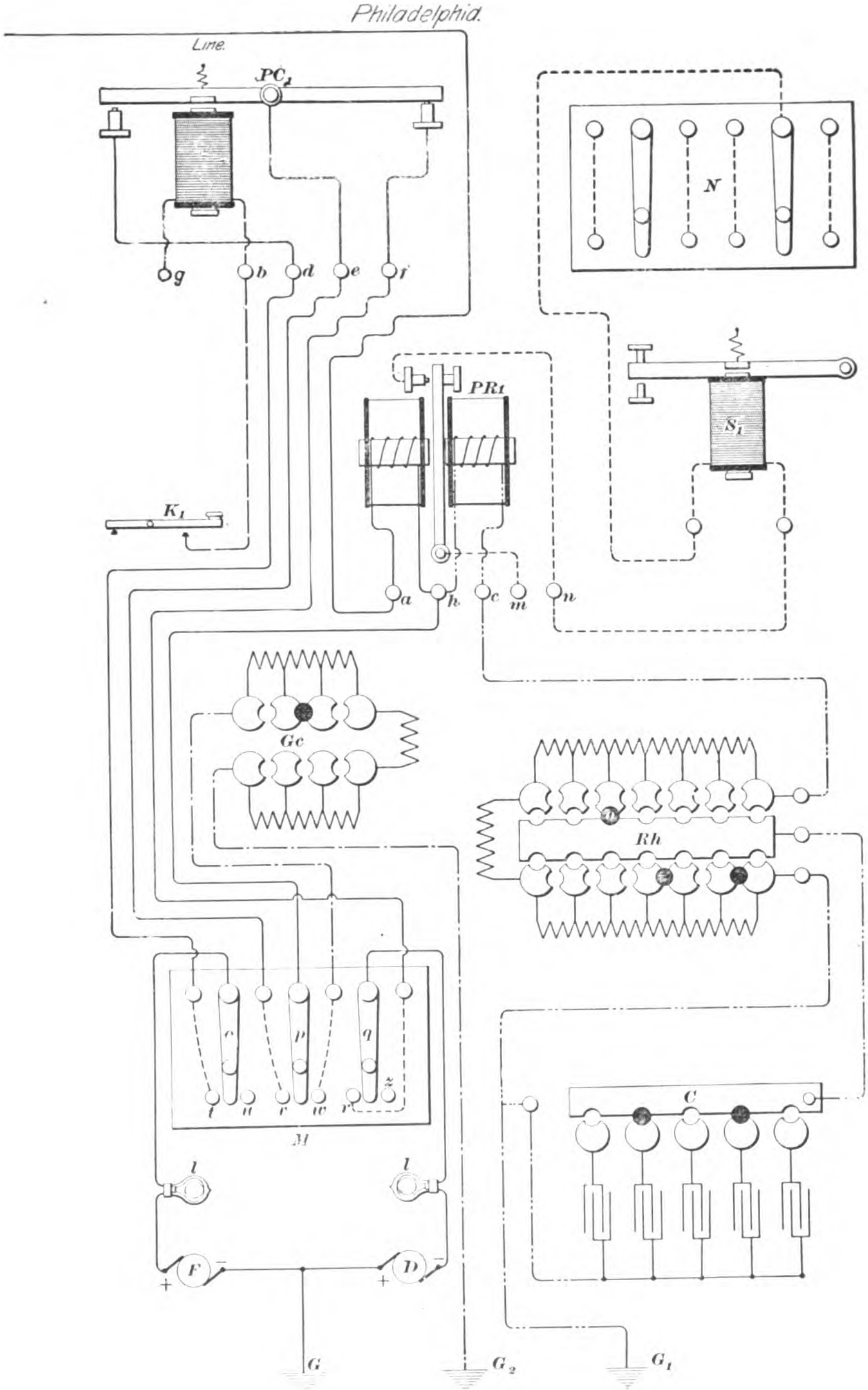
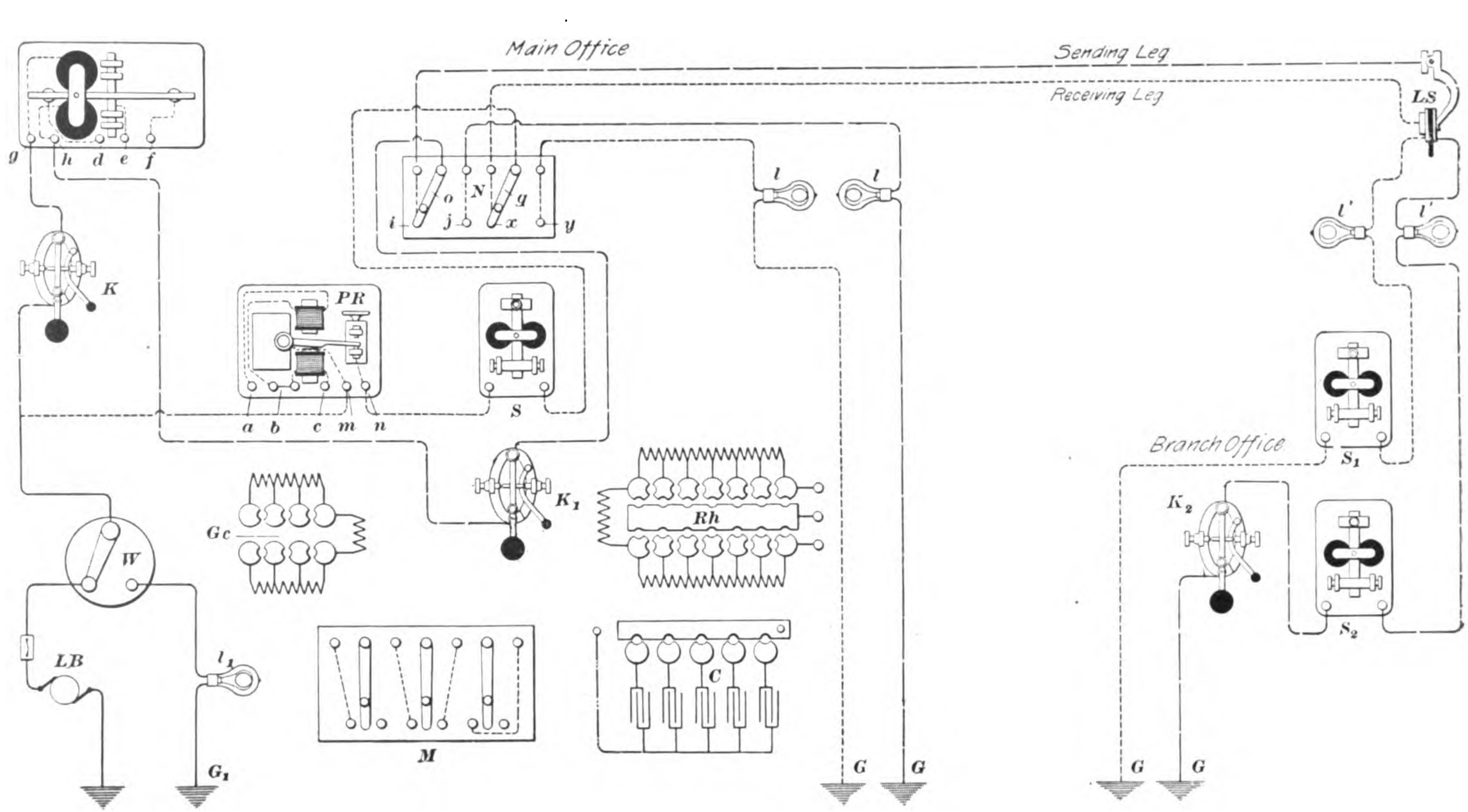

Philadelphia
Line
PC1
N
PR1
S1
K1
g
b
d
e
f
a
h
c
m
n
Gc
Rh
C
M
l
l
F
D
G
G2
G1

FIG. 44.



Main Office
Sending Leg
Receiving Leg
LS
g
h
d
e
f
K
PR
S
a
b
c
m
n
N
o
q
i
j
x
y
l
l
l'
l'
S_1
S_2
Branch Office
K_1
K_2
Gc
Rh
W
LB
l_1
M
C
G
G
G
G
G_1

Fig. 45.

of *Gc* should be equal to the internal resistance of the main battery *B*. *PC* represents a continuity-preserving pole changer suitable for use with gravity cells, such as already shown in Figs. 38 and 39. *K* is the sending key and *S* is the receiving sounder.

117. Polar Duplex Operated by Dynamos.—In Fig. 44 is shown the arrangement of the polar duplex when dynamos are used to operate the system. The walking-beam type of pole changer and the switch *M* replace the continuity-preserving pole changer and the simple switch *H* shown in Fig. 43 in which gravity main-line batteries were used.

In order to avoid confusion, the local receiving and sending circuits will be shown separately in Fig. 45. The contact buttons *u* and *z* on the switch *M*, Fig. 44, are idle, or insulated, and are used merely upon which to rest the arms *o* and *q* when it is desirable to entirely cut off the main-line dynamos *D* and *F*. When the system is in operation, the switch arms *o*, *p*, and *q* rest upon the buttons *t*, *v*, and *r*, respectively. When *p* rests upon the button *w*, the main circuit is connected through the ground coil *Gc* to the ground at G_1 instead of through the pole changer and dynamo *F* or *D* to the ground *G*. Thus, the polar relay is entirely disconnected from the home dynamos. This is the position of the switch arm *p* for balancing the system. The resistance of the circuit from *w* through the ground coil *Gc* to the ground G_1 is made equal to that of the circuit from *v* through the pole-changer contacts, one lamp *l*, and one dynamo to the ground *G*. *Gc* is practically equal in resistance to that of one of the lamps *l*. *N* is the form of switch used where a dynamo is employed to operate the local sending and receiving circuits.

118. Local Circuits Supplied From One Dynamo. In Fig. 45 is shown the connections for the sending and receiving circuits in Western Union offices where a 23-volt dynamo *L B* is used to supply current for the pole changer and sounders in both the sending and receiving sides of the

circuit. All sounders in the receiving side are controlled by the polar relay *PR*, and the pole changers and sounders in the sending side are controlled either by the key *K* or K_1 at the main office, or by the key K_2 at the branch office.

Sounders are included in the sending circuit at the branch office to enable the branch-office sending operator to hear his own writing and, also, to enable the main-office and branch-office operators to communicate with each other over the sending side. Sometimes a sounder is placed in the sending circuit at the main office, especially when the pole changer is adjusted so close that it is difficult for the main-office operator to read from the sounds made by it. The receiving side cannot well be used for communication between the main and branch offices, and, consequently, no keys are included in that side. For the convenience of the operator on the receiving side at the main office, the sending side is often extended over to the receiving table, where an extra key K_1 is inserted in the sending circuit. This enables the receiving operator to communicate, without leaving his desk, with the distant main office. Of course he cannot do this if the sending side is in use at that time. The pole-changer and sounder coils have the same resistance, usually 4 ohms, in each instrument. The branch-office loop, containing on the receiving side, or receiving *leg*, as it is called, the sounder S_1, and on the sending leg the sounder S_2 and the key K_2, is connected through a wedge and spring jack *L S* at the loop switchboard in the main office with the table switch *N*, as shown in the figure. When the switch arms *o* and *q* rest on the buttons *i* and *x*, respectively, the main-office sending and receiving circuits are in series with the branch-office sending and receiving circuits, respectively.

By means of various resistance lamps *l'*, *l'*, all loop circuits are made to have about the same resistance, so that any branch office may be connected through the loop switch to the duplex set, and the 23-volt dynamo will still furnish the proper amount of current. The branch-office loop may be readily cut off by moving the switch arms, *o* to *j* and

q to y. This substitutes two locally grounded circuits, each containing a lamp l, for the branch-office sending and receiving legs. These lamps l, l have the proper resistance, so that shifting the switch arm o from i to j and the switch arm q from x to y does not change the strength of the current. By means of the switch W, the 23-volt dynamo LB may be cut off and the circuit connected to the ground G_1 through the lamp l_1. This is convenient when there is a battery or dynamo in the circuit at the loop switch or elsewhere, or when another duplex set connected to this same dynamo is repeating into this set.

119. Several Loops in One Circuit.—It is practicable to connect several offices in one circuit on either or both the sending or receiving legs of a duplex or quadruplex circuit. In Fig. 46 the regular office set operated by local gravity batteries LB and LB_1 is shown connected with the two branch offices A and B through the loop switches LS and LS_1. IB and IB_1 are intermediate gravity batteries connected in the sending and receiving sides of the circuit, respectively. These batteries must have their poles so connected at the switch LS, as shown in the figure, that IB will be in series with LB, and IB_1 in series with LB_1, otherwise they will be opposing instead of assisting one another. In offices where only dynamos are used, there would be no gravity batteries at LB, LB_1, IB, and IB_1. The resistance of the loop circuits would then be so adjusted that the local-circuit dynamo, such as LB in Fig. 45, would furnish the desired amount of current. Or, two small dynamos of proper voltage used as intermediate batteries, one in place of IB and the other in place of IB_1, could be employed. In this case there would be no batteries at LB and LB_1.

With the switch arm O resting upon the contact button i, the sending leg may be traced from the ground G_3 through K_3, S_3, IB, LS, LB, the magnet of the pole changer PC, K, K_1, the switch arm O, i, LS_1, S_4, K, G_4, and through the ground back to G_3. With the switch arm Q resting on x, the receiving leg may be traced from the ground G_1

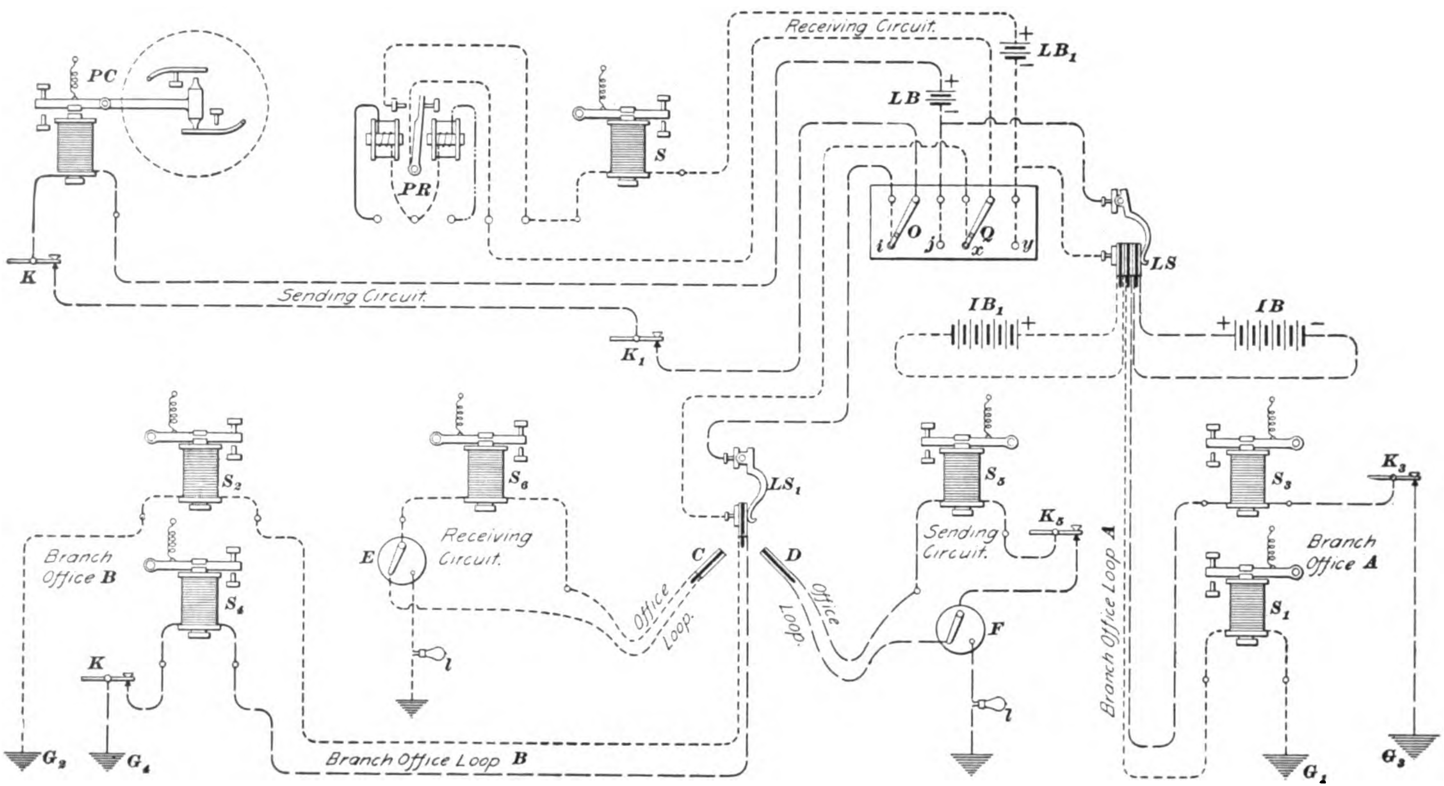

PC
K
PR
S
Receiving Circuit.
LB
LB₁
i O j Q x y
LS
Sending Circuit.
K₁
IB₁
IB
S₂
S₆
LS₁
S₅
K₅
S₃
K₃
Branch Office B
S₄
K
E
Receiving Circuit.
C
Office Loop.
D
Office Loop.
Sending Circuit.
F
l
Branch Office Loop A
Branch Office A
S₁
G₂
G₄
Branch Office Loop B
G₁
G₃

FIG. 46.

through S_1, IB_1, LS, LB_1, S, the contact points of the polar relay PR, the switch arm Q, x, LS_1, S_2, G_2, and through the ground back to G_1.

Extra main-office sending and receiving circuits may be easily included by inserting the wedge C in the spring jack LS_1 on the receiving side, and the wedge D on the sending side of the wedge already in the jack. The switches E and F must be turned to the left. By turning either or both of these switches to the right, either or both of the receiving and sending legs extending to the branch office B may be cut off. By turning the switch arm O to j and the switch arm Q to y, all the loop circuits are cut off, leaving only S and LB_1 in the receiving, and K, the magnet of PC, and LB in the sending sides.

TO BALANCE THE POLAR DUPLEX.

120. In explaining how to **balance the polar duplex,** we will consider that a line between Scranton and Philadelphia is to be worked on this system and that Scranton, Fig. 43, is the home office and Philadelphia, Fig. 44, is the distant office, and suppose that we desire to balance the home set.

1. *To Center Armature of Polar Relay.*—Scranton will first request Philadelphia to ground his circuit. Philadelphia will do this by turning the switch arm p to w, thus cutting off all source of current at Philadelphia by inserting the ground coil Gc between the polar relay and the ground in place of the pole changer and the dynamos. Then the home office will ground his set by turning the switch H to r, thus cutting off the battery at the home end. Now, with all source of current cut off, adjust the polar-relay armature until it will remain against either stop, or move with equal force from the middle position toward one side or the other. This adjustment, called *centering the armature of the polar relay*, is to make the pull due to the permanent magnetism equal on each side.

2. *To Obtain Resistance Balance.*—Having centered the armature, turn on the home battery, in this case by turning the switch *H* to *p*. If there is now more current in one winding of the differentially wound polar relay than in the other, the armature will be held more firmly against one contact point than against the other, which must be overcome by adjusting the amount of resistance in the artificial line by changing the plugs in the rheostat *Rh* until the armature will again remain against either contact point, or move with equal force toward one side or the other from the middle position, as before. When this is done, the resistance of the line and artificial circuits are equal. This adjustment is called the **resistance** balance. Although this is usually the case, still, strictly speaking, it is not necessarily the resistances of the two circuits that are made equal, but, rather, it is the magnetizing effects of the line and the artificial-line coils.

If the rheostat is incorrectly adjusted, the signals from the distant office may be too light in one position of the home key and too heavy, or "sticky," in the reverse position. Hence, it is important to test and, if necessary, to alter the adjustment of the rheostat until the incoming signals are equally good when the home key is open or closed. Furthermore, the incoming signals should still be good when dots are being rapidly made on the home key. The rapid manipulation of the home key alone may not show that the rheostat was improperly adjusted. This method of obtaining a resistance balance should always be followed, especially in wet weather and on poor wires.

3. *To Obtain a Static Balance.*—If the capacity of the artificial line does not balance that of the line, there will be a kick at the instant the home battery is reversed, due to opening or closing the home key. A kick indicates that the line and artificial line have not the same capacities, or that one charges and discharges more quickly than the other. To eliminate this kick, it is necessary to adjust the capacity of the condenser, or its point of connection with the rheostat, by means of the plug *o* until the kick disappears. The

best way to do this is to ask the distant office to cut in, that is, to shift the switch arm *p* from *w* to *v*, and to close his key K_1, Fig. 44. This will close the home (Scranton) polar relay *PR*. If the kick does not appear when the relay contact is closed, it surely cannot cause trouble at any other time, for that is the actual position of the home relay armature when the distant office is making a dot or dash and when the home relay armature must remain closed, that is, in contact with its front stop to which the local battery is connected. Hence, with the distant key closed, adjust the capacity of your condenser and then, if necessary, adjust the position of the plug *o* in the rheostat so as to retard or hasten the discharge from the condenser, until the kick disappears entirely. This adjustment is called the **static balance.** The nearer the peg *o* is placed to the end of the rheostat that connects with the artificial coil of the relay, that is, the less resistance that there is between the peg *o* and the relay, the quicker will the condenser charge and discharge.

121. Adjustment of a Battery Pole Changer.—The proper adjustment of the pole changer is very essential to the successful operation of the system in which it is used. The method of adjusting the clock-face pole changer, illustrated in Fig. 39, is as follows: Adjust the lever *n* by means of the limit screw *o* and the one below it, which is not shown in the figure, so that it will have a play of $\frac{1}{32}$ inch, which is about the same as is ordinarily given to a sounder, care being taken that the armature cannot strike the iron cores. Then, by means of the screw *o*, reduce this play to $\frac{1}{64}$ inch. This will hold the movable contact *e* on the forward end of the lever in its middle position. Now raise the screw *c* until the spring *d* barely touches *c*, being careful not to turn the screw *c* too far. Similarly, lower the screw *b* until the spring *a* barely touches *e*. Finally, raise the screw *o* until the lever has its working play of $\frac{1}{32}$ inch. The contact *e* in moving from one extreme position to the other should momentarily, in about its middle position, touch one spring

before parting from the other. If it leaves one before touching the other, the circuit will be momentarily opened. On the other hand, it must not remain in contact with both springs any longer than is absolutely necessary, because the battery is short-circuited from the instant *e* touches one spring until it parts from the other. This period during which the battery is short-circuited can be reduced almost to nothing by carefully adjusting the instrument.

The student should have no difficulty in adjusting the B. & O. pole changer, illustrated in Fig. 38, if he thoroughly understands the principle of this pole changer and the adjustment just explained.

122. Remarks Concerning Dynamo Pole Changers.—The dynamo walking-beam pole changer is apt to require more attention than any other one instrument in either the polar duplex or quadruplex system. The method of adjusting and caring for it is the same for both systems. The contact points of the dynamo pole changer cannot be adjusted as closely as those used with gravity batteries. The dynamo pole changer uses two dynamos of, say, 350 volts each, one positive and the other negative; whereas, the battery pole changer uses only one battery of 350 volts. With the dynamos there is a pressure of 700 volts tending to jump across the air-gap between the contact points. The introduction of dirt or the slightest jar between these two points will aid the electromotive force to establish an arc that acts as a fair conductor for the current, which at once flows through the beam from one dynamo to the other. In the gravity-battery arrangement, the highest pressure that can be short-circuited is 350 volts.

With the pole changer properly adjusted there is a spark at the break, but this legitimate spark is not nearly so harmful as the arc that hangs on when the instrument is so adjusted as to break improperly.

The tension of the spring may be so great that when the magnet releases the armature, the lever will fly to the other contact with such momentum that it rebounds more or less,

causing an arc to form at this insecure contact. An arc will also be formed if the lever is not promptly released. This inability to promptly release the lever may be due either to the trunnion being too tight or to the weak tension of the spring necessary when the local battery is too weak. The first may be remedied by properly adjusting the trunnion; the second, by strengthening the battery and increasing the tension of the spring.

123. Adjusting a Dynamo Pole Changer.—A dynamo pole changer may be properly adjusted in the following manner: First, be certain that the current through a 4-ohm pole changer is not less than 250 milliamperes. For fast work, a current of 275 milliamperes is not too strong. Then adjust the contact points so that you can scarcely hear your own signals on your own pole changer when you send on the key controlling it. Next adjust the tension of the spring so that the down stroke will be just a little heavier than the up stroke, and see that the trunnion is neither loose nor binding. The expert quadruplex attendant adjusts the pole changer almost entirely by sound, because sight adjustment, aside from the preliminaries, is very deceptive. When the pole changer has been adjusted to have minimum play, and gives at the same time low but distinct signals, the tendency to arc is reduced to a minimum.

With the pole changer adjusted to have a minimum play, a sounder is often connected in series with the pole-changer magnet and key in order that the operator may hear his own signals. When there is a sounder in series with the pole changer, it will be necessary to hold down the sounder lever while adjusting the pole changer in order to hear only the signals on the latter.

124. Mr. Willis H. Jones, in "The Telegraph Age," makes the following remarks concerning the way some operators balance the polar duplex:

"Many operators adjust the condenser while the armature of the home relay rests upon the back contact point, and seem to be satisfied when the kick can no longer be heard.

They apparently forget that the 'sound' of the kick will disappear with a less amount of 'static' eliminated when the lever rests upon the back stop than when it rests upon the contact point, because in the former position the armature must cross the intervening space before it can produce a signal, while in the latter, it needs but make a start.

"Some operators believe that they are equally successful in equating by giving the armature a temporary bias in order to make it more sensitive, but no one will deny that by this plan the magnetic line balance is practically destroyed. Of course an endeavor is made to replace the lever in its former position, but such an action is plainly mere guesswork. If there are any that doubt this statement, let them try the plan on a poor wire, and, after having recentered the lever, as they believe, again ground the circuit at each end. It will be found that the experiment may have to be repeated many times before the armature can be found sufficiently 'centered' to remain where placed without further adjustment.

"To make matters worse, after having destroyed the magnetic equilibrium of the main and artificial line on the displaced armature, frequently attempts are made to mend matters by readjusting the rheostat while the distant office writes.

"When the apparatus is finally considered to be balanced, what are the actual conditions under which the operator is expected to work? Simply this—a practically lopsided relay, and a false line balance. It may work satisfactorily at the start, but the margin is very small, and a slight change in the atmospheric conditions may necessitate another balance."

125. The insulation of a line will vary with the weather, and the lower the insulation, the lower will be the apparent resistance and capacity of the line. Hence, a change in the weather that is sufficient to alter the insulation of the line may require a readjustment, to a greater or less extent, of both the rheostat and the condenser. This remark applies

with even more force to a quadruplex than to a duplex circuit, and the student should not forget this fact when he is at work on such systems. Polar relays on duplex circuits require 25 milliamperes to properly work them.

BRIDGE DUPLEX SYSTEM.

126. The bridge system shown in Fig. 47 is similar in its action to a Wheatstone bridge. *S* is a rheostat so arranged that, as the lever is turned upwards, resistance is taken out of the *a c* arm of the bridge and is added to the *a d* arm, and *vice versa* if the lever is moved in the other direction. The four arms of the bridge are *a d*, *a c*, $d\,G_1$, and

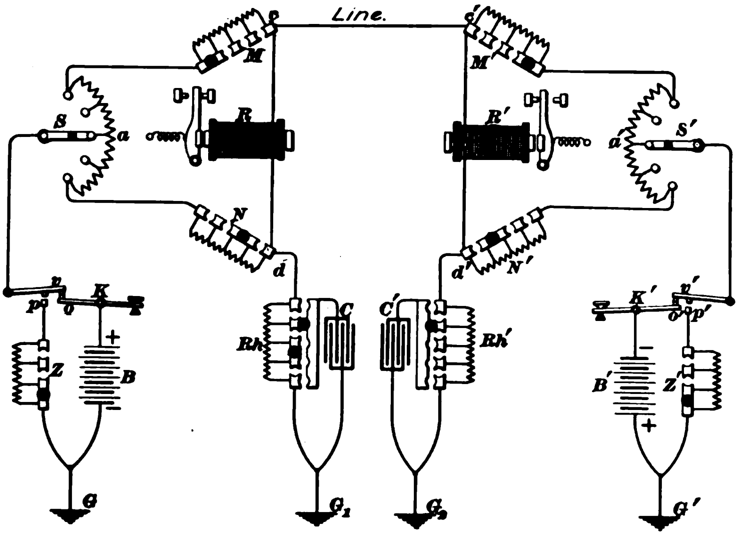


FIG. 47.

from *c* through the line and apparatus at the other station to the grounds *G'* and G_2. Hence, the resistance of the artificial line at each end must be equal to the resistance of the line wire plus the resistance from the distant end of the line to the ground through the apparatus at the distant

station, assuming, as is usually the case, that the resistance of *a c* is equal to that of *a d*. In any case, the following proportion must be satisfied: Resistance of *a c* : resistance of *a d* :: line resistance + resistance from *c'* through all paths at right-hand station to grounds *G'* and G_2 : resistance of the artificial line $d\,G_1$. When this is the case, there is no difference of potential between the points *d* and *c*.

127. *M*, *M'*, *N*, and *N'* are adjustable resistances and *K* represents a continuity-preserving transmitter. When the key is pressed down, the lever *o* lifts the lever *v* off the contact point *p*, momentarily short-circuiting the battery in order to avoid opening the circuit between the ground *G* and the line. In practice, the continuity-preserving transmitter illustrated in Fig. 5 may be employed on a land line. The adjustable resistance *Rh* and condenser *C* constitute an artificial line, and *Z* is a resistance that is adjusted to equal the internal resistance of the battery *B*.

The resistance *Z*, key *K*, and battery *B* are arranged and used in the same manner as already explained in connection with the Stearns differential duplex. The apparatus and connections at the two stations are similar.

128. From Fig. 47, it will be seen that if *a c* bears the same relation to *a d* that the circuit from *c* through the line and apparatus at the distant station to ground bears to $d\,G_1$, then the relay *R*, which in this case corresponds to the galvanometer in a Wheatstone bridge, will not be affected by the outgoing current from the battery *B*, for the same reason that the galvanometer in the Wheatstone bridge will not be deflected when the bridge is balanced. If the key *K'* at the distant station is pressed down and *K* is up, i. e., open, some current will pass along the line and at the point *c* will divide, a part of it passing through and operating the relay *R*. The position of the key *K* will in no wise affect the operation of the relay *R*, because the position of the key *K* does not alter the resistance of the circuit between *a* and *G*. Thus the relay at one station will be operated only by the key at the distant station.

129. Adjustment of resistances is made in *a c* and *a d*, first by the resistance boxes *M* and *N*, and, finally, by the rheostat *S*. If the resistance from *c* through the line and apparatus at the distant station to the ground is 4,000 ohms, then a resistance of 1,000 ohms in *a c*, 2,000 in *Rh*, and 500 in *a d* would properly balance the bridge. The connection between the condenser *C* and the resistance box *Rh* should be adjusted until the artificial line charges and discharges in the same manner as the line, so that no momentary kick would be made by the relay.

130. Comparison Between Bridge and Differential Duplex.—The bridge duplex is superior to the differential duplex in that it requires less condenser capacity in the artificial line, and the resistances and condensers can be more readily adjusted to suit the varying conditions of the line. However, the bridge duplex is inferior to the differential duplex in that it requires more battery power to produce the same strength of current in the relay. This inferiority of the bridge duplex has excluded it from use on long land circuits. On short lines of low resistance, where an excessively high electromotive force would not be required and when batteries of low resistance can be used, it is preferable to the Stearns differential duplex, but it is not preferable to the polar duplex.

131. Bridge Duplex Used on Submarine Cables. The bridge principle is used wherever submarine cables are duplexed; but, while the principle is the same, the apparatus used is quite different from that shown in this figure. The bridge duplex, as applied to submarine cables, will be explained in connection with submarine telegraphy.

MORRIS SINGLE-BATTERY DUPLEX.

132. The **Morris single-battery duplex,** invented by Mr. R. H. Morris of the Western Union Telegraph Company, requires a main-line battery only at one end. It is a

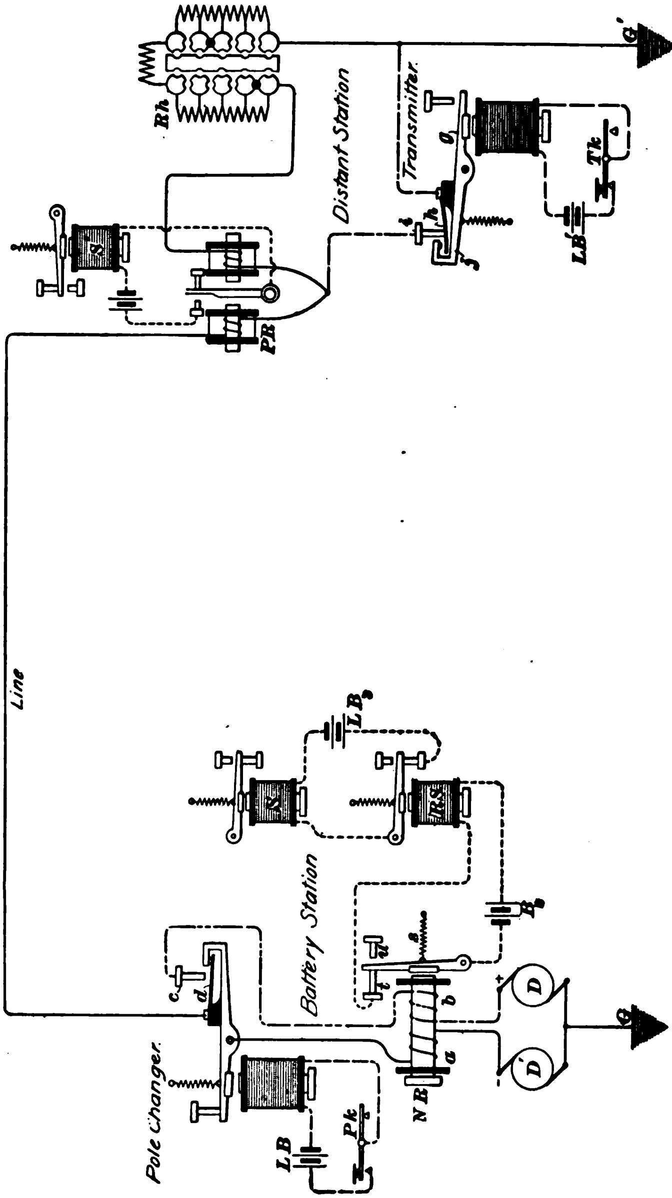

Distant Station
Transmitter
Battery Station
Pole Changer
Line
Rh
PR
LB
Pk
NB
Tk
G
G'
D
D'

FIG. 48.

great improvement over a somewhat similar system, called the Edison-Smith duplex, and has proved to be one of the most useful and economical systems for short lines; it is considerably used, especially in New York city and the immediate vicinity.

133. The **general arrangement** of the apparatus is shown in Fig. 48. The various instruments shown are the same as those used in the duplex and quadruplex systems. It will be noticed that an ordinary continuity-preserving transmitter is used at the battery station as a pole changer. This instrument is used in preference to one of the walking-beam pattern in order that the benefits of a continuity-preserving device may be obtained. Where a low electromotive force is used, a transmitter connected as a pole changer may be beneficially substituted for the ordinary dynamo walking-beam pattern, as the tendency to spark will be small.

134. One distinctive feature of the Morris duplex lies in the use of a differential relay, called a **neutral relay.** However, this relay is not used differentially, and is practically a single relay because the current never flows differentially through the two coils. Thus, one current does not neutralize the effect of the other. Moreover, the direction in which the cores are magnetized is never reversed. The coils are so wound and connected that when current from the negative dynamo D' circulates through the coil a, the iron is magnetized in the same direction as when current from the positive dynamo D circulates through the coil b. When the pole changer shifts the line from one coil of the neutral relay to the other coil, there is a moment when the two dynamos are in series and no current flows over the line. In this condition of affairs, there is quite a strong current through both coils of the neutral relay, but the current is in such a direction through the two coils as to preserve the existing direction of the magnetization of the relay. Hence, the magnetization of the neutral relay does

not even fall to zero, much less does it reverse when the pole changer is in operation. Consequently, the magnetization produced at reversal tides the relay over the period of reversal and thus avoids the kick that is so objectionable.

135. *Rh* is an adjustable resistance. When the transmitter at the distant station is closed, this resistance and one coil of the polar relay *PR* are short-circuited and the line is connected through one coil of the polar relay and through the transmitter to the ground *G'*. When the transmitter is open, both coils on the polar relay and the resistance *Rh* are connected in series between the line wire and the ground *G'*. The resistance in *Rh* is made so high that when it is in the circuit, the current is reduced to one-fourth the strength that it possesses when the transmitter is closed. But both coils of the polar relay are in series when the transmitter is open and the current flows through the two coils in such a direction that they help each other, and the magnetization produced is still sufficient to operate the polar relay when the current is reversed by the pole changer at the battery station.

The spring of the neutral relay is so adjusted that when the transmitter at the distant station is closed, the current is strong enough to overcome it and to attract the armature. But when the distant transmitter is opened the resistance *Rh* is included in the circuit, and consequently the current is reduced to one-fourth its previous strength, and the magnetism produced in the neutral relay is not sufficient to overcome the spring, and, hence, the armature is released. Therefore, the neutral relay can be closed only by increasing the strength of the current to four times its smaller value and its operation is entirely independent of the direction of the current. On the other hand, the polar relay is operated by reversing the direction of the current and is independent of the strength of the current used.

136. Arrangement of Sounders.—At the battery station, a repeating sounder *R S* has its circuit closed when the relay armature is against its front stop, and the ordinary,

or reading, sounder *S* has its circuit closed when the armature of the repeating sounder is against its front stop. The arrangement of these two sounders at the battery station is such as to avoid any danger of a false signal when the pole changer short-circuits the two dynamos through both coils. When the distant transmitter is closed, causing the neutral relay armature to rest against the front stop *t*, the increase in the magnetization of the neutral relay, due to the short-circuiting of the dynamos, can do no harm. Furthermore, experience with this duplex has shown that, even when the distant transmitter is open, the increment of current in the neutral relay, when the two dynamos are short-circuited, does not produce a false signal. This may be due to the fact that the duration of the short-circuiting is much less than the time required for the second coil of the neutral relay, which is empty, to build up from zero. Moreover, it would be necessary, before a false signal could be produced on the sounder *S*, for the armature of the neutral relay to move from the back stop *u* to the front stop *t* and for the armature of the repeating sounder to also move from its back to its front stop. This movement requires time. Whatever may be the true explanation, the short-circuiting at the pole changer is so brief that no false signals are produced. It is a disputed point as to whether a repeating sounder is necessary. However, the apparatus was originally set up that way and it has never been changed.

OPERATION.

137. Both Keys Open.—Let both keys *Tk* and *Pk* be open, then the armature of both relays *NR* and *PR* will be resting against their back stops and the sounders *S* and *S'* will be open. The negative dynamo *D'* will be sending current through the coil *a*, pole changer, line, both coils of the polar relay *PR*, the resistance *Rh*, ground plate *G'*, and back through the ground to the negative dynamo *D'*. The direction of this current is such that the polar relay is held

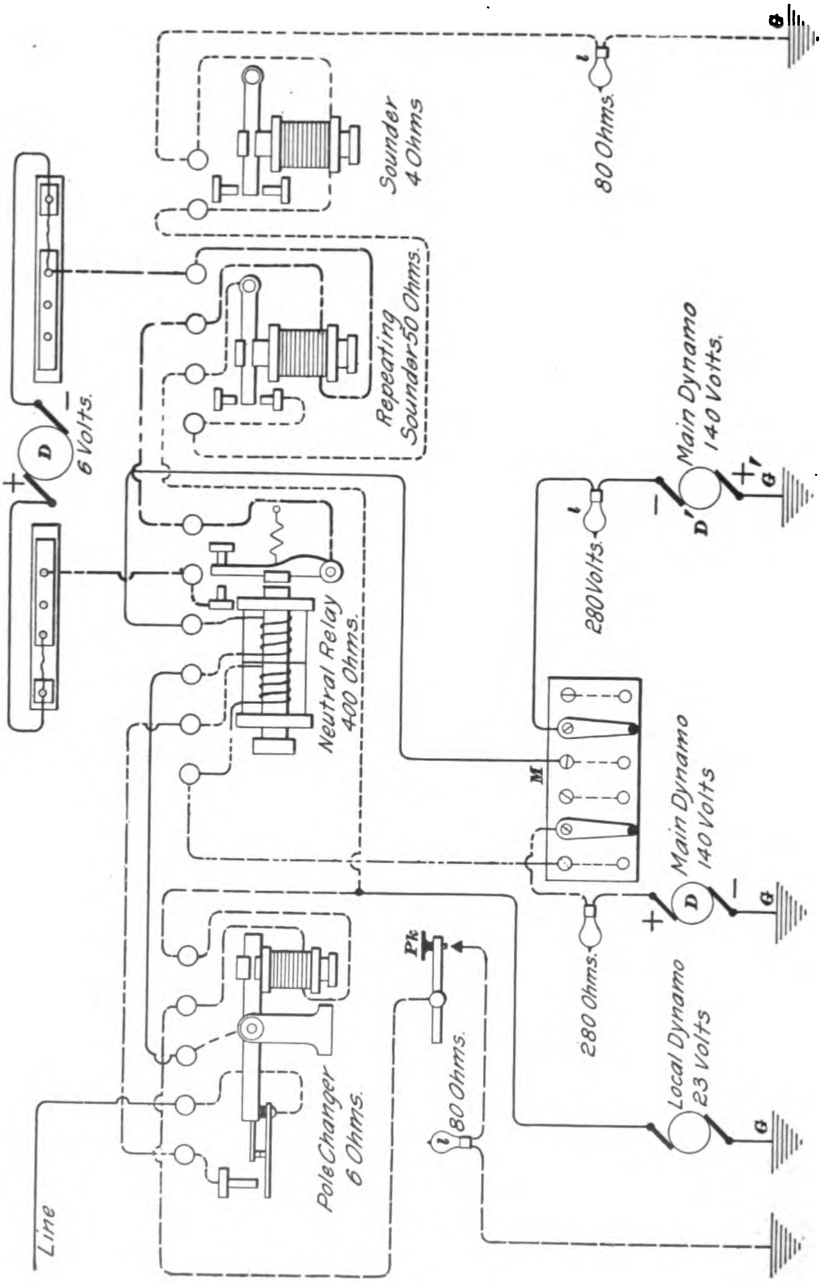

Sounder
4 Ohms
80 Ohms.
Repeating
Sounder 50 Ohms.
6 Volts.
D
Main Dynamo
140 Volts.
280 Volts.
Neutral Relay
400 Ohms.
M
Main Dynamo
140 Volts
280 Ohms.
Local Dynamo
23 Volts
Pk
80 Ohms.
Pole Changer
6 Ohms.
Line

FIG. 49.

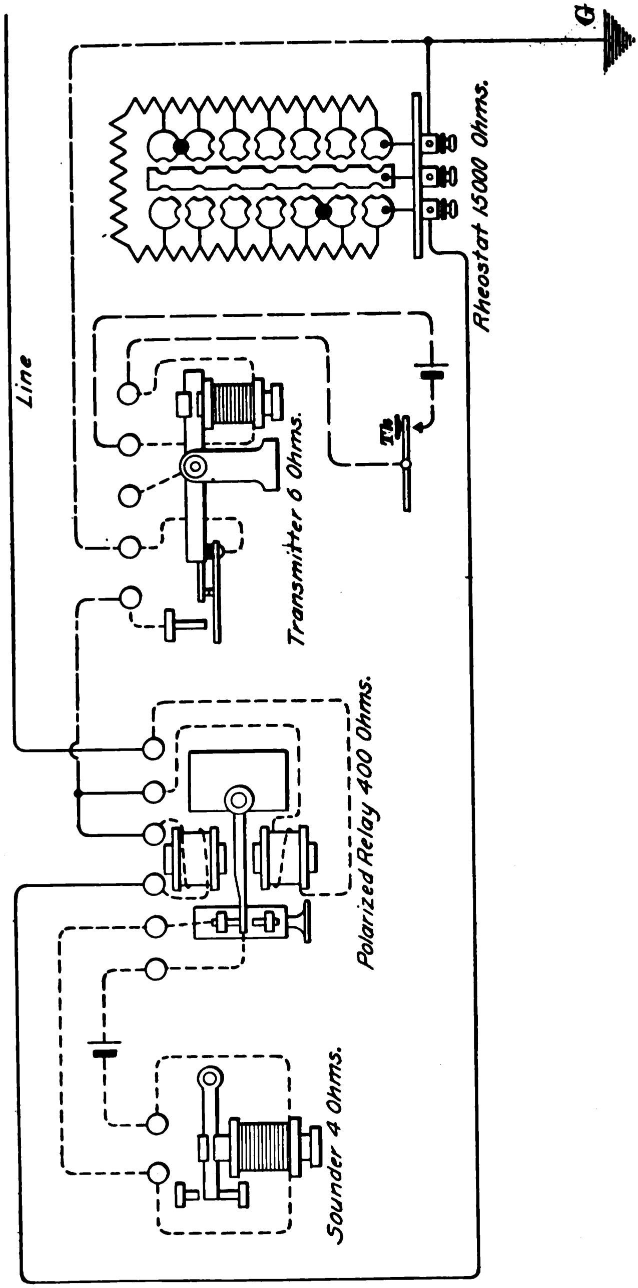

Line
G
Rheostat 15000 Ohms.
Transmitter 6 Ohms.
Polarized Relay 400 Ohms.
Sounder 4 Ohms.

FIG. 50.

open, and because the resistance *Rh* is in the circuit, the strength of the current is not sufficient to overcome the retractile spring *s* of the neutral relay; hence, the neutral relay is also open.

138. Key *Pk* Closed.—Let the key *Pk* be closed. This will close the pole changer, thus shifting the line from the negative dynamo *D'* to the positive dynamo *D* and reversing the direction of the current throughout the circuit. The neutral relay will not be affected, because the strength of the current is the same as before, but the polar relay will be closed. Hence, by closing the key *Pk* at the battery office, a signal is produced at the distant office only.

139. Both Keys Closed.—Suppose that while the key *Pk* is closed the key *Tk* is also closed. This will cause the transmitter to close and short-circuit the resistance *Rh* and one coil of the polar relay, while the current will increase to four times its former strength. Although there is now only one coil of the polar relay in the circuit, still the current has been sufficiently increased in strength to more than make up for the fewer number of turns in the coils of the polar relay; moreover, closing the key *Tk* does not reverse the direction of the current. Hence, the polar relay is not affected and remains closed as long as the battery-station key *Pk* remains closed. But increasing the current to four times its former value closes the neutral relay *NR* at the battery station. Hence, both relays are closed when the two keys are closed.

140. Key *Tk* Closed.—If now the key *Pk* be opened, *Tk* remaining closed, the line will be shifted from the positive to the negative dynamo. This will reverse the direction of the current through the circuit, without causing any change in its strength, and, hence, only the polar relay will be opened. Therefore, the key at one station controls only the relay at the other station, and the operation of a key at one station does not interfere with the signals that are being received by the relay at the same station.

141. To Balance Morris Duplex.—The Morris single-battery duplex is balanced at the battery station by simply adjusting the retractile spring of the neutral relay so that the armature will properly respond to the signals from the distant station, at the same time that the battery-station key is being operated. The polar relay at the distant station requires no adjustment after its armature has been properly centered in the manner explained in Art. **120.** The resistance *Rh* is so adjusted as to make the maximum current four times as great as the minimum.

142. The **actual connections** of the apparatus at the two offices are clearly shown in Figs. 49 and 50. The two arms of the switch *M* in Fig. 49 are turned to the left when the apparatus is in use. The 50-ohm repeating sounder is supplied with current from a 6-volt dynamo and the other local circuits are supplied, as usual in Western Union offices, from a 23-volt dynamo. Lamps having the proper resistance are connected in the various circuits to help regulate the strength of the current. No primary batteries are used at the battery station, and at the distant office only enough gravity cells to operate the transmitter and the sounder are required.

DIPLEX.

143. The **diplex** is a system of telegraphy by which two messages may be simultaneously transmitted in the same direction over one wire. The form described here should be thoroughly understood, for it is an essential feature of the quadruplex systems.

144. The principle of the diplex may be readily understood by the help of Fig. 51, in which *P R* is a polarized relay; *N R*, a neutral relay, so called because its operation depends on *an increase in the strength of the current and not on the direction of the current; P C*, a pole changer; and *T* a transmitter. The transmitter is so connected that when the key is open, only one cell *B'* is connected between the wires *d*

and *e*. When the key is depressed, the lever *a* first touches the lever *b*, thereby short-circuiting, momentarily, the battery *B*, which consists of three cells, before it lifts *b* off *c*. When the lever *a* has lifted *b* off *c*, the two batteries *B* and *B'* are connected in series, making one battery of four cells across the two wires *d* and *e*. Hence, the number of cells in the circuit has been increased from one to four; consequently, with the same resistance in the circuit, the strength of the

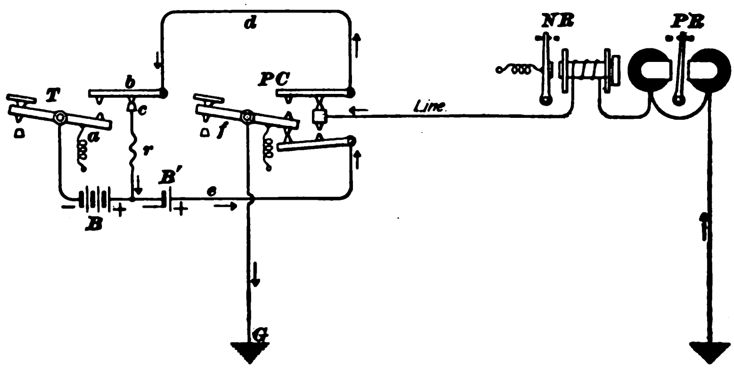


FIG. 51.

current will be four times as great as before. If the weaker current has a strength of 1 unit, then the stronger current will have a strength of 4 units. That is, the ratio of the two currents is 1 to 4. In order to keep the resistance of the circuit the same whether *B* is cut in or out, it is necessary to insert the resistance *r*, which is equal to the internal resistance of the battery *B* in the circuit when the battery *B* is cut out.

145. When the key *f* of the pole changer *PC* is open, that is, up, the line is connected to the wire *d*, and the ground *G* to the wire *e*. When the key is depressed, these connections are reversed. Hence, the pole changer, when operated, reverses the polarity of whatever battery happens to be connected by the transmitter *T* across the two wires *d* and *e*. The operation of the transmitter varies the current from 1 to 4 units, or *vice versa*, and the pole changer merely

reverses the direction of this current through the line whether it be 1 or 4 units. Thus the transmitter and the pole changer do their work independently of one another.

The student should clearly understand the action of these two instruments when they are combined in this manner. There are four possible positions of these two keys. If the student does not clearly understand that the operation of the pole changer does not affect the strength of the current, and that the operation of the transmitter does not affect the direction of the current in the line, he should draw on a separate piece of paper the three other possible positions of the two keys and note the strength and direction of the current in the line in each case. The tongue, or armature, of the polarized relay will move whenever the direction of the current is reversed, no matter whether the strength of the current is 1 unit or 4 units. The reversal of the 4-unit current will perhaps make the polarized relay operate more vigorously than will the reversal of the 1-unit current, but the 1-unit current will operate it and the intensity of the click of the sounder that is controlled by the polar relay will be the same in either case.

146. The neutral relay, however, will tend to attract its armature no matter in which direction the current flows through it, and if the current is only strong enough to overcome the retractile spring, the relay will close its local circuit. The spring is adjusted so that the magnetism produced by the 1-unit current will not be strong enough to overcome it, but the magnetism produced by the 4-unit current will readily overcome the spring and close the local circuit. Hence the message sent by the operator at the transmitter T is received by the operator at the neutral relay NR, and the message sent by the operator at the pole changer PC is received by the operator at the polarized relay PR. Furthermore, these two messages do not interfere with each other when the apparatus is properly adjusted.

147. Elimination of False Signals.—If the pole changer reverses the direction of the current while the

4-unit current is flowing, in which case the neutral relay is closed, the neutral relay tends to release its armature at the instant of reversal, because when the whole battery is reversed, and, consequently, the direction of the current through the neutral relay is reversed, the magnetism of the neutral relay must fall to zero before it can increase to its normal strength in the opposite direction. If the interval of no current in the neutral relay, which lasts while the battery is momentarily short-circuited, is sufficiently prolonged, a mutilation of the signal, or a **false signal** as it is called, will be produced that will seriously interfere with the successful operation of the system However, by adjusting the pole changer so that the interval of no current in the line and relay is as short as possible, and, furthermore, by using a repeating sounder that is closed on the back stop of the neutral relay, and an ordinary sounder that is closed, in turn, on the back stop of the repeating sounder, the tendency to produce false signals can be overcome. When the local circuit is connected to the back stop instead of to the front stop of the neutral-relay armature, a reduction in the magnetizing force of the relay that will allow the armature to momentarily break away from the front stop will not produce a false signal by closing the ordinary sounder circuit, *unless the time interval is sufficient* for the relay armature to cross the gap between the front and rear stops, and to make contact with the rear stop. Furthermore, both the repeating sounder and the ordinary sounder require some time before their magnetism can build up from zero to a strength sufficient to start the movement of their armatures. Hence, if the relay armature does momentarily close the repeating-sounder circuit, the duration of contact may be too short to allow the repeating sounder, in turn, to close the circuit of the ordinary sounder, and even if this should happen it may last so short a time that the ordinary sounder cannot build up and make a signal.

148. Whenever a repeating sounder is connected to the back stop of a relay and the signals are to be read by sound,

then a second sounder must be used, and the second sounder must be connected to the back stop of the repeating sounder, otherwise, the signals will be reversed; that is, dots and dashes will be transformed into spaces, and *vice versa*. This second sounder is frequently called the **reading sounder.**

QUADRUPLEX SYSTEM.

149. The principle of all **quadruplex systems** in which two messages are sent in each direction simultaneously over one line wire is about the same. In the Stearns duplex system, the differential relay responded only to signals sent from the distant office; the connection and disconnection of the home battery did not affect the home relay because it was differentially wound. In the polar duplex, the polar relay at the home office responded to the reversals of the distant battery but not to the reversals of the home battery, because the polar relay was also differentially wound. In the diplex system that has been described, it was shown how one message could be transmitted by increasing and decreasing the strength of the current, independent of its direction, while another message is being sent by reversing the direction of the current, independent of its strength. If in the diplex already explained, we wind both the neutral and polar relays differentially and connect them at the home station, as shown in Fig. 52, the operation of the home transmitter and pole changer will not affect these relays. This is evidently a combination of the principles involved in the Stearns duplex, the polar duplex, and the diplex. The student should thoroughly understand each of the systems mentioned in order to comprehend the complete quadruplex systems that will follow. As in the duplex systems, the artificial line is here made equal in resistance and capacity to the line wire. In this figure, whatever current finds its way from the battery, through the transmitter and the pole changer, to the point *h* will there divide equally. One half will flow through the coil *n* on the neutral relay, the coil *p* on the

polarized relay, the line, the ground plate G_1, the ground, and the ground plate G back to the battery; the other half will flow through the coils m and o, the artificial line, ground plate G_2, the ground, and the ground plate G, back to the battery. The coils n and p are called the *line coils*, and the coils m and o, the *artificial-line coils*. The two relays are differentially wound and so connected that current flowing from the home battery, dividing at h, and flowing equally through the line and artificial-line coils will not magnetize or *affect either relay, no matter what may be the strength or direction of this current.* The coil m neutralizes the effect of the coil n, and o neutralizes p when the current for all the coils comes from the home battery and divides equally at h.

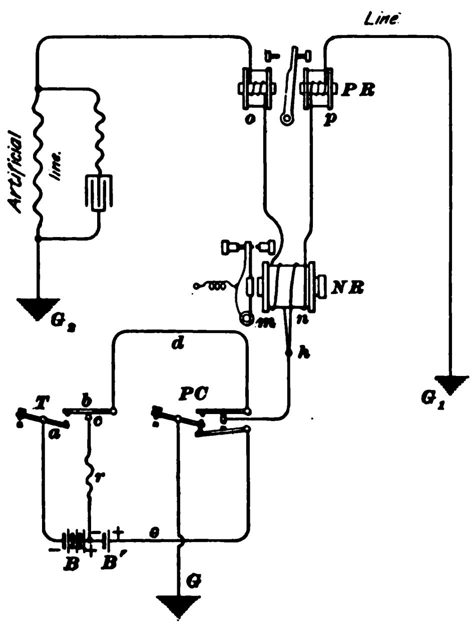


FIG. 52.

150. In the next step, which is illustrated by Fig. 53, a neutral relay NR_1 and a polar relay PR_1 are connected at the distant station in series with the line. In this figure the resistance and capacity of the artificial line are adjusted until the current from the battery at the west station divides into two equal parts at the point h and passes in opposite directions in the two coils of NR and PR. Such being the case, it is evident from preceding explanations, that the operation of the pole changer and transmitter at the west

station will not operate the neutral relay NR nor the polar relay PR at that station. The current that finds its way over the line and through the neutral and polar relays NR_1 and PR_1 at the eastern station is free to operate those relays, provided it has the proper strength and direction. If the line current is strong enough, it will close the neutral relay NR_1, no matter what its direction may be; and the same current will close the polar relay PR_1, if it flows in the proper

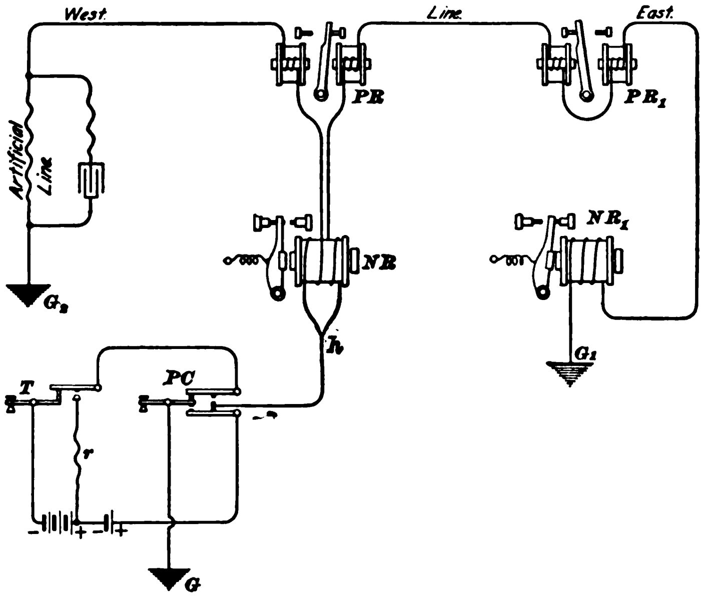


FIG. 53.

direction, no matter what its strength may be. The operation of the pole changer PC will not affect PR, because the latter is differentially wound, nor will it affect the neutral relay NR or NR_1, because merely a change in the direction of the current will not operate a neutral relay. Hence the only relay affected by the operation of the pole changer PC is the polar relay PR_1 at the distant station. The operation of the transmitter T will not affect NR because the latter is differentially wound, nor will it affect PR or PR_1, because merely

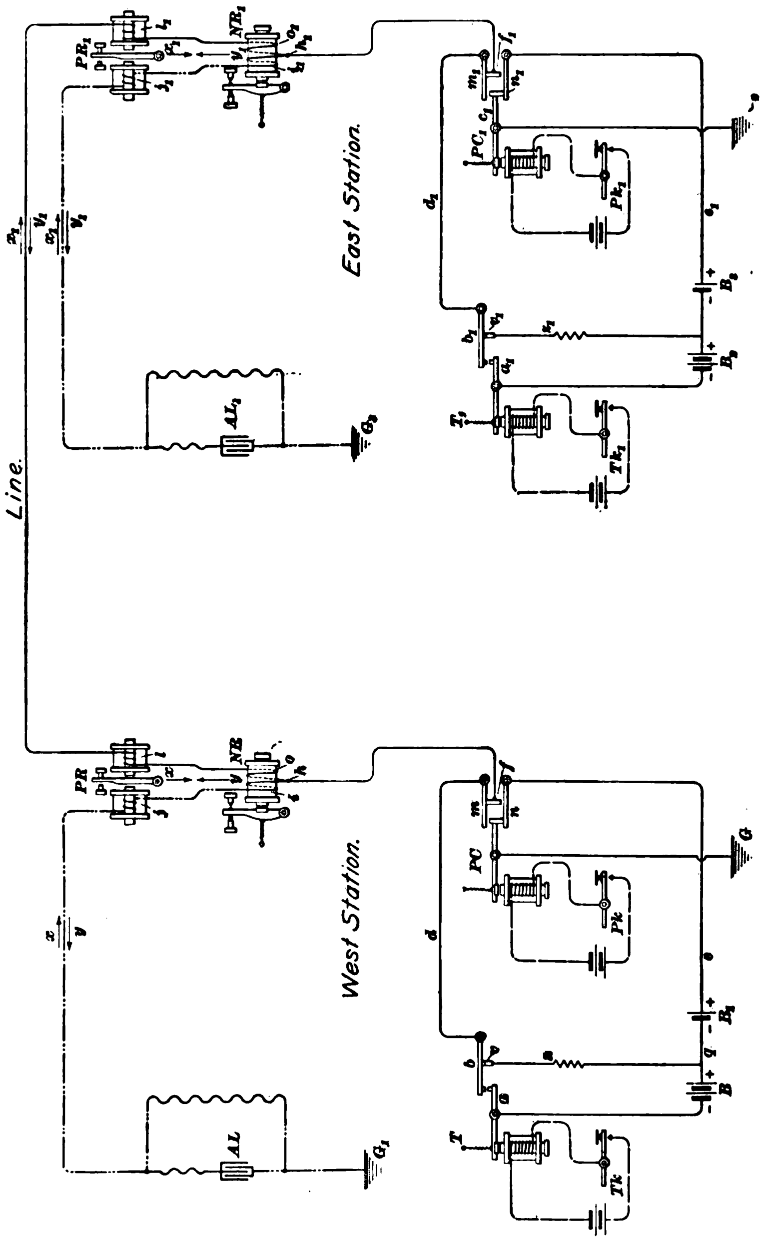

Line.
East Station.
West Station.
PR
NR
AL
PC
Pk
Tk
PR1
NR1
AL1
PC1
Pk1
Tk1

FIG. 54.

an increase or decrease in the current will not change the polarity of a polar relay. Hence the only relay affected by the operation of the transmitter *T* is the neutral relay $N R_1$ at the distant station. Therefore, one operator at *T* and another at *PC* may send messages simultaneously, the message sent at *T* being received by an operator at $N R_1$ and the message sent at *P C* by an operator at $P R_1$.

151. The next step consists in arranging the apparatus in exactly the same manner at both ends, so that two messages may be sent simultaneously in each direction without interfering with each other. This arrangement is shown in Fig. 54. In order to have a clear diagram to use in explaining the system, the apparatus in this figure has been reduced to as simple a form as possible, and all local-sounder connections have been omitted. Diagrams showing the practical form and arrangements of the instruments will be given later. The arrangement of apparatus at the two ends is exactly similar, and the four relays are differentially wound. The artificial line *A L* is so adjusted that the resistance from *h* through *A L* and G_1 to *G* equals the resistance from *h* through the line coils *o* and *l* and the line to the ground at the east station. $A L_1$ is similarly adjusted, so that the resistance from h_1 through $A L_1$ and G_2 to G_3 equals the resistance from h_1 through the line coils o_1 and l_1 and the line to the ground at the west station. The resistance of the ground return should, strictly speaking, be included in the above circuits, but it can usually be neglected without appreciable error. The battery *B* has twice the electromotive force of B_1, as is indicated, by giving *B* twice as many cells as B_1. Hence, if B_1 has an electromotive force of 100 volts, *B* will have an electromotive force of 200 volts. When B_1 alone is connected between the wires *d* and *e*, the electromotive force will be 100 volts; when both *B* and B_1 are connected in series between *d* and *e*, the electromotive force will be 300 volts. Hence, if the strength of the current in the first case is represented as 1 unit, the current in the second case will be 3 units.

TABLE 3.

No.	Keys.				Pressure at Point.		Current in			Effective Current.		Relays Operated.			
	West.		East.		h. West.	h_1. East.	West.	Line.	East.	West.	East.	West.		East.	
	Pk.	Tk.	Pk_1.	Tk_1.			AL.	L.	AL_1.	Relays NR and PR.	Relays NR_1 and PR_1	PR.	NR.	PR_1.	NR_1.
1	Open	Open	Open	Open	−100	−100	$\frac{100}{R}(x)$	0	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,A\,L)$	$\frac{100}{R}(x_1\,A\,L_1)$	Open	Open	Open	Open
2	Closed	Open	Open	Open	+100	−100	$\frac{100}{R}(y)$	$\frac{200}{R}(y\,x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,L)$	$\frac{100}{R}(x_1\,L)$	Open	Open	Closed	Open
3	Open	Closed	Open	Open	−300	−100	$\frac{300}{R}(x)$	$\frac{200}{R}(x\,y_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(x\,A\,L)$	$\frac{300}{R}(y_1\,L)$	Open	Open	Open	Closed
4	Closed	Closed	Open	Open	+300	−100	$\frac{300}{R}(y)$	$\frac{400}{R}(y\,x_1)$	$\frac{100}{R}(x_1)$	$\frac{100}{R}(y\,L)$	$\frac{300}{R}(x_1\,L)$	Open	Open	Closed	Closed
5	Open	Open	Closed	Open	−100	+100	$\frac{100}{R}(x)$	$\frac{200}{R}(x\,y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,L)$	$\frac{100}{R}(y_1\,L)$	Closed	Open	Open	Open
6	Closed	Open	Closed	Open	+100	+100	$\frac{100}{R}(y)$	0	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,A\,L)$	$\frac{100}{R}(y_1\,A\,L_1)$	Closed	Open	Closed	Open
7	Open	Closed	Closed	Open	−300	+100	$\frac{300}{R}(x)$	$\frac{400}{R}(x\,y_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(x\,L)$	$\frac{300}{R}(y_1\,L)$	Closed	Open	Open	Closed
8	Closed	Closed	Closed	Open	+300	+100	$\frac{300}{R}(y)$	$\frac{200}{R}(y\,x_1)$	$\frac{100}{R}(y_1)$	$\frac{100}{R}(y\,A\,L)$	$\frac{300}{R}(x_1\,L)$	Closed	Open	Closed	Closed
9	Open	Open	Open	Closed											
10	Closed	Open	Open	Closed	+100	−300	$\frac{100}{R}(y)$	$\frac{400}{R}(y\,x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,L)$	$\frac{100}{R}(x_1\,L)$	Open	Closed	Closed	Open
11	Open	Closed	Open	Closed	−300	−300	$\frac{300}{R}(x)$	0	$\frac{300}{R}(x_1)$	$\frac{300}{R}(x\,A\,L)$	$\frac{300}{R}(x_1\,A\,L_1)$	Open	Closed	Open	Closed
12	Closed	Closed	Open	Closed	+300	−300	$\frac{300}{R}(y)$	$\frac{600}{R}(y\,x_1)$	$\frac{300}{R}(x_1)$	$\frac{300}{R}(y\,L)$	$\frac{300}{R}(x_1\,A\,L_1)$	Open	Closed	Closed	Closed
13	Open	Open	Closed	Closed	−100	+300	$\frac{100}{R}(x)$	$\frac{400}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,L)$	Closed	Closed	Open	Open
14	Closed	Open	Closed	Closed	+100	+300	$\frac{100}{R}(y)$	$\frac{200}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{100}{R}(y_1\,A\,L_1)$	Closed	Closed	Closed	Open
15	Open	Closed	Closed	Closed	−300	+300	$\frac{300}{R}(x)$	$\frac{600}{R}(x\,y_1)$	$\frac{300}{R}(y_1)$	$\frac{300}{R}(x\,L)$	$\frac{300}{R}(y_1\,L)$	Closed	Closed	Open	Closed
16	Closed	Closed	Closed	Closed	+300	+300	$\frac{300}{R}(y)$	0	$\frac{300}{R}(y_1)$	$\frac{300}{R}(y\,A\,L)$	$\frac{300}{R}(y_1\,A\,L_1)$	Closed	Closed	Closed	Closed
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

152. Sixteen different combinations may be formed with the four keys, thus giving sixteen different current combinations. These sixteen possible combinations are tabulated in Table 3.

R in the table refers to the resistance from the point h through the line to the ground G_2 and G_3 at the east station, or from h_1 through the line to the ground G and G_1 at the west station. It is also equal to the resistance from the point h through the artificial-line side at the west station to the ground G_1, or from h_1 through the artificial-line side at the east station to the ground G_3. The resistance of the earth return is in each case neglected.

The letters in parentheses, in columns under "Effective Current," refer to the direction of the current and to the branch carrying the largest current. Thus $\frac{100}{R}$ $(x_1\ A\ L_1)$ means that an effective or excess current of $\frac{100}{R}$ amperes is flowing through the artificial-line coils of the relays at the east station in the direction of the arrow x_1.

Closing the key Tk closes the transmitter T, and closing the key Pk closes the pole changer PC; that is, it causes the positive pole of the battery to be connected to the line, and the negative pole to the ground G. Reversing the battery in this way, so that the point f is shifted from the negative to the positive pole of the battery, will close the distant polar relay.

153. An effective current of the strength $\frac{100}{R}$, which we may call 1 unit, is not strong enough to close the neutral relays when their springs are properly adjusted; and the polar relays are so connected that a current flowing through their artificial-line coils j and j_1 in the direction of the arrows x and x_1, respectively, or through their line coils l and l_1 in the direction of the arrows y and y_1, respectively, will hold the polar relays open. That is, the polar-relay coils are so connected when the apparatus is first set up that

this will be the case. Hence, any current through either or both windings of the polar relay that will magnetize the relay in the same direction as the currents specified above, will hold the polar relay open, and any current that will reverse the direction of this magnetization will close the polar relay. The student must remember this fact.

In order to close the neutral relay, the intensity of the resultant magnetization produced by the current in the two coils must be equivalent to that produced by $\frac{300}{R}$ amperes through one coil only. The direction of the current in the various coils is indicated in the table by the letters x, y, x_1, and y_1, to be found on the various arrows in the figure. It will be noticed that the arrow x_1 coincides in direction with the arrow y, and y_1 with x. The arrows x_1 and y_1 are not absolutely necessary, but, by using them, the explanations are made clearer.

154. It may be well to add here the fact that some of the current flowing over the line from the east to the west station may go to ground G_1 through the coils i and j and the artificial line, instead of through the pole changer and transmitter circuit to the ground G. This, however, is an advantage rather than a disadvantage, because the direction of this current through the artificial-line coils is always in the proper direction to assist the incoming current through the line coils. Sometimes, when dynamos or batteries of the same electromotive force must be used on both short and long lines, a resistance box is placed in the circuit between the dividing point h and the point f. By this means, too large a current in the relays on the short lines can be prevented by increasing the resistance in the box. As far as the operation of the relays alone is concerned, the use of this resistance is advantageous, as it forces a larger proportion of the incoming line current through the artificial-line coils of the home relays. This resistance is shown in the Jones quadruplex system, an explanation of which will be given later.

155. Fig. 55 is merely a simplified diagram of the quadruplex system. B and B_1 represent the entire group of batteries, or generators, at each end of the line, respectively. PR and PR_1 represent the polarized relays, one at each end of the line; and NR and NR_1, the neutral relays. The crosses at PC and PC_1 represent the pole changers that govern the direction of the current sent to the line; and the crosses at T and T_1, the transmitters that govern the strength of the current. Practically the same notation is used as in Fig. 54, so that in the following explanations either figure may be referred to.

This figure is shown in order that a complete analysis of all the currents in the line and the ground branches of the relays for each of the sixteen possible combinations may be the more easily made. The formation of these different combinations is explained in the following articles.

156. First Combination.—In the first combination, No. 1 in the table, all four keys are open and, consequently, the negative poles of the short-end batteries, having an electromotive force of 100 volts, are connected to the points h and h_1. Then we have -100 in columns 6 and 7. Since these two electromotive forces oppose each other, there will be no current in the line L or in the line coils o, l, o_1, and l_1 of the four relays; hence, we have 0 (zero) in column 9. There is current, however, of an intensity of $\frac{100}{R}$, in the direction of the arrows x and x_1 in the artificial-line coils of all relays. The intensity of this current is not great enough to close the neutral relays, and its direction is such as to hold the polar relays open. Hence, we have $\frac{100}{R}$ (x) for column 8 and $\frac{100}{R}$ (x_1) for column 10. Since there is no current in the line coils of the four relays, as indicated by 0 in column 9, it is evident that the effective current has a strength of $\frac{100}{R}$ and flows in the direction of the arrow x in

the artificial-line circuit $A\ L$ at the west end, and in the direction of the arrow x_1 in the artificial-line circuit $A\ L_1$ at the east end. This is indicated by $\frac{100}{R}\ (x\ A\ L)$ and

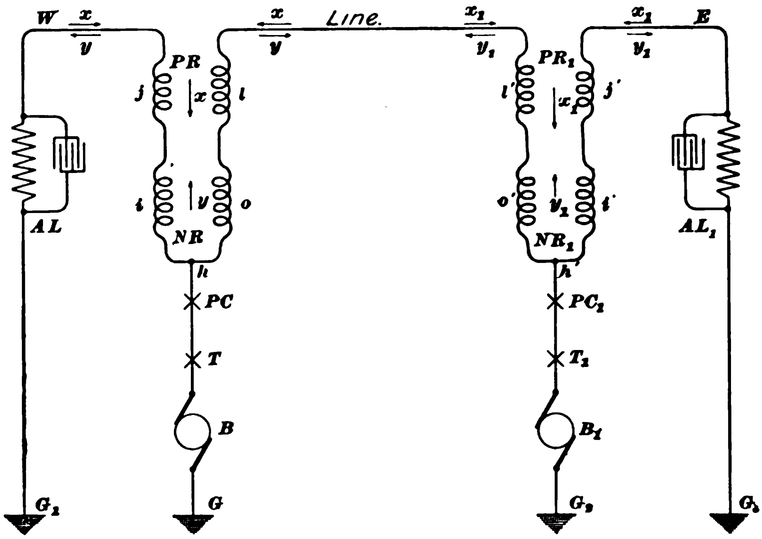


FIG. 55.

$\frac{100}{R}\ (x_1\ A\ L_1)$ in columns 11 and 12, respectively. All the relays will be open, as indicated, in columns 13, 14, 15, and 16.

157. Second Combination.—*Pk* is the only key closed in this combination. Closing the key *Pk* reverses the short-end battery B_1 in Fig. 54, causing the potential at h to be $+100$. Consequently, B_1 and B_2 are now in series, giving $\frac{200}{R}\ (y)$ in the line coils o and l, and $\frac{100}{R}\ (y)$ in the artificial-line coils i and j. The $\frac{200}{R}\ (y)$ in o and the $\frac{100}{R}\ (y)$ in i will give an effective current of $\frac{100}{R}\ (y)$ in o because the current flows from h through the two coils o and i in opposite directions around the iron core; hence, the $\frac{200}{R}\ (y)$ in o

neutralizes $\frac{100}{R}$ (*y*) in *i* and still has left $\frac{100}{R}$ (*y*) with which to magnetize the neutral relay *N R*. This current is too weak, however, to close this relay. Hence, closing the pole-changer key *Pk* does not affect the neutral relay *N R*.

As in the case of the neutral relay *N R*, the current $\frac{200}{R}$ (*y*) in *l* and the current $\frac{100}{R}$ (*y*) in *j* flow in opposite directions around the cores of the polar relay, giving an effective current equivalent to $\frac{100}{R}$ (*y*) in *l* alone, which will, on account of the direction in which it flows, continue to hold the polar relay *PR* open. Or, we may consider that the current of $\frac{100}{R}$ (*y*) now flowing in the coil *j* tends to close the polar relay, but that the current $\frac{200}{R}$ (*y*) in the coil *l* tends to keep it open, and since $\frac{200}{R}$ is twice $\frac{100}{R}$, the resultant magnetism, which is due to $\frac{100}{R}$ (*y*) in the coil *l*, will hold *PR* open. Hence, closing the key *Pk* does not affect either of the home relays *N R* or *PR*.

There is a current of $\frac{200}{R}$ (x_1) in l_1, and $\frac{100}{R}$ (x_1) in j_1. The current in j_1 is the same in strength and direction as before and tends to hold the polar relay open, but $\frac{200}{R}$ (x_1) in l_1 tends to close the relay, hence the resultant magnetism which is due to $\frac{100}{R}$ (x_1) in l_1 will close PR_1, as stated in column 15. The resultant of $\frac{200}{R}$ (x_1) in o_1 and $\frac{100}{R}$ (x_1) in i_1, is $\frac{100}{R}$ (x_1) in o_1. This is not sufficient current to close NR_1, hence it remains open. Therefore, when *Pk* alone is closed, the only relay that responds is the polar relay PR_1 at the distant end.

158. Third Combination.—The only key closed in this combination is *Tk*. Closing the key *Tk* connects the long end of the battery, that is, both *B* and B_1 in series, to the point *h* at the west station; hence, we have −300 volts at *h* and −100 at h_1. The current in the line circuit will be $\frac{200}{R}$ $(x\,y_1)$. The current in *i* and *j* will be $\frac{300}{R}$ (x); hence, the effective current that is due to $\frac{200}{R}$ (x) in *l* and $\frac{300}{R}$ (x) in *j* will be $\frac{100}{R}$ (x) in *j*. The resultant magnetization will hold the polar relay *PR* open.

The resultant magnetization of the neutral relay *NR* is due to $\frac{200}{R}$ (x) in *o* and $\frac{300}{R}$ (x) in *i*; this is equivalent, as in the polar relay *PR*, to the magnetization produced by a current of $\frac{100}{R}$ (x) in the coil *i*. This current is not strong enough to close the neutral relay *NR*, hence it remains open.

Since the full battery, 300 volts, at the west station opposes the short-end battery of 100 volts at the east station, the effective electromotive force in the line circuit, that is, the difference of potential between the points *h* and h_1, will be 200 volts in the direction of the arrows *x* and y_1. Hence, the current in the line coils l_1 and o_1 will be $\frac{200}{R}$ (y_1). The difference of potential between the point h_1 and the ground G_2 is 100 volts, due to the short-end battery B_3. This difference of potential tends to send a current of $\frac{100}{R}$ amperes through the artificial-line circuit $A\,L_1$ in the direction of the arrow x_1. Hence, the current in the artificial-line coils j_1 and i_1 is $\frac{100}{R}$ (x_1). Now the currents in the line and artificial-line coils of the east relays circulate around the iron cores in such a direction that they help each other in magnetizing the relays; hence, the

resultant magnetization due to a current of $\frac{200}{R}$ (y_1) in the line coils and a current of $\frac{100}{R}$ (x_1) in the artificial-line coils is equivalent to that produced by a current of $\frac{300}{R}$ (x_1) in the artificial-line coils j_1 and i_1. The direction of this current in the coil j_1 is such that the polar relay PR_1 remains open, but $\frac{300}{R}$ in i_1 is strong enough to close the neutral relay NR_1. Hence, when the key *Tk* that controls the number of cells connected to the circuit at the west station is closed, the only relay closed is the neutral relay NR_1 at the distant east station.

159. Fourth Combination.—In this combination, the two keys *Tk* and *Pk* are closed. Hence, the positive pole of the whole battery at the west station is connected to h, giving that point a potential of +300 volts, h_1 remaining at −100, as in all preceding combinations. The current in the line and in the coils o, l, l_1, and o_1 will be $\frac{400}{R}$ $(y\,x_1)$, and the current in the artificial line and in the coils i and j will be $\frac{300}{R}$ (y). Hence, the effective current, due to the difference between $\frac{400}{R}$ (y) in the line and $\frac{300}{R}$ (y) in the artificial line, will be $\frac{100}{R}$ (y) in the line coils o and l. Now, a current of $\frac{100}{R}$ (y) in the coil l is equivalent in its magnetizing effect, both in direction and intensity, to a current of $\frac{100}{R}$ (x) in the artificial-line coil j, but a current in the artificial-line coil j in the direction of the arrow x will hold the polar relay open. Therefore, the polar relay PR is held open by the effective current $\frac{100}{R}$ $(y\,L)$.

Furthermore, this effective current $\frac{100}{R}(y\,L)$ through the coil o is not strong enough to close the neutral relay NR. The current in the coils l_1 and o_1 is $\frac{400}{R}(x_1)$, and in j_1 and i_1 the current is $\frac{100}{R}(x_1)$. Hence, the resultant current $\frac{300}{R}(x_1)$ is not only strong enough to close NR_1, but it is also in the right direction to close the polar relay PR_1. Hence, the closing of the two western keys closes only the two eastern relays.

160. Similarly, the currents in the line and artificial-line circuits and the relays affected by the other various positions of the four keys may be worked out. The table is complete except for the ninth combination, which is left blank in order that the student may fill in these spaces for himself, and thereby acquire a better knowledge of the system.

161. Either side of a quadruplex can be used as a duplex; the polar side as a polar duplex, or the neutral side as a Stearns duplex. Duplex sets were excluded from the main office of the Postal Telegraph Company in Philadelphia, which was completed in September, 1900, and only single and quadruplex sets were installed. By this arrangement a second side is always available, when required on a circuit that is at the time being worked duplex.

QUADRUPLEX TERMS.

162. It will be well to give here some of the terms commonly used in quadruplex telegraphy. The battery B_1, Fig. 54, is called the *short end*, and B the *long end;* sometimes, however, the term *long end* means the whole battery, that is, both B and B_1. The point q, Fig. 54, is termed the *tap*, and the branch $q\,v$, the *tap wire*. That portion of the

quadruplex that is operated by opening and closing the transmitter key is called the *neutral*, *common*, or *No. 2 side*; and that portion that is operated by the pole-changer key is called the *polar* or *No. 1 side* of the system. These terms are also applied to the relays; that is, the relay that is operated by the increase and decrease in the strength of the current is called the *neutral*, *common*, or *No. 2 relay*; and the relay that is operated by a change in the direction of the current through it is called the *polar* or *No. 1 relay*. *Excess current* means the excess of current in one winding of a relay over the current in the other winding of the same relay. The coil, lettered *Gc* in most of the diagrams, that is included in the circuit in place of the transmitting apparatus and source of current at one end when the system is being balanced, is called the *ground coil*. It is used to replace whatever resistance there may be in the transmitting apparatus when the latter is cut out of the circuit. By this means the resistance from the line through the office apparatus to the ground is kept the same whether the transmitting apparatus is cut in or out.

The pull that can be allowed on the armature of either relay without interfering with the proper working of the system is called the *margin*. The margin is sometimes defined as the pull or number of turns (either up or down) that may be given to the retractile spring of the neutral relay without interfering with the incoming signals on that instrument. The margin on the neutral relay, which we prefer to define as the difference in pull on the armature of the neutral relay due to the difference between the strength of the current produced respectively by the short end and long end of the distant battery, that is, the difference in pull produced in the open and closed positions of the distant transmitter, may be increased by increasing the ratio of the strength of the current in these two positions of the transmitter. This may be done by increasing the electromotive force of the long end of the battery, or by decreasing the electromotive force of the short end of the battery; or by properly altering, in some quadruplex systems, certain

resistances included in the circuit. Evidently, the margin on the polar relay is the pull due to the short end of the battery, for the reversal of the short end gives the smallest force that must move the armature. Hence, to increase the margin on the polar relay, the electromotive force of the short end of the battery must be increased or the resistance of the circuit must be decreased.

The coils *Cr* and Cr_1, Fig. 56, which are in series with the condensers in the artificial line, are often called the *retarding* or *retardation coils*, because they retard the charge and discharge of the condensers.

163. The principles of the quadruplex telegraph system having been fully explained, it now remains to show several improvements that are used in the practical operation of the system, and, also, the manner in which the apparatus is arranged when dynamos are used in place of primary batteries. One of the difficulties to be overcome in quadruplex systems is to prevent the armature of the home neutral relay from being released when the distant pole changer passes through its middle position and reverses the direction of the current. This change in the direction of the current reverses the magnetism of the neutral relay, and, hence, there is an interval, although very small, during which the neutral relay, in passing from one direction of magnetization to the other, possesses no magnetism.

164. Advantage of Repeating Sounder.—To diminish the evil effect due to the reversal of the distant pole changer when the distant transmitter is closed, Edison inserted a repeating sounder between the relay and the reading sounder, connecting the circuit of the magnet of the repeating sounder to the back stop of the neutral relay and the circuit of the reading sounder to the back stop of the repeating sounder. This arrangement has already been explained in connection with the diplex telegraph system.

If the reversal in the magnetism of the neutral relay should occur while the relay is closed, although it might be of sufficient duration to break the front contact, still no click

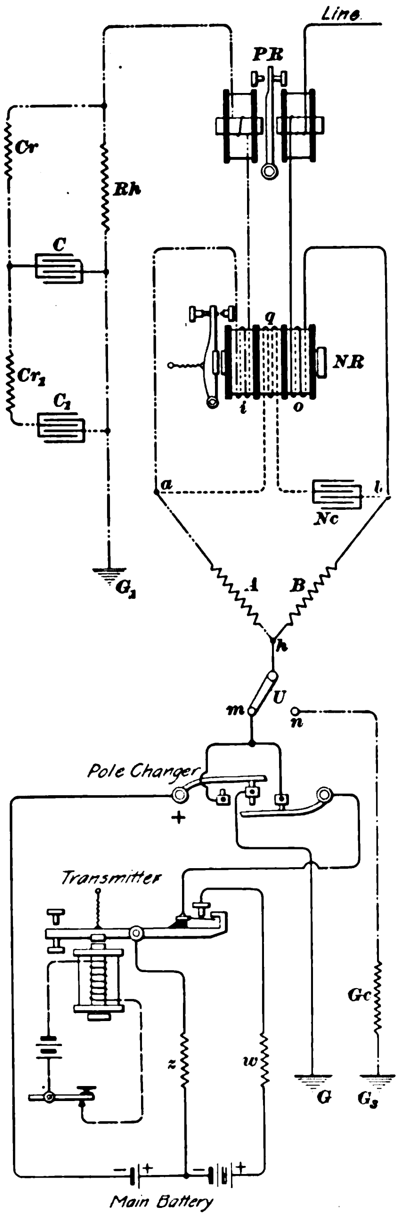


FIG. 56.

will ordinarily be heard on the receiving sounder, because the lever does not have sufficient time to cross the gap and touch the back stop, and thereby close the circuit containing the repeating sounder. It is evident, therefore, that the relay points should not be placed too near each other, nor the fact overlooked that there is such a thing as a proper adjustment of those points.

165. Smith Extra Coil and Condenser Device.—To still further reduce the evil effect due to the interval of no magnetism in the neutral relay when it should remain closed, an arrangement, shown in Fig. 56, is used by the Western Union Telegraph Company. It was introduced by Mr. Gerritt Smith in 1884 and is known as the **Gerritt Smith device.**

In this figure it will be noticed that the neutral relay *NR* has three distinct windings on each core. (In this figure only one core is shown.) In addition to the usual line

and artificial-line coils *o* and *i*, respectively, there is an extra coil *q* between the other two coils. This coil *q* is connected in series with a condenser *Nc*, and across the line and artificial-line circuits, from *a* to *b*, as shown. There are also two coils *A* and *B* of 300 ohms resistance each. The object of these two equal resistances *A* and *B*, the condenser *Nc*, and the extra coil *q* is to tide the neutral relay over the period of reversal. This coil *q* is wound and connected in such a direction that it tends to help the other coils close the relay.

When the distant pole changer short-circuits its battery while the home neutral relay is closed on account of the distant transmitter being closed, the condenser discharges through this coil *q* in such a direction as to tend to hold the relay closed. The current that charges back through the coil *q* when the distant pole changer again restores the line current, circulates around the relay coils in a direction opposite to that of the current that has just ceased, and tends to hold the armatures to the cores until the reverse current coming over the line from the distant end reaches its full strength. This reverse current charges the condenser in an opposite direction, causing the charging current to flow in the same direction through the extra coil as did the preceding discharging current. Hence, the charging current, which has a maximum strength when the distant pole changer first connects the opposite polarity to the line and decreases in strength as the line current approaches its steady maximum value, also tends to hold the relay closed. These charging and discharging currents are at a maximum when the line current passes through zero, and since both the discharging and charging currents passing through the extra coil are in the same direction and tend to magnetize the relay in the same direction as the reversed line current, it is evident that the period of no magnetism is considerably reduced.

166. If there was no resistance *A* and *B* in the circuit *a*–*h*–*b*, the terminals *a* and *b* of the condenser and extra

coil would never have any difference of potential; hence, there would be no charging or discharging current to flow through the extra coil. The difference of potential between *a* and *b* will depend on the products of the currents and the resistances in the circuits *a–h* and *b–h*. In order not to destroy the balance between the line and artificial-line circuits, *A* and *B* must be equal in resistance.

It is necessary to so arrange the connections of the coil *q* that the charging currents from the line and condenser will circulate around the ordinary and extra coils of the relay in the same direction. Long theoretical explanations could be given to show that this coil *q* and the condenser will always tend to tide the relay over the period of the reversal when the neutral relay is closed. However, the fact that practical experience has shown this to be the case is sufficient reason for this arrangement.

167. Three-Coil Neutral Relay.—The **three-coil neutral relay,** as it is called, is shown in Fig. 57. The iron cores are extremely short, and no more iron is used in the relay than is really necessary; the moving parts are made

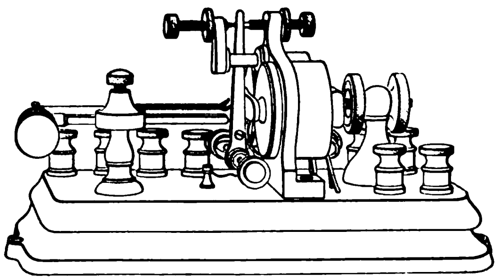


FIG. 57.

as light as possible, so that both the magnetic and the mechanical inertia are reduced to a minimum. As a result of this construction the relay is very quick-acting.

The cores in the neutral relay used by the Western Union Company have a diameter of $\frac{1}{2}$ inch and a length of $1\frac{3}{16}$ inches. The armature lever is $2\frac{3}{4}$ inches long, while the coils are $1\frac{1}{16}$ inches in length and $1\frac{1}{2}$ inches in diameter.

168. The way in which the coils are wound is shown in Fig. 58. In all quadruplex relays it is very necessary that the coils forming the two halves of the differential winding shall have the same number of turns and the same resistance. In order that this will be the case, the first coil that is wound on the core *a* is connected in series with the second coil on the core *b*; these two coils, so connected, form one half of the differential winding. The other half of the differential winding consists of the first coil that is wound on *b* connected in series with the second coil on *a*. The third coil that is wound on *a* is connected in series with a third coil wound on *b*, the two together forming the extra coil.

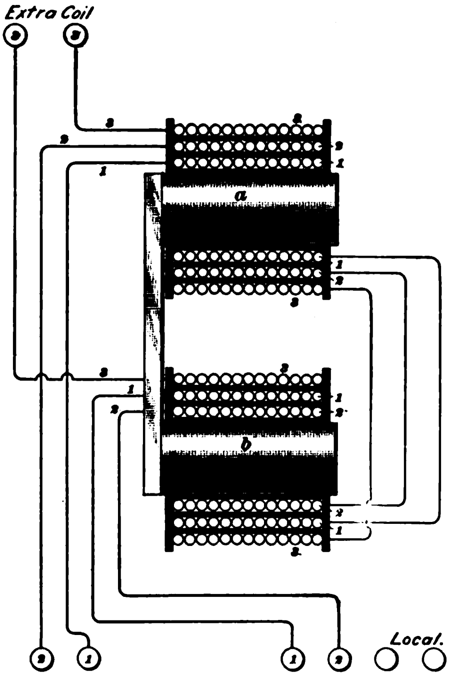


FIG. 58.

The binding posts marked *3* form the terminals of the extra coil; the binding posts marked *2*, the terminals of the artificial-line coil; and the binding posts marked *1*, the terminals of the line coils.

Each coil on each core contains 1,800 turns of about No. 36 B. W. G. silk-covered wire. Each half of the differential winding has a resistance of about 225 ohms, while the extra coil has a resistance of from 400 to 450 ohms. The third coil has a higher resistance than the other two because it is wound on the outside, and, hence, requires more wire for the same number of turns. For long-line circuits,

the line and artificial-line coils are sometimes wound to have a resistance of 400 ohms each.

169. The manner in which resistances and condensers are connected together to form the artificial line in the Western Union quadruplex system is shown in Fig. 56. *Rh* is the main resistance that is adjusted to equal the resistance in the line circuit to the ground at the distant station. The condenser *C* is so connected around this resistance that its charging and discharging current must flow through the resistance *Cr*. The condenser C_1 is so connected that its charging and discharging current must flow through both resistances *Cr* and Cr_1. The resistances *Rh*, *Cr*, and Cr_1, and the condensers *C* and C_1 are all adjustable, so that the resistance and capacity of the artificial line can readily be adjusted to equal that of the line circuit.

170. Ground Coil.—*U* is a switch that ordinarily rests on contact button *m* when the system is in operation, but the arm is turned to *n* when it is necessary to balance the set. Turning the arm of the switch *U* to *n* cuts out the main battery, transmitter, and pole changer, and grounds the receiving apparatus directly through the so-called **ground coil** *Gc*. The resistance of *Gc* is made equal to the resistance of the circuit from *h* through the main battery to the ground at *G*.

171. It frequently happens when the weather is very stormy and wet that it is impractical to obtain the margin necessary for the successful working of the neutral side of the quadruplex. In such a case it is better to close the neutral side and not attempt to use it, but to work the set as a polar duplex simply. When this is done, it is frequently necessary, in order not to have an excessive current, to include a resistance *w*, Fig. 56, in series with the whole battery. The increase in the strength of the current from the battery is due to leakage from the line through wet trees, insulators, and posts. Moreover, when only the polar side is in operation, less current is required than would be

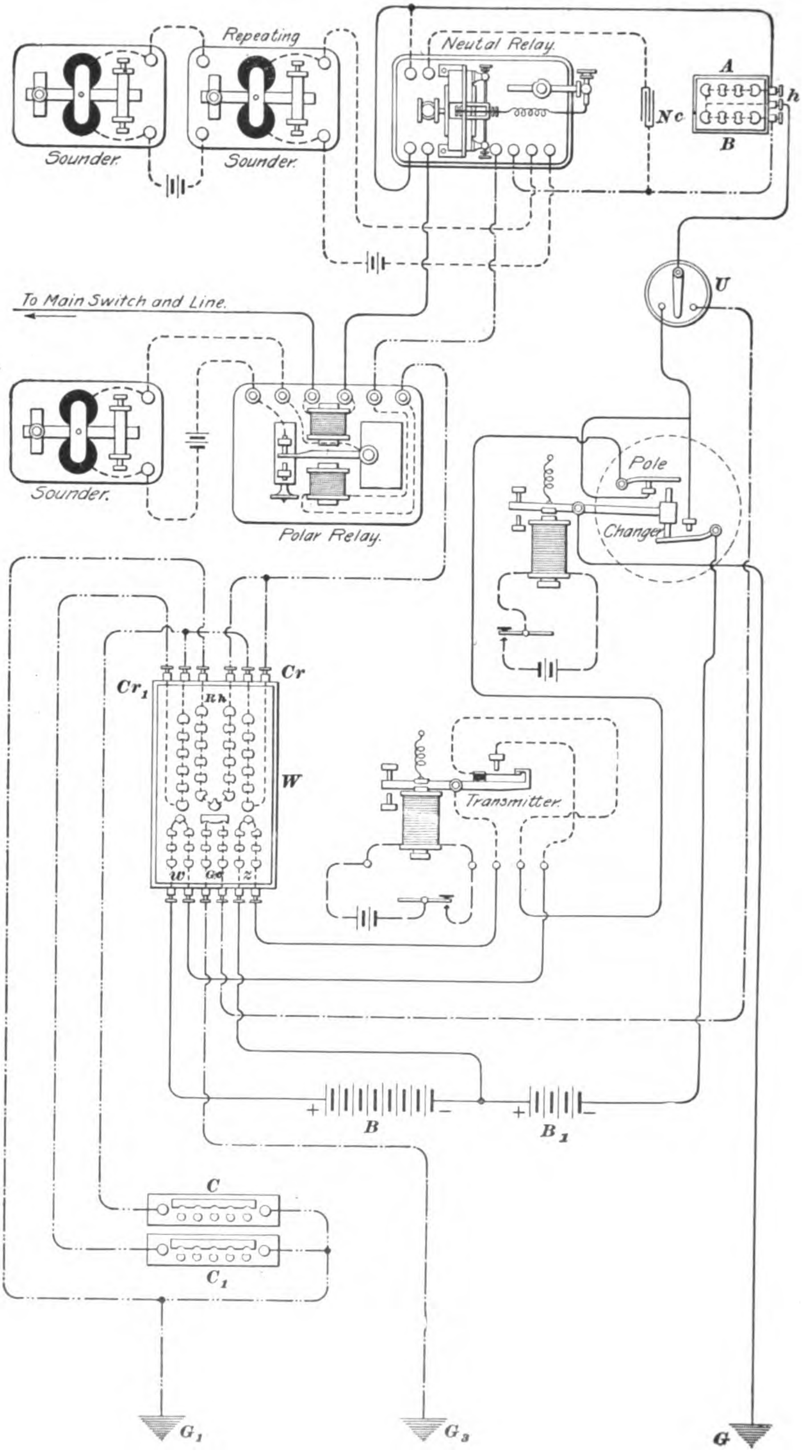
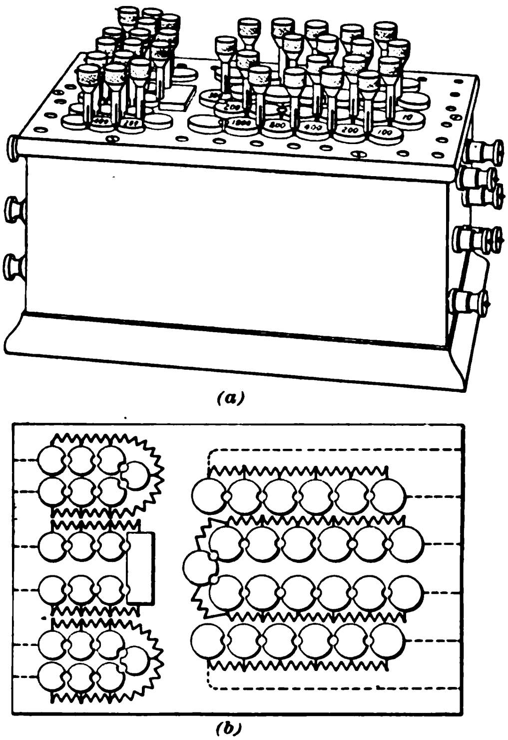

Repeating
Sounder
Sounder
Neutal Relay
Nc
A
B
h
U
To Main Switch and Line.
Sounder.
Polar Relay.
Pole
Changer
Cr
Cr1
Rh
W
w
Ge
z
Transmitter
B
B1
C
C1
G1
G3
G

FIG. 59.

given by the whole quadruplex battery, but preferably more than would be given by the short-end battery alone. When the weather clears and the system can be again worked as a quadruplex, this resistance *w* is cut out.

WESTERN UNION BATTERY QUADRUPLEX.

172. Fig. 59 shows the practical arrangement of the **Western Union quadruplex system,** in which gravity batteries are employed for both main and local circuits.



(a) (b)

FIG. 60.

The various condensers and instruments are lettered exactly as in Fig. 56. In connection with the neutral relay a repeating sounder, controlling an ordinary sounder, is used

for the reason already explained. The pole changer is of the clock-face type, and the transmitter is one of the ordinary continuity-preserving kind. The box *W* contains all the various resistance coils except the two *A* and *B* that are used in connection with the extra coil on the neutral relay. The resistance *Gc* is made equal to the resistance of the battery circuit; that is, to the internal resistance of the whole battery *B* and B_1. Thus, when the switch *U* is turned to the right, the point *h* to which the neutral and polar relays are connected is joined directly to the ground G_3 through the resistance *Gc*, so that the resistance offered to the incoming current is the same as in the working condition of the apparatus.

173. Fig. 60 (*a*) shows the general appearance of the box *W*, which contains six separate adjustable resistances, there being six binding posts on each end of the box; the resistance of these coils is adjusted by means of numerous pegs. In Fig. 60 (*b*) is shown, in a clearer manner, the six separate resistances just mentioned. The wave lines represent the resistances, usually non-inductively wound coils of German-silver wire, that are contained in the box and connected to the insulated brass pieces on the top of the box as indicated.

DYNAMO QUADRUPLEX SYSTEMS.

174. A different arrangement to that which has already been explained is necessary when dynamos are used in the quadruplex systems in the place of primary batteries. For the sake of economy, one dynamo supplies current for all circuits requiring about the same voltage, in which case it is impossible to reverse the line and earth connections of the dynamo without also reversing the polarity for all other line circuits that are supplied by that same dynamo. Hence, in duplex and quadruplex systems, one dynamo is used to supply negative current, and another to supply positive current. The machines themselves are never reversed; the

line connection is merely shifted from one machine to the other. Furthermore, it is sometimes desirable to make one dynamo supply both the long-end and short-end currents of one polarity, and another dynamo to supply both the long-end and short-end currents of the opposite polarity. It is a well-known fact that we can increase and decrease the current in a circuit by increasing or decreasing the resistance in series with a dynamo that generates a constant electromotive force.

PRINCIPLE OF WESTERN UNION DYNAMO QUADRUPLEX.

175. In applying dynamos to quadruplex telegraphy it is desirable to retain, as far as possible, the same apparatus used with gravity cells. With the exception of the extra resistances that are required, in the Western Union quadruplex, the same apparatus has not only been retained but it has, if anything, been simplified. In Fig. 61 is shown the theoretical arrangement of instruments when dynamos are used to supply the current for this quadruplex system.

The pole changer and the dynamos *D* and *D'* are arranged in the same manner as in the polar duplex, and the continuity-preserving transmitter is the same as the one used in several systems that have already been described. It is necessary in a quadruplex system, not only to be able to reverse the current and to vary the strength of the current in the ratio of 1 to 3 or 1 to 4, but it is also necessary to keep the resistance of the circuit at each terminal station as constant as possible. It would not do to directly insert or remove a resistance in such a manner as to appreciably alter the resistance of the whole system.

176. The arrangement of resistances shown in this figure was devised by Mr. S. D. Field for the Western Union Telegraph Company. In this figure, two resistance coils, one of 1,200 ohms and another of 900 ohms, called the *added resistance* and *leak coil*, respectively, are so arranged in connection with the pole changer and the transmitter that the

resistance of the circuit remains practically constant in all possible positions of these two instruments. The lever *f* of the pole changer is connected to a point *a* where the circuit

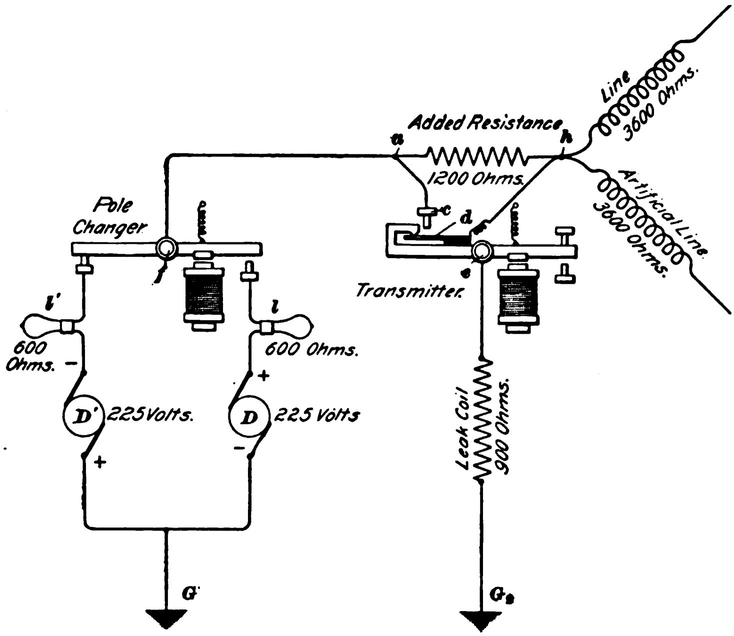


FIG. 61.

branches, one branch being directly connected to the stop *c* on the transmitter, and the other branch through the added resistance of 1,200 ohms to the point *h*.

The line and artificial-line circuits come together at the point *h*, which is also connected directly to the tongue *d* of the transmitter. The 900-ohm leak coil is connected between the lever *e* of the transmitter and the ground G_2.

177. Let us suppose that the line circuit, which includes the line coils of the neutral and polar relays and the apparatus in the line circuit at the distant station, has a resistance of 3,600 ohms, then the artificial-line circuit will have the same resistance. In series with each dynamo is a lamp of

600 ohms, which is necessary to protect the dynamos from injury due to an accidental short circuit.

178. Resistance of Circuit Is Constant.—The resistance of the circuit from *h* to the ground through the transmitter and pole changer at the home office to incoming currents is constant whether the transmitter is open or closed. With the transmitter open, the added resistance, 1,200 ohms, is in series with the 600-ohm lamp *l* or *l'*, making 1,800 ohms in this path. This 1,800 ohms, however, is in parallel with the 900-ohm leak coil, and, hence, the combined resistance of these two paths from *h* to the ground is

$$\frac{900 \times 1,800}{900 + 1,800} = 600 \text{ ohms.}$$

When the transmitter is closed, the *added resistance is short-circuited*, because the tongue *d* touches the contact stop *c*; and the *leak coil is on open circuit*, because the tongue *d* no longer touches the hook of the lever *c*. Hence, the only resistance between the point *h* and the ground through the transmitter and pole changer is the 600-ohm lamp in the dynamo circuit.

Therefore, the resistance from *h* to the ground through the transmitter and pole changer is the same, 600 ohms, in both positions of the transmitter. Evidently, the resistance is also the same in the two positions of the pole changer, because there is a similar 600-ohm lamp in series with each dynamo. Moreover, the resistance of the artificial line remains the same, namely, 3,600 ohms; hence, the combined resistance to incoming currents of all possible paths from *h* to the ground at the *home station* is always

$$\frac{3,600 \times 600}{3,600 + 600} = 514 \text{ ohms.}$$

Therefore, the incoming line current has a path of the same resistance from *h* to the ground in the open and closed positions of both the transmitter and pole changer. Since the same is also true at the distant end, it follows that the

resistance of the circuit is the same for all sixteen combinations of the four keys, as long as the resistance of the line circuit remains constant.

179. Furthermore, it can be shown that the total current supplied by either dynamo to one quadruplex circuit arranged in this manner is the same in both the open and closed positions of the transmitter. This remark does not strictly apply to intermediate positions of the two pole changers (one at each end). In the intermediate position of the pole changer, both dynamos, with their 600-ohm lamps, are on open circuit, but the time during which this is the case is extremely short when the pole changer is properly adjusted. It probably has some effect on the distant neutral relay, due to the fact that the line retards the arrival of the reversed current; and the neutral relay, although exceedingly quick in magnetizing and demagnetizing, has some magnetic inertia, though the amount may be very small, that must be overcome; hence, some time is required to reverse its magnetism. The momentary absence of the current does not cause any trouble in the polar relay, for, as has already been explained, the tongue of the polar relay will remain on whichever side it happens to be at the instant when the current ceases.

When the transmitter is open, the resistance from G through either dynamo circuit to the point h is 1,800 ohms. From the point h to the ground through both the line and the artificial-line circuits the resistance is 1,800 ohms, since the line and artificial-line circuits are in parallel with each other. This 1,800 ohms is in parallel with the 900-ohm leak coil; hence, the total resistance from h to the ground through the line, artificial line, and leak coil is

$$\frac{1,800 \times 900}{1,800 + 900} = 600 \text{ ohms.}$$

This resistance is in series with the 1,800 ohms in the dynamo circuit (1,200 in the added resistance and 600 in the lamp); hence, the total resistance of the circuit to which the dynamo

supplies current, in the open position of the transmitter, is 1,800 + 600 = 2,400 ohms.

180. When the transmitter is closed, the added resistance is short-circuited and the leak coil is on open circuit. Then the resistance from the ground G through either dynamo to the point h is 600 ohms, and the path from h to the ground consists only of the line and the artificial-line circuits, which have a combined resistance of 1,800 ohms. Thus the total resistance of the circuit to which the dynamo supplies current in the closed position of the transmitter is 600 + 1,800 = 2,400 ohms, the same as in the open position of the transmitter. Therefore, since the resistance remains the same, the current supplied by the dynamo will remain the same.

The amount of current that will flow into the line in the two positions of the home transmitter may be calculated as follows.

181. Transmitter Open.—It was shown in the last paragraph of Art. **179** that the total resistance of the circuit to which either dynamo supplies current when the transmitter is open is 2,400 ohms; hence, if the dynamo generates an electromotive force of 300 volts, there will be flowing between the ground G and the point h a current of

$$\frac{300}{2{,}400} = .125 \text{ ampere, or } 125 \text{ milliamperes.}$$

This current divides at the point h and flows through three paths. The same quantity evidently flows through the artificial-line circuit as flows through the line circuit, because the two circuits are exactly equal in resistance; hence, by calculating the total current that flows through these two circuits, the strength of the current that flows in the line circuit may be found by dividing the result found by 2. The joint resistance of the line and the artificial-line circuit, which are in parallel, will evidently be one-half of 3,600 ohms, or 1,800 ohms. This 1,800 ohms is in parallel with the leak coil of 900 ohms. The total current will divide

inversely in proportion to the resistance in these two circuits, and the sum of the currents in the line and artificial-line circuits will be to the total current supplied by the dynamo as the joint resistance of the three paths, 600 ohms $\left(=\frac{1,800 \times 900}{1,800 + 900}\right)$, is to the joint resistance of the line and artificial-line circuits, 1,800 ohms. Consequently, the sum of the two currents that will flow in the line and in the artificial-line circuits will be

$$\frac{600}{1,800} \times 125 = 41.6 \text{ milliamperes,}$$

and the current in the line will be one-half of 41.6, or 20.8 milliamperes.

182. Transmitter Closed.—When the transmitter is closed, the 1,200-ohm added resistance is short-circuited through the contact stop *c* and the tongue *d* of the transmitter, Fig. 61, and the 900-ohm leak coil is cut out of the circuit. With the transmitter in this position, the total resistance of the circuit will be 600 ohms + 1,800 ohms = 2,400, as before, and the total current is also the same. The total current will be 125 milliamperes, and one-half of this, or 62.5 milliamperes, will flow through the line.

183. Ratio of the Two Currents.—When the transmitter was open, the current in the line was 20.8 milliamperes; when closed, the current was 62.5 milliamperes. From this fact, it is evident that closing the transmitter increases the current *in the line* from 20.8 milliamperes to 62.5 milliamperes; that is, in the ratio of about 1 to 3. Nevertheless, the resistance of the home circuit to incoming currents and the total current remains the same in both positions of the transmitter.

It is frequently desirable to have the ratio of the current increase 1 to 4 instead of 1 to 3. In order to accomplish this, it is only necessary to increase the 1,200 ohms in the added resistance to 1,800 ohms, and to decrease the 900 ohms in the leak coil to 800 ohms. It can be shown in the same manner

as above that the ratio of the strength of the current in the two positions of the transmitter will now be as 1 to 4.

184. Added Resistance and Leak Box.—In order to readily accomplish this change in the added resistance and leak coil, the resistance box shown in Fig. 62 is used. Between the binding posts *a* and *b* two coils are joined in series, one of which has a resistance of 600 ohms and the other a resistance of 1,200 ohms; and between the binding posts *c* and *d*, two coils are joined in series, one of which has a resistance of 100 ohms and the other a resistance of 800 ohms. The resistance between the binding posts *a* and *b* will be 1,800 ohms when there is no plug in the hole at *e*. When, however, a plug is put in the hole at *e*, the resistance between *a* and *b* is only 1,200 ohms, because the 600-ohm coil is short-circuited. When there is no plug in the hole at *f*, the resistance between *c* and *d* is 900 ohms, and when there is a plug in the hole at *f*, the resistance between *c* and *d* is only 800 ohms. Hence, it is evident that with one plug in the hole at *e* we have an added resistance of 1,200 ohms and a leak coil of 900 ohms. By shifting this plug from *e* to *f*, the added resistance is 1,800 ohms and the leak coil 800 ohms; hence, it is a very simple matter to change the ratio of the current from 1 to 3 to 1 to 4.

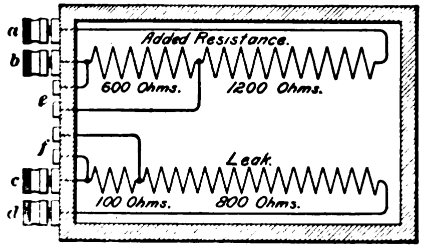


FIG. 62.

185. Western Union Dynamo Quadruplex. — Fig. 63 is a diagram of the Western Union quadruplex, showing the connections of the main-line and artificial-line circuits when dynamos are employed. The local circuits for the sounders, transmitter, and pole changer are shown in Figs. 67 and 68. The apparatus and connections in Fig. 63 are lettered, as nearly as possible, as in the preceding figures.

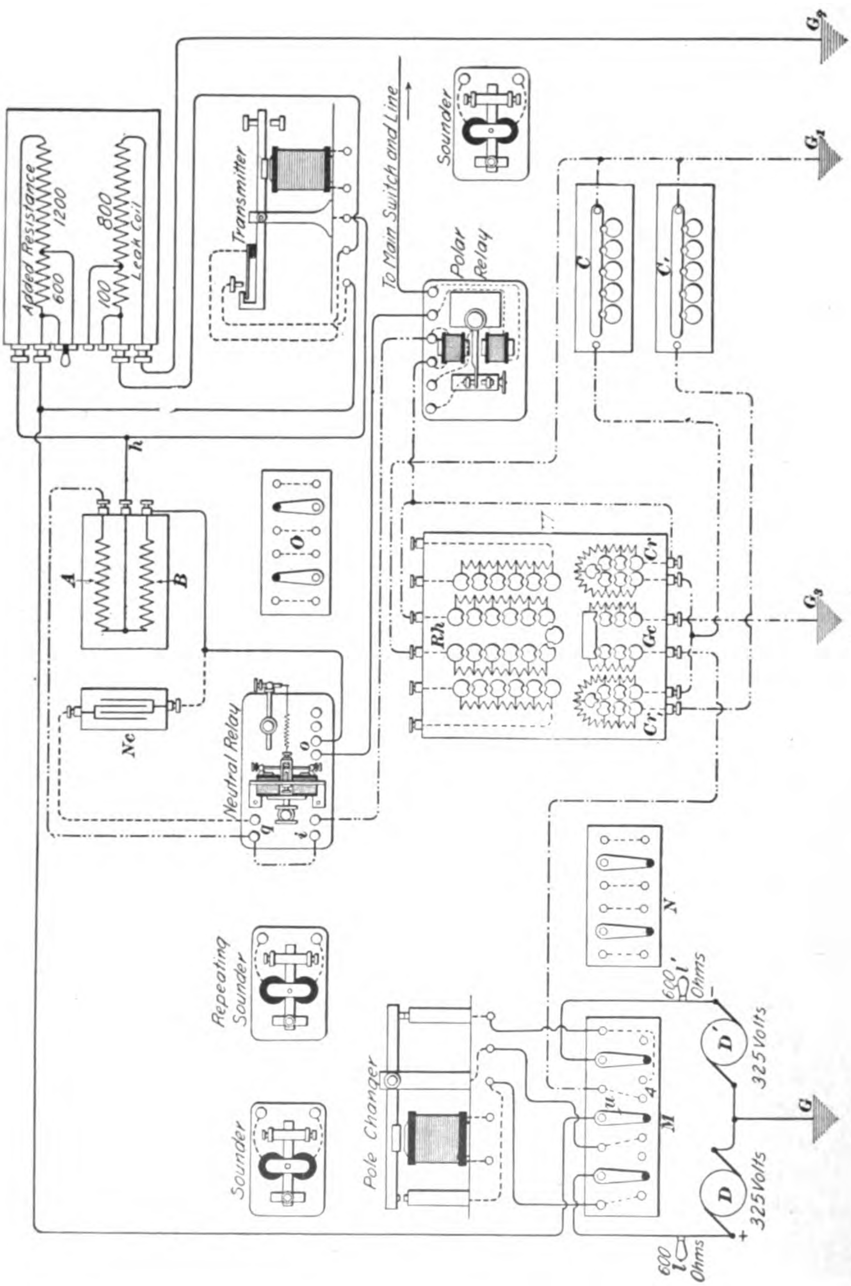

Added Resistance
600
1200
100
800
Leak Coil
Transmitter
To Main Switch and Line
Sounder
Polar Relay
C
C,
Rh
Gc
Cr
Cr,
A
B
h
Nc
O
Neutral Relay
Repeating Sounder
Sounder
Pole Changer
M
N
D
D'
325 Volts
325 Volts
600 l Ohms
600 l' Ohms
G
G1
G2
G3

FIG. 63.

The three arms of the switch *M* are all turned to the left when the system is in working order. The arm *u* of the switch *M* is turned so as to rest on the right-hand button *4* when the set is being balanced. This disconnects the two dynamos *D* and *D'* and the pole changer entirely from the circuit, and connects the neutral and polar relay through the center arm *u* of the switch and through the ground coil *Gc* to the ground G_2. In series with each dynamo is a lamp *l* or *l'*, having a resistance of 600 ohms. The various resistances are placed in boxes and means provided for readily adjusting both them and the condensers. The latter are usually placed under the table. The box *W* contains all the resistance coils for the artificial line; that is, the resistances *Rh*, *Cr*, and Cr_1, and, also, the ground coil *Gc*. *Nc* and *A B* represent the condenser and resistances, respectively, that are used in connection with the extra, or third, coil of the neutral relay.

FREIR SELF-POLARIZING RELAY.

186. In quadruplex telegraphy, where two messages are simultaneously sent in the same direction, one by reversals and the other by changes in current strength, a difficulty is encountered in accurately recording signals of the latter class that is due to a period of no current through the neutral relay at the moment of current reversal. The armature of the neutral relay when attracted by the stronger current will be momentarily released when the current is reversed and will make a movement toward the back or working contact, which, if completed, would cause a false signal.

The object that Mr. Freir had in view when designing his self-polarizing relay was to produce a neutral relay that would be very sensitive to changes in the strength of the current but which would avert, as far as possible, the false movement of the relay armature during the cessation of current at the moment of reversal.

187. The Freir relay, although called a self-polarizing relay, is, in reality, not a polarized relay. It does not respond to a change in the direction of the current, and, therefore, cannot be used except as a neutral device. Like all "common-side" relays, it is operated only by alterations in the *strength of the current*. It derives its name from the fact that its armature becomes alternately positive and negative by reversals of the current.

188. The **Freir self-polarizing relay,** shown in Fig. 64, has three parallel coils *A*, *B*, and *C* wound on soft-iron cores. To each end of each core is fastened a soft-iron extension that forms a pole piece, three of which *a*, *b*, and *c* are shown in the figure. There are two soft-iron armatures, one resting in the pole piece *b* and the other in a similar pole piece at the other end of the coil *B*. These armatures are fastened to an aluminum frame in the same manner as the armatures of the new standard Western Union polarized relay illustrated in Fig. 22. The magnets and armatures are enclosed in a brass case with a rubber top in a similar manner. The retractile spring *e*, in Fig. 64, tends to hold the tongue *D* against the stop *p*. The three electromagnets are connected in series, their coils, however, being so wound and connected that a current passing through them in one direction produces a south pole at *a* and *b* and a north pole at *c*. At the same time, the south pole at *b* produces, by induction or by actual contact, a south pole in that portion of the armature that is between the pole pieces *a* and *c*. Thus, with this direction of current, the south pole at *a* tends to repel and the north pole at *c* to attract the armature. If this current is strong enough, *D* will be moved from *p* against *q* and will remain there until the

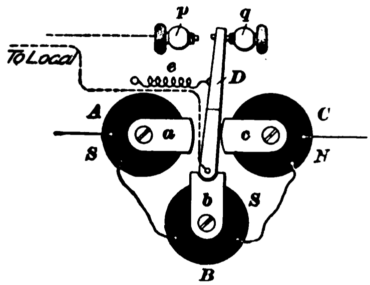


FIG. 64.

strength of the current is sufficiently diminished to allow the spring *e* to pull it against the stop *p*. Whenever the current is reversed by the operation of the distant pole changer, there will be a momentary cessation of current through the coils *A*, *B*, and *C*, but with a relay constructed in this manner, the momentary absence of current is not of sufficient duration to permit the armature to be sufficiently released to allow *D* to return to the back stop *p*. When the current is reversed, a north pole is produced in *a*, *b*, and in that portion of the armature that lies between *c* and *a*, while a south pole is produced in *c*. Hence *c* continues to attract the armature and *a* to repel it. Thus, although the magnetism of the several pole pieces is reversed, their respective attractions and repulsions remain unchanged.

189. This relay has proved to be a very satisfactory instrument. Aside from the self-polarizing principle, the absence of yokes, the small amount of iron in the cores of the magnet, and the excellent disposition of the cores, pole pieces, and armature, and the light weight and consequent small inertia of the moving parts, make this relay work very quickly and efficiently. Furthermore, it requires no condensers or other devices that are necessary on the neutral side of some quadruplex systems in order to tide the neutral relay over the interval of no magnetism while the direction of the current is being reversed.

190. Each coil of this relay consists of two separate windings, so that the relay can be connected differentially in the circuit the same as any differentially wound relay. Each half of the winding on one core contains about 2,350 turns of wire and has a resistance of 133⅓ ohms. This makes 400 ohms in the main-line and artificial-line circuits. The method of winding this relay is shown in Fig. 65, which is a view of the relay as it appears when looked at from above, all the details that might tend to complicate the figure being omitted. The binding posts are shown along the top of the figure. When the current flowing into the relay divides equally at *h*, half flowing out at *m* and half out at *o*, it will

be found by tracing the direction of the current in each coil around the iron core, that the two coils on each core neutralize each other; hence, the relay is not magnetized. If, however, the current does not divide equally at *h*, then the relay is energized and the armature will close the local circuit if the difference in the strength of the current in the two halves is sufficient to overcome the opposing spring.

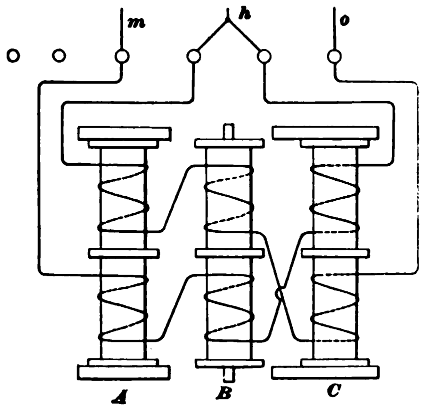


FIG. 65.

191. Adjustment. In order that the contact points of the Freir relay will not remain permanently closed, there is attached to the tongue a retractile spring that has a tension strong enough to keep the relay open when it is magnetized only by the smaller current employed in the quadruplex system. The adjustment of the spring is identical with that of the ordinary neutral relay.

The proper position of the armature lever between the two magnets is shown in Fig. 64. The space between the lever *D* and the pole piece *a* should, under ordinary conditions, be at least twice as great as that between armature *D* and pole piece *c*. Ordinarily *c* should be placed $\frac{1}{32}$ inch from the armature and *a* about three times that distance, or $\frac{3}{32}$ inch, from the armature. As the magnet *A* repels the armature and the magnet *C* attracts it, it is natural to suppose that if the magnet *A* were nearer the armature it would help *C* move the armature, but that is not the case. Under normal conditions the repelling magnet *A* should not help the magnet *C* do its work, and for that reason it is pulled away from the armature, as stated. If the repelling magnet is placed too close to the armature, the lines of force

from *C* will cut through and weaken the polarity of the armature and so reduce the attraction of the latter for *C*.

The third coil may seem to be superfluous, and easily dispensed with. This is not the case, however, because it has, in practice, proved to be beneficial in bringing the repelling coil closer to the armature, when the effective current on a long circuit is weakened by the leakage due to wet weather and when the repelling magnet is actually needed in order to help a feeble incoming current move the armature. This enables the repelling lines of force to cross the intervening gaps in their endeavor to reach the opposite polarity, and their transit being in the same direction as those of the attracting magnet, the movement of the armature is accelerated by their combined strength.

A relay very similar to the Freir self-polarizing relay, but without the repelling coil, has been used in England. A strong point in favor of the third, or repelling, coil is found in the fact that the three-coil arrangement has given satisfaction where the English two-coil relay has failed.

NEW STANDARD WESTERN UNION QUADRUPLEX.

192. Fig. 66 gives the diagram of connections of the new standard quadruplex of the Western Union Telegraph Company, in which the new standard apparatus and dynamos are used. In order to keep the diagram as clear as possible, all sounders and local circuits have been omitted. They will be shown in Figs. 67 and 68. The apparatus to which it is desirable to call particular attention is the Freir self-polarizing relay, which is now being introduced in place of the ordinary three-coil neutral relay, the new form of polar relay, and the resistance boxes *Rh* and *V*, which are slightly different in form from any previously shown. The use of the Freir relay has improved the working of the system and does away with the condenser *Nc* and the coils *A* and *B* shown in Fig. 56, as they are not needed to bridge this relay over the interval of no magnetism due to the

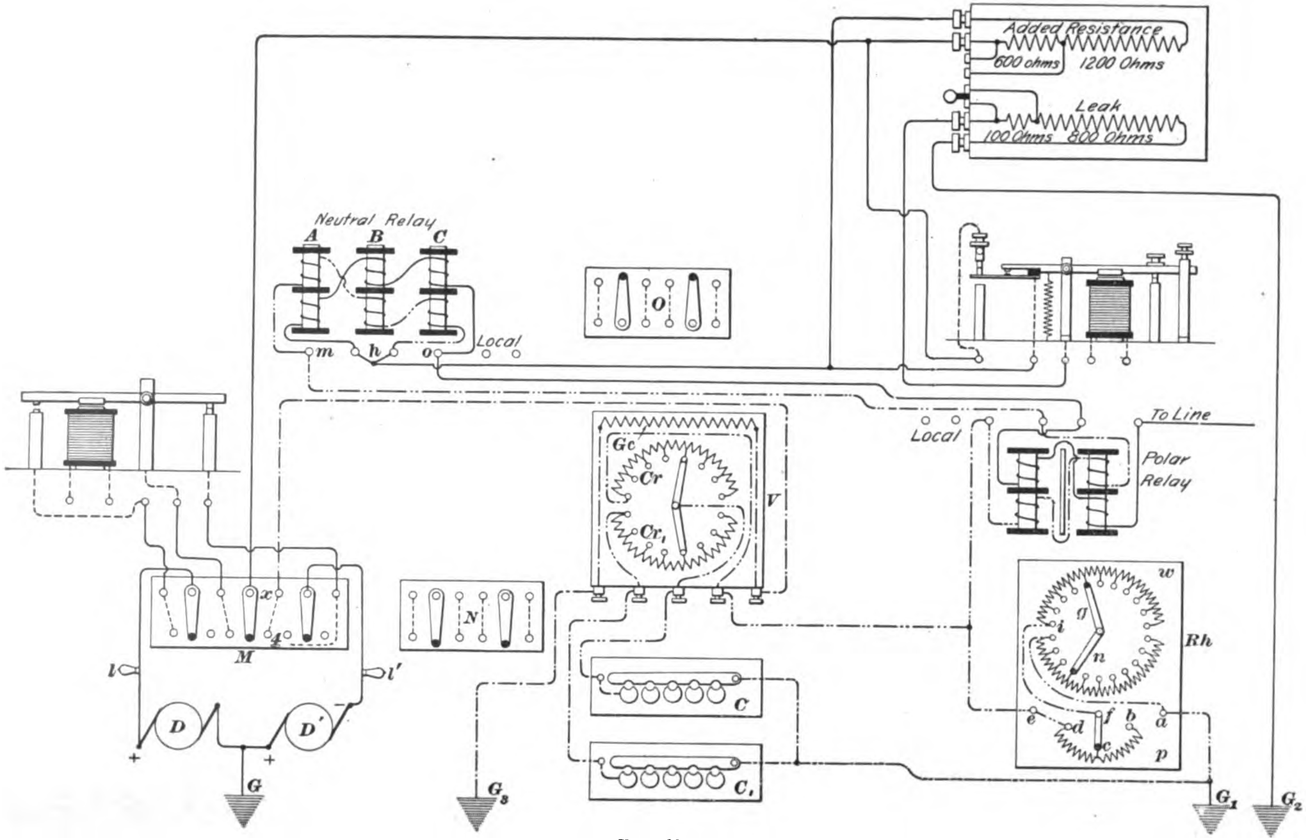
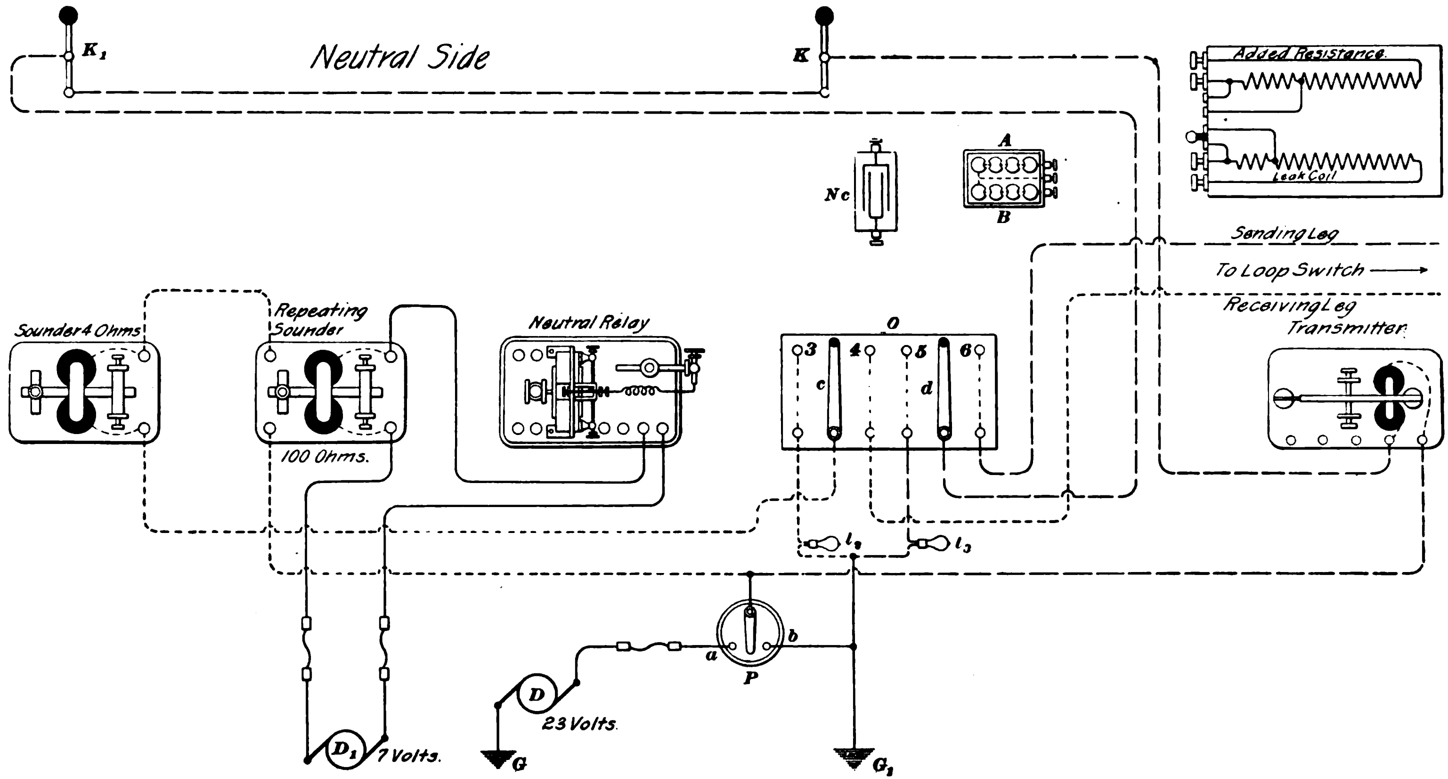

Added Resistance
600 ohms
1200 Ohms
Leak
100 Ohms
800 Ohms
Neutral Relay
A
B
C
m
h
o
Local
O
To Line
Local
Polar Relay
Gc
Cr
Cr,
V
M
x
4
N
l
l'
D
D'
+
G
G₃
C
C,
w
g
i
n
Rh
e
d
f
b
a
c
p
G₁
G₂

FIG. 66.

reversal of the distant pole changer. The Freir relay merely replaces the older form of neutral relay and does not change the principle of this quadruplex system in any way.

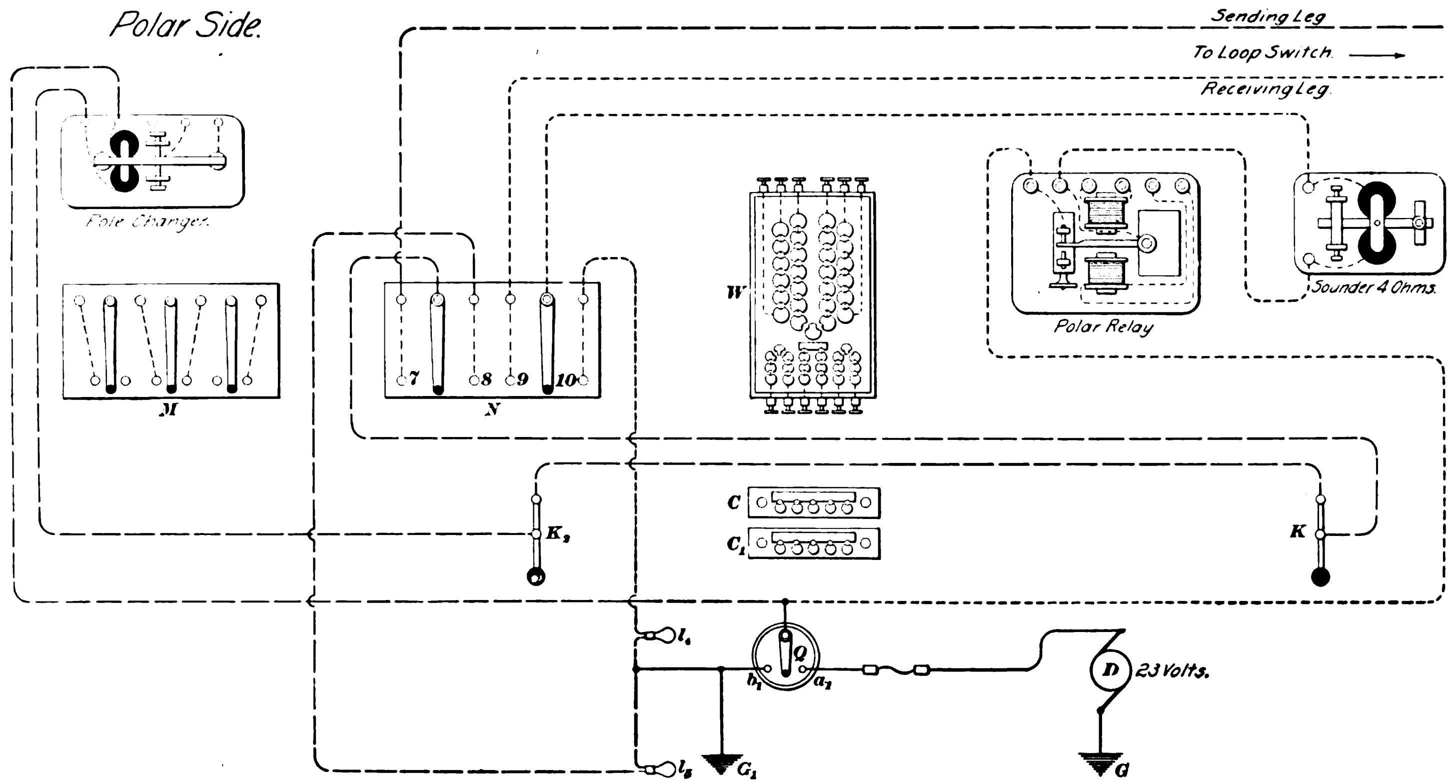
193. The resistance box *Rh* contains the resistance for the artificial line corresponding to *Rh* in Fig. 56. In Fig. 66 both the top *w* and the front *p* of the box containing the resistance *Rh* are shown. On the front *p* of the box is a switch arm *f* that connects the contact button *i* with any one of the contact buttons *b*, *c*, or *d*. Between these contact buttons are two coils, each of which has a resistance of 3,000 ohms. When the arm *f* rests on *b*, both of these coils are connected in series in the artificial-line circuit; when the arm rests on *c*, one of these coils is cut out; and when it rests on *d*, both coils are cut out. The arm *g* on the top of the box makes a contact with any one of eleven buttons; the arm *n* may similarly be placed in contact with any one of eleven buttons. The amount of resistance in the circuit between *a* and *e* depends on the positions of the arms *g*, *n*, and *f*. There are ten coils in the upper part of the rheostat *Rh*, each coil having 400 ohms resistance, and ten coils in the lower part of the same box that have 40 ohms resistance each.

194. The box *V* contains a coil *Gc*, corresponding to the ground coil *Gc*, in Fig. 56. This coil is included in the circuit for the purpose of balancing the system. The ground coil *Gc*, which need not be adjustable, has a resistance of 600 ohms, which is equivalent to the resistance of the lamp in each dynamo circuit. The coils *Cr* and Cr_1 are adjusted by means of two radial arms. These coils correspond to the coils *Cr* and Cr_1, respectively, in Fig. 56, and the condensers *C* and C_1 correspond to the condensers *C* and C_1, respectively, in the same figure. The total resistance in the upper, or *Cr*, portion of the box is 525 ohms, and the total resistance in the lower, or Cr_1, portion of the box amounts to 1,000 ohms. Thus the resistance *Cr* may be adjusted from 0 to 525 ohms, and the resistance Cr_1 from 0 to 1,000 ohms. Usually, the condenser *C* should have about



Neutral Side
K1
K
Added Resistance
Leak Coil
Nc
A
B
Sending Leg
To Loop Switch
Receiving Leg
Transmitter
Sounder 4 Ohms
Repeating Sounder
100 Ohms.
Neutral Relay
O
3
4
5
6
c
d
l2
l3
a
b
P
D
23 Volts.
D1
7 Volts.
G
G1

FIG. 67.



Polar Side.
Sending Leg
To Loop Switch
Receiving Leg
Pole Changer
Sounder 4 Ohms.
Polar Relay
M
N
W
7
8
9
10
C
C1
K
K2
Q
a1
b1
D
23 Volts.
G
G1
l4
l5

FIG. 68.

twice the capacity of C_1', since it equalizes the charge on the near end of the line, which is greater than the charge toward the center of the line. This charge is to a large extent equalized by the condenser C_1. These radial-arm resistance boxes are not extensively used, because operators have found that boxes requiring the use of plugs in their adjustment are more reliable, because plugs make firmer connections than do the radial arms.

195. The switch *M* has already been shown in connection with quadruplex and duplex systems. When the three arms of the switch rest on the left-hand contact buttons, the apparatus is properly connected for use. In order to balance the quadruplex, the switch arm *x* should be turned to the right until it rests on the contact button *4*. This cuts off both dynamos, the transmitter, and the pole changer, and connects the receiving apparatus directly to the ground through the ground coil *Gc*.

196. Local Connections.—Figs. 67 and 68 show the connections for the local circuits of the Western Union quadruplex system when dynamos are used, Fig. 67 represents the neutral, common, or No. 2, side of a complete set. Fig. 68 represents the polar, or No. 1, side. In this figure, in order that the apparatus and connections on the neutral side may appear to the student as they would if he were facing that side of the table instead of the polar side, it is only necessary for him to look at the figure upside down. In both of these figures the apparatus is arranged and lettered the same as it is in Fig. 63. The local circuits for Fig. 66 would be connected in the manner shown in these two figures. The repeating sounder that is controlled by the neutral relay is operated by the 7-volt dynamo D_1, which is used for operating all repeating and ordinary 100-ohm sounders in the main office of this company. All 4-ohm sounders, pole changers, and transmitters are supplied with current from the same 23-volt dynamo *D*.

The local circuits are so arranged that they may be extended through the loop switchboard to a branch office. On

the neutral side, shown in Fig. 67, the receiving circuit is controlled by the repeating sounder, which, in turn, is controlled by the neutral relay. On the polar side, shown in Fig. 68, the receiving circuit is controlled by the polar relay. Both receiving circuits are shown by dotted lines; the sending circuits, one of which includes the pole changer and the other the transmitter, are shown by dash lines. It will be noticed that two keys are placed in each of the sending circuits; the second key in each circuit is to enable the receiving operator to break and communicate with the distant end without having to leave his position. Of course, it is only allowable for him to break when the sending operator on that side is not using his key.

197. The switches *O* and *P* in Fig. 67 and *N* and *Q* in Fig. 68 are used in the same manner as are those that were described in connection with the polar duplex. When the system is in operation and the local circuits are not to be extended to any branch office, the arms of the switch *N* should rest on the contact buttons *8* and *10*; the arms *c* and *d* on the contact buttons *3* and *5*; and the switches *P* and *Q* on the contact buttons *a* and a_1, respectively. With the switches in this position, the receiving circuit on the neutral side, Fig. 67, may be traced from the ground *G* through the 23-volt dynamo *D*, contact button *a*, arm of the switch *P*, contact points of the repeating sounder, the magnet of the reading sounder, the switch arm *c*, contact button *3*, the lamp l_2, to the ground G_1. The transmitter circuit may be traced from the ground *G* through the 23-volt dynamo *D*, contact button *a*, arm of the switch *P*, the magnet of the transmitter, keys *K* and K_1, the switch arm *d*, contact button *5*, the lamp l_3, to ground G_1. The two circuits on the polar side may be traced in the same manner, and the student should be able to do this for himself.

198. When the receiving and sending circuits are to be extended to branch offices, the sending and receiving legs on one side are ordinarily connected to one branch office,

and the sending and receiving legs on the other side to another branch office. It is not necessary that both sending and receiving circuits should be extended to the same branch office. The branch offices are able to receive the messages that are coming in through the neutral and polar relays, and to send out messages by controlling the transmitter and pole changer. In order to extend these receiving and sending circuits to branch offices, the arms of the switch *N*, in Fig. 68, are turned to the left until they rest on contact buttons *7* and *9*, and the arms of the switch *O*, in Fig. 67, are turned to the right until they rest on contact buttons *4* and *6*; the arms of the switches *P* and *Q* remain on buttons *a* and a_1 as before.

The receiving circuit on the neutral side, shown in Fig. 67, may be traced from the ground *G* through the 23-volt dynamo *D*, switch *P*, contact points of the repeating sounder, the magnet of the reading sounder, the switch arm *c*, contact button *4*, the receiving leg to the loop switchboard, the main switchboard and line wire to the branch office, and then through a sounder to the ground at the branch office. The sending circuit on the same side may be traced from the same ground *G*, through the 23-volt dynamo *D*, the switch *P*, the magnet of the transmitter, keys *K* and K_1, the switch arm *d*, contact button *6*, sending leg to the loop switchboard, the main switchboard and line to the branch office, and then through a sounder and key to the ground at the branch office. The connections through the loop switchboard and the branch office are exactly the same as those shown in connection with branch-office circuits in the polar duplex system. It will be noticed that the lamps l_2, l_3, l_4, and l_5 are not in the circuit when the arms of the switches *N* and *O* are turned so as to extend the circuits to the loop switchboard and branch offices. Each one of these lamps has a resistance equal to the resistance in one leg of the branch-office loop, so that the current through the sending and receiving sides is the same in both positions of the arms of the switches *N* and *O*. When the sets are not in use, all connections with the 23-volt dynamo are

broken by turning the switches P and Q to the contact buttons b and b_1, respectively.

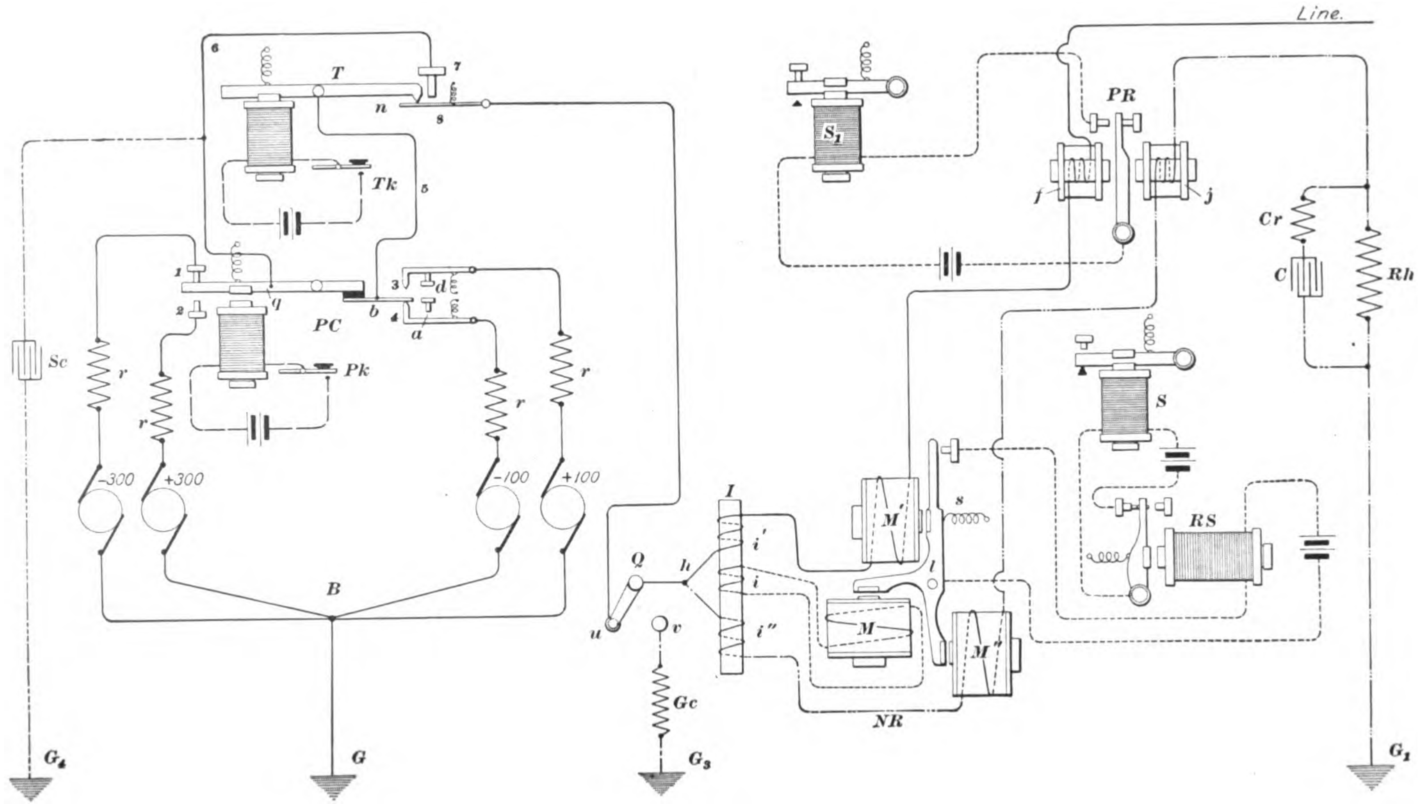
199. The quadruplex apparatus shown in Figs. 67 and 68 is arranged on a large table that is divided into four parts, one quarter being for each operator. Sitting side by side are two operators, one of whom is sending through the pole changer while the other is receiving through the polar relay. Facing these two operators are the other two, one of whom is sending through the transmitter while the other is receiving through the neutral relay.

JONES QUADRUPLEX SYSTEM.

200. The quadruplex system used by the Postal Telegraph Company is known as the **Jones quadruplex,** from its inventor, Mr. F. W. Jones. Its principal features are shown in Fig. 69.

Dynamos are used for generating the current for the line and local circuits. For operating the main-line circuits, four machines are used. They are adapted, respectively, to deliver current to the line at the following pressures: one +130 volts, one −130 volts, one +350 volts, one −350 volts. On different lines, different voltages are used; the lower electromotive force ranging from 75 to 135 volts, and the higher from 225 to 400 volts. 100-volt and 300-volt machines are indicated in the figure merely for convenience in explaining the system. These machines each have one of their poles connected to a common ground G.

201. PC is a pole changer that is worked by the key Pk in the local circuit. The pole changer, which has a slightly different construction than any previously shown, serves simply to control the polarity of the current going to the line. T is a transmitter that is worked by the key Tk in a local circuit and serves simply to control the strength of the current going to the line, irrespective of its polarity. The two parts of the lever of the pole changer are insulated from



Line.
T
7
6
n
8
Tk
5
1
2
3
4
q
b
d
a
PC
Pk
Sc
r
r
r
r
-300
+300
-100
+100
B
G
G4
S1
PR
f
j
Cr
C
Rh
S
RS
M'
M
M''
s
l
I
i'
i
i''
h
Q
u
v
Gc
G3
NR
G1

FIG. 69.

each other at *b*. This pole changer makes contact either at *1* and *4* or at *2* and *3*; *1* and *2* are fixed contact stops while *3* and *4* are spring contacts. The lever, when it moves upwards, may be made touch the spring *3* before it leaves the spring *4*; and when it moves downwards, it may be made touch the spring *4* before it leaves the spring *3*, thus making a continuity-preserving pole changer only at the lower voltage end. The stops *a* and *d* may be adjusted until the circuit is reversed in this manner. Thus in the middle position of the lever, the two machines −100 volts and +100 volts are momentarily in series and preserve a continuous circuit from the lever of the transmitter *T* to the ground *G*. The higher voltage machines are not arranged in this manner because the sparking at the contact stops *1* and *2* would be injurious.

202. Non-inductive resistance coils *r*, usually of 800 ohms each, are connected directly in series with each dynamo. A condenser *Sc*, called the **spark condenser,** is generally connected between the lever *q* of the pole changer and the ground, in order to reduce the spark at the contact stops *1* and *2*, which are connected to the higher voltage dynamos. The extra current that otherwise would cause a bad spark when the circuit is broken at either stop *1* or *2* is opposed by the discharge from the condenser *Sc*, thus preventing the spark, or at least reducing its intensity.

203. Jones Neutral Relay.—*NR* is a triple-magnet relay wound differentially, but not polarized, and, therefore, responding to currents in either direction. It is a special form of a neutral relay. The spring *s* is so strong that incoming currents from the distant 100-volt dynamos will not close the relay, but those from the distant 300-volt dynamos will. The two electromagnets M' and M'' are magnetically independent of each other in the sense that their cores are not magnetically connected in any manner, but they act in conjunction upon one armature lever. The cores are made as short as possible and have a very narrow slot running to the center of the core. This slot is for the purpose of cutting

off induced, or eddy, currents. The magnets M' and M'' are balanced with respect to outgoing currents in the ordinary manner, and although not so shown in this figure, each core has two separate coils, connected respectively in the main and artificial lines as shown in Fig. 70. The two coils on each magnet oppose each other when outgoing currents are flowing through them.

As the two magnets pull in conjunction on the same armature lever, when an unbalanced current circulates through the line and artificial-line coils, the magnetic effect of arriving currents is augmented; and as the cores of these magnets are independent of each other, the time required for the reversal of the magnetism of both cores is not increased beyond that incurred were only one of them in circuit. It is thus possible to preserve, or prolong, the magnetic pull of the neutral relay by reducing the time of reversal of the magnetism in the cores. M is a smaller magnet that acts on a third arm of the armature lever. The magnetic pull of this magnet assists the pull of the other two magnets.

The armature of the relay is made of aluminum and is very carefully balanced. The retractile spring s and the magnets M' and M'' have all the adjustments found in an ordinary relay. The magnets occupy the positions shown in the figure; that is, M is below M' and about on a level with M''.

204. I, in Fig. 69, is an induction coil having two primary coils i' and i'', and one secondary coil i. The magnet coils M' and M'' and the two primary coils i' and i'' are differentially wound. The coil i' is connected in series with M' in the line circuit, and i'' in series with M'' in the artificial-line circuit. The object of this device is to prevent the mutilation of the signals received by the neutral relay, by preventing the armature from falling back upon the back stop when it should not do so. One of the primary coils of the induction coil I is wound and connected so as to neutralize the effects of the other primary coil. Under the

influence of currents for outgoing signals, the secondary coil *i* of the induction coil has no current induced in it, because the two primary coils neutralize each other's effects. But incoming currents passing through the primary coil will induce an instantaneous current in the secondary coil *i*, which passing through the magnet coil *M* will magnetize it. The effect of the current thus set up in the secondary coil and made to act on the neutral relay is adjusted so that the induced secondary current will not be sufficient to pull the armature away from the back stop. When, however, the armature lever is against its front stop, and, therefore, in closer proximity to the core of the relay, the secondary current will be sufficient to hold up the armature, although the strength of the current in the coils *M'* and *M"*, consequent upon a reversal of polarity, may momentarily cease.

Suppose that while the lever of the transmitter *T* is depressed, in order to transmit a dash on the neutral side, the lever of the pole changer moves from its depressed to its raised position. The electromotive force in the circuit will change from + 300 to − 300, and, therefore, the current passing through the home relay will change in direction, and in so doing, it will pass through its zero value. This change in direction will tend to suddenly release the armature of the neutral relay and reattract it, thus tending to break the dash that the relay *N R* is receiving. The change in the current passing through the coil *i'* will induce a current in the coil *i* that will pass through the coil *M* and that will be at its maximum strength as the current in the line and coil *i'* passes through zero. This current, therefore, acts on the armature *l* to prevent it from fluttering and touching the rear stop when it should remain against the front stop. The current induced in the secondary coil *i* is always strongest when most needed; that is, when the current in the line is varying most rapidly, as it does when it passes through zero.

205. *PR* is a differential polarized relay, responding to positive currents coming from the distant station, but held

against its back stop by negative currents from the distant station.

Starting at the dividing point *h*, the line circuit may be traced through the primary coil *i'*, the coil *M'*, the line coil *f* of the polar relay, to the line; similarly, the artificial-line circuit may be traced from *h* through the primary coil *i''*, the coil *M''*, the artificial-line coil *j* of the polar relay, and the artificial line, to the ground G_1. When the pole changer *PC* is closed, because the key *Pk* has been closed, the +300-volt machine is connected through contact *2* and the wire *6* to the stop *7*; and the + 100-volt machine is connected through contact *3* and the wire *5* to the lever *n*. When the pole changer *PC* opens, the polarity is reversed, the −300-volt machine being connected to the stop *7* and the −100-volt machine to the lever *n*. When the transmitter *T* is open, the lever *n* presses against the spring *8* and holds it away from the stop *7*, thus connecting either the +100-volt dynamo or the −100-volt dynamo to the point *u* on the switch *Q*. When the transmitter is closed, due to the closing of the key *Tk*, the lever *n* separates from the spring *8*, allowing the latter to rest against the stop *7*. This instrument is evidently a continuity-preserving transmitter.

206. Both Keys Open.—When *Tk* and *Pk* are both open, the −100-volt dynamo is connected in the circuit and the path of the current may be traced from the −100-volt dynamo through *r–4–5–n–8–u–* to *h*, where it divides between the line and artificial-line circuits. This current is neither strong enough to operate the distant neutral relay, nor in the right direction to operate the distant polar relay; hence, neither of them will be closed.

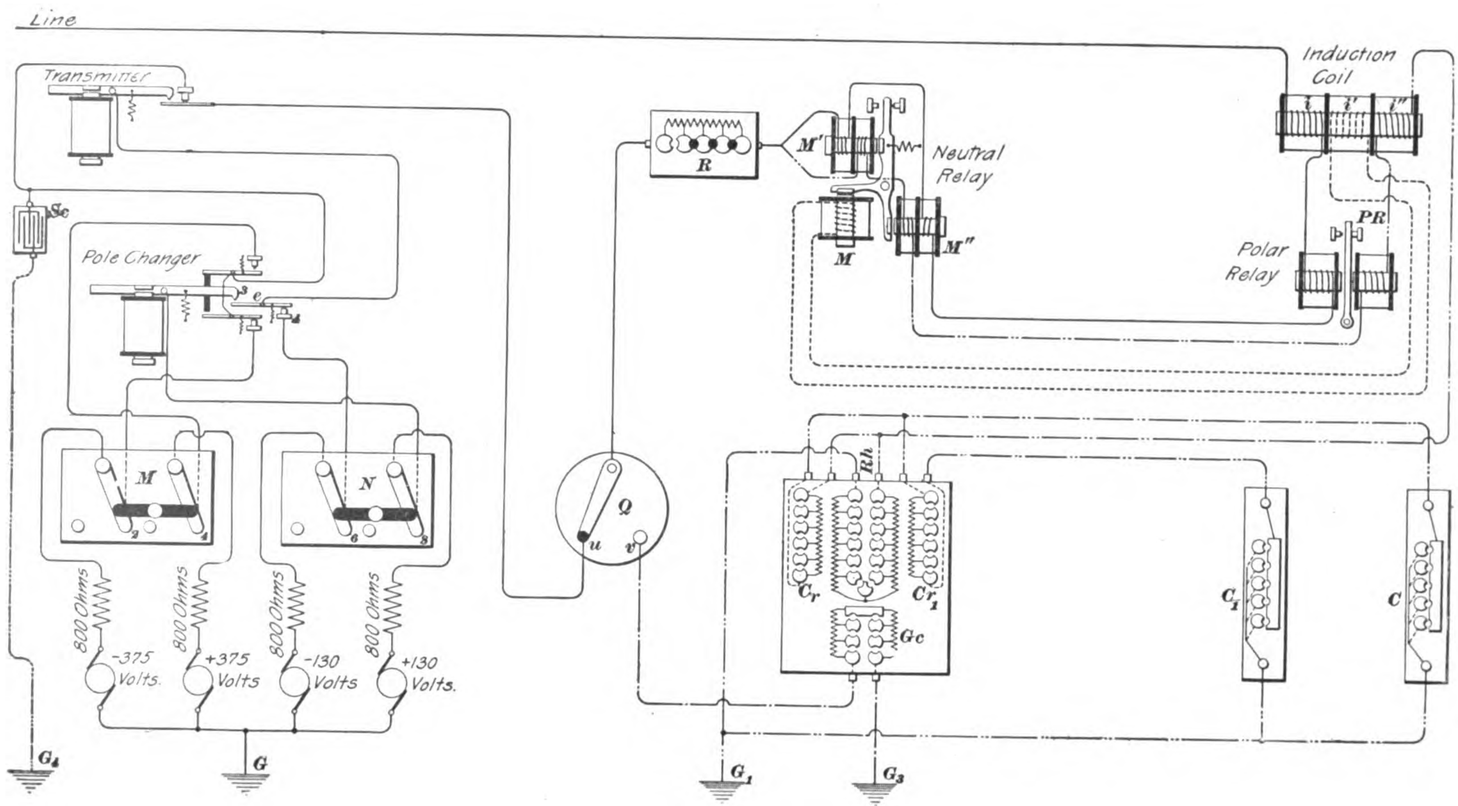
207. Pole-Changer Key Closed.—When the key *Pk* is closed, current at the pressure of +100 volts flows in the circuit from the +100-volt dynamo over the path *r–3–5–n–8–u–* to *h*, where it divides between the line and artificial-line circuits. This current will operate the distant polar relay, because it flows in the right direction, but it is not strong enough to operate the distant neutral relay.

208. Transmitter Key Closed.—When the transmitter is closed, due to closing the key *Tk* (the key *Pk* being open), a current at a pressure of −300 volts flows in the circuit from the −300-volt dynamo over the path *r–1–q–6–7–8–u–* to *h*, where it divides between the line and artificial-line circuits. This current will operate the neutral relay at the distant station, because it is strong enough to overcome the spring; but it will not operate the distant polar relay, because it is in the wrong direction.

209. Both Keys Closed.—When both the pole changer and the transmitter are closed, due to the closing of both keys *Pk* and *Tk*, a current at a pressure of +300 volts flows in the circuit from the +300-volt dynamo over the path *r–2–q–6–7–8–u–* to *h*, where it divides between the line and artificial-line circuits. This current is strong enough to operate the distant neutral relay and is in the right direction to also operate the distant polar relay, so that both relays at the distant station will cause the local circuits of the reading sounders to be closed.

210. The complete analysis of the currents in the line and artificial-line coils of the relays for each of the sixteen possible combinations of the four transmitting keys (two at each end), is exactly the same as that already given in Table 3 in connection with the quadruplex systems previously described.

211. A Pony, or Repeating, Relay.—*R S* is used in this quadruplex system in place of the repeating sounder shown in preceding systems. It is connected to the back stop of the neutral relay, and an ordinary sounder *S* is connected to the back stop of the **pony, or repeating, relay** *R S*. The object of so connecting the pony relay *R S* and the reading sounder *S* has already been explained. The sounder S_1 is connected to the front contact stop of the polar relay *PR* in the usual manner. In large offices the local circuits of all the sounders are supplied with current from a 40-volt dynamo. One pole of this dynamo is

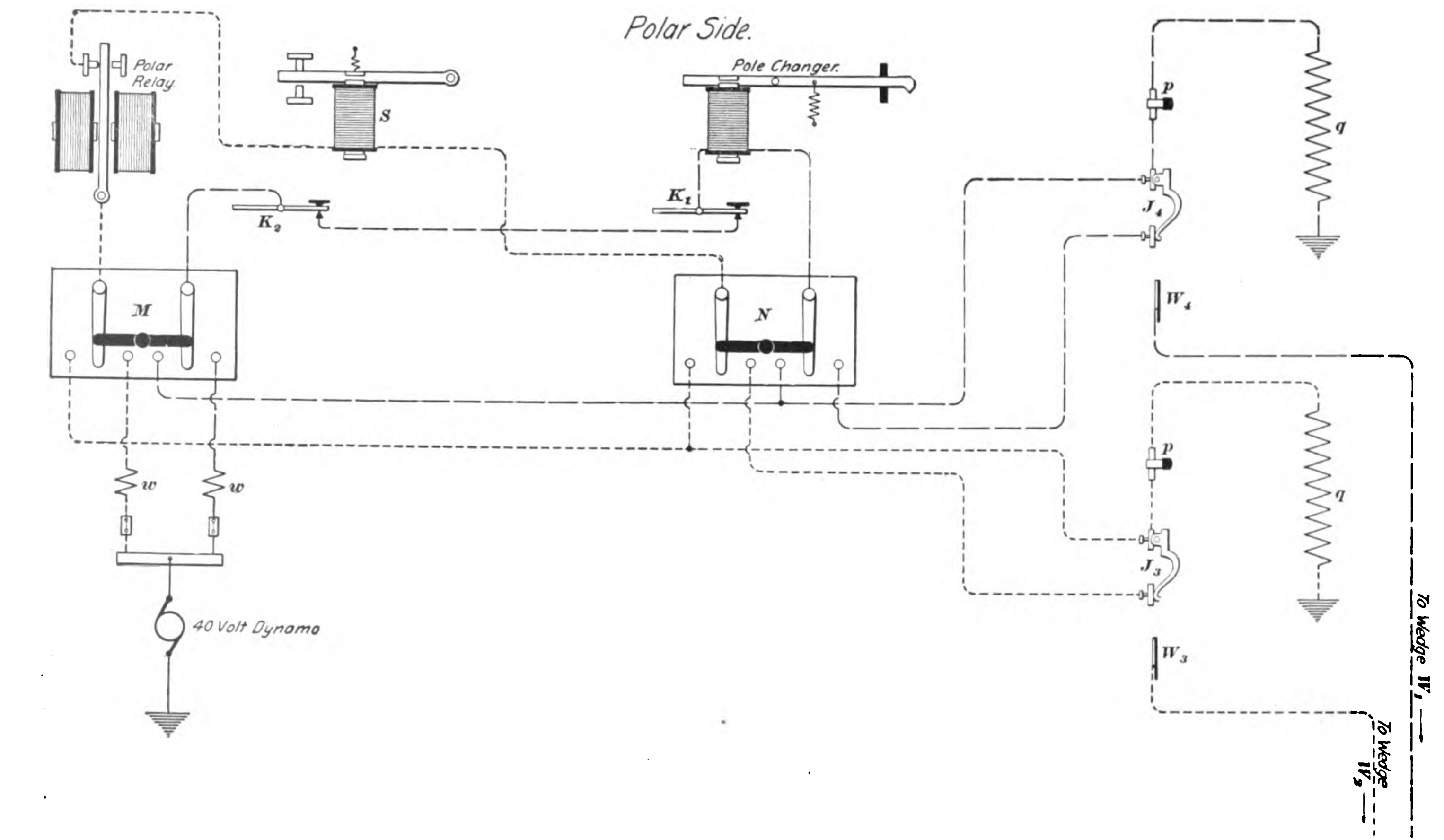


Line
Transmitter
Pole Changer
M
N
800 Ohms
800 Ohms
800 Ohms
800 Ohms
-375 Volts.
+375 Volts
-130 Volts
+130 Volts.
G
Q
u
v
R
M'
M
M''
Neutral Relay
Induction Coil
i
i'
i''
PR
Polar Relay
Rh
Cr
Cr1
Gc
C1
C
G1
G3

FIG. 70.

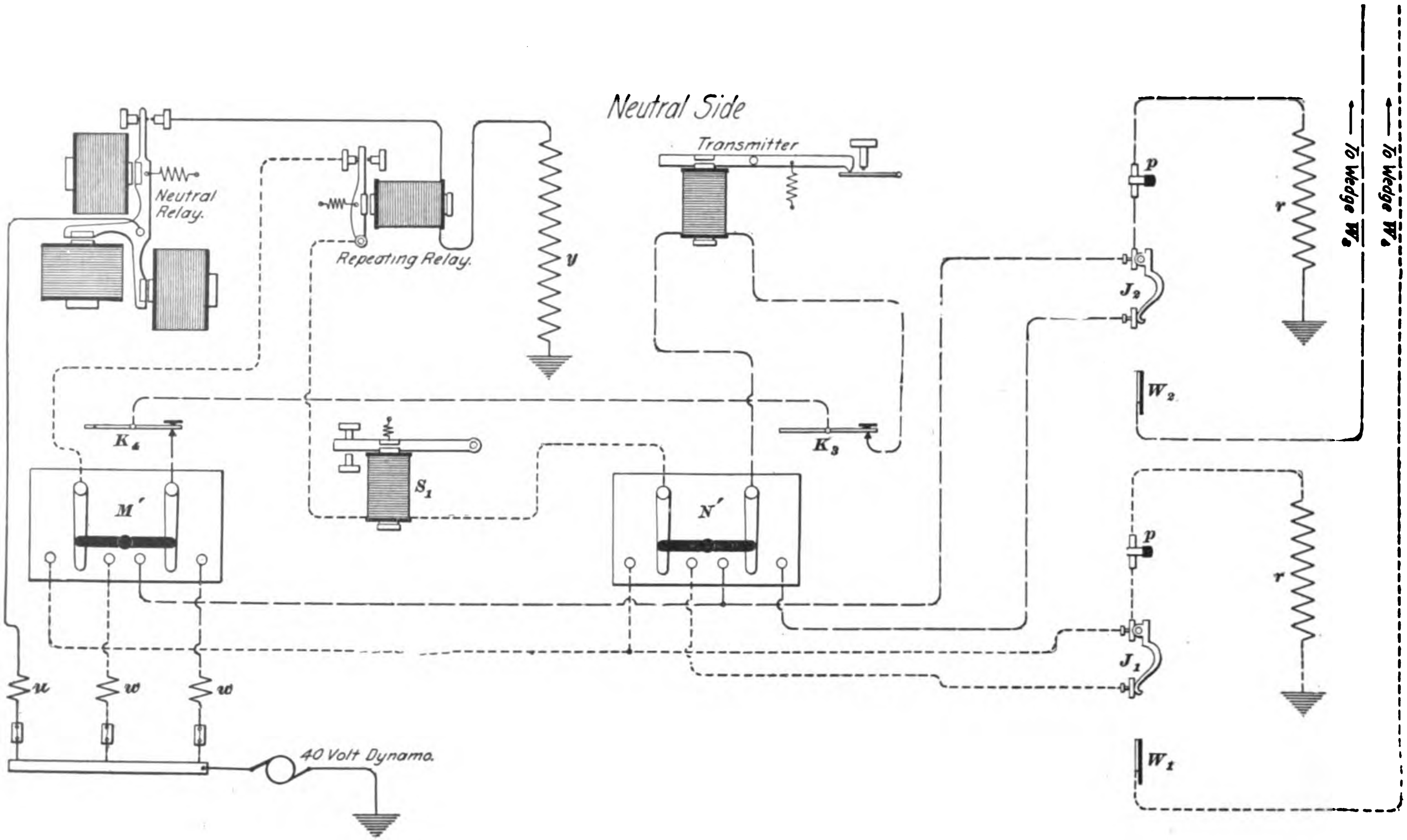
connected to the ground, while from the other pole leads are taken through non-inductive resistance coils of about 30 ohms, to the various sounders, the magnets of the pole changer and transmitter, to the ground. This arrangement of the local receiving and sending circuits will be shown more fully in Figs. 71 and 72. The switch *Q* in Fig. 69 is used for grounding the circuit through the coil *Gc*, leaving all transmitting apparatus cut off. This is for the purpose of balancing and properly adjusting the relays to incoming currents from the line. The resistances *Rh* and *Cr* and the condensers *C* constitute the artificial line, which is adjusted in the manner explained in connection with the duplex systems.

212. Practical Arrangement.—The practical arrangement of the apparatus in the Jones quadruplex system is shown in Fig. 70. This figure is lettered the same as the preceding one. The switches *M* and *N*, to which the dynamos are connected, are located on the desks on which the quadruplex apparatus is placed. They are used in this case simply to connect and disconnect the dynamos. When the quadruplex set is in use, the switches *M* and *N* are pushed to the right so that the arms rest on the contact buttons *2*, *4*, *6*, and *8*. When the arms are in the intermediate, or left-hand, positions all the dynamos are cut off. The pole changer, although somewhat different in form from that shown in Fig. 69, accomplishes exactly the same result. The higher voltage machines are never short-circuited. The lower voltage machines, however, are momentarily short-circuited when the lever is in the middle position, because the lever *3* touches the lever *e* before the latter is pushed away from the stop *4*. The interval during which the lower voltage machines are short-circuited is extremely small. All resistance coils are contained in one box, the circuits through which are plainly indicated. The two condensers C and C_1, the adjustable resistances Cr and Cr_1, and the resistance *Rh* constitute the artificial line. The magnets M' and M'' of the neutral relay each have two coils,



Polar Side.
Polar Relay.
S
Pole Changer.
K₁
K₂
M
N
w
w
40 Volt Dynamo
p
q
J₄
W₄
J₃
W₃
To Wedge W₁
To Wedge W₂

FIG. 71.



To Wedge W4
To Wedge W3
Neutral Side
Transmitter
Neutral Relay.
Repeating Relay.
y
r
p
J2
J1
W2
W1
K4
K3
S1
M′
N′
u
w
w
40 Volt Dynamo.

FIG. 72.

as shown, one coil on each magnet being connected in the line circuit, and one in the artificial-line circuit. The two coils on the one magnet oppose each other when they are both supplied with current from the home-station dynamos.

213. Between the contact button *v* of the switch *Q* and the ground G_2 is the ground coil *Gc*. It is equal in resistance to that of the circuit through the transmitter, pole changer, 800-ohm resistance coil, and dynamo to ground *G*. The resistance of this latter circuit, exclusive of the 800-ohm non-inductive resistance coil, is practically negligible and, hence, *Gc* is practically equal to the resistance of that coil, that is, 800 ohms. When the arm of the switch *Q* is turned to the contact button *v*, the resistance of the home quadruplex set from the line to the ground is evidently the same as when the arm is on the contact button *u*. The arm of the switch *Q* is placed on contact button *v* when the system is being balanced.

214. Local Connections.—The local connections for both the polar and neutral sides of the Jones quadruplex system, for use in an office having a loop switchboard and dynamos, are shown in Figs. 71 and 72. The arrangement of the loop switches shown in these figures is that employed by the Postal Telegraph Company, and differs somewhat from the arrangement of the loop switches of the Western Union Telegraph Company. The upper part of each jack on the loop switchboard is connected through a pin plug *p* and a resistance *q* to the ground. When the pin plug *p* is removed, the upper part of the jack is disconnected from the ground. When the quadruplex set in a main office is not to be connected with any branch office, nor arranged so that it will repeat into another quadruplex set, the pin plugs *p* will all be in place, there will be no wedges in the jacks, the switches *M* and *M'* will be turned toward the right, and the switches *N* and *N'* will be turned toward the left. With the apparatus arranged in this manner, the receiving circuit on the polar side may be traced from the dynamo through the switch *M*, the polar-relay contact points, the

sounder S, the switch N, the jack J_3, the pin plug p, resistance coil q, and back through the ground to the dynamo.

The student should now be able to trace the sending circuit on the polar side, and also the sending and receiving circuits on the neutral side. On the neutral side, the circuit through the contact points of the repeating relay or sounder and the magnet of the ordinary sounder S_1 resembles that through the contact points of the polar relay and the magnet of the sounder S on the polar side. The contact points of the neutral relay and the magnet of the repeating relay are in a third separate, or independent, circuit between the dynamo and the ground. The non-inductive resistance coils are made of German-silver wire, and have about the following resistances: r, r, 120 ohms each; y, 170 ohms; q, q, 130 ohms each; w, w, w, w, 30 ohms each; and u, 30 ohms.

215. One Set Repeating Into Another.—When it is desirable to repeat from one quadruplex set into another, it is only necessary to connect the loop switches on each side by means of flexible wires terminating in wedges that are insulated on one side, and to turn the switches M, N, and N' toward the right, and M' toward the left; or M may be turned toward the left, and M', N', and N toward the right. That is, by inserting the wedge W_2 in the jack J_2, and the wedge W_3 in the jack J_3, the receiving corner of the polar side of one quadruplex set may be made to repeat into the sending corner of the neutral side of a second quadruplex set. And by inserting the wedge W_1 into the jack J_1, and the wedge W_4 into the jack J_4, the receiving corner of the neutral side of the second set may be made to repeat into the sending corner of the polar side of the first quadruplex set.

The student should be able to trace out the circuits for himself, and should also understand that when the wedges are inserted in the manner described above, the polar and neutral sides shown here will belong to two entirely different quadruplex sets. For instance, the polar side may belong to the quadruplex system extending from New York to Buffalo, and the neutral side to the quadruplex system

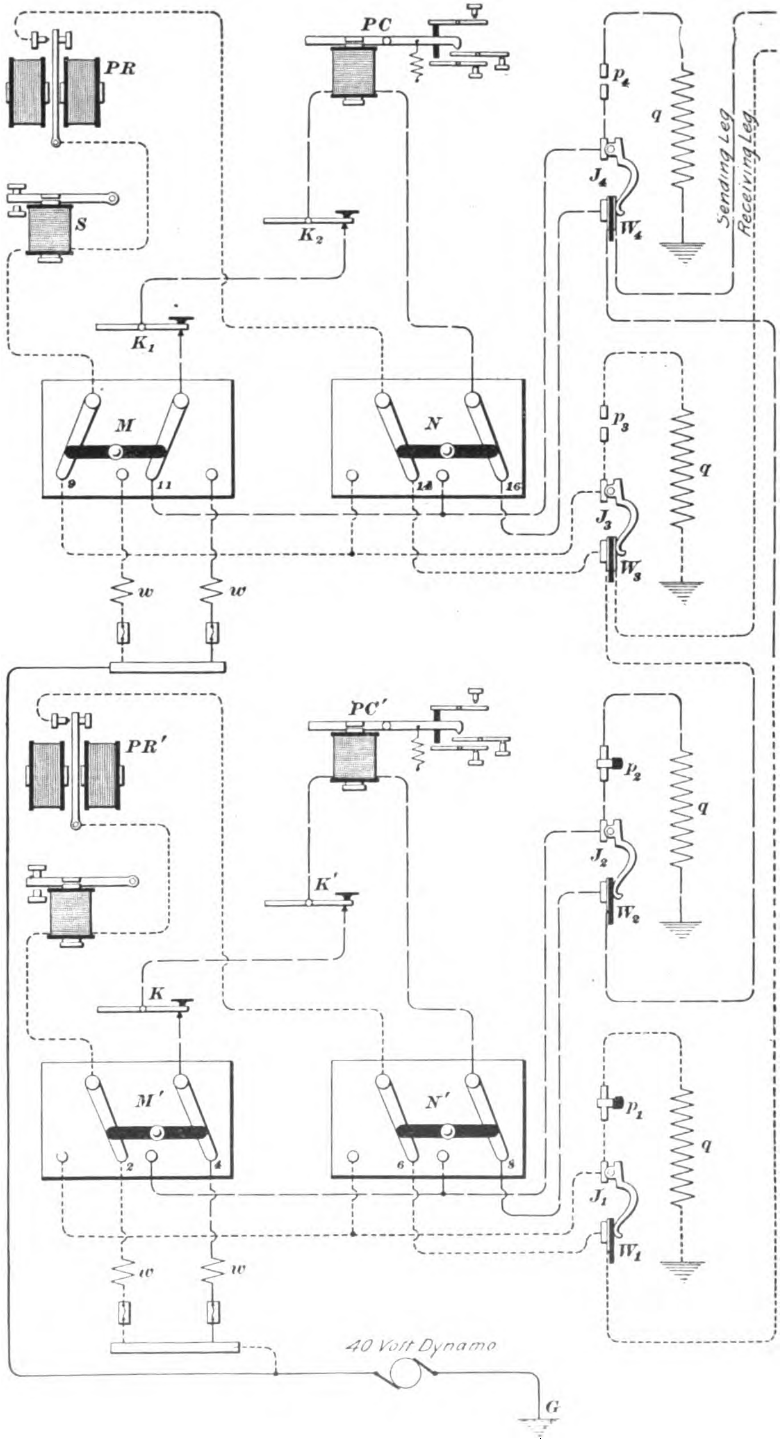

PC
PR
S
K2
K1
M
N
9
11
14
16
p4
q
J4
W4
Sending Leg
Receiving Leg
p3
J3
W3
w
PC'
PR'
K'
K
M'
N'
2
4
6
8
p2
J2
W2
p1
J1
W1
40 Volt Dynamo
G

FIG. 73.

extending from New York to Baltimore. Therefore, when the jacks are connected together by means of cords terminating in single wedges, in the manner just explained, we have the polar side of the Buffalo quadruplex repeating into the neutral side of the Baltimore quadruplex set.

In order to change this arrangement, so that one side will no longer repeat into the other, it is only necessary to turn the switches *M* and *M'* toward the right, and *N* and *N'* toward the left. Each side will then work independently.

216. Postal Telegraph Loops.—The Postal Telegraph Company's loop system is further illustrated in Fig. 73. This figure shows a method employed for connecting a branch office with the quadruplex set, so that the branch office may receive on one leg and send on another. When the switch *M* is turned toward the left, the switches *N*, *M'*, and *N'* toward the right, the pin plugs p_3, p_4 removed, and the single wedges W_1 and W_2 inserted in the jacks J_1 and J_2, and two single wedges W_3 and W_4 inserted in each of the jacks J_3 and J_4, respectively, the polar relay *PR* controls the pole changer *PC'*, and also sends its message through the receiving leg to the branch office, which is not included, however, in this figure. Thus the message that is received on the polar relay *PR* is sent to the branch office and, by means of the pole changer *PC'*, is repeated into another quadruplex set and is thus sent to another distant main office. This circuit may be traced from the ground *G*, through a 40-volt dynamo, fuse, resistance *w*, contact button *4* on switch *M'*, the keys *K* and *K'*, the pole changer *PC'*, switch *N'*, contact button *8*, jack J_2, wedge W_2, wedge W_3, jack J_3, contact button *14* on switch *N*, contact points of the polar relay *PR*, sounder *S*, switch *M*, contact button *9*, jack J_3, wedge W_3, receiving leg of the branch-office loop, and through the branch-office sounder (not shown in this figure) to the ground. It will be seen that when the plug p_3 at the jack J_3 is removed, the receiving leg of the branch-office loop circuit replaces the resistance *q* that is connected between the ground and the upper part of this jack.

The other circuit through the polar relay *PR'*, the pole changer *PC*, and the sending leg of the branch-office loop may be traced in a similar manner. In order to disconnect the branch-office loop, and to make the two circuits work independently of each other, it is only necessary to replace the plugs p_3 and p_4 and to turn the switches *M* and *M'* toward the right, and *N* and *N'* toward the left.

217. With all the wedges and the pin plugs p_1 and p_2 in place, the three switches *N*, *M*, and *N'* turned toward the right, and *M'* toward the left, the two circuits will repeat into each other. In this case it is immaterial whether the pin plugs p_3 and p_4 are in or out of place.

With the plugs p_3 and p_4 removed, and the three switches *M'*, *N'*, and *N* turned toward the right, and *M* toward the left, the two circuits not only repeat into each other, but the message is sent to the branch office, as explained in Art. **216.** Furthermore the branch office, by operating the key in the sending leg, can send a message through the pole changer *PC*, provided *PR'* remains closed, to the distant main office that is connected with the contact points of the pole changer *PC*. By operating a key in the receiving leg, the branch office can send a message through the pole changer *PC'* to the other distant main office that is connected with the contact points of the pole changer *PC'*. Thus two messages can be sent simultaneously from the branch office, one to each terminal office; however, the terminal offices cannot send on the same side of a quadruplex, and not at all on a duplex system at the same time; hence, in the latter case the system is only worked single, and not duplex. This will be more fully explained under the heading of "Multiplex Repeaters."

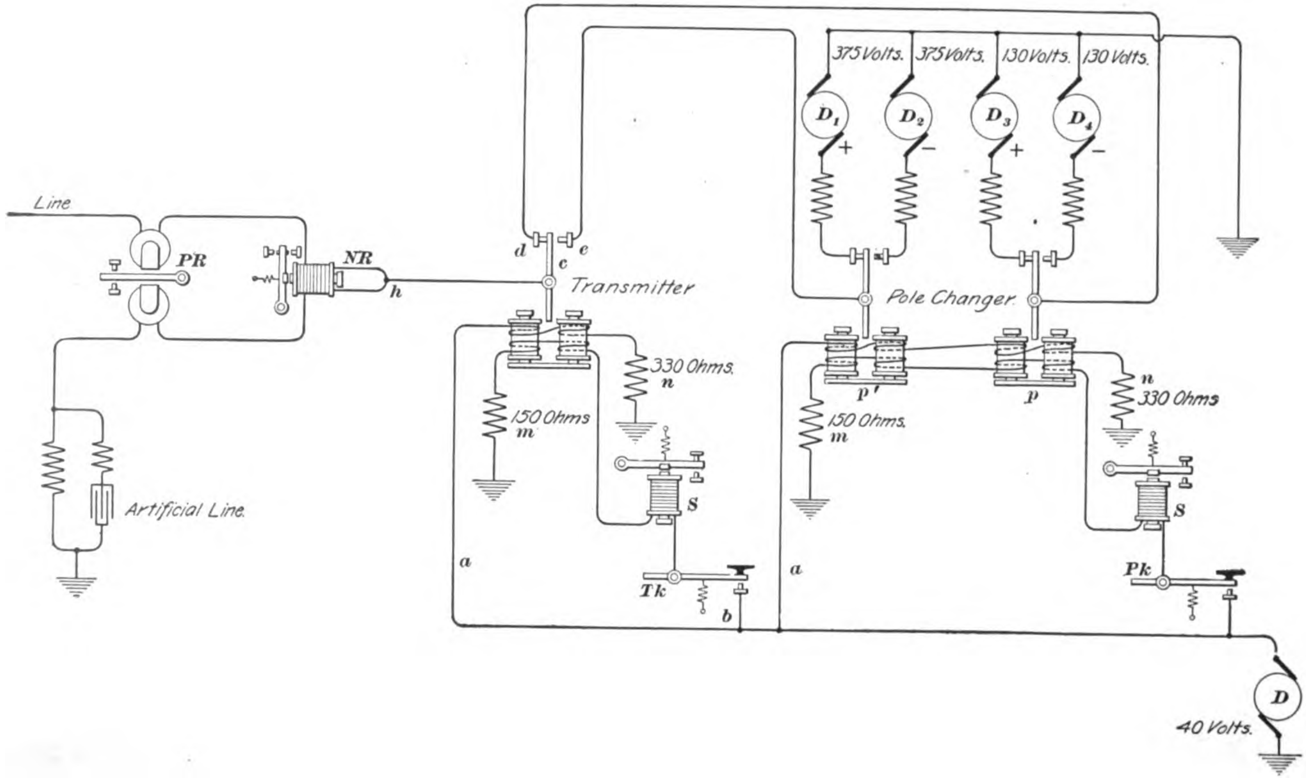
HOUGHTALING POLARIZED TRANSMITTER AND POLE CHANGER.

218. A polarized transmitter and pole changer that do not depend in any way on springs for their operation have been introduced on some of the Postal Telegraph Company's

fastest circuits, where they are reported to have done excellent work. These instruments, which are intended for use in connection with multiplex telegraph systems, are the invention of Mr. W. A. Houghtaling, and are known as the **Houghtaling polarized transmitter and pole changer.** They are shown in Fig. 74 in connection with the ordinary quadruplex key system of the Postal Telegraph Company, but are, however, applicable to any of the common systems. The local magnets of the transmitter and pole changer are provided with double windings, one of which is connected permanently in circuit with the dynamo *D* through a resistance *n*, and the other through a key, reading sounder *S*, and resistance *m*, so arranged that the current passes in opposite directions through the two windings around the cores of the transmitter and pole changer. The resistance coil *n* in the permanent circuit has such a value that the strength of the current in this circuit is one-half that in the key circuit; or, in other words, the total resistance of the permanent circuit is double that of the circuit that includes the key and sounder.

With this key system, two of the polarized instruments mounted on one base form the pole changer, and one, separately mounted, is used as a transmitter. As the action of the local circuits is the same in each case, a description of the operation of the transmitter will be sufficient.

219. Referring to the diagram, the key *Tk* in the circuit of the transmitter is open and the magnet cores are energized by the current in the circuit *a–n* to a strength of, say, one unit, which tends to move the tongue *c* against the contact *d* and thus connects either the + or − 130-volt dynamo D_3 or D_4 to the point *h*. If the key *Tk* is closed, the cores of the magnets will be energized by a current in the circuit *b–Tk–S–m* to a strength of two units, which, being exerted in an opposite direction, not only cancels the effect of the current set up in the circuit *a–n*, but it also causes the tongue *c* to be moved with a force of one unit over against the contact *e*. This connects either the + or − 375-volt



Line
PR
NR
h
d
c
e
Transmitter
330 Ohms.
n
150 Ohms
m
S
Tk
b
a
Artificial Line.
375 Volts.
375 Volts.
130 Volts.
130 Volts.
D_1
D_2
D_3
D_4
+
−
+
−
Pole Changer.
p'
p
150 Ohms.
m
n
330 Ohms
S
Pk
a
D
40 Volts.

FIG. 74.

dynamo D_1 or D_2 to the point *h*. The instruments *p* and *p'*, similar in all respects to the transmitter, constitute a pole changer. They are both controlled by the one key *Pk* and operate as a single instrument to produce reversals of the current for one set of signals. The transmitter varies the strength of the current for another set of signals.

220. The inventor says that in any instrument depending on a retractile spring for the motion of its armature in one direction and on magnetic attraction for its motion in the other, the action is not the same in both directions. As the armature approaches its limiting stop toward which the spring is drawing it, the tension of the spring becomes less, and the armature travels faster in the first part of its journey than it does in the latter portion; while, as it approaches the poles of the magnet, the reverse is the case. In the polarized instrument the movement is the same in either direction.

A long duplex circuit worked through repeaters equipped with this style of instrument is said to have its efficiency increased by the possibility of a microscopical adjustment of the relay points of the opposite set, and it is claimed that the double winding of this transmitter neutralizes the spark due to self-induction. That is, the electromagnetic induction of one coil on a magnet is neutralized more or less by that of the other coil on the same magnet, thus reducing the sparking at the contact points of the keys. The inertia of the moving parts being small permits a rapid movement of the tongue from one stop to the other, which, no doubt, makes the interval of no current during reversals much smaller than is possible with the present dynamo pole changer.

HEALY QUADRUPLEX.

221. In Fig. 75 is shown the quadruplex system devised by Mr. C. L. Healy and known as the **Healy quadruplex.** It is used by the New York Quotation Company. The same principle is used as is found in those systems that have

already been explained; namely, the reversal of the polarity of the current for working the distant polar relay, and an increase and decrease in the strength of the current for operating the distant neutral relay. The arrangement of the apparatus is somewhat different, however.

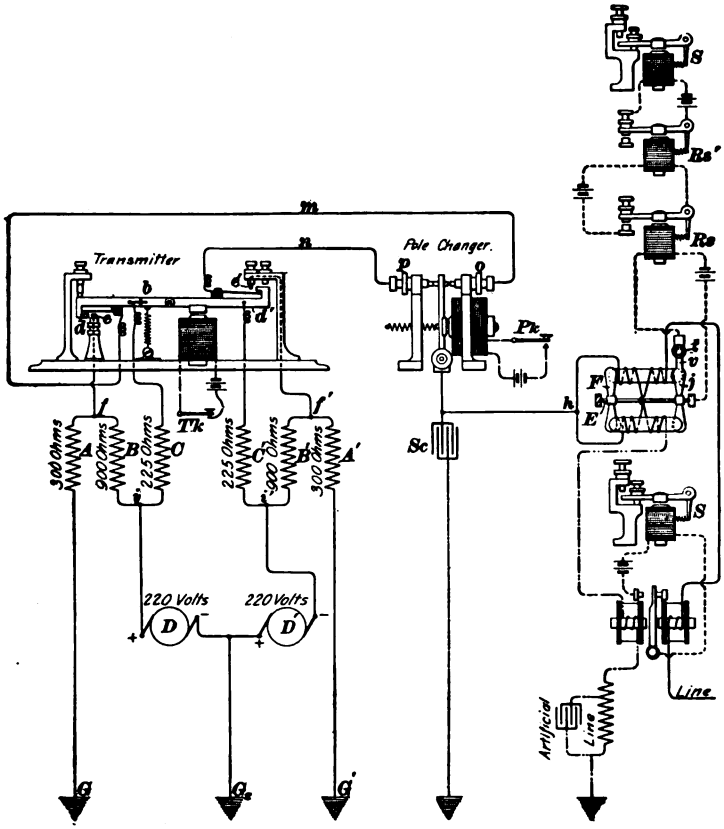


FIG. 75.

222. The transmitter consists, practically, of two ordinary continuity-preserving devices. The two levers are mechanically fastened together but are insulated from each other by the insulating material *b*; thus, one magnet really operates two transmitters of the ordinary form. When the

key *Tk* is closed, as shown in the figure, the wire *m* is connected with the end of the lever *d* and, hence, to the coil *C*; the wire *n* is connected with the end of the lever *d'* and, hence, to the coil *C'*. Consequently, when the key is closed, the positive pole of the dynamo *D* is connected through the resistance *C* to the end of lever *d* and wire *m* to the front stop *o* of the pole changer, and the negative pole of the dynamo *D'* is connected through the resistance *C'* to the end of the lever *d'*, and the wire *n* to the rear stop *p* of the pole changer. Thus the opposite poles of two similar dynamos are connected through exactly similar resistance coils, and through the transmitter to the front and rear stops of the pole changer. When the pole changer is closed, a positive machine will be connected to the point *h*; and when open, a negative machine will be connected to the same point *h*.

When the transmitter is open, the positive pole of the dynamo *D* will be connected through the resistance *B*, the point *f*, stop *e*, and wire *m* to the stop *o* of the pole changer; and the negative pole of the dynamo *D'* will be connected through the resistance *B'*, stop *e'*, and wire *n* to the stop *p* of the pole changer.

In the closed position of the transmitter, the current from the dynamo has two paths, one through the resistance *C* and the line to the ground at the distant station, and the other through the resistances *B* and *A* to the ground *G*. In the open position of the transmitter, no current can flow through the coil *C*, because it is open at *d*. The pole changer, by opening and closing, merely shifts the line and artificial-line circuits that come together at *h* from a machine of one polarity to that of the opposite; and the transmitter, by varying the arrangement of the resistances between the dynamo and pole changer, alters the strength of the current so as to give the ratio desired.

223. Resistance of Circuit Is Constant.—The resistance from the point *h*, through the pole changer, transmitter, resistance coils, and dynamo is the same in all

positions of the pole changer and transmitter. Evidently the position of the pole changer does not alter the resistance of this circuit in any way. The position of the transmitter itself alters the arrangement of the resistances, but does not alter the total resistance between *h* and the ground at the home station. The resistance from *h* through the transmitter to the ground will evidently be 225 ohms when the transmitter is closed, because the resistance from *i* to G_2 through the dynamo is perfectly negligible.

When the pole changer is closed and the transmitter is open, the point *h* is connected through the wire *m* and stop *e* to the point *f*, from which point it has two paths, one through the resistance *A* and the other through the resistance *B* and dynamo *D* to the ground. The joint resistance of these two coils since they are in parallel will be

$$\frac{300 \times 900}{300 + 900} = 225 \text{ ohms.}$$

It will be noticed that this is exactly equal to the resistance of the coil *C*; hence, the resistance from *h* through the transmitter to the ground is 225 ohms in either the open or closed position of the transmitter. Since the resistance from the ground through the transmitter to the point *h* is the same in both positions of the transmitter and pole changer, it follows that the total resistance of the circuit is the same in all possible combinations of the four transmitting keys, two at each end.

224. The **ratio of the current** in the line, between the open and closed position of the transmitter, may be calculated in the following manner, assuming that the line and artificial-line circuits each have a resistance of 1,800 ohms: In the closed position of the transmitter, the resistance in the circuit consists of the 225 ohms in the coil *C*, the 1,800 ohms in the line, and the 1,800 ohms in the artificial line. The line and artificial-line circuits are in parallel and, hence, their joint resistance is 900 ohms. This resistance added to 225 ohms gives 1,125 ohms; hence, the current in

the circuit under consideration, if each dynamo generates 220 volts, will be

$$\frac{220}{1,125} = .196 \text{ ampere, or } 196 \text{ milliamperes.}$$

Half of this current, that is, 98 milliamperes, will flow through the line and the same amount through the artificial line.

When the transmitter is open, the coil C will be on open circuit and the current from the dynamo will divide at the point f, part going toward the line and part through the coil A to the ground G. The resistance of the circuit from the point f to the ground now consists of three branches, one branch passing through A, one through the line, and one through the artificial line. The joint resistance of the line and artificial line is 900 ohms, as before, and this amount will be in parallel with the 300 ohms in the coil A; hence, the resistance from f to the ground through these three paths will be

$$\frac{900 \times 300}{900 + 300} = 225 \text{ ohms.}$$

This resistance is in series with the coil B that contains 900 ohms; hence, the total resistance of the circuit is $225 + 900 = 1,125$ ohms. The total current will be $220 \div 1,125 = .196$ ampere, or 196 milliamperes. This current will divide at the point f inversely as the resistance of the two paths; hence, we have the proportion 900 (joint resistance of the line and artificial line) is to $\frac{900 \times 300}{900 + 300} (= 225)$ as the total current flowing in both circuits, 196 milliamperes (which is the same as the current in the coil B), is to the current flowing toward the line from the point f. Hence the current flowing toward the line from the point f equals

$$\frac{225 \times 196}{900} = 49 \text{ milliamperes.}$$

One half of this current, or 24.5 milliamperes, will flow through the line and the other half through the artificial line.

When the transmitter is closed, the current in the line is 98 milliamperes; when open, the current is 24.5 milliamperes; from which fact it is evident that closing the transmitter increased the current in the line in the ratio of 1 to 4. In order to have the ratio 1 to 3 instead of 1 to 4, the resistances A and A' should be 400 ohms each; B and B', 800 ohms; and C and C', 267 ohms.

225. The **neutral relay** used in this system is different from any heretofore considered. The straight cores on which the coils are wound are made from very soft iron wire, as there are no yoke pieces; hence, the magnetism of the relays will reverse very rapidly on account of the low self-induction of the electromagnets due to the absence of iron yokes and the small quantity of good soft iron in the cores. The cores are about 2½ inches long and have a wire space of about 2 inches. Each core has two wires wound upon it, which form the two windings that go to make up a differential relay. It is preferable to wind these two wires upon the cores side by side, so that the differential action will be directly between adjacent turns, through which the current from the home generator circulates in opposite directions, rather than between the magnetism produced by such currents in the cores. In the figure, however, the two windings are represented, for the sake of clearness, as occupying separate longitudinal sections. Between and parallel with the cores is a brass shaft E that is held by centering screws at its ends. On the ends of the shaft E are secured two armatures F and j that move at right angles to the cores. These armatures are made light in weight, especially at the extreme ends, so as to reduce the inertia. The ends of the cores are beveled, and the two armatures, being of like shape, resemble the blades of a propeller. The armatures overlap the beveled ends of the cores and passing on opposite sides of the latter are simultaneously attracted or released by the cores; so that, being rigidly fastened to the brass shaft, they help each other. The armature j has an extension v working between two contact points and

connected with an adjustable retracting spring (that is not shown in the figure because it is at right angles to the paper).

The inventor of this relay claims that, since the wire space extends nearly over the whole length of the non-movable iron parts, there being no yoke over which wire cannot be wound, these magnets can be wound with larger wires, giving, nevertheless, a greater number of convolutions with the same or a greater resistance than it has heretofore been possible to obtain. Hence, the electromagnet should be more efficient than the ordinary relay. Furthermore, the core being short and there being no yokes, the reversals of magnetism take place very rapidly, and the time of no magnetism in the core, during the time that the reversals are taking place, is said to be reduced one-half.

226. Pole Changer.—The **pole changer,** although somewhat different in form, is really equivalent to the walking-beam type that has been already described. The arrangement of the contact stops, it is claimed, will enable a very close and positive adjustment to be made, so that the interruption of the current while the armature is shifting from one stop to the other lasts for a very small interval of time. A condenser *Sc* is connected between the lever of the pole changer and the ground to reduce the sparking between the lever and the stops *p* and *o*.

227. Sounders on Neutral Side.—In order, apparently, to avoid using the Smith arrangement of condenser and resistances, or the Jones induction-coil device, or the Edison system of one repeating sounder and one reading sounder, Mr. Healy devised the arrangement of two repeating sounders *Rs* and *Rs'* and one reading sounder *S*, which are connected as shown in Fig. 75. The repeating sounder *Rs* has its circuit closed when the neutral-relay armature rests against its *back stop t*. The second repeating sounder *Rs'* has its circuit closed when the armature of the first repeating sounder *Rs* rests on its front stop. The reading sounder *S* has its circuit closed when the armature of the second repeating sounder *Rs'* rests against its back stop.

By this arrangement it is claimed that the time necessary to cause any mutilation of the received signals is doubled and that, in practice, this arrangement has been found to greatly increase the working margin of the neutral side.

ROBERSON QUADRUPLEX.

228. The **Roberson quadruplex** system, the invention of Mr. O. R. Roberson, uses alternating sine wave currents. At present this system is in use in the New York Office of the Western Union Telegraph Company. When properly handled, this quadruplex will work *four-cornered* (that is, four messages may be transmitted simultaneously) better in extremely wet weather and on a smaller wire than will most of the other quadruplex systems. The principal objections to its use are the necessity of expert handling and the reluctance of telegraph companies to adopt a system employing alternating currents. The inductive effect on adjacent circuits makes the chief operators very backward, but without any real good reason, in advocating its adoption.

229. In this system, one message is transmitted by positive and the other by negative pulses, although there is sent to line at all times a series of weak alternating currents. On short lines, signals may be transmitted by merely sending a series of positive or negative pulses, according to which key is depressed; but on longer lines, signals are sent by increasing the strength of one polarity or the other, or of both, of the current normally flowing to line—that is to say, the positive pulses are strengthened by depressing one key, while the negative pulses are strengthened by depressing the other. Thus with both keys open, only weak alternating pulses are sent to line, while on their depression, strong positive, or strong negative, or strong pulses of both polarities are transmitted as one or the other or both of the keys are depressed. There is employed at each station an alternating-current dynamo provided with suitable collector rings and connections for sending to line positive and negative

pulses for the two sets of signals, and further means are provided for normally feeding weak, alternating pulses, at a frequency of about 40 periods per second, into the main line, and for sending positive and negative currents of increased strength into the main line on the depression of one or the other or both of the keys, as above outlined.

230. Fig. 76 (*a*) represents waves of positive pulses that are transmitted for the purpose of closing one relay at the receiving station. Fig. 76 (*b*) represents waves of negative pulses that close the second relay at the receiving station, while Fig. 76 (*c*) represents waves of both positive and negative pulses for simultaneously closing both relays at the receiving station.

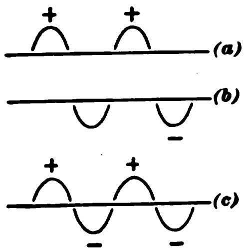


FIG. 76.

231. Fig. 77 represents the current generator and the transmitting and receiving apparatus at one station. One terminal of the armature winding *a* of the alternating-current generator is connected to a ring *b*, which is insulated from the shaft *e* of the dynamo; the other terminal of the armature is connected to segment *1*. The segments *1*, *2*, *3*, and *4* constitute a hub that is rigidly fastened to, but insulated from, the shaft *e*. On the periphery of the hub rest two brushes *i* and *j* connected, respectively, with conductors *11* and *13*. As shown in the figure, one armature terminal is connected through the segment *1* and the brush *i* with wire *11*, while the segment *3*, which is insulated from segment *1*, is connected through the brush *j* with the wire *13*. The segments *2* and *4*, which are insulated from *1* and *3*, are always connected together and with the hub *b* by the wire *8*, and thence to earth by the wire *10*. Also, on the shaft *e* is placed another hub, composed of segments *5* and *6*, segment *6* being permanently connected by conductor *9* through the hub *b* to the ground, while segment *5* affords an insulated terminal either for wire *12* or *14*, according to its position. By means

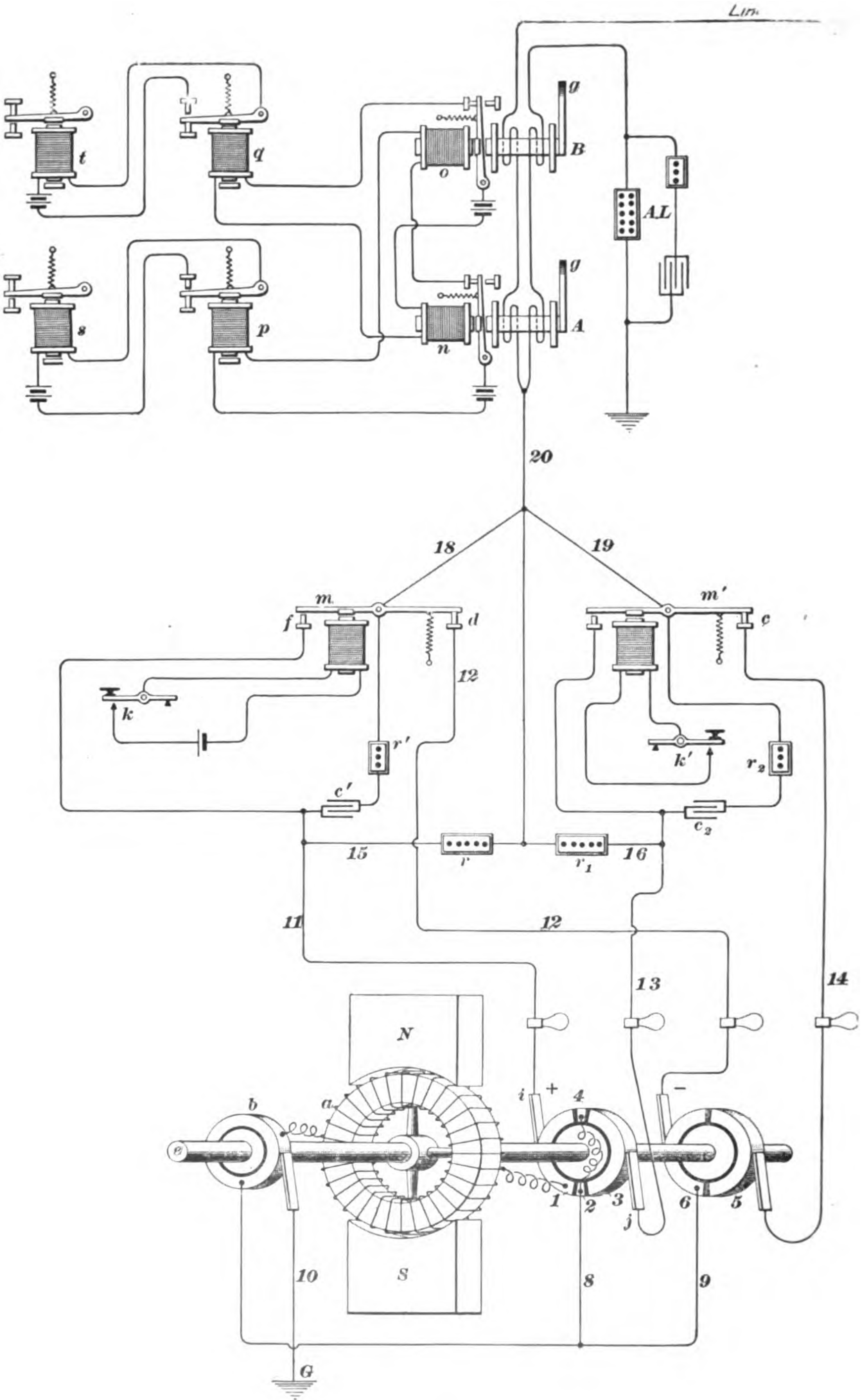

Lin
g
B
g
A
AL
t
q
s
p
o
n
20
18
19
m
m'
f
d
c
12
k
k'
r'
r2
c'
c2
15
r
r1
16
11
12
13
14
N
S
b
a
i
+
4
−
1
2
3
j
6
5
10
8
9
G

FIG. 77.

of the hub *5–6*, therefore, a ground connection is afforded from the main line for currents received from a distant station, either through wire *12* or *14*. When, as in the position shown in the figure, the wire *12* is connected through a brush with segment *6*, the main line is connected through the wire *18*, to back contact *d*, wire *12*, segment *6*, wire *9*, hub *b*, and wire *10* to the ground *G*. After a half rotation of the dynamo armature, however, and when segment *6* is in contact with the brush to which wire *14* is joined, the main line is given a ground connection through wire *19*, back contact *c*, wire *14*, segment *6*, wire *9*, hub *b*, and wire *10*. On closing the key *k*, connection between the armature lever *m* and conductor *12* will be broken; but in this case, in one position of the dynamo armature, a ground connection will be afforded by way of wire *18*, the front contact *f*, wire *11*, segment *1*, the dynamo armature *a*, hub *b*, and wire *10*, and at another position, when wire *11* touches either segment *4* or *2*, there will be a ground connection through wire *8*, hub *b*, and wire *10*. During that part of the rotation when the brush *i* rests on segment *3*, there will be no connection between wire *11* and the ground, because segment *3* is insulated, but a path to ground will be afforded, as before, through wire *14*, segment *6*, and conductors *9* and *10* to the ground *G*. Thus while the dynamo armature is making a certain half revolution, the front stop and back stop of one transmitter are both connected to ground, one by way of the armature, the other directly. At the same time, the front stop and back stop of the other transmitter are both disconnected entirely from the ground. During the next half revolution, however, these connections are all reversed. Thus one transmitter has control of the strength of the pulses while positive pulses are being generated, and the other while negative pulses are being generated.

232. When the key *k* is depressed, positive pulses, like those shown in Fig. 76 (*a*), will be transmitted from the dynamo through segment *1*, brush *i*, wire *11*, front stop *f*, armature lever *m*, and conductors *18* and *20*. The length

of the pulses will be somewhat less than a full positive wave, depending on the width of segments *4* and *2* and their surrounding insulating material. When segment *1* is in contact with brush *i*, the pulse generated is transmitted to the line; but when the shorter segments *2* and *4* are brought into contact with brush *i*, the line will be disconnected from the dynamo and grounded, thus affording the line an opportunity to discharge. Furthermore, the armature *a*, when in contact with brush *i*, is disconnected from brush *j* and wire *13*, so that while wire *11* is receiving a positive pulse no current will flow out over wire *13*. At the next half rotation, however, segment *1* is brought into contact with the brush *j*, and a negative pulse, which is then being generated in the armature, will be transmitted through wire *13*. Thus, as the armature rotates, wires *11* and *13* are alternately connected with the armature of the dynamo, and are fed alternately, the former with positive and the latter with negative pulses, while the main line at the termination of each positive and negative pulse is disconnected from the dynamo and is connected to earth to permit it to discharge.

The wires *11* and *13*, while ready to receive pulses from the dynamo, will not be fed with full currents except when the armature levers *m* and *m'* touch their front contacts. If both *k* and *k'* are depressed at the same time, the two conductors *11* and *13* will receive strong positive and negative pulses, as above described. These branches, however, will receive considerable current, regardless of the position of the levers *m* and *m'*, from the fact that connections to the main line are provided by the wires *15* and *16*, the particular purpose of which will be more fully described presently.

233. Receiving Apparatus.—The two relays *A* and *B*, are each provided with permanent horseshoe magnets *g*, soft-iron cores, and coils *h*, as shown in Fig. 78. It may be assumed that relay *A* at the distant station is closed by the depression of key *k* at the transmitting station, and *B* by the depression of key *k'*. The cores and permanent magnets are so arranged that the positive pulses sent to line on

the depression of the key at the distant station corresponding to *k* will add to the permanent magnetism of *A* and will neutralize or diminish that of *B*, while by the depression of the key at the distant station corresponding to *k'*, the permanent magnetism of *A* will be diminished and that of *B* increased. By this means, the depression of key *k* at the transmitting end will attract the armature of relay *A* at the receiving station, while the armature of *B* will be attracted on the depression of key *k'*. Also, on the simultaneous depression of both keys *k* and *k'* and the transmission of successive positive and negative pulses over the main line, the armature of relays *A* and *B* at the receiving end will both be attracted to a signaling position.

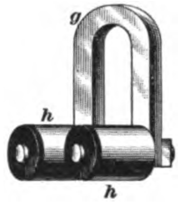


FIG. 78.

But it is to be noted that on the simultaneous transmission of positive and negative pulses, positive pulses will not act on the positive relay nor negative pulses on the negative relay as they would if only positive pulses or only negative pulses were being transmitted, from the fact that a rapid succession of positive and negative pulses through the coils of an electromagnet will tend to produce a neutral, or nonmagnetic, effect; whereas, positive or negative pulses alone will each produce strong magnetic actions. To overcome this difficulty, auxiliary electromagnets *n* and *o*, the branch circuits *15* and *16*, and the rheostats *r* and r_1 are necessary on long circuits, although in the case of shorter lines the branches *15* and *16* may be omitted. In the New York office, two carbon rods of 6,000 ohms resistance each are used in place of the rheostats *r* and r_1.

234. Operation.—If positive pulses only are received from a distant station, the armature of relay *A* will be attracted, thus breaking the local circuit, including the electromagnet *o*, but the local circuit, including the electromagnet *n*, will remain closed and will still exert a retracting pull on the armature of *A*. That is to say, if only positive pulses are received from the distant station, the pull of *A*

on its armature is sufficient to overcome the pull of the opposing electromagnet *n* and the spring. Likewise, if only negative pulses are received from the distant station, the pull of *B* on its armature is sufficient to overcome the pull of *o*, as has just been described in respect to the armature of *A* under the influence of positive pulses alone. Thus on the transmission of only positive pulses for one message, or of only negative pulses for the second message, the armature of *A* or *B*, respectively, will be attracted by their retracting magnets *n* or *o*, respectively, but with insufficient force to hold the local circuits closed.

If, however, both positive and negative pulses, like those shown in Fig. 76 (*c*), are transmitted from a distant station, the armatures of *A* and *B* will both be attracted and the circuits of both *o* and *n* will be broken, thereby leaving the armature subject only to the influence of *A* and *B*. In this case, the magnetism of *A* and *B* is much weaker than if the relays were subject to pulses of only one polarity, but while weaker, these relays are still able to pull their armatures with a force almost equal to that which they would have under the influence of pulses of only one polarity, with the local circuits through the retracting magnets *n* and *o* closed.

To still further equalize the actions of relays *A* and *B* under the influence of pulses of one or of both polarities, the branches *15* and *16*, with the rheostats r and r_1, are provided. By this means positive and negative currents will at all times be transmitted, although of much less strength than are those due to closing one or both keys. Also, pulses from the dynamo will be constantly directed to the line, but owing to the resistances r and r_1 they will be of comparatively small strength. These weakened pulses, when received from a distant station, will flow through the main-line coils of *A* and *B* and will produce an effect tending to neutralize the effects of stronger currents of one polarity. For example, if at the distant station the key *k* is depressed, strong positive pulses will flow through the main-line coil of relay *A*. At the same time, however, owing to the presence of the rheostat r_1 in the branch *16* at the distant station,

weakened negative pulses will be received in alternate order, thereby tending to neutralize, in a degree, the magnetism produced by the stronger positive pulses. Thus, not only is the armature of the relay *A* under a retractive force from the magnet *n*, but the magnetism that would be produced in *A* by the strong positive pulses will be considerably reduced by the weakened negative pulses. By both of these agencies, the armature of *A* will be under substantially the same tendency to move toward the front contact as when strong positive and negative pulses are alternately transmitted.

235. In Fig. 77, *A L* represents the ordinary artificial line of a duplex or quadruplex system, while at the left are represented repeating sounders *p* and *q* and reading sounders *s* and *t*, such as are used in some quadruplex systems where the main-line relays close their local circuits on the back contacts. Branches, including condensers and rheostats, are placed around the front contacts of the transmitters and serve to dissipate sparks arising at such points. The branch around the front contact of *m* includes condenser c' and the rheostat r', while the branch around the front contact of m' includes the condenser c_2 and the rheostat r_2. It may also be noted that the presence of branches *15* and *16*, including the resistances r and r_1, respectively, serve a similar purpose. The local receiving circuits may be arranged so that no intermediate repeating sounders are necessary and the grounded segments *2* and *4* may be omitted. This arrangement is shown in "The Telegraph Age," April 1, 1901.

236. The apparatus may be arranged on the bridge plan instead of as a differential system. In case this is done, the relays *A* and *B* will have only one winding, instead of a differential winding; they will be connected in the cross-branch of a bridge, the arms of which consist of the main line, the artificial line, and two more arms, each of which contains a resistance. The arrangement will be similar to that shown in Fig. 47. The resistance will be so

adjusted as to compel the current from the home transmitting apparatus to divide between the line and artificial line in such a ratio as to produce no difference of potential at the terminals of the cross-branch that contains the two relays *A* and *B*. The transmitting apparatus will be exactly the same as shown in Fig. 77.

BALANCING THE QUADRUPLEX.

237. Theoretically, a quadruplex balanced in identically the same manner as is the polar duplex should suffice for both the first and second sides; and, in fact, too great a proportion of those detailed to look after the apparatus consider their work finished when such a balance has been obtained. In practice, however, this is not sufficient to obtain the maximum efficiency. Even the careful adjustment of the No. 2 relay afterwards, although helpful, must necessarily be experimental and cannot be depended on.

NOTE.—These remarks, this method for balancing the quadruplex, and the suggestions on locating and remedying quadruplex disturbances, were given in various numbers of "The Telegraph Age" by Mr. Willis H. Jones.

There is something that interferes with the evenness of the incoming signals produced by the distant battery, aside from the period of "no magnetism" heretofore explained, and that something is an excess of magnetism in one coil of the neutral relay over and above that in the other. Now, if all relays were perfect, both in proper ohmic resistance and magnetic density, there would be little trouble, but, unfortunately, they are not. When new they pass a regulation test and give satisfactory results, but, like all devices, they are liable to deteriorate more or less. A stroke of lightning or an accidental excess of heat may burn the silk insulation around the copper winding and cause a few of the convolutions to be cut out in one coil. The damage may be very small, but it will cause a proportionate inequality in the density of the magnetic lines of

force set up in the iron core by the two currents from the home battery, although flowing with equal strength in both the main-line and artificial-line coils. In other words, if an ammeter showed that the strength of the current flowing in each coil of the relay was of identically the same value, the magnetism in the relay, produced by the current in the slightly defective coil, would be somewhat less than that in its side partner, because there would be a less number of convolutions of wire. Hence, the excess of magnetic energy in the stronger coil would antagonize the incoming signals. This antagonism must not occur. When the statement is made that the current should flow equally through each coil, it really means that the magnetic energy in the two coils must be of identical value.

238. If you balance a quadruplex possessing, say, a slightly defective polar relay and a perfect neutral relay, in the manner stated, the result will be that in order to magnetically equate for the polar relay, more current must traverse the weaker coil than passes through the other. This inequality of current strength can only be obtained by a corresponding difference in ohmic resistance of the main and artificial lines. Hence, if the current is adjusted until this polar relay is unaffected by the operation of the home pole changer, the balance so obtained will necessarily be false. If false, the evenly wound neutral relay will receive more current through one coil than through the other, as its coils are in the same path as the polar-relay coils, and are fed by the same currents. As the same rule applies equally to both relays, the excess of current strength in one coil of an imperfect relay will interfere with the incoming signals in the perfect relay.

It must not be supposed, however, that the defective polar relay described is to be met with very frequently, but there are so many combinations continually arising on the various circuits, that a practically similar state of affairs actually exists in a greater or less degree. But whether such conditions arise or not, the neutral relay is the weaker

instrument, and attention should be devoted entirely to it, even at the expense of the polar side, if necessary, as the latter instrument can dispense with considerable of its working margin without material injury. To attain the highest degree of efficiency, therefore, the following plan for balancing a quadruplex is given.

JONES'S METHOD.

239. Center Armature of Polar Relay.—*First*, ask the distant office to ground. This is done in Fig. 59 by turning to the right the arm of the switch *U*, in Fig. 63 the arm *u* of switch *M*, in Fig. 66 the arm *x* of the switch *M*, and in Fig. 70 the arm of the switch *Q*. After you have done likewise at your home station, center the armature of the polar relay in the manner explained in connection with the polar duplex.

240. Resistance Balance by Polar Relay.—*Second*, cut in your home battery by turning the switches mentioned in Art. **239** to the left, and, by adjusting the artificial-line rheostat *Rh*, balance in the usual manner. To do this, first close your transmitter and then adjust the rheostat in the open and closed positions of your pole changer until the armature of your polar relay will remain on either side.

241. Resistance Balance by Neutral Relay.—*Third*, with the switches mentioned in the preceding articles still turned to the left, that is, with the batteries "cut in," close your key on the second, or neutral, side and tell the distant office to cut in and dot on his second, or neutral, side only.

Pay no attention to the polar side, but consider your No. 2 relay and the pole changer an ordinary Stearns duplex set and proceed to balance as if you were handling that apparatus. In other words, while the distant office is "dotting" for you on the neutral side only, turn the retractile spring of the neutral relay down; that is, weaken the spring so as

to make it as sensitive to interference from your own home battery as possible, and yet respond to the dots made at the distant station. Then proceed to adjust the rheostat until you can close and open the key controlling your pole changer without its having the slightest influence on incoming signals.

242. Static Balance.—*Fourth*, to eliminate the kick due to the electrostatic capacity of the line, commonly termed the "static," ask the distant office to close his key on the polar side only, keeping his neutral, or No. 2, side open, the home key on the neutral side being closed. This places the local contact points on each home relay in their most sensitive position. Then, as before, turn down the retractile spring until the tension is very slight, and devoting your attention to the neutral relay alone, adjust the condensers and retarding coils until the home reversals fail to produce a kick. Since most of the static discharge is usually from that portion of the line nearest the home office, the condenser that discharges through one resistance should have about twice the capacity of the other. Adjust the condenser as well as you can, that is, until one plug gives too great a discharge and the next one too little, and then adjust the resistances in the retarding coils until the desired static balance is obtained.

243. To Adjust Neutral Relay.—*Fifth*, ask the distant office to write for you on the neutral, or No. 2, side while he dots on the other; then adjust the retractile spring of the neutral relay to the signals as you would if it were an ordinary relay. While adjusting, your transmitter key should be closed and the neutral relay should be adjusted until the distant signals are clear. When you reverse your pole changer, reverse it slowly at first, in order to make sure that the signals come equally clear under each reversal, then reverse it rapidly by dotting rapidly. Since dots often come clearly when words will not, it is better to test the signals coming from the distant office from the writing rather than from the dots made by the distant operator.

244. The preceding method of balancing a quadruplex system, in addition, of course, to the proper adjustment of the pole changer, has been more or less followed by quadruplex experts for years and the superiority of such a balance has been shown by its success. Since the kicks, when obtaining the static balance, invariably disappear from the polar relay first, it follows conclusively that the polar relay must not be depended on to tell when a perfect balance has been obtained. After having followed the instructions up to this point, it is time to turn your attention to the apparatus at the other end of the wire. This statement may surprise some, but it is a fact, nevertheless, that it is the duty of the home office to determine and to notify the distant office when his transmitting apparatus is not properly adjusted and when his battery is out of order.

245. Adjustment of the Dynamo Pole Changer.—The proper way to adjust a dynamo pole changer was explained in Art. **123,** in connection with the polar duplex. That article should be thoroughly understood by the student before he studies this one, which applies to the further adjustment and testing of the pole changer when it is used on a quadruplex system.

When the pole changer has been adjusted so as to have a minimum play, and at the same time gives low but distinct signals, the tendency to arc is reduced to a minimum. The receiving operator on the neutral side of the quadruplex at the distant office will then find that his relay is getting the maximum increase in current for a working margin. If the contact points of the walking-beam pole changer are too far apart, the duration of "no current to the line" will be so great that the neutral relay of the quadruplex set at the distant office will have time to partially demagnetize. As a result, it will allow its armature lever to be pulled from the contact point by the spring at the very time, perhaps, that it is making a signal, thus mutilating it.

Suppose that an operator at the home station believes that the distant pole changer is not properly adjusted; then he

should proceed in the following manner: He will first request the distant operator to close the key on the transmitter side of the desk, thus placing the home neutral-relay armature in position for making a dash. He will then ask the distant operator to dot on the key controlling the distant pole changer, the transmitter at the home station being kept closed. As soon as the home operator hears the dots on the polar side, he should turn his main-battery switch to the ground, in order to cut off all current except that from the distant station. Now, if the distant pole changer is improperly adjusted, there will be a kick on the home neutral relay every time that the key on the polar side at the distant office is manipulated, in spite of the fact that the signals may be received in good order on the polar side of the home station. If such is the case, the home operator should say to the distant operator: "Your reversals break up the second side." The home operator will pronounce the adjustment of the distant pole changer all right when the home neutral relay, or second side, is no longer improperly interfered with.

HANCOCK'S METHOD.

246. Another method of balancing a quadruplex system was described by Mr. B. P. Hancock in "The Telegraph Age." This plan, which we will call the **Hancock method,** is also based on a neutral-relay balance.

Not infrequently, after an apparently perfect balance has been obtained by the usual method, the polar relay having been used as a medium, it is found that when the distant office is cut in, the neutral side shows unmistakable signs of an imperfect equilibrium. This result may be due to inequalities between the windings of the polar or neutral relay, as has already been explained, or it may be that inductive currents are so much in evidence, and keep up such a rattle on the instruments under attention, that it is impossible to tell when a perfect balance has been reached.

Whatever the cause may be, some reliable method is needed to secure a practically true balance of the neutral side—the one object of marked solicitude at all times. The following method has given satisfactory results to Mr. Hancock and his associates for some time.

247. Center Armature of Polar Relay.—While the Hancock system makes use only of the neutral relay as the medium for obtaining the balance, it is best to begin by grounding the circuit at both ends and adjusting the polar relay until the armature rests indifferently on either stop or vibrates properly between them.

248. Resistance Balance.—In making a **resistance balance,** cut in your battery and adjust your rheostat until you have a line balance. Then have the distant office cut in by opening his neutral side and closing his polar side. Now take your own battery off the line by placing the arm of the ground switch on the grounded contact button, and turn the spring of the neutral relay down to the very lowest tension necessary to hold the armature in an open position, making certain that the magnets are sufficiently far from the armature to make only a slight tension necessary to produce that result. When this has been done, it will be found, when you restore your battery to the line and close the key on the neutral side, that if the balance is at all defective, your neutral relay will respond to the movement of your pole changer—closing when you open the pole changer and opening on the reversal, or *vice versa.*

To obtain a balance, place your pole changer in such a position that your neutral relay remains closed; gradually alter the resistance of your rheostat until, with the least change in resistance, the neutral-relay armature opens. The quickest way to reach this result is to remove the plug that will insert 1,000 ohms into the artificial-line circuit and note the effect on the neutral-relay armature. If it opens, replace this plug and unplug, say, 400 ohms. If now the relay does not open, remove another plug, adding, say, 100 ohms to the circuit; continue adding resistance until a

grinding movement appears in the neutral relay; then unplug about 10 ohms more, and you have the desired result.

Should the neutral relay fail to open when plugs are removed from the rheostat, proceed in the same manner, but insert the plugs instead of removing them. It is apparent that if the home battery does not manifest itself under these conditions it is not likely to do so at all.

249. Static Balance.—To find the **static balance,** turn the neutral-relay spring just high enough to keep the armature quiet when your keys are at rest; then adjust the condensers and retardation coils so that the neutral relay is not affected by your reversals. A perfect static balance is of the utmost importance if satisfactory results are to be obtained.

HOW TO LOCATE AND REMEDY QUADRUPLEX DISTURBANCES.

250. One of the most perplexing problems with which newly assigned chiefs and those detailed to oversee and care for quadruplex apparatus meet is, how to determine and locate a fault directly it is reported. To do this quickly and with any degree of certainty necessitates not only a thorough knowledge of both the mechanical construction and the theory of the apparatus, but a careful and persistent observation of each accompanying "symptom" as the various disturbances appear from time to time.

Nevertheless one must not be discouraged should the task of locating the disturbance by the observance of one or more of the numerous signs prove to be at fault. The most experienced experts are frequently compelled to make several tests before finally arriving at a definite conclusion, on account of the similarity of certain features accompanying faults of a widely different character. But as a rule, the most frequently occurring disturbances can be readily determined with a reasonable degree of certainty, after a

comparatively short experience, if one will but take the trouble to learn the significance of the ever-present guides, of which the following are the most trustworthy.

WIRE FAULTS.

251. Open Line.—If, while you manipulate the key on the No. 1 side of the desk, the *polar relay records your own signals* promptly and distinctly, even though you get the "back stroke," that is, even if the armature returns to its back stop when you release your key, and the removal or insertion of plugs in the rheostat has no disturbing effect on the signals, you may be certain that the *line wire is open.*

252. Crossed or Grounded Line.—Should the *signals be broken up*, however, or otherwise interfered with by the process, it will denote that the *line wire is closed*, but *that it probably is crossed or grounded at some unknown point.* If it is simply grounded, you will be able to center the armature of the polar relay when you turn the home switch to the earth, exactly as you would were this ground the legitimate compensating ground coil in the quadruplex apparatus at the distant office.

253. Foreign Current From Line. — Should the lever, under the above conditions, persist in clinging strongly to one pole of the magnet, it shows the presence of a current of electricity, which is probably from some foreign circuit with which the wire is crossed. Of course, it is possible that the current you get may be legitimate, and that the distant station, through defective or improper adjustment of the apparatus, may be unable to make you hear him; but where you have completely lost the office at the other end of the circuit, it is pretty safe to attribute the current to a cross.

254. To determine on which side of a repeating station the wire has failed, it is only necessary to listen to the

signals produced on your relay by manipulating your own key. If the fault is beyond the repeating station, the signals will be recorded on your relay and sounder a fraction of a second after your key makes contact. In other words, your own signals will apparently lag just behind the motion of your wrist.

DEFECTIVE APPARATUS.

255. It sometimes happens that while the wire "quads" O. K. at this end (to use familiar language), the distant office fails to get four corners out of his apparatus. It is in such cases that the skill of a chief operator is most severely tested, and when an opportunity is presented for him to help out of a difficulty an inexperienced quadruplex attendant at a small repeating station.

Let us assume, for the purpose of demonstration, that the wire and the apparatus at the other end of the circuit are O. K., but still the distant operator is unable to read our signals clearly on one or perhaps either of his relays. We will also assume that our apparatus is arranged for dynamos and that the trouble is in our own set.

256. The process to be followed would be to first ask the distant office to state the nature of the fault, in order that the search may be made in the right direction. If he says that the signals are distinct on his common side only when our polar side is quiet, it is more than likely that our pole changer is improperly adjusted. After we have cleaned the contact points and have adjusted them as closely as is possible, without giving them a tendency to spark, ask the distant office to ground and to listen to his own neutral relay while we manipulate our pole changer, while our full battery is connected in the line—that is, with our transmitter closed. If under these conditions the distant operator hears no click on his neutral relay, the fault will have been eliminated.

257. It frequently occurs that the distant operator cannot hear our signals on his neutral relay. When we are notified of this fact, we should immediately examine the tongue of our transmitter, as well as the wire attached to the "leak box" in the Western Union quadruplex. In nearly every case, the trouble will be found at one of these points. Perhaps the adjustment of the contact points is such as to prevent the tongue from being pulled away from the upper post when the transmitter is opened, thereby making no connection with the leak coil. Under these conditions, our full battery will continue to go to the line by way of the upper post of the transmitter, regardless of its position, and the neutral relay at the other end of the wire will, therefore, remain closed.

For a similar reason, the distant neutral relay will remain open, irrespective of the position of our transmitter, should the tongue of the latter cling to the lower contact point. In the latter disarrangement of the device, the 900-ohm leak coil in the Western Union quadruplex will always be connected, and, consequently, the electromotive force will be reduced to a strength equal to that of a short-end battery.

258. Defect in Leak-Coil Circuit.—Should the wire attached to the leak coil in the Western Union quadruplex become broken or disconnected, the neutral relay at the distant station will remain closed, regardless of the position of our transmitter, because the short route that reduces our electromotive force is now unavailable.

259. Defect in Ground-Coil Circuit. — Again, we will suppose that the station in difficulty informs us that, notwithstanding the fact that his balance is apparently all right, on attempting to work the apparatus, he finds that both of his relays are more or less interfered with by his own battery. One pole of his battery may cause the incoming signals to be either light or heavy, as the case may be, while the other pole may have the opposite effect—possibly shutting out altogether the incoming signals.

We should immediately suspect our own ground coil of

being the cause of the trouble. It is quite evident that the apparatus at the other end of the wire is out of balance, and it therefore follows that the abnormal resistance to which the rheostat had been adjusted, while our end was grounded, disappeared the moment that we turned our switch to battery again.

The explanation of that fact is that an open ground coil will compel the incoming current to find a ground through our rheostat or the leak coil, either of which contains a much greater resistance than does the proper compensating ground coil. The balance at the distant station will, therefore, be false, because, after we have cut in, the actual resistance of the circuit will be much less than the resistance in the artificial line at the distant station.

A loose connection of the wire that is connected to a ground coil, or an ink-covered disk on the rheostat, may add a resistance of several hundred ohms to the ground coil and thus destroy its usefulness. If the fault cannot be quickly repaired, the distant station should adjust his rheostat to the incoming signals on his neutral relay, while we dot or write for him on our transmitter only, in accordance with the method of balancing that has been given.

260. Defective Ground Wire.—If, after obtaining a correct balance at both the home and distant stations, the maximum current is very much less than it should be, it is probable that the ground wire from the dynamos or battery is loose at one or both ends, or that it is open at one end. If it is open at one end, the current is forced to reach the ground through the artificial line instead of through the ground wire, thus reducing the current to about one-half its strength, because the resistance in the path of the current to the ground is about double its normal value.

BATTERY FAULTS.

261. One Pole of Battery Open.—When the distant office, after taking a careful balance, informs us that he can hear our signals on his neutral relay only when our

key on the polar side is closed (or open, as the case may be), it is possible that one pole of our battery is open, or, at least, that the current is not passing through the pole changer.

The quickest way to verify this fact would be for us to push our switch so close to the ground bottom that the point of a lead pencil will make contact between them. Then, by alternately opening and closing the key controlling the pole changer, and while we are inserting the point of the pencil between the button and switch arm, a current of electricity will cause a spark to appear the instant that contact is made. The absence of the spark will show that none of the current reaches that point, while the position of the lever of the pole changer will indicate which polarity is missing.

262. Should it be impossible to restore the battery at once, it will still be possible to get a duplex out of the quadruplex apparatus. This may be done by so setting your key on the polar side that the lever of the pole changer will rest on the "good" pole of the battery. You may then utilize the common or neutral side as a duplex. Do not attempt, in this case, to transmit on one side of the quadruplex and receive on the other side, as inexperienced operators have frequently attempted to do, because the apparatus will not work since both sides cannot be properly balanced. You will simply destroy both sides by the operation.

263. Defective Cell.—Many of the troubles found in connection with quadruplex systems are due to loose connections, broken wires, defective batteries, punctured condensers, and defective resistance boxes, in addition to the bad condition of the various contact points. A defective cell in either the long-end or short-end battery is very often the cause of considerable trouble. If there is a defective cell in the long-end battery at the distant office, the fault will appear only when the distant office has his transmitter key closed. If the cell is so bad as to actually open the battery circuit, the polar relay will not be affected when the

distant pole changer is operated, as long as the distant transmitter is closed; and the operation of the distant transmitter will not operate the home neutral relay at all. On the other hand, should there be a defective cell in the short end of the distant battery, the trouble will appear in either position of the distant transmitter, and the current will be too weak to even operate the polar side.

264. Defective Tap Wire.—A break in the tap wire at the distant station will interrupt all current when the short end of the distant battery is connected to the line, as it should be when the transmitter is open. In this case, the polar relay will work all right when the distant pole changer is operated, provided the distant transmitter is closed. When the distant transmitter is open, neither side will work.

265. There are symptoms that, although pointing strongly in a certain direction, may possibly be due to an entirely different cause from the one suspected. For example, after having taken a careful balance and adjusted the apparatus for the best results, it is frequently found that, in spite of these efforts, the incoming signals on the neutral relay are still more or less interfered with as soon as the distant office begins to send on the polar side. This sign of trouble naturally points to an improper adjustment of the distant pole changer, and in a great majority of the cases, this will prove to be the disturbing element. In order to be certain that the home apparatus is not defective, it is well to exchange the set, temporarily, with another that is known to be in good condition. Should there still be no improvement and you are sure that the wire itself is perfectly clear, it will then be in order to suspect the distant battery.

266. Margin Too Small.—It is possible that the strength of the incoming current, due to the short end of the distant battery, too nearly approaches the strength of the current due to the long end of the distant battery. When such a condition exists, it is customary to notify the distant office that his proportions are incorrect, meaning, of

course, that the respective currents from his short-end and long-end batteries are not reaching us in the proper ratio of 4 to 1, or 3 to 1, as the case may be.

This discrepancy may arise from a variety of causes, but in nearly every instance (assuming that the wire is perfectly clear and free from escapes) the trouble will be found to be due to a defective or improperly adjusted transmitter, dirty contact points, a defective leak coil, or a loose connection of the wire attached to the leak coil at the distant station. Possibly one contact point of the distant pole changer is black from oxidation, thereby causing a higher resistance in one position of the pole changer than in the other.

It is quite evident that a dirty or improper contact between the tongue of the transmitter and the lever bar might add a resistance of hundreds of ohms to the route of the current. The effect of such a condition on the current in the Western Union quadruplex will be identical to increasing the resistance of the leak coil by just that many additional ohms. Under these conditions, the resistance of the 600-ohm lamp in the dynamo circuit plus the 1,800 ohms in the added resistance coil will be considerably less, in proportion to the resistance through the tongue and the leak coil, than it should be. Hence, a much larger proportion of the total current might be forced through the line to the distant relays than is intended. Therefore, an abnormal condition, through the chance resistance of a distributing element, may cause the strength of the current due to the short end of the battery to be very nearly equal in value to that due to the long end. A loose connection at the binding post of the leak coil will also increase its resistance and so increase the short-end current in the line in the same manner.

In verification of the above, it is only necessary to call attention to the fact that when it is desired to increase the short-end current under normal conditions, it is done by simply adding 100 ohms to the leak coil by removing the plug from the right-hand hole of the leak-and-added-resistance box, which contains that amount of surplus resistance to be used for this very purpose. The addition of a resistance

in the leak-coil circuit, therefore, increases the strength of the current from the short-end battery, but does not necessarily alter the value of the current from the long-end battery.

267. Improperly Adjusted Transmitter.—It quite frequently happens that the stronger current is greatly reduced in value, notwithstanding that the dynamo or battery may be furnishing full pressure. Under these conditions, the working margin of the neutral relay will appear to be very small. In all probability, the source of this small margin will be found in a double contact between the tongue of the transmitter and both the upper and the lower contact points, owing to an improper adjustment of the transmitter. Should the tongue accidentally touch the lever bar so imperfectly as to cause a high resistance at that point, during the time it should make contact only with the stop, a much smaller proportion of the total current will flow through the line and distant relays than was intended; hence, it may cause the strength of the current due to the long end of the battery to be very nearly as small as that due to the short end.

268. If, during wet weather, the system has been worked as a duplex only and an extra resistance *w*, Figs. 56 and 59, in the battery circuit was necessary in order not to have an excessive current, this resistance must be cut out when the wet weather clears and the system is to be used again as a quadruplex. If this resistance *w* is not cut out at the distant end, it will be found that the margin on the home neutral relay is very small. When it is suspected that the weakening of the incoming current, when the long end of the distant battery is connected to the line, is due to the fact that this resistance is still included in the circuit at the distant end, the distant operator should be requested to see that this resistance is cut out.

269. Experience Required.—It requires considerable actual experience to be able to nicely adjust the apparatus; but one of the safest guides to follow is to see that the contact points of all transmitting apparatus are as close

together as they will work without sparking, and give to the spring a tension that will not cause a jar as the armature rebounds. At the same time, see that the lever works freely in the trunnion without destroying the good contact. The down stroke of all armatures should be slightly stronger than the up stroke.

Above all things, see that the spring on the pole changer does not cause the lever to tremble, or vibrate, when released by the local magnet, and remember that the closer together you get the pole-changer points, the better will the man at the other end get your signals on his neutral relay.

MEASURING INCOMING CURRENT.

270. The most important thing to bear in mind in making tests of the incoming current is that no matter what value the ammeter, or current indicator, gives for the strength of the current from the long-end battery, the strength of the current due to the short end of the distant battery should be approximately just one-third or one-fourth that due to the long end, according to whether the distant station is giving you a proportion of 3 to 1 or 4 to 1. When an improper ratio between the incoming line currents in the open and closed positions of the distant transmitter is suspected, the manner in which the strength of the current from the distant battery may be measured, assuming, of course, that the wire itself is clear and free from abnormal escapes, is as follows.

271. Western Union Method.—If the current is to be measured at the desk of a Western Union quadruplex set, proceed in this manner:

1. Ask the distant office to close both keys.
2. Turn the home switch to the ground button.
3. Remove the main-line wire from the binding post of the polar relay (usually the binding post at the extreme right), and insert the wedge of the ammeter between the

line wire and the binding post, using finger pressure to make a firm connection.

4. Note the deflection of the needle of the ammeter, and record the reading as the value of the current from the distant long-end battery, that is, with the distant transmitter key closed.

5. Cut in the battery and say to the distant office: "Open the key on the polar side only." Then ground the wire again and proceed as before. The reading now shown by the needle of the ammeter will represent the strength of the current from the long-end battery, but due to the other pole of the battery, and should be practically the same as that due to the other polarity. Neutral quadruplex relays require from 45 to 60 milliamperes. Hence the strength of the current from the distant long-end batteries should give a value within these limits.

6. Cut in again and say: "Open the keys on both sides of the table." Then ground and measure as before. The needle will denote the value of the current from one pole of the distant short-end battery. The other polarity is measured in a like manner, after first requesting the distant office to close the key on the polar side only. These two measurements of the current from the distant short-end battery should also agree in value. Polar relays on quadruplex circuits require from 15 to 18 milliamperes for the value of the current from the distant short-end battery.

272. Postal Telegraph Method.—In order to measure the ratio between the strength of the incoming current in the open and closed positions of the distant transmitter in the Postal Telegraph arrangement of connections, insert the wedge, to which the milliammeter is connected, between the lever of the ground switch and the ground button. In Fig. 70, for instance, insert the milliammeter wedge between the arm of the switch *Q* and the ground button *v*. The current flowing through the milliammeter, when in this position, will be somewhat smaller than the current actually flowing in the line coils of the

relays; nevertheless, the milliammeter reading will be proportional to the strength of the current in the line coils, and, consequently, if the reading of the milliammeter is reduced one-third when the distant transmitter is opened, then the current in the line coils is also reduced to one-third its previous strength.

To test the home battery, have the distant office ground his end, and insert your milliammeter wedge between the lever of the ground switch Q and the battery button u, Fig. 70. Then, by opening and closing the transmitter key, the ammeter will indicate the difference between the current from the long-end and short-end batteries.

273. If the ratio between the electromotive forces, or the ratio between the added and leak resistances in the Western Union quadruplex, or the ratio between the resistance A, B, and C in the Healy quadruplex at the distant station are correct, the value of the long-end measurements (irrespective of battery polarity) should be represented by a figure practically either three or four times as great (depending on the ratio employed) as that obtained by the short-end measurement.

274. Galvanometer to Determine Condition of Circuit.—When the Kansas City office of the Postal Telegraph Company was equipped, a galvanometer was included in the multiplex circuits in order that the condition of each multiplex circuit between the home office and the other terminal, or repeater, station could be told at a glance, thus avoiding the necessity of trying a balance and, consequently, saving much time. If one coil of a differentially wound galvanometer be permanently connected in the line circuit and the other coil in the artificial-line circuit, it can easily and quickly be determined if the current from the home station divides equally between the two circuits mentioned and, also, if the ratio between the minimum and maximum current is the one desired.

275. Defective Condensers. — Sometimes the condensers in the artificial line will be punctured by a lightning

discharge during a thunderstorm. When this happens, the artificial line is short-circuited, and no amount of adjustment of the resistances or condensers will balance the line. The defective condenser must be replaced by a good one before a balance can be obtained.

DISTURBANCES DUE TO TROLLEY CURRENTS.

276. In some localities where trolley or electric-light plants are located, the potential of the earth frequently becomes so high through leakage or otherwise that if one end of a telegraph wire be buried in the earth at that point and grounded at a distant station, a current will flow through the conductor from the point of the highest potential to the normal ground at the other end of the circuit. Should such a condition exist, the office at the station possessing the normal ground would apparently find his apparatus out of balance. If the foreign electromotive force from the distant ground is, say, 10 volts positive, it will add that many volts pressure to the positive pole of the battery located at that point, and equally oppose 10 volts to the negative pole, actually causing a difference of 20 volts between the two polarities. The neutral relay at the station possessing the normal ground will therefore be more strongly magnetized by the incoming current from one pole of the battery than from the other. This will render impossible the adjustment of the retractile spring on the home neutral relay to suit the strength of both currents.

Now, in order to ascertain whether the inequality thus found in the two currents is due to the presence of an auxiliary electromotive force, ground the wire at each end of the circuit, thereby cutting off both batteries, and then measure the current with an ammeter. Should the ammeter show an undue deflection (still assuming the wire to be clear), you may properly attribute the source of the disturbance to the leakage of current from a trolley or

electric-light plant, which gives the earth at that point a certain electrical potential.

277. Remedy.—When this disturbance in potential between two stations is constant and permanent, the remedy is to insert a few cells of battery in the common ground wire running to the dynamo; or, in the case of the gravity battery quadruplex, between the ground (*G*, Fig. 59) and the pole changer. The value of the electromotive force of the inserted cells must be identical with that producing the earth current, and the direction, of course, should be in opposition to the disturbing element; that is to say, if a foreign current from the ground is being forced into the wire with a pressure of, say, 10 volts positive, 10 volts positive must be inserted against it in order to destroy its detrimental effect.

278. To Determine Number of Cells Required. To determine the number of cells to be inserted, ground the wire at both ends of the circuit and note the deflection of the needle of an ammeter connected in the line circuit. Then insert a few cells of battery in the common ground wire and again observe the deflection. If the strength of current, as shown by the ammeter, has been increased in value, it will indicate that the wrong end of the row of cells has been placed toward the line. Reverse their position, and measure as before. Continue inserting or subtracting cells until the needle returns to zero.

It is important that the cells used for this purpose should have little or no appreciable internal resistance, as an appreciable resistance would be equivalent to increasing the resistance of the dynamo or battery circuit, which would be wrong. A gravity battery, therefore, would not be desirable. A storage battery would be an ideal one for this purpose. As the value of the earth current must necessarily fluctuate more or less between the periods of wet and dry weather, it would be well to have a few cells of battery in reserve, which could be switched in or out of circuit as occasion required.

BRANCH OFFICES CONNECTED TO MULTIPLEX SETS.

279. It is often desirable to extend the receiving and sending sides of duplex and quadruplex circuits to a branch office. The general method of doing this where dynamos or primary cells are used is shown in Fig. 79. Where batteries are used, it is customary, in order to get the same current, to increase the number of cells when the circuit is extended to a branch office. The method of doing this is shown in connection with the pole changer in Fig. 79. When the arm of the switch Q rests upon the contact button *1*, the magnet of the pole changer is connected in series with the key K and the battery B. When the arm of the switch Q is placed on contact button *2*, the pole changer is placed in series with both batteries B and B_1, the sending side of the branch-office loop, the sounder S_2, and the key K_2 at the branch office. The circuit in this case is completed through the ground from G_2 to G_3.

Where dynamos are employed as shown in connection with the polar relay, it is not convenient to increase or decrease the electromotive force of the dynamo, and in order to keep the current the same, a resistance, usually a lamp l in Western Union offices, is placed in the circuit when it is not extended to the branch office. N is the usual form of switch used in connection with the local circuits of duplex and quadruplex sets where dynamos are employed. Only such connections of this switch are shown here as are necessary to explain the figure. When the arm a rests on contact button *10*, the dynamo D, contact points of the polar relay, the main-office sounder S and the lamp l are placed in series; the return circuit is through the ground from G_1 to G. When the switch arm a rests on contact button *9*, the branch-office receiving side, including the branch-office sounder S_1, is placed in circuit in place of the lamp l. The circuit may then be traced from the ground G through the dynamo D, contact points of the polar relay, the main-office sounder S, switch arm a, contact button *9*,

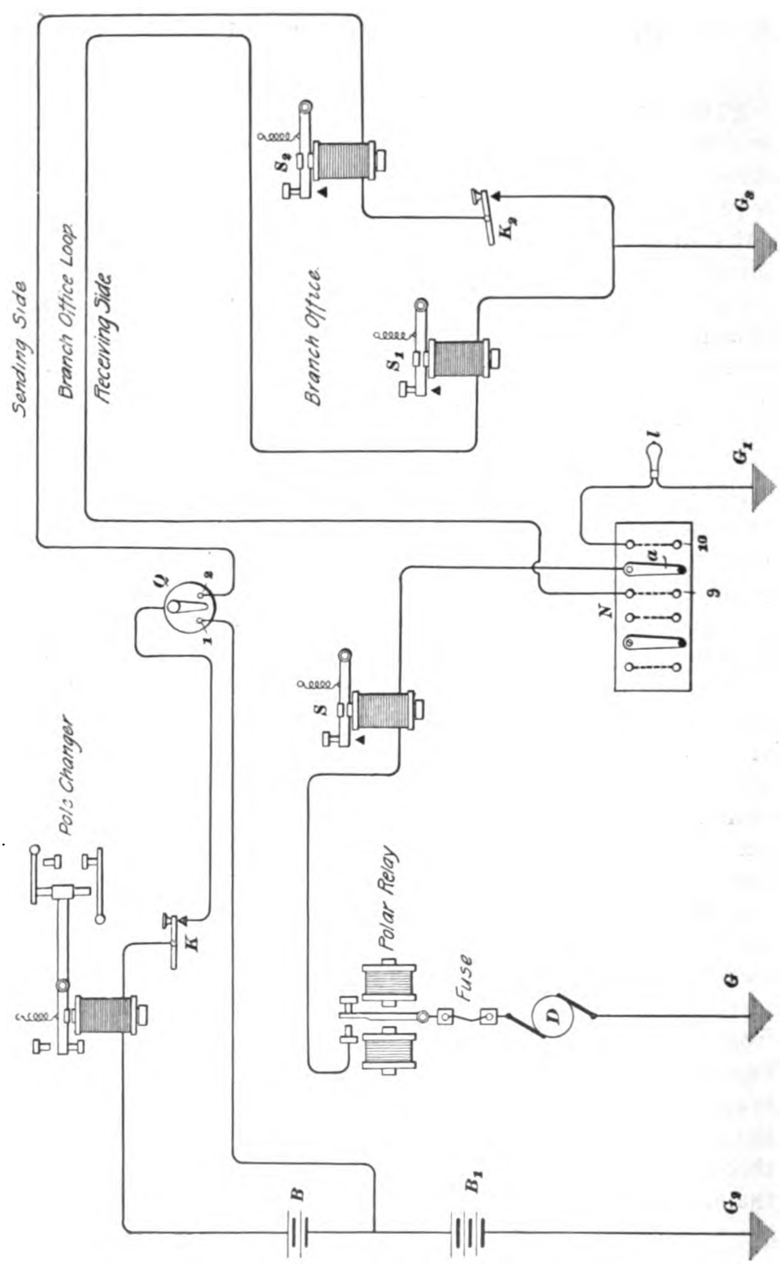

Sending Side
Branch Office Loop
Receiving Side
Branch Office
S_2
K_2
G_3
S_1
l
G_1
10
a
9
N
Q
2
1
S
Pole Changer
K
Polar Relay
Fuse
D
G
B
B_1
G_2

FIG. 79.

the receiving side of the branch-office loop, the sounder S_1, and ground G_3 back to the ground G. Obviously, in order to have the same current through the sounder S in both positions of the switch arm a, the lamp l should have a resistance equal to that of the branch-office sounder S_1 and the line wire (receiving side) between the main and branch offices. In offices where dynamos are employed, there would be a main switch at which the line wire would terminate, and usually a loop switch at which the branch-office loop would terminate, but these switches have been omitted here for the sake of simplicity.

TELEGRAPHY.

(PART 5.)

COMBINATIONS OF REPEATERS AND MULTIPLEX SETS.

MULTIPLEX REPEATERS.

POLAR DUPLEX REPEATERS.

1. Dynamo Arrangement.—It is a very simple matter to connect two duplex sets so that the receiving side of set No. 1 will repeat into the sending side of set No. 2, and the receiving side of set No. 2 into the sending side of set No. 1. Two duplex sets, arranged to repeat in this manner, are shown in Fig. 1. Each set is arranged as usual when dynamos are used to supply the current. The dynamo *D* (a 23-volt machine in Western Union offices) supplies current for all local circuits. With the switch arms *o*, *q*, *o'*, *q'*, and *F* turned to the left and F_1 to the right, the polar relay *PR* in set No. 1 controls the pole changer PC_1 in set No. 2, and the polar relay PR_1 in set No. 2 controls the pole changer *PC* in set No. 1. The two sets are connected together through the jacks and wedges *LS* and LS_1 at the loop switchboard. The receiving side of one set becomes the sending side of the other set; hence the dot lines are

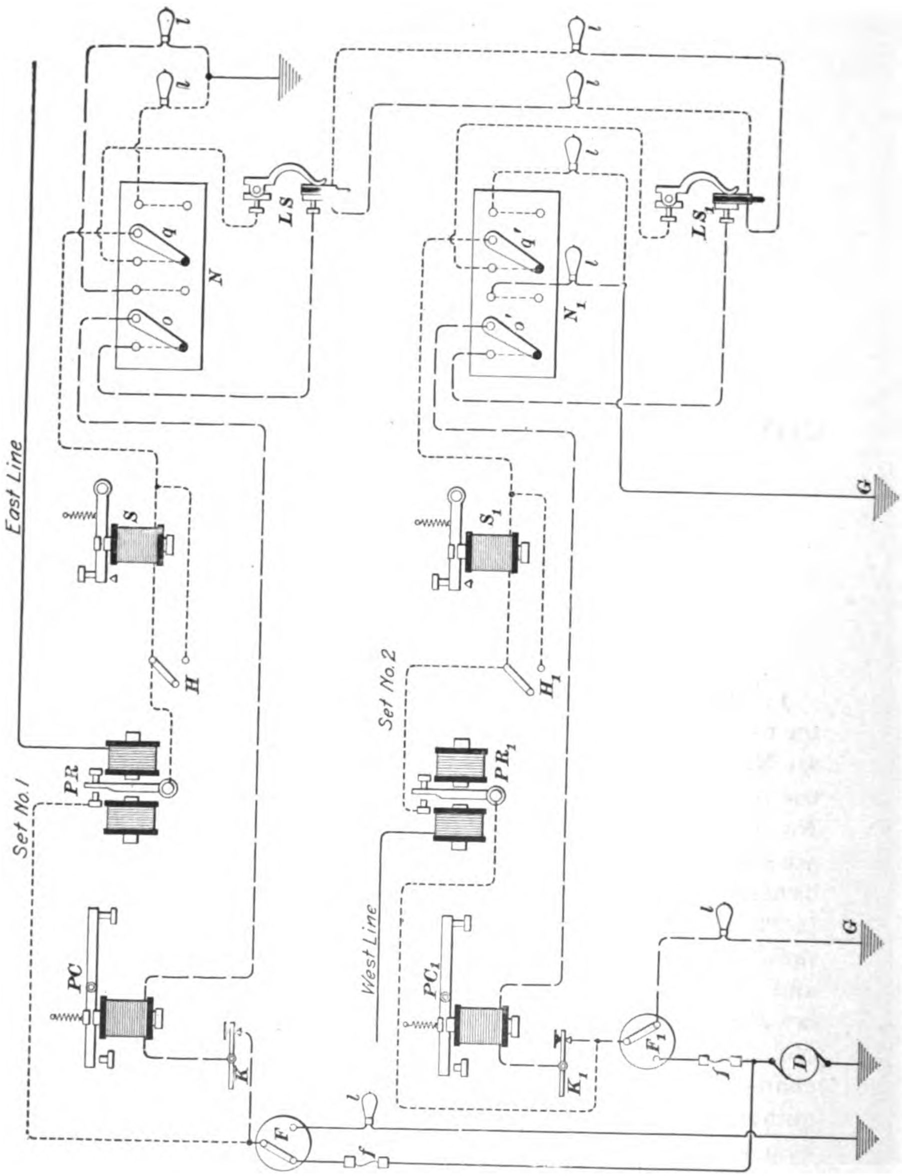

East Line
Set No. 1
Set No. 2
West Line
PR
PC
K
F
f
l
S
H
N
q
o
LS
G
PR_1
PC_1
K_1
F_1
D
S_1
H_1
N_1
q'
o'
LS_1

FIG. 1.

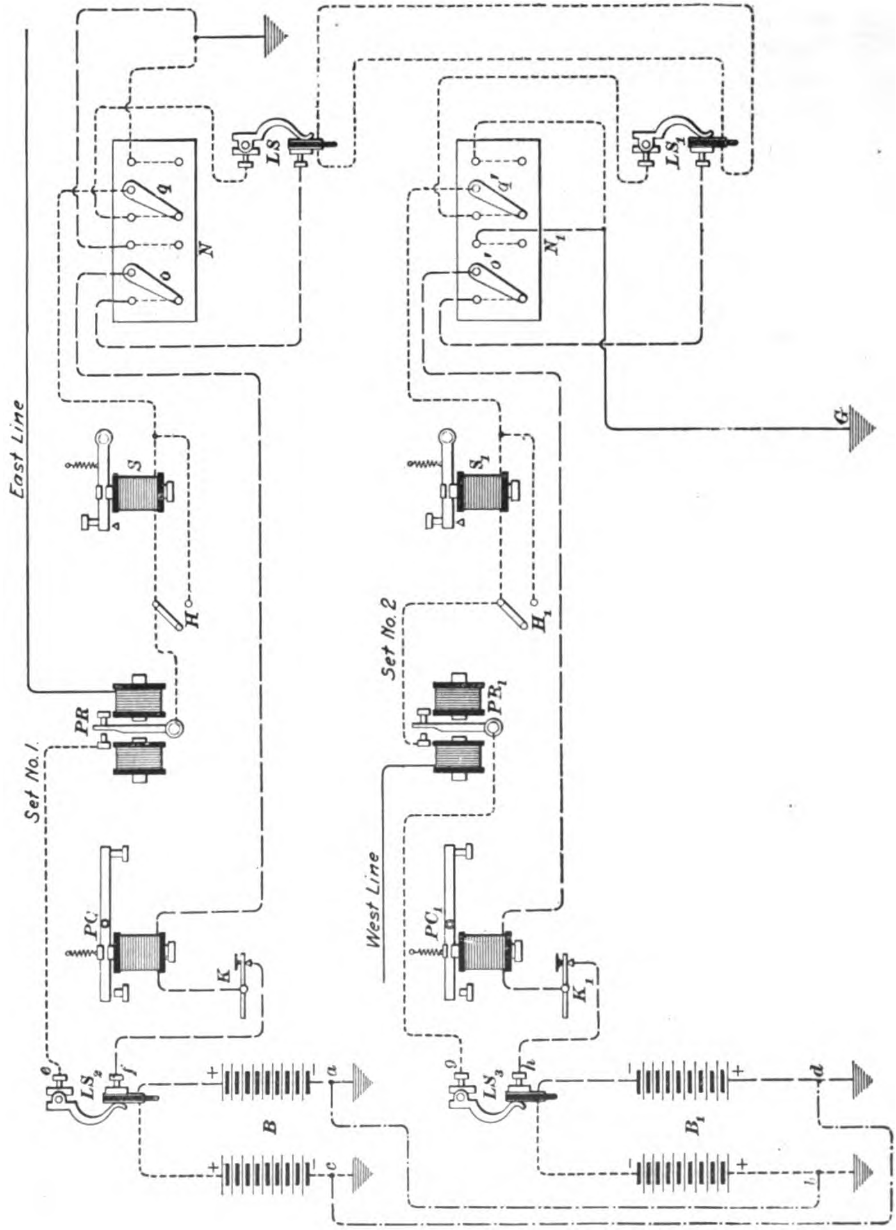


FIG. 2.

changed to dash lines and the dash lines to dot lines at the lamps in the cord circuits between the two spring jacks LS and LS_1. The incoming signals from the east line operate the polar relay PR, and this in turn operates the pole changer PC_1; thus the signals coming in over the east line are repeated into the west line. Similarly, signals coming in over the west line are repeated into the east line.

When the two sets are in operation as a duplex repeater, there is no need of the sounders S and S_1. By closing the switches H and H_1, the sounders may be short-circuited. Thus their resistance may be cut out of the circuit and the current increased somewhat. Switches for this purpose are quite convenient, especially where gravity cells are used for local batteries. The two sets may be readily disconnected and arranged in two entirely independent sets, although supplied with current for the local circuits from the same dynamo D. To do this turn the switch arms o, q, o', and q' to the right and the switches F and F_1 to the left.

2. Battery Arrangement.—In offices where gravity batteries are used, the polar duplex may be arranged as shown in Fig. 2. The arrangement is exactly the same as in the preceding figure except that the wires e, f, g, and h run through jacks at the loop switchboard to gravity batteries, instead of through three-point switches on the desk to a dynamo, and no lamps are required. The lamps are not required because the correct number of cells are supposed to be used in the batteries B and B_1 to give the proper current. The batteries B and B_1 may be main-line batteries with one terminal of each grounded, or they may be intermediate batteries, in which case they would not be grounded, but would be connected as shown by the lines $a\,b$ and $c\,d$. In the former case care must be taken to connect the proper pole of each battery to the wedges, so that they shall not oppose one another. If one set of batteries, B, for instance, is strong enough, then both sides of the wedge in the jack LS_1 should be simply grounded or else connected with the negative poles of the batteries B at a and c. The switch

arms o, q, o', and q' are used in the same manner as explained in connection with the dynamo arrangement shown in Fig. 1.

QUADRUPLEX REPEATERS.

3. It is sometimes necessary on long circuits to repeat from one quadruplex set into another. This can readily be done by connecting the repeating sounder on the common side of the first set so that it will operate the transmitter of the second set, and the repeating sounder of the second set

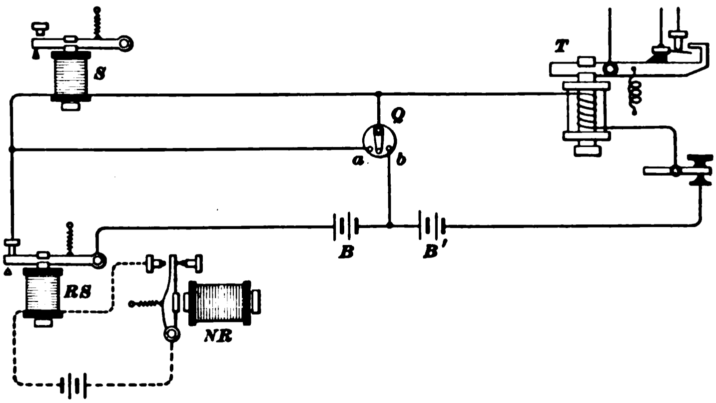
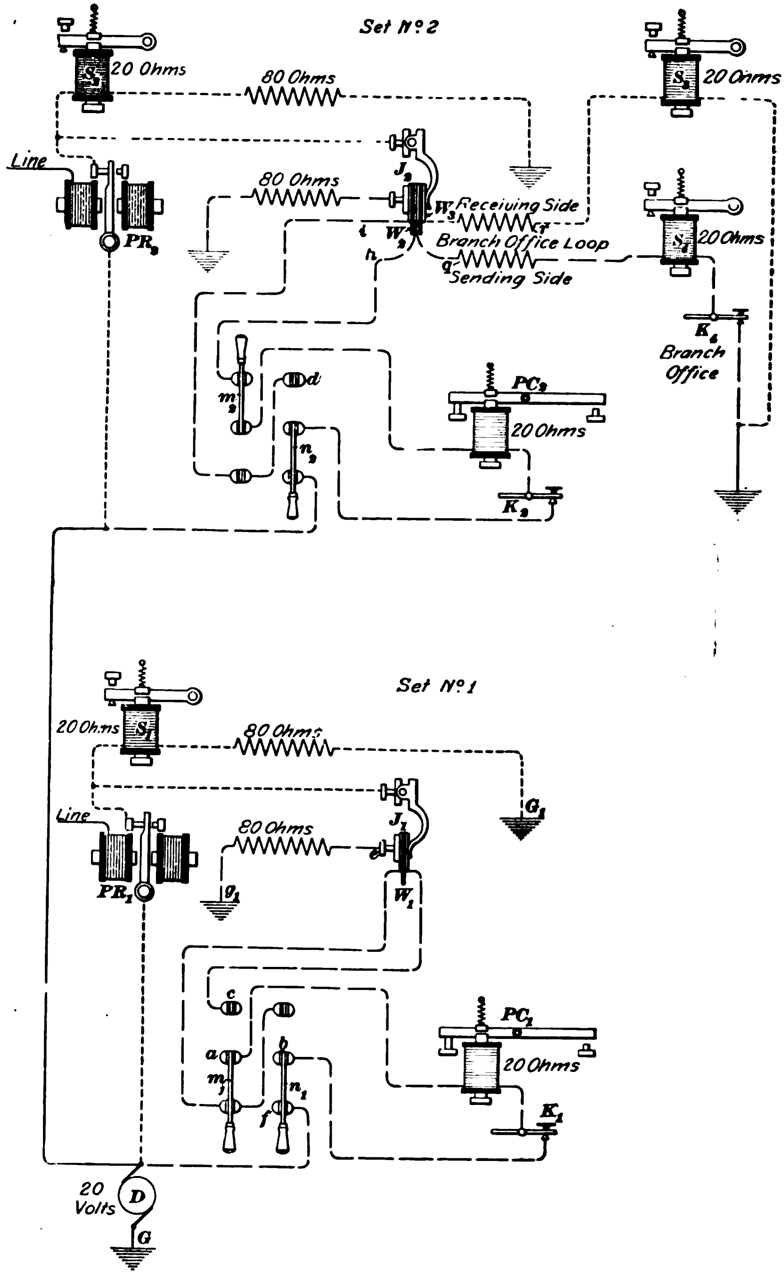


FIG. 3.

so that it will control the transmitter of the first set. On the polar sides, the polar relay of the first set controls the pole changer of the second set, and, conversely, the polar relay of the second set controls the pole changer of the first set.

If the wires are in good condition, it is immaterial whether the polar side of one set repeats into the polar or common side of the other set. If, however, conditions are such that the polar side of two quadruplex sets are working better than the common sides, then it might be better to repeat from the polar side of one set into the polar side of another, and from the common side of one into the common side



Set No. 2
20 Ohms
80 Ohms
20 Ohms
Line
80 Ohms
Receiving Side
Branch Office Loop
Sending Side
20 Ohms
Branch Office
PC2
20 Ohms
Set No. 1
20 Ohms
80 Ohms
Line
80 Ohms
PC1
20 Ohms
20 Volts

FIG. 4.

of the other. By doing this, one side is working in good condition, while the other side may be working in a more or less indifferent manner; then if necessary the poorer side may be abandoned and still leave the other side in workable condition. On the other hand, if the polar side of one set repeats into the common side of the second, and the polar side of the second repeats into the common side of the first, then both sides may work indifferently, if both common sides are not in first-class condition. The advantage of one or the other method will depend on how poor one side is working.

4. In Fig. 3 is shown the diagram of connections, where gravity batteries are used, whereby the repeating sounder *R S* of one set controls the transmitter *T* of another set. The switch *Q* is so connected that when the arm rests on contact button *b*, the two sets are working independently. When the arm of the switch *Q* is in the middle position, the two batteries are both in series with the transmitter *T* and the sounder *S*. This enables the attendant operator to read the signals by means of the sounder *S*. When the arm of the switch *Q* is placed on the contact button *a*, the two batteries *B* and *B'* are both connected in series with the transmitter *T* as before, but now the sounder *S* is short-circuited. If the current is too strong with the sounder *S* short-circuited, it may be left in the circuit.

The arrangement between the two sets on the polar side is so similar to this that it seems unnecessary to give it here.

ARRANGEMENT OF LOCAL CIRCUITS ON CANADIAN PACIFIC RAILROAD.

5. On the Canadian Pacific Railroad, the local sounders, pole changers, and transmitters are wound to a resistance of 20 ohms. They could all be connected in multiple to a 6-volt dynamo, but in nearly every office where dynamos are used, the local circuits of the multiplex sets are connected as shown in Fig. 4. Each half of a quadruplex set,

or half-repeater, is treated as a duplex set. By resistance coils each local circuit of the multiplex and repeater sets is brought up to 100 ohms resistance and the local-circuit dynamo gives from 20 to 25 volts, the former voltage being usually found to be sufficient.

The lower half of the figure shows one set as ordinarily arranged. Starting from the dynamo D, the receiving circuit passes through the contacts on the relay PR_1, 20-ohm sounder S_1, 80-ohm coil, ground G_1, and back through G to the dynamo D. A branch, or leg, passes through jack J_1, but is open at c. The sending circuit may be traced from the dynamo D through the switch n_1, key K_1, 20-ohm pole changer PC_1, switch m_1, wedge W_1, back contact c of the jack J_1, 80-ohm coil, ground g_1, and back to the dynamo D.

6. Local Circuit Extended to Branch Office.—To extend the local circuits of a duplex set to a branch office, the loop wedge W_3 is inserted in the spring jack on top of the wedge W_2, the switch m_2 is turned up and the switch n_2 down, as shown in the upper portion of the figure. The circuits are then as follows: Receiving side; dynamo D, polar relay PR_2, sounder S_2, 80-ohm coil, ground; also from the relay contact through the leg to the top of the jack J_2, front of the wedge W_3, coil r, receiving side of the branch-office loop, branch-office sounder S_3, and ground. The resistance coil r is adjusted so as to give the circuit a total resistance of 100 ohms from the wedge to the branch-office ground. Sending side; dynamo D, switch n_2, key K_2, pole changer PC_2, switch m_2, front of the wedge W_2, back of the wedge W_3, coil q, sending side of the branch-office loop, branch-office sounder S_4, key K_4, and ground. The resistance from the wedge to the branch-office ground is 80 ohms, including the sounder S_4. The resistance of the pole changer PC_2 is included in this circuit, thus making the total resistance 100 ohms, the same as on the receiving side.

7. One Set Repeating Into Another.—To work these sets as repeaters, the wedges of the two sets are exchanged, wedge W_1 of the No. 1 set being inserted in jack J_2, wedge W_2

in jack J_1, and the table switches m_1, m_2, n_1, and n_2 turned up. The circuit may then be traced from the ground G, through the dynamo, contacts of relay PR_1, sounder S_1 and 80-ohm coil to ground G_1; also from the relay contact to the top of the jack J_1, front of the wedge W_2, which is now supposed to be inserted in the jack J_1, wire h, switch m_2, pole changer PC_2, key K_2, switch n_2 to d, wire i, back of the wedge W_2, lower part e of jack J_1, 80-ohm coil, and ground g_1. The circuits from No. 2 set are the same. A break at the contacts of either relay will open its sounder and also the pole changer of the other set. Thus signals received from the line on No. 1 set are automatically transmitted over the line connected to No. 2 set, and *vice versa*.

8. In many places on Canadian Pacific lines, storage batteries are used in place of dynamos, in which case no resistances are inserted in the local circuits but extra cells are used, providing the necessary power when the quadruplex or duplex systems are extended to branch offices. When storage cells are used for main batteries, a switch, consisting of a series of spring jacks and wedges, is so designed that the jack is normally open and a wedge when reversed cannot be inserted. The negative pole of the battery is connected to the top of a wedge and the positive pole to the bottom. It is predicted that shortly storage cells will replace gravity batteries even for locals at wayside stations; the storage cells will be charged at some central point and distributed by train to the wayside stations.

MULTIPLEX SINGLE-WIRE REPEATERS.

9. It is often desirable to arrange a duplex or one side of a quadruplex system, in connection with a single wire running to another office, so that the message being received over the multiplex system may be sent over the single wire to the branch office, and so that the branch office may send through the multiplex apparatus at the nearer station to

the distant multiplex station. An arrangement of apparatus that will accomplish this is very convenient and often very necessary, and is known as a **multiplex single-wire repeater.** An arrangement of apparatus for accomplishing this same purpose in connection with city branch-office lines is known as a *defective-loop repeater.*

10. Defective-Loop Repeaters.—Large telegraph companies frequently rent out lines to brokers and others. Where only one wire is rented to a broker, it is sometimes desirable or necessary that the subscriber for this rented wire shall be connected to one side of a duplex or quadruplex set. The apparatus must then be arranged so that the party renting the wire can send or receive over the one wire. Furthermore, it sometimes happens that one side of a branch-office loop will be out of order or defective. It is then desirable to arrange the apparatus so that the branch office may send or receive over the remaining good leg of the branch-office loop. By arranging the apparatus so that this can be accomplished, much time is saved while the defective leg is being repaired. In either of the above cases, an arrangement to accomplish the desired purpose is usually designated as a **defective-loop repeater,** because it is so often used to utilize the good leg of a temporarily disabled branch-office loop.

The branch-office loop arranged in this manner cannot of course be worked double, that is, one message cannot be sent and another received simultaneously over the one wire; but a single wire, that is, one arranged so that messages can be sent either way, but not in both directions at the same time, is better than none at all, and as such it must be considered. A device of this kind should be kept at all main offices where loop circuits are connected with multiplex sets, for use in case of emergency.

11. To Prevent Repeating Back.—In all repeaters used in connection with multiplex systems, it is essential, of course, that means be provided to prevent the repeating back of a message to the original sending station. In

multiplex single-wire repeaters, this is usually accomplished by the application of the Toye-repeater principle, whereby a resistance is substituted in place of a branch-office circuit, when that circuit is opened; or by the Downer arrangement, whereby an extra battery is included in the higher resistance circuit; or by using half of almost any of the standard single-wire repeaters. The Downer, Moffat, and Half-Milliken repeaters may all be classed as defective-loop repeaters.

DOWNER REPEATER.

12. An arrangement of apparatus and circuits called the **Downer repeater** is shown in Fig. 5. The only additional apparatus not already required in the multiplex set is the repeating transmitter that is operated by the polar relay. The polar relay and the pole changer shown here belong to a regular duplex or quadruplex set.

13. Operation.—When the arm of the switch *Q* rests on the contact button *1*, the pole changer may be controlled, as usual, by an operator at the key *K*. In this position of the switch, the branch-office circuit is cut out. When the arm of the switch *Q* is placed on contact button *2*, the branch-office operator receives whatever messages come through the polar relay and repeating transmitter; or by manipulating his key K_1, he can send a message through the pole changer to the distant office—provided the polar relay is receiving no message and is closed. The operation of the polar relay opens and closes the branch-office line at the stop *c*, but, although it does open and close the branch-office line at this point, it does not open the circuit through the magnet of the pole changer, because the tongue *b* touches the lever *a* before it is pulled away from the stop *c*. Hence the pole changer is not operated. When the repeating transmitter is closed, the circuit may be traced from *G* through the batteries *B* and B_1, the magnet of the pole changer, key *K*, switch *Q*, contact button *2*, tongue *b*, stop *c*,

branch-office line, sounder S_2, key K_2, ground G_1, back to the starting point G. When the repeating transmitter, which by the way is a continuity-preserving transmitter, opens, the tongue *b* comes in contact with the lever *a* and keeps the magnet of the pole changer closed through the following circuit: the battery B_1, magnet of the pole changer, the key K, switch Q, contact button 2, tongue *b*, and lever *a* of the repeating transmitter, back to the battery B_1. The number of cells in the batteries B and B_1 are so proportioned that the current through the magnet of the

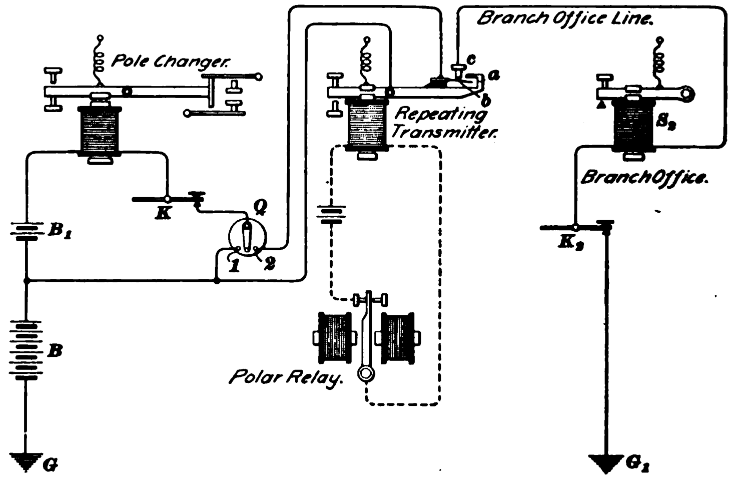


FIG. 5.

pole changer is the same in both positions of the repeating transmitter. Hence, the operation of the polar relay, which causes the repeating transmitter to send the message on to the branch office, does not operate the pole changer. When the branch-office operator wishes to send a message, the polar relay must remain closed in order to keep the repeating transmitter closed. In this position of the repeating transmitter, the tongue *b* rests against the stop *c* and the lever *a* is insulated from both *b* and *c*. The pole changer can now be controlled by the key K_2 or K. Thus it is evident that the branch-office operator may receive a message

from one corner of the quadruplex set, or from the receiving side of a polar-duplex set, without the message being repeated back through the pole changer to the original sending station, and, furthermore, he may send a message to the distant quadruplex station through the pole changer.

MOFFAT'S DEFECTIVE-LOOP REPEATER.

14. Battery Arrangement.—The principle of Moffat's defective-loop repeater is well illustrated in Fig. 6. It is an application of the Toye-repeater principle; namely, the substitution of a resistance in place of the branch-office line circuit when the repeating transmitter opens. The arrangement shown in the figure illustrates the application of this principle to a polar duplex or to the polar side of the quadruplex system. It may also be applied to the neutral side of the quadruplex, in which case the pole changer and polar relay, shown in the figure, will be replaced, respectively, by the transmitter and repeating sounder on the common side of the quadruplex, the repeating transmitter magnet being connected to the back stop of the repeating sounder.

15. Operation.—The operation of this defective-loop repeater is as follows: When a message is coming over the quadruplex wire and through the polar relay, whose local circuit passes through the magnet of the repeating transmitter, the latter is operated. Thus, the circuit to the branch office is opened and closed at the stop *c* of the repeating transmitter, and hence the message may be read from the sounder *S*.

Although the repeating transmitter opens and closes the branch-office circuit, it does not open and close the circuit through the magnet of the pole changer; for in the closed position of the repeating transmitter, the circuit through the pole changer is closed through the tongue *b* and contact *c*, and the circuit may then be traced as follows: From ground *G*, through battery *B*, pole-changer magnet, tongue *b*,

contact *c*, branch-office line, sounder *S*, key *K*, ground G_2, and back to the original starting point *G*. The current in this circuit is sufficient to keep the pole changer closed. When the repeating transmitter is open, the pole changer

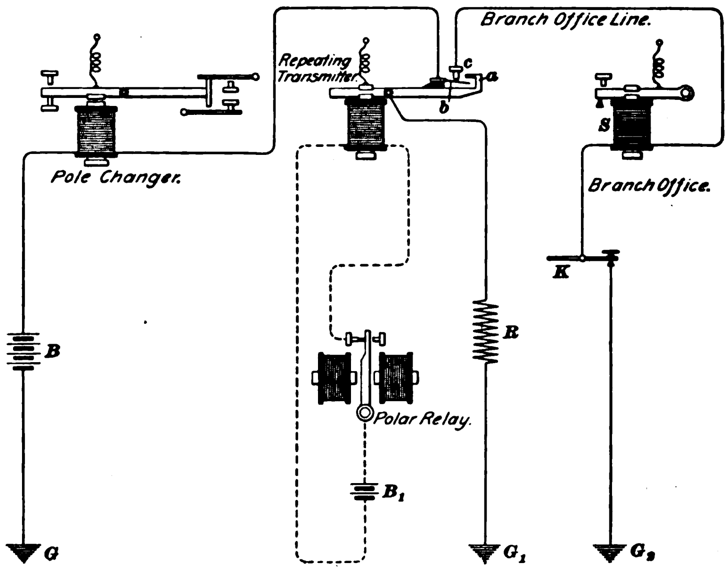


FIG. 6.

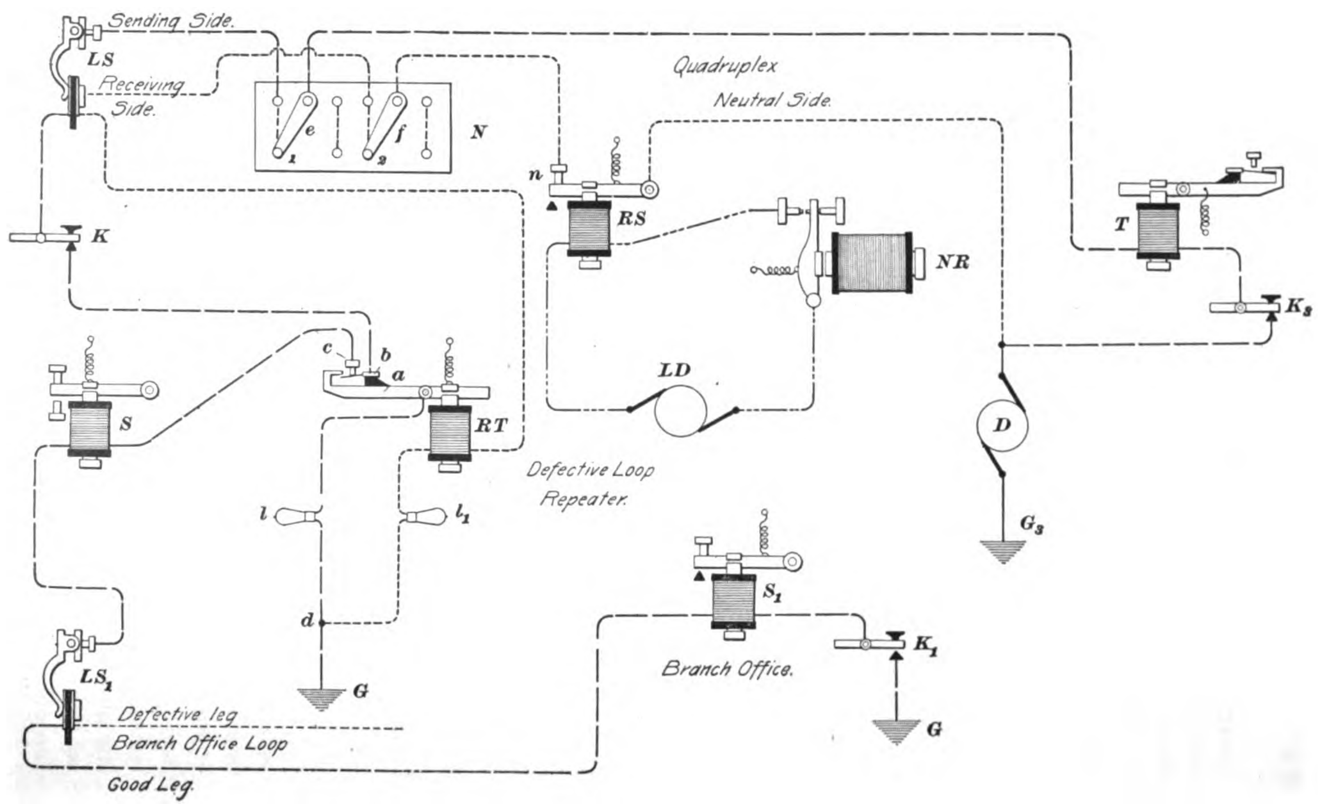
will still be kept closed by a current in the following circuit: From ground *G*, through battery *B*, magnet of the pole changer, tongue *b*, lever *a*, resistance *R*, ground G_1, and back to the starting point *G*.

16. The resistance *R* is made equal to that of the branch-office circuit, so that the same current will flow through the pole-changer magnet in both the open and closed position of the repeating transmitter. Furthermore, the repeating transmitter is a continuity-preserving device; consequently, the pole-changer circuit is not even opened when the repeating transmitter shifts from the open to the closed position, or *vice versa*. It is very necessary that the pole-changer circuit shall not be operated when a message is

being received through the polar relay. If this were not so and the operation of the polar relay should operate the pole changer, the message coming through the polar relay would be sent back by the operation of the pole changer to the same station from which it was sent.

17. To Send From Branch Office.—When the operator at the branch office is sending a message through the repeating office to the other end of the multiplex system, no message can be received over the polar relay, and it remains in its normal closed position, which causes the tongue *b* to remain in contact with the stop *c*. The operation of the key *K* will, in this position of the repeating transmitter, open and close the circuit containing the magnet of the pole changer; hence, the operator at the branch office can send a message through the near end of the multiplex system to the far end of the same system. Thus, the operator at the branch office can both send and receive through a duplex system or either side of a quadruplex system over one line wire.

18. Dynamo Arrangement.—The arrangement of Moffat's defective-loop repeater in Western Union offices, where dynamos are used, is shown in Fig. 7. The branch-office circuit is connected through a wedge to the loop switch LS_1, and the common side of the quadruplex is connected to the loop switch *LS*. The repeating apparatus consists merely of a repeating transmitter *R T*, two lamps *l* and l_1, the sounder *S*, and the key *K*. The latter two instruments enable the attendant operator at the repeating office to receive and send as well as to adjust and balance the system. The arms of the switch *N* rest upon the contact buttons *1* and *2* when the quadruplex apparatus is used in connection with the defective-loop repeater. It will be noticed that the repeating sounder *RS*, instead of being connected to the reading sounder on the common side of the quadruplex, is, in this case, connected directly with the switch *N* so that it controls the repeating transmitter. The repeating sounder is so connected that when it is in operation



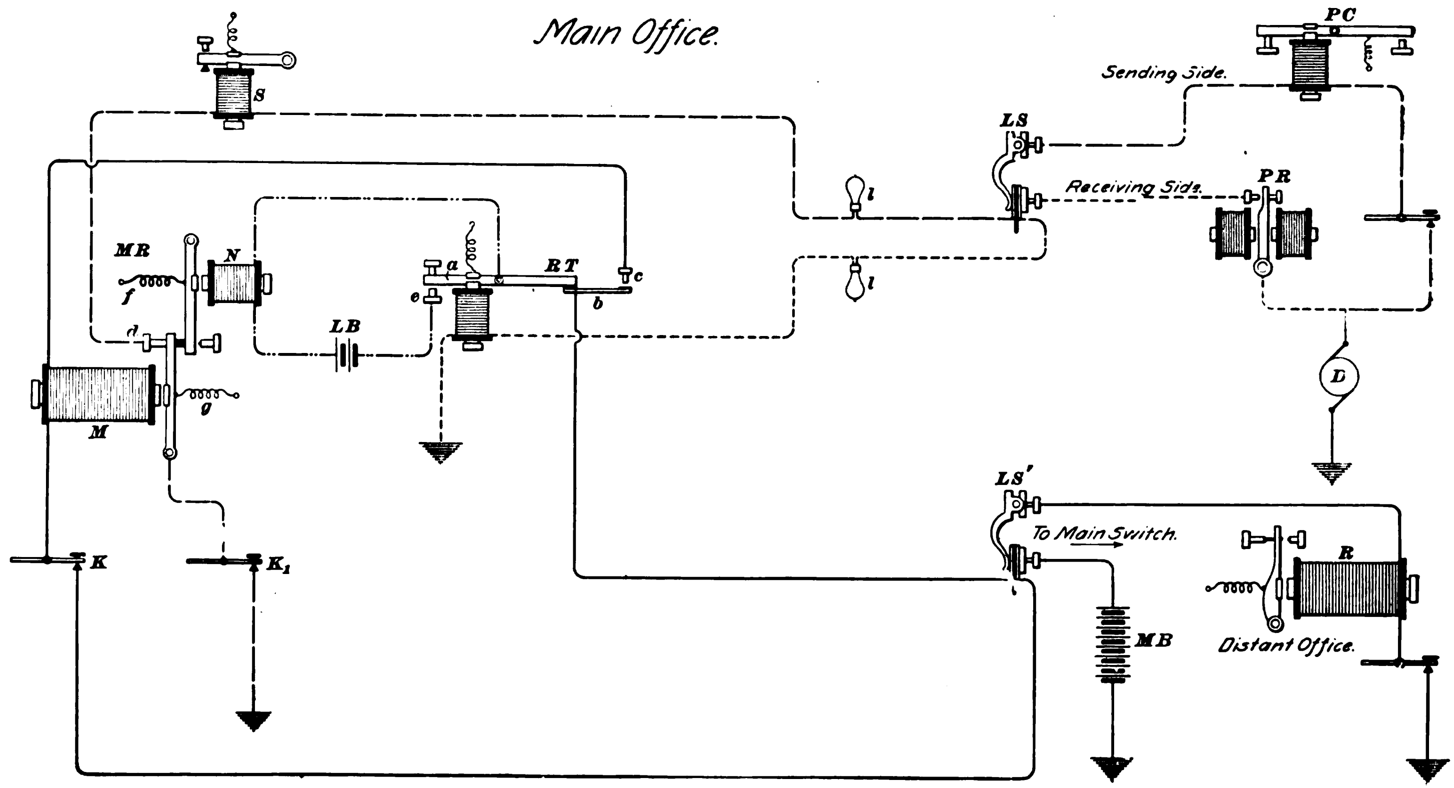
Sending Side.
LS
Receiving
Side.
e
f
1
2
N
Quadruplex
Neutral Side.
n
RS
NR
T
K
K3
c
b
a
S
RT
LD
D
Defective Loop
Repeater.
l
l1
G3
S1
d
LS1
K1
G
Branch Office.
Defective leg
Branch Office Loop
Good Leg.
G

FIG. 7.

it opens and closes the good leg of the branch-office loop at the stop *c*, but it does not open the sending side that passes through the quadruplex transmitter *T*. This is very necessary in order to prevent the operation of the transmitter *T* and the repeating of the message coming through the neutral relay *N R* back to the original sending station.

19. When the local circuit of the repeating sounder is open at *n*, the repeating transmitter will open the good leg of the branch-office circuit at *c*, and the sending side may be traced from G_2 through the dynamo *D*, key K_2, transmitter *T*, switch arm *e*, contact button *1*, loop switch *L S*, key *K*, the tongue *b*, lever *a*, lamp *l*, ground *G*, and back to the starting point G_2.

When the repeating sounder *R S* is closed at *n*, as shown in the figure, the repeating transmitter *R T* will close, causing the tongue *b* to make contact with the stop *c*. The circuit through the transmitter *T* is now closed through the good leg of the branch-office circuit, instead of through the lamp *l*. The sending side may now be traced from G_2, dynamo *D*, key K_2, transmitter *T*, switch arm *e*, loop switch *L S*, key *K*, tongue *b*, stop *c*, the sounder *S*, loop switch $L S_1$, good leg of the branch-office loop, the branch-office sounder S_1, and key K_1, to the ground *G*, and back to the starting point G_2. Thus the sending circuit through the magnet of the quadruplex transmitter *T* is kept closed and the current is kept the same in strength in both positions of the repeating transmitter *R T*. This is accomplished by making the resistance of the lamp *l* equal to that of the good leg of the branch-office loop, which it replaces when the repeating transmitter *R T* opens. Hence the branch office may receive a message coming through the neutral relay; furthermore, the branch-office operator may send a message through the transmitter *T*, provided the repeating transmitter *R T* is kept closed by the repeating sounder *R S*. This defective-loop repeater may also be used on the polar side of the quadruplex or in connection with the polar duplex.



Main Office.
PC
Sending Side.
LS
Receiving Side.
PR
S
MR
N
RT
a
c
e
b
f
d
LB
l
l
D
M
g
K
K1
LS'
To Main Switch.
R
MB
Distant Office.

FIG. 8.

20. The lamp l_1 has such a resistance that the current furnished by the dynamo D will have the proper strength for working the repeating transmitter $R\,T$. When the magnet coils of T and $R\,T$ are equal in resistance, as they usually are, the lamps l and l_1 will each have the same resistance; consequently, these two lamps l and l_1 may be replaced by one lamp, if it is connected between the point d and the ground G.

As the branch-office line wire is used for both receiving and sending, it is evident that the branch-office key K_1 must be in the half of the loop used. Hence, should the sending leg of the loop fail, the branch-office operator must reverse the sending and receiving sets, or else he must cut in his key in the receiving or good leg of the loop. The chief operator at the loop switch merely reverses the wedge of the branch-office loop in order that the good leg of the branch-office loop will face outwardly.

21. Where Used.—The Moffat detective-loop repeater is generally used where the resistances of all loops are approximately equal. When such is the case, the repeater is ready for instant operation the moment the two loops are inserted in the respective spring jacks at the loop switchboard, and it seldom requires attention or readjusting.

HALF-MILLIKEN REPEATER.

22. Where it is necessary to connect a polar duplex or one side of a quadruplex set with a main line, so that the distant end of this main line may both send and receive through one wire from the polar duplex, or the one side of the quadruplex, the **Half-Milliken repeater** may be used. This accomplishes for the long main line the same object as the defective-loop repeater does on short lines. The defective-loop repeater is not very suitable for use on long lines because the resistance of a long line is constantly changing more or less, whereas the Half-Milliken repeater

is perfectly satisfactory. Fig. 8 shows the Half-Milliken repeater connected through a loop switch *L S* with the duplex set, and through the loop switch *L S'* with the main battery, a main line, and a distant office. In a large office, the loop switch *L S'* would be connected by means of a flying loop to a main switchboard, to which the main line and the main battery are connected. The Half-Milliken repeater consists only of the Milliken double relay *M R* and a repeating transmitter *R T*. The sounder *S* and the keys *K* and K_1 are used for the convenience of the operator at the repeating station in reading the signals, adjusting the instruments, and communicating with the two distant offices. The Half-Milliken repeater is located at the main office containing the loop switches *L S* and *L S'*, the main battery *M B*, and the polar relay *PR* and the pole changer *P C*, which belong to a duplex or quadruplex set.

23. Operation.—In their normal condition all circuits are closed. Suppose that the polar relay is receiving a message over a duplexed wire. The opening of the polar relay *PR* will open the repeating transmitter *R T*. This will open the circuit containing the magnet *M* at *c* and the circuit containing the magnet *N* at *e*. But the spring *f*, being stronger than the spring *g*, will hold the circuit closed at *d*. Thus the sending side is not opened when the receiving side opens. However, the opening of the circuit at *c* opens the main-line circuit, and hence the distant-office relay *R* opens when the polar relay *PR* opens. Closing the polar relay will restore all circuits again to their normal closed position.

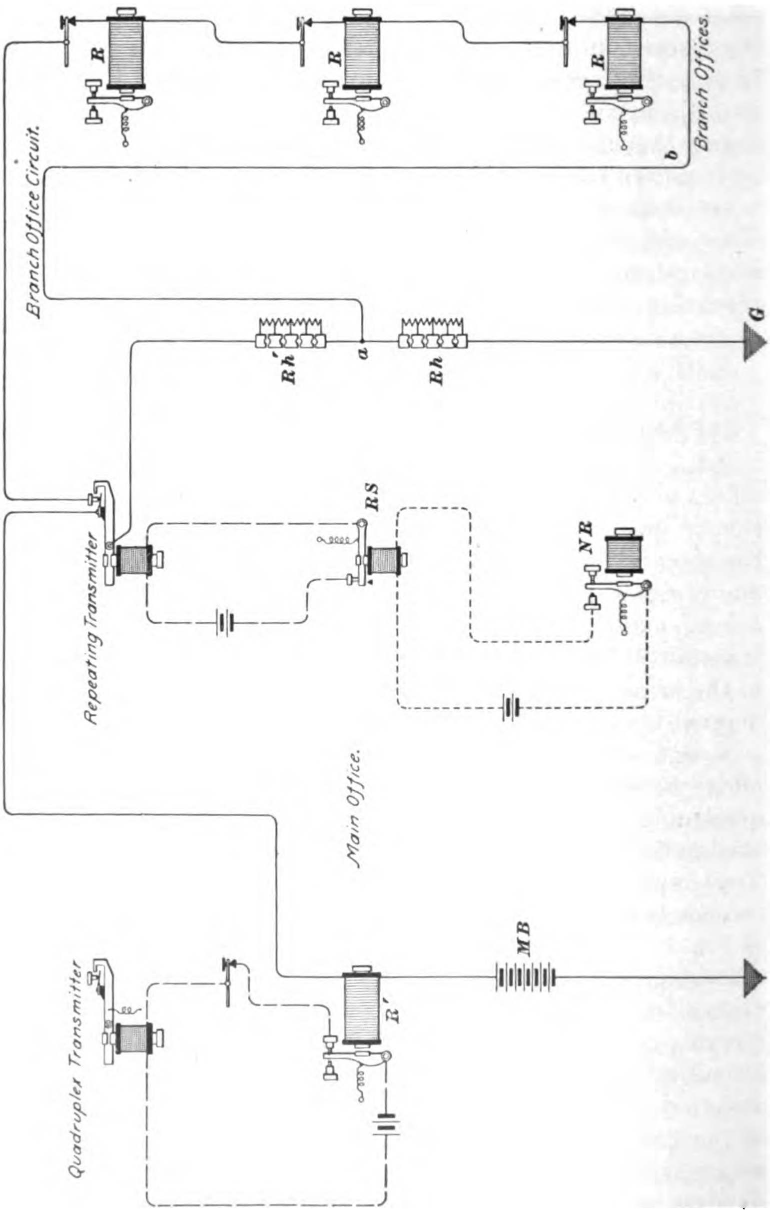
Suppose now that the distant office desires to send through the sending side of the duplex set. The distant office will open his key, thereby cutting off the current from the magnet *M*, and since the circuit through *N* has not been opened, the armature of the relay *M* will open the sending side of the duplex set at *d*. This will open the pole changer *P C* and, therefore, send a space from this main, or repeating, office over the duplexed wire to the polar relay at the distant main

office where the other end of the duplex set is located. When the distant office again closes his key, all circuits will again be restored to their normal closed position, thus sending a dot or dash to the distant main office. It has therefore been shown that the distant office is able to both send and receive by means of the Half-Milliken repeater through the duplex, or one-half of a quadruplex, set to the main office where the other end of the multiplex set is located. Moreover, this message may also be read on the sounder *S* at the main, or repeating, office.

REPEATER WITH RELAYS IN BRANCH-OFFICE LOOP.

24. Where it is necessary to connect a number of branch offices or a long line in circuit with a polar duplex or one side of quadruplex set, relays must be used in the place of the sounders for the same reason that relays are used on main lines. The branch-office circuit is then equivalent to a long main line, but the magnet of the pole changer or transmitter of the multiplex set cannot be connected directly in the branch line, but must be operated by a relay whose magnet is in the branch line.

Sometimes, six or eight offices are connected in one branch-office circuit in connection with a duplex or one side of a quadruplex set. Where this is the case, relays should be used and the apparatus connected as shown in Fig. 9. The Toye-repeater principle is used here. Practically the only difference between this and the defective-loop repeater shown in Fig. 7 is a substitution of relays for sounders at the branch offices and the use of a relay *R'* at the repeating office for controlling the quadruplex transmitter. When a return circuit, as shown here, is used, instead of grounding the circuit after passing through the last branch office, a resistance box *Rh* may be used. This box allows the resistance of the branch-office loop to be increased so that ordinary relays suitable for use with the main-line battery *M B* or a dynamo may be used.



Branch Office Circuit.
Branch Offices.
R
R
R
b
a
Rh'
Rh
G
RS
NR
Repeating Transmitter
Main Office.
MB
B'
Quadruplex Transmitter

FIG. 9.

Evidently the resistance of *Rh'* should be equal to the total resistance of the branch-office circuit back to the point *a*. In case the branch-office circuit is grounded and there is no return wire *b a*, then only one resistance box *Rh'* will be necessary, and its resistance should be made equal to the resistance of the one branch-office wire and all the branch-office relays to the ground at the most distant branch office. The resistance *Rh'*, as in the Toye repeater, causes the relay *R'* and, consequently, the quadruplex transmitter to remain closed when the repeating transmitter is open.

BRANCH-OFFICE SINGLE OR DUPLEX ARRANGEMENT.

25. Fig. 10 shows an arrangement whereby the apparatus at a branch office may be used in a single or duplex circuit. When the switches *E* and *F* are turned to the left,

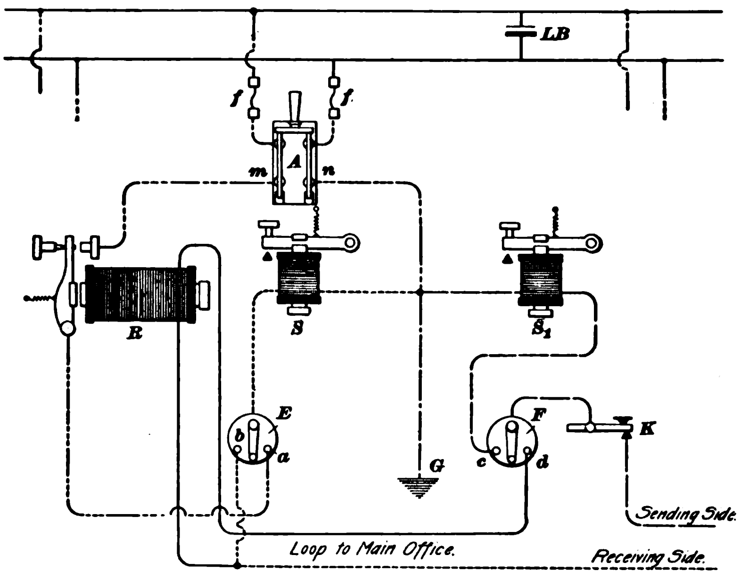


FIG. 10.

the apparatus is arranged to work on the sending and receiving sides of the duplex set at the main office. In this case

the sending side may be traced through the key *K*, switch *F*, contact button *c*, sounder S_1 to the ground *G*; and the receiving side through the contact button *b*, switch *E*, and the sounder *S*, to the ground *G*.

To use the key *K*, relay *R*, and the sounder *S* as a single Morse set, the switches *E* and *F* are both turned to the right. Then the circuit may be traced from the sending side of the loop through the key *K*, switch *F*, contact button *d*, relay *R*, to the receiving side of the loop. With the switches in this position, the sounder S_1 is on open circuit. Thus in the circuit from the main office there is now only the key *K* and the relay *R*, which controls the sounder *S*.

The local circuit containing this sounder is supplied with current from the local battery *L B*, which is arranged here as it would be if it were a storage battery that supplied several local circuits. If a gravity battery were used, it would be connected between the points *m* and *n* and no switch *A* would be necessary. It would supply only this one local circuit.

DILLON BRANCH-OFFICE QUADRUPLEX REPEATER.

26. Mr. James B. Dillon gave in the "Telegraph Age," March 16, 1900, an arrangement suitable for use in Western Union offices by which a branch-office loop may be connected in circuit with the multiplex apparatus at a repeating station, in such a manner that the terminal offices on the multiplex sets may work single, but without interference from the branch office, although the latter is able to hear and break either terminal of the multiplex that may be sending. Thus the branch office can take a drop copy without requiring help in order to break one of the distant senders, and the branch office can send to both terminal offices.

Such an arrangement is often of considerable use to chief operators in large offices where newspapers desire to send the same copy to two stations by repeating through the

office where the newspaper branch-office loop terminates. The difficulty with most of the present temporary makeshifts is that, while the newspaper office can send to both terminals at once, the latter cannot hear each other, which frequently leads to confusion.

The arrangement and connection of the apparatus for accomplishing the object desired is shown in Fig. 11. The transmitter T and the repeating sounder RS constitute the common side at the Dallas main office of a quadruplex system extending from Dallas to Galveston. Of course the apparatus on the polar side can be substituted in place of that shown here on the common side. T_1 and RS_1 constitute the apparatus on the common side at the Dallas main office of the quadruplex system between Dallas and St. Louis. The local connections only are shown here. The quadruplex apparatus is shown connected to the jacks A and B, as in most Western Union offices. The two wires from the contact stop and lever of RS_6 would, in practice, be run to opposite sides of the front wedge in jack B, and the wire from the lever of RS_6 would run to the front side of the middle half-wedge, instead of being connected as shown here. However, the repeater will work all right either way.

27. Operation.—Normally, all circuits are closed. Opening the key in the transmitter circuit at the distant Galveston office will open the local circuits controlled by the repeating sounders RS, RS_6, and RS_7. This will cause the message to be heard at the Dallas main office on RS_6 and RS_7. Furthermore, the operation of the repeating sounder RS_6 will cause the message to be repeated through the quadruplex transmitter T_1 of the St. Louis set at Dallas to St. Louis, and the operation of the repeating sounder RS_7 will cause the message to be heard on the sounder S in the receiving leg at the branch office. Operating the transmitter key at the distant St. Louis office will operate the repeating sounders RS_1, RS_2, and RS_3. Thus the message will be heard in the main office at Dallas on RS_2 and RS_3.

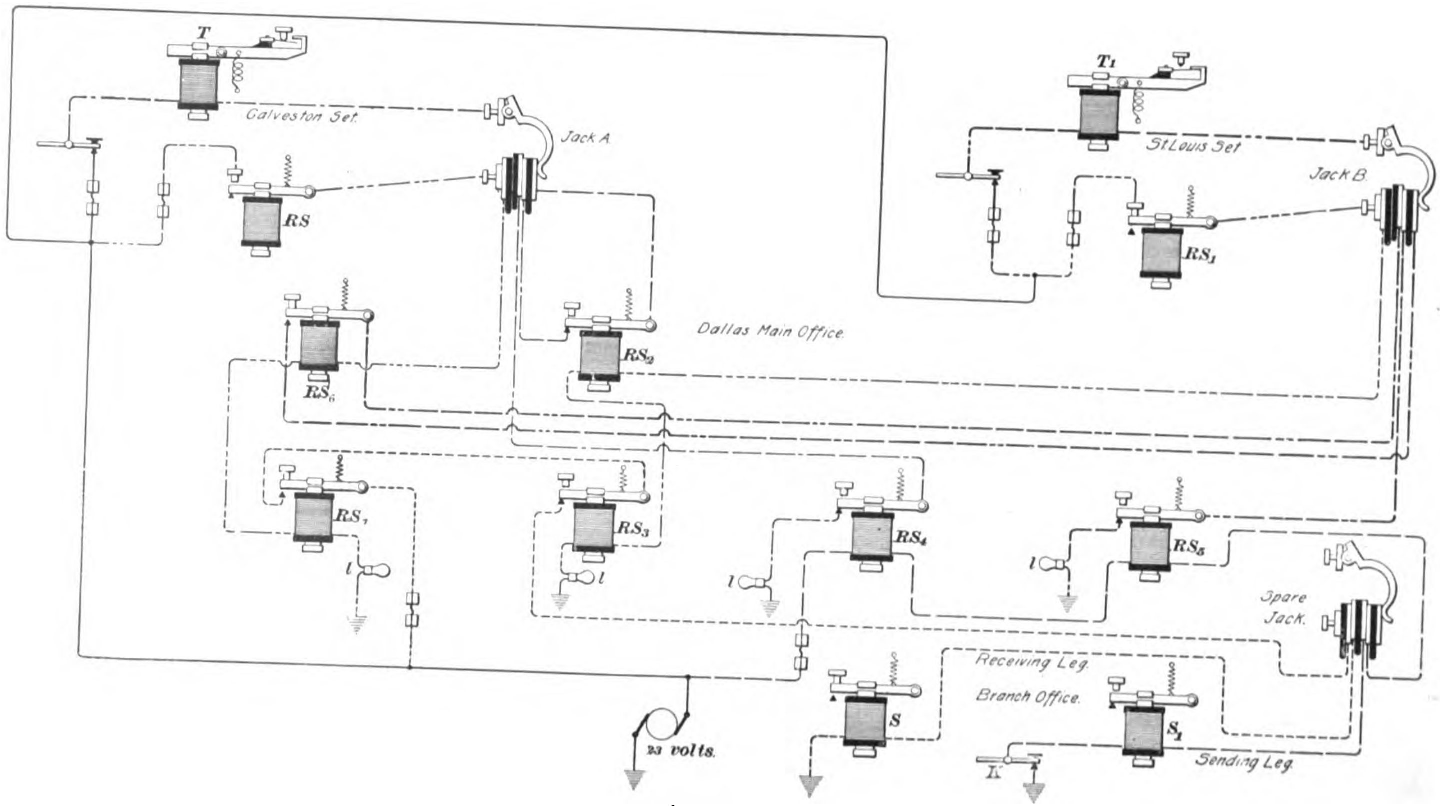

T
Galveston Set
Jack A
RS
T_1
St Louis Set
Jack B
RS_1
RS_6
RS_2
Dallas Main Office
RS_7
RS_3
RS_4
RS_5
l
Spare Jack
Receiving Leg
Branch Office
S
S_1
K
Sending Leg
23 volts

FIG. 11.

Furthermore, the operation of the repeating sounder RS_3 will evidently operate the transmitter T in the Galveston set at Dallas, causing the message to be sent to Galveston, and the operation of the repeating sounder RS_8, provided RS_7 remains closed, will cause the message to be sent through the receiving leg of the branch-office loop to the branch-office sounder S.

28. Double-Sending Possible Between Terminal Stations.—Operators at Galveston and St. Louis can send simultaneously, provided the key K at the branch office in the sending leg is closed, and the messages will be repeated properly at Dallas. Thus the two ends can work double, provided the branch-office key is kept closed. However, the branch office cannot, in this case, read either message because the two messages will interfere with each other in the receiving leg of the branch-office loop, due to the simultaneous operation of the two sounders RS_7 and RS_8. If the branch office sends by operating the key K, then the repeating sounders RS_4 and RS_5 are operated. The operation of RS_4, provided RS_2 remains closed, causes the message to be repeated through the transmitter T of the Galveston set at Dallas to Galveston. Similarly, the operation of the repeating sounder RS_5, provided RS_6 remains closed, causes the message to be repeated through the transmitter T_1 of the St. Louis set at Dallas to St. Louis. Hence the branch office can send to both ends of the main circuit by operating the key K in the sending leg at the branch office. When the branch office is sending, the local circuits of both repeating sounders RS and RS_1 must remain closed in order to keep RS_6 and RS_2 closed; hence, no message can be received either from Galveston or St. Louis while the branch office is sending and, therefore, in this case the line can only be worked single.

29. Thus any one of the three offices, St. Louis, Galveston, or the branch office in Dallas, can send to the other two by working the line single; and the two terminal offices,

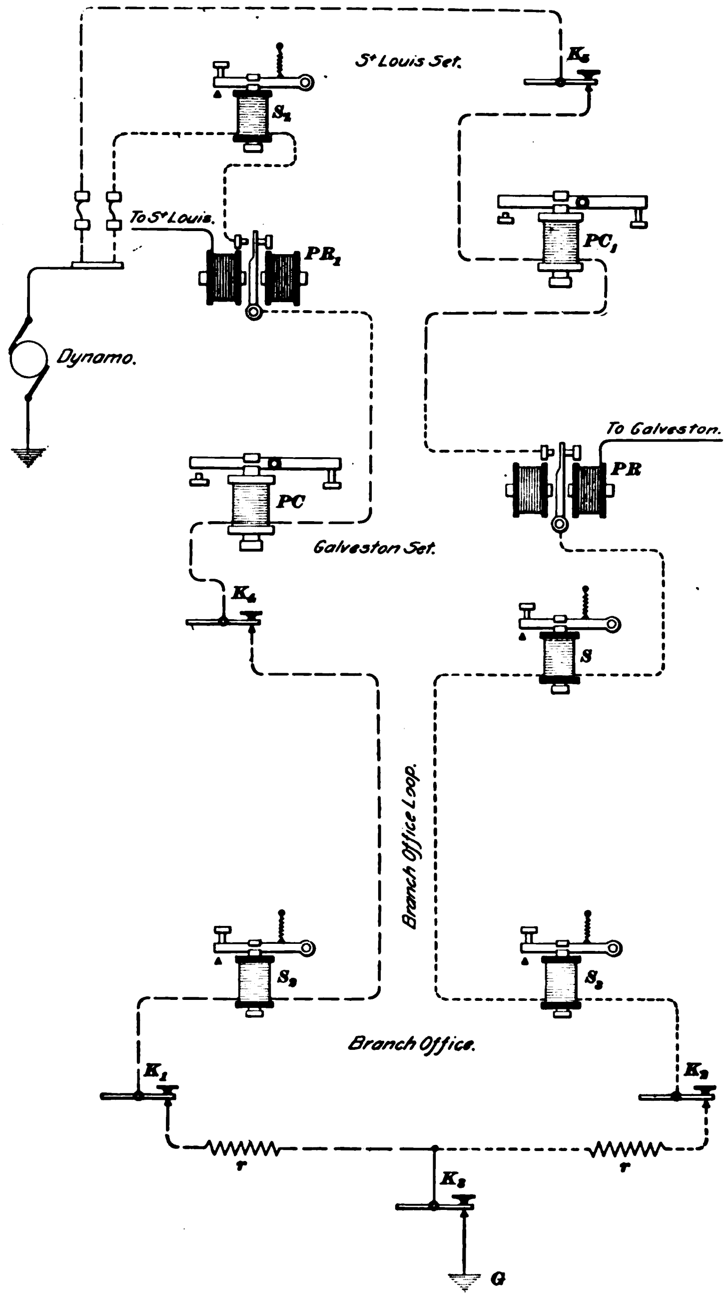

St Louis Set.
K5
S1
PC1
To St Louis.
PR1
Dynamo.
To Galveston.
PR
PC
Galveston Set.
K4
S
Branch Office Loop.
S2
S3
Branch Office.
K1
K2
r
r
K3
G

FIG. 12.

St. Louis and Galveston, can work the line double if the message is not intended to be received at the branch office in Dallas and provided the branch-office key in the sending leg is kept closed.

POSTAL TELEGRAPH BRANCH-OFFICE QUADRUPLEX REPEATER.

30. The same result obtained by the arrangement of the apparatus given in Fig. 11 may be accomplished in a much simpler manner by an arrangement shown in Fig. 12 that may be used in Postal Telegraph offices. For the sake of simplicity, all switches have been omitted in this figure. The apparatus in the upper part of the figure is located at the Dallas repeating office and represents the polar duplex, or the polar side of a quadruplex set, the other end of which is in St. Louis. The apparatus in the middle of the figure represents a polar duplex, or the polar side of a quadruplex set, the other end of which is in Galveston. As in the preceding figure, only the local connections are here shown. The only extra piece of apparatus used is the key K_3 at the branch office. It is connected, as shown, between the junction of two resistance coils r, r and the ground G. The resistance coils r, r are adjusted to give all local instruments their required current. These two resistances can be located at the main office instead of at the branch office.

31. Operation.—The operation of the key K_3 sends the message to the repeating office at Dallas, to St. Louis, and to Galveston. For, opening the key K_3 opens the circuit through the magnets of both the St. Louis and the Galveston pole changers $P\ C_1$ and $P\ C$, respectively, at the Dallas repeating office; hence the message is repeated through these pole changers to St. Louis and Galveston. Operating the key K_1 at the branch office sends the message to the Dallas repeating office, where it operates the pole changer $P C$ and so repeats the message to Galveston. Operating the key K_2, similarly, sends the message to the Dallas repeating office and to St. Louis. Evidently, a message

may be sent from the Dallas repeating office to the branch office and to Galveston by operating the key K_4; similarly, a message may be sent from the Dallas repeating office to the branch office and to St. Louis by operating the key K_6.

32. The operation of the pole-changer key at St. Louis will send the message to the Dallas repeating office and to the branch office, the message being received on the sounders S_1 and S_2, respectively; and by the repeating action of the pole changer $P C$, the message will also be sent to Galveston. Similarly, Galveston can send to the Dallas repeating office, the branch office, and to St. Louis; furthermore, St. Louis and Galveston can be sending simultaneously and each message will be received at the Dallas repeating office, at the branch office, and at one of the two terminal stations. When the branch office sends by means of the key K_3, the line between Galveston and St. Louis can only be worked single.

The arrangement given here enables an operator at the branch office to send to the repeating office and to either terminal station by the key K_1 or K_2, or to the repeating office and to both terminal stations by key K_3. Furthermore, he can hear the message sent from both ends when they are working double. Consequently, there should be no confusion at any time due to the operator at either end or in the branch office not hearing the others sending.

DOUBLE-LOOP REPEATER.

33. It is sometimes desirable to connect two branch offices with a duplex set or one side of a quadruplex set at the main office in such a manner that both branch offices may receive the message coming over the receiving side of the multiplex set, and also allow either branch office to send to the other branch office and through the sending side of the multiplex set at the nearer main office to the distant main office. An arrangement of apparatus that will accomplish this is called a **double-loop repeater.**

Fig. 13 illustrates a double-loop repeater that is frequently used. It consists of three transmitters, a repeating sounder, and one ordinary sounder. As in all repeaters, it

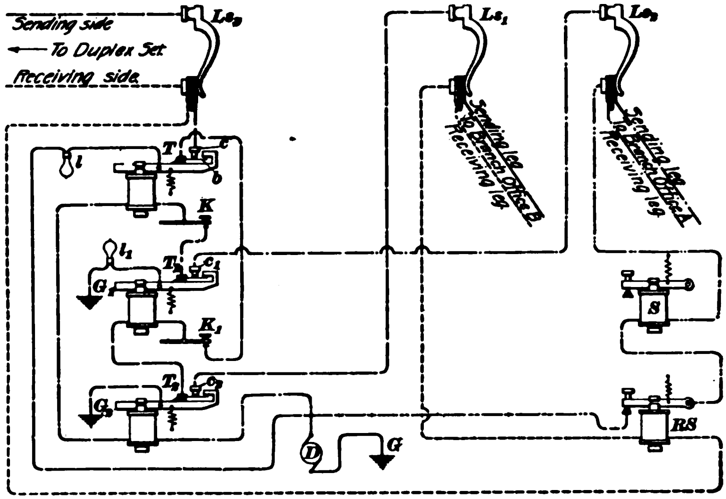


FIG. 13.

is very necessary that the opening of the key in the sending circuit at either branch office or at the repeating station shall not leave the sending circuit open at the repeating station.

34. Operation.—In explaining the operation of the double-loop repeater, we will first assume that all circuits are in their normal condition, that is, closed. Suppose now that the polar relay in the duplex set connected to the loop switch Ls_3 in the figure opens the receiving side. This will cut off the current from the magnet of the repeating sounder *R S* and also from the sounder in the receiving leg at the branch office *B*. Furthermore, the opening of the repeating sounder *R S* will cut off the current from the sounder *S* and also from the sounder in the receiving leg at the branch office *A*. Hence, the opening of the circuit at the polar relay has cut off all current from the receiving legs of the two branch-office loops and from the sounder *S*.

The sounder S is used to enable the attendant to read the signals in order to judge whether the circuit is working properly and to communicate with the branch office.

35. Suppose that the branch office A desires to send to the branch office B and through the sending side of the duplex set to the distant main office. When the key in the sending leg at the branch office A is opened, there will be no current through the magnets of the transmitters T and T_2, thus allowing these two transmitters to open. The opening of the transmitter T will open the sending side of the duplex set at contact stop c and, hence, operate the sending side of the duplex set. When the transmitter T opens, however, the tongue of the transmitter is connected through the lever, lamp l, and dynamo D, to the ground G. Since the lamp l has a resistance equal to that of the sending side of the duplex set that was cut out at c, the current flowing through the magnet of the transmitter T_1 will remain constant and thus the transmitter T_1 will be kept closed. This is essential in order that the sending circuit from the branch office A shall not be opened at the repeating station. The opening of the transmitter T_2, by disconnecting the tongue from the contact stop c_2, has opened the sending leg running to the branch office B; and by connecting the tongue to the ground G_2, the opening of the transmitter T_1 has been prevented by the substitution of a circuit to the ground G_2 for the sending leg from c_2 through the branch office B. Thus the opening of the key in the sending leg at the branch office A has opened the sending leg to the branch office B and the sending side of the duplex set, but has not opened the sending leg of the branch office A at the repeater. No lamp is required between the lever of the transmitter T_2 and the ground G_2, because the lamp l is in the circuit between G_2 and the dynamo whenever the transmitters T and T_2 are open.

36. Suppose that the circuits are again in their normal closed condition and that the key in the sending leg at the branch office B is opened. This will open the circuit through

the transmitter T_1 and also through the sending side of the duplex set. When the transmitter T_1 opens, it opens the sending leg to the branch office A at contact c_1, but the tongue of this transmitter T_1 comes into contact with the lever and makes a connection through the lamp l_1 with the ground G_1, thus keeping the transmitters T and T_2 closed. Thus the opening of the key in the sending leg at the branch office B has opened the sending leg running to the branch office A and also the sending side of the duplex set. Furthermore, the operation of the transmitters has been such that the sending leg from the branch office B has not been opened at the repeating station. Thus it has been shown that both branch offices may receive a message from the receiving side of the duplex set and that either branch office may send to the other branch office and through the sending side of the duplex set to the distant main office.

THREE MULTIPLEX SETS CONNECTED TOGETHER.

37. A method of arranging three quadruplex sets in such a manner that they will be in communication with one another when worked as a single line, or where any two can be worked double, provided the third station keeps his key closed, is shown in Fig. 14. This arrangement was given by Mr. J. B. Dillon, in the "Telegraph Age," April 1, 1900. The repeating sounders shown in this figure can be replaced by transmitters properly connected or by pony relays of the proper resistance. The resistance of the various circuits should be adjusted by the use of lamps or resistance coils to allow the various instruments the proper amount of current.

38. Operation.—If when all keys are closed and quadruplex A wishes to work with B and C, the operation is as follows: Opening the key at the distant office A causes polar relay A and the repeating sounders $R\ S$ and $R\ S_1$ to

open, thereby opening the circuits passing through the pole changers of the quadruplex sets *B* and *C*, respectively, thus sending the signal to the distant quadruplex stations *B* and *C*.

Should the distant office *B* desire to break, the opening of his key will cause the polar relay *B* and the repeating sounders RS_3 and RS_2 to open, thereby opening the circuits passing through the pole changers of the sets *A* and *C*—it, of course, being understood that the operator at the pole-changer key at the distant office *A* will close his key when he hears the opening of his sounder controlled by his polar relay, and thus permit the office *C*, as well as the office *A*, to hear what the operator at the pole-changer key at the distant office *B* has to say.

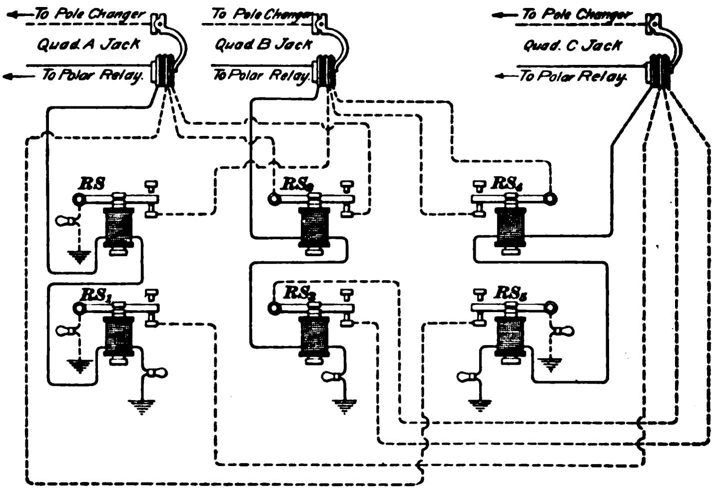


FIG. 14.

Should the distant operator *C* desire to send, the opening of his key will open the polar relay at the set *C* and cause the repeating sounders RS_4 and RS_5 to open the circuit passing through the pole changers of the quadruplex sets *B* and *A*, respectively. It will thus be seen that each

station can hear and converse with any other as a single-circuit arrangement.

39. Two Offices Working Double.—To show how any two offices can work double, provided the third station keeps his key closed, suppose that *A* and *B* desire to work double, while the key at the distant office *C* is kept closed. The path of the current through the pole changer of the *A* set may be traced through the front wedge in the quadruplex *A* jack, the cord, and contact points of the repeating sounder RS_2, thence back to the other side of the same wedge, through the center half-wedge, the cord, and the contact points of the repeating sounder RS_6 to the ground. As the repeating sounder RS_2 is controlled by the polar relay of the *B* set, it will be readily seen that the distant *A* operator will then hear what the distant *B* operator has to say. The path of the current through the pole changer of the *B* set may be traced through the front wedge in the quadruplex *B* jack, the cord, contact points of the repeating sounder RS_4, the cord, the other side of the same wedge, the center half-wedge, thence through the contact points of the repeating sounder RS to the ground. As the repeating sounder RS, which controls the pole changer of the *B* set, is in turn controlled by the polar relay of the *A* set, it is evident that the distant *B* operator will hear what the distant *A* operator has to say.

40. If *A* and *C* wish to work double, *B* must keep his key closed. The repeating sounder RS_1 will then operate the pole changer of the set *C*, and the repeating sounder RS_6 will operate the pole changer of the set *A*. Confused signals, due to the sending at both *A* and *C*, which operate the repeating sounder RS and RS_4 (as well as RS_1 and RS_5), will pass through the pole changer of the set *B*; hence neither message can be read at the distant office *B*. Should *B* and *C* desire to work double, *A* must keep his key closed.

41. While the third quadruplex will be practically dead, as far as business is concerned, when the other two are

working double, attention is merely called to the fact that doubling is practicable, as explained, should it be desirable to connect three quadruplex sets for special or report matter (worked as a single line).

CARE OF MULTIPLEX SINGLE-WIRE REPEATERS.

42. The repeating transmitters of multiplex single-wire repeaters must be kept in good order, the contacts must be kept clean, and the tongue of the transmitter must not be too stiff. If the contacts of the repeating transmitter become dirty, a message coming over the polar relay or the neutral relay will be repeated back through the pole changer or transmitter to the original sending station. For it is evident that a dirty contact may prevent the repeating transmitter from holding the pole changer or transmitter of the multiplex set closed when a message is coming through the polar or neutral relay. In case a single-wire repeater is used at both ends of the multiplex system, utter confusion might result from defective contacts on both repeating transmitters.

The second source of trouble may be due to the fact that the current through the pole changer or transmitter of the multiplex set is not the same in the two positions of the repeating transmitter. This may be due to a weakening of one of the batteries, or to the fact that the resistance used in repeaters (depending on the principle used in the Toye repeater) to take the place of the branch circuit in the open position of the transmitter is not properly adjusted. If the two currents are unequal for either of the reasons given above, and if the spring of the pole changer or transmitter of the multiplex set is adjusted properly for the stronger current, the instrument may open when the weaker current passes through it instead of remaining closed as it should. This, of course, may be avoided by making the strength of the current through the pole changer or transmitter of the multiplex set the same in both positions of the repeating transmitter.

If the tongue of the quadruplex transmitter is too stiff, it will not break contact properly with the lever, as it should do, when the repeating transmitter is opened; especially will this be the case should the local battery in the quadruplex transmitter be weak at the same time. The faults that have been enumerated do not include, of course, faults due to the improper adjustment and balance of the duplex or quadruplex system itself. The latter have already been given in connection with the adjustment and balancing of the quadruplex system.

BRANCH-OFFICE SIGNALING DEVICES.

43. Where wires are rented to brokers or others, it is necessary in order to report any trouble that may occur in their circuits that they shall be able at all times to signal the main office, which is responsible for the condition of the line.

As vibrating bells or buzzers are generally used in connection with these branch-office signaling devices, it will be well to describe them first. The only difference between a vibrating bell and a buzzer is that, in the case of the bell, the vibrating armature of the electromagnet is allowed to tap a gong, whereas in the buzzer it merely vibrates between two stops. The construction and operation of the annunciators that are used in this connection will be clear from the diagrams in which they are shown.

VIBRATING BELL.

44. Construction.—The bell used for battery call work is usually of the type known as the **vibrating** or **trembler bell,** one form of which is shown in Fig. 15. The hammer of this bell is arranged so as to vibrate rapidly back and forth and to strike the gong at each vibration, producing a continuous succession of sounds. *D* and *D'* are two electromagnets having cores *F* and *F'* of soft iron secured to a soft iron yoke piece *Y*. *G* is a soft iron armature

mounted by means of a flat spring S secured to a post P, so as to vibrate freely in front of the cores F and F'. The armature carries a hammer, as shown, adapted to strike the gong a sharp blow when the armature is pulled toward the magnet cores. If the circuit through the magnets passed from one binding post T through the coils directly to the other binding post T', then closing the circuit containing a suitable battery would cause the hammer to strike the gong a single blow.

A succession of blows might be produced by rapidly making and breaking the circuit at the point from which the signal was being sent; but this would be an unsatisfactory method. Therefore, the armature of the bell is so arranged as to make and break the circuit by its own vibration. In this way a rapid and continuous succession of strokes is produced as long as the terminals of the battery are connected to the two binding posts T and T'. To bring about this result, the circuit between the binding posts of the bell is made as follows: From the binding post T, which is insulated from the frame of the bell, a wire leads to one terminal of the coils D and D', which are connected together in series. A wire leads from the other terminal of D' to the metallic post N, which is insulated from the metal framework and provided with a contact screw M. While the armature is at rest, a contact spring X, carried by the armature, rests against the contact screw M, thus carrying the circuit to the armature and the post P. This post P is connected with the frame of the bell, as is also the post T', so that the circuit from P to T' is completed through the metal frame itself. When a current is sent through the coils,

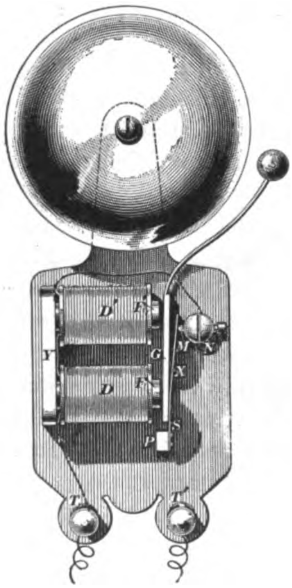


FIG. 15.

the armature will be drawn forwards, thus causing the hammer to strike the gong. This movement, however, will break the circuit by causing the spring *X* to move out of contact with the screw *M*. This interrupts the flow of current through the coils, and therefore allows the armature to spring back, it being no longer attracted by the magnet cores. In doing this, contact is again made between the spring *X* and the screw *M*, thereby completing the circuit and again energizing the magnets, thus producing another stroke of the hammer. This process is repeated as long as the battery circuit remains closed. The spring *X* is provided so that the circuit will not be broken quite as soon as the armature starts to move toward the cores. Its function is to prolong the time during which the circuit is closed, so as to allow the magnets to exert a pull on the armature until the hammer is almost in contact with the bell.

45. Design.—These bells are manufactured in almost numberless styles, many of which are of exceedingly poor design, from both mechanical and electrical standpoints. A good battery bell should be so well constructed that none of its parts are likely to work loose because of the rapid and violent vibration of the hammer. The point of the screw *M* and also the surface on the spring *X* should be tipped with platinum, in order that the surface of the contacts may be kept clean, as platinum will not corrode under ordinary atmospheric conditions, and is, moreover, not much affected by the electric spark, which is sometimes very heavy between these contacts. Silver, being cheaper, is frequently used in place of platinum, and is superior to copper, brass, and iron. The screw *M* should be provided with a locknut, or with some other means of locking it securely in any position to which it has been adjusted. If this is not done, the vibration of the armature will cause the screw to gradually work back until finally it reaches a point where the spring *X* will not make contact with it. This locking is sometimes accomplished by splitting the post *N*, so that the screw threads in the two halves exert a

combined action on the screw, due to the elasticity of the parts of the post.

46. Prevention of Sticking.—Means must be provided for preventing the armature from coming into actual contact with the poles of the electromagnet, as the residual magnetism will cause it to stick and not allow the spring *S* to move it back at once or at all. This may be done in a number of ways, one of which is to secure a thin strip of copper to the surface of the armature which would otherwise come in contact with the poles. Another way is to insert a small pin of brass or copper into the ends of the poles in such a manner that it will project slightly beyond the pole surfaces. Either of these methods should prevent actual contact between the iron surfaces and therefore eliminate this tendency to stick; which is particularly great where the magnets and armature are not of the best quality of soft annealed iron, because hard iron retains its residual magnetism with more tenacity. In a first-class bell these parts are made of the softest grade of wrought iron, so as to be readily demagnetized when jarred by the striking of the armature against the cores.

47. Adjustment.—The adjustment of battery bells is a very simple matter, for usually the turning of the screw *M* until it occupies the desired position is all that is required. The best position may be determined by gradually turning this screw, while the circuit is closed, until the hammer vibrates in such a manner as to produce a succession of hard, sharp blows against the gong. If the screw *M* is too far back, the circuit will be opened before the armature has acquired sufficient momentum to carry the hammer to the gong; or it may be so far back as not to allow the circuit to be completed at all. On the other hand, if the screw is too far forwards, the spring *X* will not be pulled away, and the circuit will not be broken; or else the break will occupy such a short space of time that the hammer will not be allowed to recede far enough to strike a proper blow upon the gong. If the adjustment by means of the

screw *M* does not produce the desired results, it may be that the armature *G* does not occupy a proper position with respect to the poles of the magnet. When the hammer rests against the gong, the distance between the armature and each of the pole pieces should be approximately the same. This adjustment, as a rule, may be made by bending the spring *S* slightly or by shifting the position of the magnets.

48. Sometimes the surface of the gong against which the hammer strikes does not occupy such a position as to allow the hammer to strike it at the proper moment. If the gong in Fig. 15 is too far to the right, the hammer will strike before the armature has moved far enough toward the pole pieces to allow them to attain the maximum pull. If the gong is too far to the left, then the armature will strike the pole pieces before the hammer strikes the gong; in either case a loss of efficiency will result. This may be remedied by bending the rod on which the hammer is mounted, but in many cases a better way is to turn or move the gong itself on its standard. These gongs are usually somewhat eccentric, due to imperfections in their manufacture, and therefore by turning them the surface against which the hammer strikes may be brought into the correct position.

49. Fig. 16 shows such a bell connected in circuit with a battery and push button. By pushing the button, the

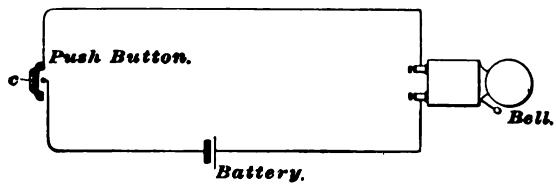


FIG. 16.

circuit is closed at *c*, thus allowing the action already described to take place. This circuit is such as would be used for an ordinary push-button call for almost any purpose.

HURD BRANCH-OFFICE SIGNALING DEVICE.

50. Loops that are extended to branch offices are usually connected through an annunciator at the main office. These annunciators are all grouped at one board, where they are looked after by an attendant. The method devised by Mr. J. B. Hurd is shown in Fig. 17. At the branch office there is a three-point switch *Q* that ordinarily remains in a central position, thus insulating the ground *G*. Ordinarily the current through the branch-office loop apparatus has not sufficient strength to attract the armature *d* of the main-office annunciator *A*. Thus the annunciator shutter *e* is ordinarily held up by the hook on the front end of

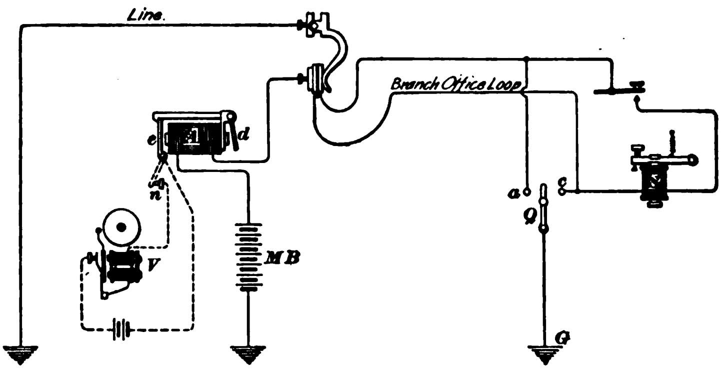


FIG. 17.

an arm that is rigidly fastened to the armature *d*. However, the branch-office operator, should he desire to attract the attention of the attendant at the main-office annunciator board, turns the arm of the switch *Q* to the contact button *c* so as to ground the low-resistance side of the circuit. This cuts out one wire of the branch-office loop and the branch-office instruments and thus allows enough current to flow from the main battery *M B*, through the coil of the annunciator *A*, one wire of the loop circuit, and the ground to drop the shutter *e* to the dotted position against the contact stop *n*.

51. It is usual to arrange the shutter of the annunciator in this manner, so that when it falls, a local circuit containing a buzzer or bell and a battery will be closed, thus attracting the attention of the attendant.

The switch *Q* is provided with two contact buttons *a* and *c* so that the ground can be connected to either side of the circuit. Thus, in case the two sides of the branch-office loop are reversed at the main office, the branch-office operator can still operate the annunciator. Behind the shutter *e* is the name of the branch office that is connected to this annunciator. The magnet of the annunciator is usually of low resistance, about 2 or 3 ohms.

DUPLEX CALL.

52. An arrangement for calling on a duplex circuit is shown in Fig. 18. An extra neutral relay *N R* and vibrating

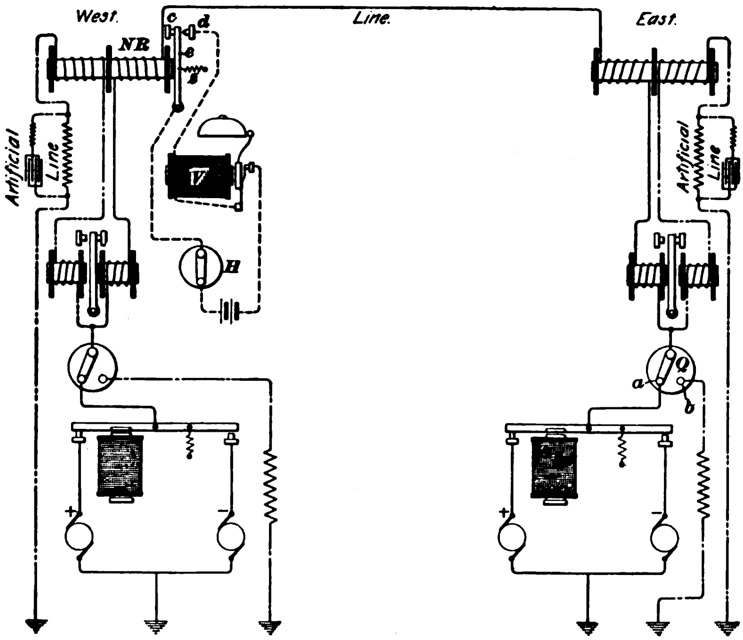


FIG. 18.

bell *V* are connected in the circuits, as shown at the west station. The connections will be the same at both stations, but only enough to explain the operation are shown. The spring *s* of the neutral relay is so adjusted that the armature will be held against the front stop *c* as long as the battery or dynamo at the distant east station is connected to the line. This is the case while the arm of the switch *Q* remains in contact with the button *a*. If the main battery or dynamo at the distant east station be disconnected and the circuit grounded by turning the arm of the switch *Q* to contact button *b*, the current from the west main battery or dynamo will divide equally through the two differential coils of the extra neutral relay. The magnetizing effect of one coil will be neutralized by the other and, consequently, the armature *e* will fall against the back stop *d* and cause the vibrating bell *V* to ring as long as the eastern operator allows the arm of the switch *Q* to remain in contact with *b* or until the western operator opens the local bell circuit by means of the switch *H*.

SIMULTANEOUS TELEGRAPHY AND TELEPHONY.

53. The transmission of telegraph and telephone messages over the same wire at the same time is called **simultaneous telegraphy and telephony.**

VAN RYSSELBERGHE METHOD.

54. The **Van Rysselberghe method** for the simultaneous transmission of telephone and telegraph messages over the same line was originated and developed by Mr. J. F. Van Rysselberghe, an official of the Belgian telegraph service. It is now being used both in Europe and America. Before describing the method of arranging the telegraph and telephone apparatus by which this simultaneous

transmission can be accomplished, it will be well to consider briefly some of the fundamental principles involved.

55. One of the difficulties to be overcome in attempting to telegraph and telephone simultaneously over the same wire is the prevention of telegraphic signals being heard in the telphone receiver. Unless this is done, much annoyance will be caused those using the telephone; besides, the secrecy of the telegraph will be destroyed. The wasting of the telephone currents in the telegraph instrument must also be avoided.

In a simple short telegraph circuit, the current will rise to its maximum value almost instantly when the key is closed and fall to zero almost instantly when the key is opened. A curve representing the current in such a circuit is about as shown in Fig. 19. The time required for the current to reach its maximum value, even on an overhead line of 350 miles in length, is ordinarily less than one-fortieth the time required to make a dot. In telegraphing at the rate of 25 words a minute, which is equivalent to about 5 Morse signals a second, there would be, if means were not taken to avoid it, 10 intense clicks every second in a telephone receiver connected between the line wire and the ground, one of these being made every time the telegraph key was closed and another every time it was opened, due to the very rapid rise and fall of the relatively large telegraph current, which is about 100 times larger than the telephone current. If the telegraph current can be made to rise and fall gradually enough, the telephone receiver will not make any click. The accomplishment of this result has made possible this method of simultaneously telephoning and telegraphing over the same wire.

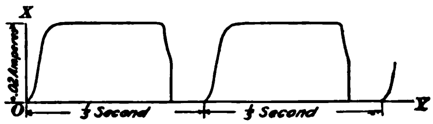


FIG. 19.

56. It is a well-known fact that the sudden rise and fall of a current in a circuit can be delayed, that is, made more

gradual, by increasing the inductance in the circuit. Furthermore, if in addition to the inductance coil, a condenser is connected from the line to the ground, the current in the line will rise and fall still more slowly. Hence, by using

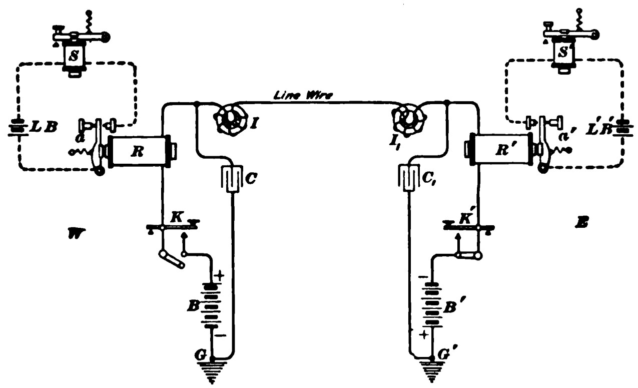


FIG. 20.

enough inductance coils and condensers, the current in the line may be made to rise and fall as slowly as desired. A simple telegraph circuit, with two inductance coils I and I_1, and two condensers C and C_1, connected in the circuit, is shown in Fig. 20.

The coils I and I_1 are called *impedance*, *retardation*, or *choke* coils, and are usually made by winding a large number of turns of insulated copper wire over a soft-iron wire core, the ends of the iron wire being brought together and overlapped, as shown in Fig. 21, so as to form a closed iron circuit for the magnetic lines of force. With a given number of turns of insulated copper wire and a given cross-section of iron, such a closed magnetic circuit will give a maximum inductance, causing a maximum opposition to a rapid rise or fall of the current. In making such a coil, it is of much more importance to have a large number of turns of copper wire and a good magnetic circuit of iron than to have a

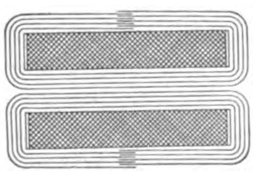


FIG. 21.

large resistance. In fact, the smaller the simple resistance can be kept the better, provided there are a sufficient number of turns. Low resistance and a large number of turns means a large coil, because large-sized copper wire must be used, and it becomes necessary to compromise in order to have neither too large a coil nor too high a resistance with a given number of turns. A choke coil of about 50 ohms resistance may be made by winding the one mentioned in Art. **68** with No. 31 B. & S. copper wire.

57. When the key *K* in Fig. 20 is closed, the inductance of the relay *R* and of the impedance coil *I* will act as a barrier to the increasing current and will prevent it from attaining its maximum strength as quickly as it would if the impedance coil *I* was not in the circuit. The greater the inductance in the circuit, the slower will the current increase and decrease. Furthermore, the condenser *C* must be fully charged before the current in the line can reach its maximum value. As fast as the current is able to get through the relay *R*, it first tends to charge the condenser *C*, and as the condenser becomes more and more nearly charged to its full capacity, more current will flow through the coil *I*, which also impedes any rapid increase in the current. The increase in the strength of the current in the line wire is thus made to take place more slowly than it would without the condenser and the impedance coil.

On opening the key *K*, the condenser *C* tends to discharge its current through the coil *I* into the line in the direction of the original current, thereby tending to prolong the current in the line and causing it to decrease more gradually. The combination of condensers and impedance coils thus opposes any rapid change in the strength of the current, and the current curve can be made to approach that shown in Fig. 22 by using the proper amount of inductance and capacity.

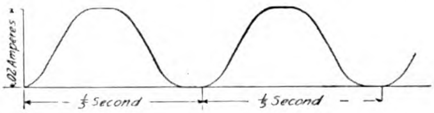


FIG. 22.

58. At the rate of 25 words a minute, there would be about 5 dots and spaces, or 5 curves, like the one shown in Fig. 22, a second. The induction coils and condensers will interfere with telegraphing at a high speed, and especially with rapid automatic systems, because the signals would be of such a short duration that there would not be time for the current to rise or fall through a sufficient range to properly operate the relays. Moreover, even if suitable relays or other instruments could be used, such rapid signaling would interfere with what we are striving for, namely, to telephone as well as to telegraph over the same line. About the lowest audible sound is produced by 16 complete vibrations per

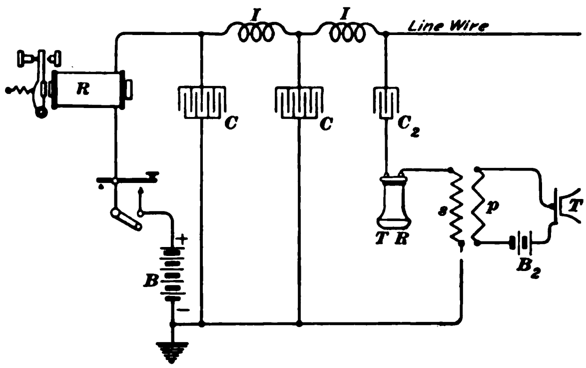


FIG. 23.

second. Therefore, an undulating current that changes at such a slow rate that it would never cause the diaphragm of a telephone receiver to move as fast as it would be moved by a current having a frequency of 16 periods per second, would produce no sound, not even a single click, in the receiver.

Now, if a telephone receiver *TR* and the secondary winding *s* of the induction coil were connected between the line and the ground, as shown in Fig. 23, but without the condenser C_2, more or less of the telegraph current would go through the receiver circuit to the ground in preference to passing through the line and the distant-office instruments. Even if this current produced no sound in the receiver, it would still be necessary (in order that the telegraph signal

made at the sending station shall affect the relay at the receiving station) to prevent the flow or leakage of the telegraph current through the receiver. To accomplish this, the condenser C_2 is connected between the receiver and the line. The condenser will not allow a continuous current to pass through it, because its resistance to such a current is practically infinite. The condenser charges and discharges very slowly when telegraph signals are being sent, thereby causing the receiver diaphragm to move in and out very slowly, but the rate of change of the current in the receiver is not great enough to cause an audible sound.

59. It has been shown that the telegraph signals do not affect the telephone receivers. It yet remains to be shown that the telephone currents sent from one end will operate the telephone at the other end, but will not interfere with the telegraph signals sent from either end.

In ordinary conversation, the average frequency of the sound waves is at least 300 complete vibrations, or periods, per second. By talking into a telephone transmitter, therefore, an alternating electromotive force is generated in the secondary winding of the induction coil, the average frequency of which is at least 300 periods per second. This rapidly alternating electromotive force will charge and discharge the condenser C_2, thereby producing in the line wire an alternating current similar to that in an ordinary telephone line. In Fig. 24 is represented such a current wave as might be produced in the line wire by the simplest sound waves having a frequency of 300 periods per second. Let the curve A in Fig. 25 represent the slowly increasing and decreasing telegraph current, and the curve B the rapidly alternating telephone current. In the line, these two will be superimposed on each other, producing a resultant curve of the form shown at C.

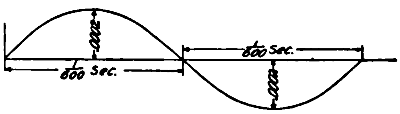


FIG. 24.

When both the telephone and telegraph are in simultaneous

operation, the telegraph current causes the diaphragm of the receiver to move in and out through a relatively large amplitude, but too slowly to make any sound. At the same time, it will vibrate very rapidly through a very small amplitude, because the telegraph current will have its strength very rapidly but very minutely increased and decreased by the telephone current. The variation in the strength of the current is enough, nevertheless, to increase and decrease the pull of the magnet on the diaphragm sufficiently to produce sound waves. One vibration is thus superimposed on the other, and the diaphragm vibrates, or trembles, very rapidly as it moves slowly in and out as the telegraph current slowly increases and decreases, and it reproduces the words spoken at the distant transmitter, but the telegraph current produces no sound.

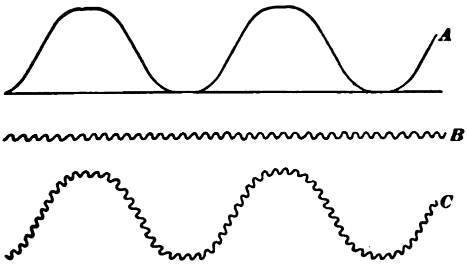


FIG. 25.

60. The question might arise as to why the telephone current does not go to the ground through the telegraph apparatus at the end where it is generated and interfere with the telegraph signals, instead of flowing through the long line wire to the distant telephone. In the first place, even if all the telephone current did go through the home telegraph apparatus, it would not affect the signals, for the telephone current is probably less than one-hundredth as large as the telegraph current, and its effect on the relay would not be apparent, as is evident from curve *C*, Fig. 25. Moreover, practically the whole telephone current will go over the line and through the distant receiver, for the following reason: It is a well-established fact that a circuit containing inductance offers more opposition, or impedance, as it is called, to the flow of an alternating current than the simple

resistance with which it opposes a direct current, and this opposition increases very rapidly as the frequency increases. For instance, a certain impedance coil, with a resistance of 500 ohms and an inductance of 8 henrys (for a current of .013 ampere), offers an impedance of 15,128 ohms to an alternating current whose frequency is 300 periods per second. This impedance is over 30 times as large as the simple resistance.

The impedance of the ordinary 250-ohm secondary coil may be as much as 4 times its resistance, but the condenser in series with it tends to reduce the impedance of this circuit, and consequently the impedance of the telephone circuit, including the receiver, the secondary coil, and the condenser, is probably not over 1,000 ohms. An induction coil having a lower resistance secondary, such as the 14-ohm coil used by the Bell Telephone Company on some of their long-distance lines, would be better in this case. In circuit with the impedance coil there is also the relay, so that the total impedance of the apparatus at one end of the line circuit shown in Fig. 20 is probably more than 50 times as great as that of one receiver circuit. To insure more satisfactory results, two impedance coils and two condensers are generally used at each end, as shown in Fig. 23, thus compelling practically all the telephone current to pass through the line and the distant telephone circuit, because the latter offers so much less opposition to its passage than the impedance coils and relays.

61. The **complete arrangement** of the telegraph and telephone apparatus is shown in Fig. 26. It is sometimes advantageous to connect a condenser of 1 or 2 microfarads capacity around the telegraph key and relay, as shown by the dotted lines at station *2*. This figure gives a complete diagram of connections for one complete metallic telephone circuit and two telegraph circuits over one pair of line wires, the ground being used as a return for the two telegraph circuits.

If a completely closed magnetic circuit of good soft iron

is used for the impedance coils *o*, enough turns of insulated copper wire to make 50 ohms have been found to be sufficient for each coil. Where only an iron core instead of a complete iron current is used, 500 ohms are often necessary. The condenser in the telephone circuit has a capacity of 3 microfarads; the condensers connected between the impedance coils and the ground have a capacity of 6 microfarads. If desirable, an ordinary telephone annunciator may be used, as shown at *D*, station *2*, in place of the bell shown at station *1*, and a push button *k* may be arranged, as shown at station *2*, to short-circuit the secondary winding *S* of the induction coil while listening. The push button *k* must be released while talking. This push button is not desirable, because if it is held closed while talking, the person listening at the other end can hear nothing. However, it may improve the working enough to warrant its use.

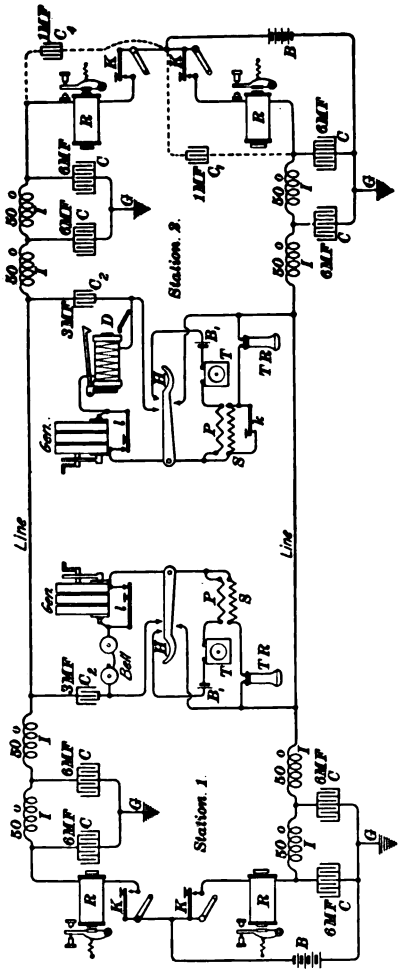


FIG. 26.

62. The push button *l* is arranged to normally short-circuit the generator armature in order to cut its resistance

out of the circuit. When the generator handle is turned to call up the distant station, this push button should be pressed, in order to open the short circuit around the generator. Most generators have an automatic device that accomplishes the same purpose when the handle of the generator is turned. *H* is the ordinary hook switch. When the receiver is on the hook, the bell and generator are connected through the condenser C_2 across the two line wires, the circuit containing the primary winding *P* of the induction coil, the transmitter *T*, and the transmitter battery B_1 is open, and the circuit containing the telephone receiver *TR* and the secondary winding *S* is short-circuited. When the receiver is removed from the hook, the bell and generator are short-circuited, the local transmitter circuit is closed, and the short circuit around the receiver and secondary is opened, leaving this latter circuit closed through the condenser C_2 across the two line wires.

63. Over one line wire it is practical to send simultaneously one telegraph and one telephone message, no second line wire being at all necessary. To do this the following changes would be made in Fig. 26: The two main-line telegraph batteries *B*, *B* and the lower ends of the two telephone sets should be directly grounded, and the two lower telegraph sets (one at each end, including the two adjacent impedance coils and the two condensers) and the lower line wire should be omitted.

CAILHO'S METHOD.

64. M. Cailho, a Frenchman, has devised a method whereby the two line wires that form one complete metallic telephone circuit are connected in parallel for one side of the telegraph circuit, the ground being used as the other side of the telegraph circuit. In this method, which is much simpler than that of Van Rysselberghe, only one

instead of two telegraph messages can be sent over the two wires.

65. The arrangement devised by M. Cailho is shown in Fig. 27. A coil consisting of two identical windings D and E of insulated copper wire, each having exactly the same resistance and the same number of turns, is wound on the same soft-iron wire core. This arrangement is similar to the bridge duplex telegraph system used on submarine cables. The telegraph currents divide at the point f into two equal parts, since the two paths have equal resistance,

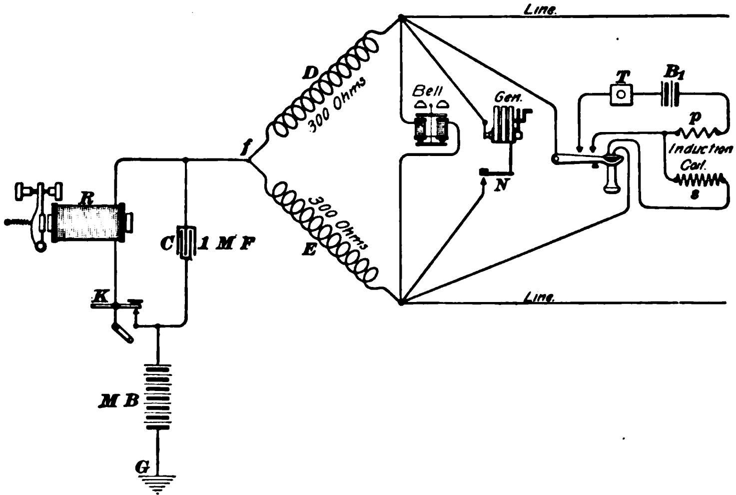


FIG. 27.

and pass through the two windings in opposite directions, so that the two coils tend to magnetize the iron core equally but in opposite directions; and, consequently, the self-induction will be practically zero and the impedance to the telegraph current will be no larger than the resistance. For the telephone currents, however, the case is different. They will have to pass through the two halves D and E in the same direction and, consequently, the impedance offered by the coil to the telephone current will be very large, thus practically forcing all this current through the telephone

where it belongs. Thus the coils prevent the telephone currents from passing through them, but as they add only one-half the resistance of one coil to the telegraph circuit (since there are two coils in parallel), they do not interfere appreciably with the telegraph signals.

66. M. Cailho has successfully used coils of lower resistance at *D* and *E*, but the induction was made high. Morse relay magnets having a resistance of 500 or 600 ohms, or 1,000-ohm telephone-bell magnets, as will be shown in Pfund's system, may be used in place of the special coils. In this case the point *f* will be the junction of the two coils of the relay magnet. This method has the advantage in that condensers are not absolutely necessary, and the extra apparatus needed is very much simpler than in Van Rysselberghe's method. Furthermore, the talking qualities of the telephone are not interfered with in the least and ordinary telephones may be used. What are known as *bridging telephones*, that is, telephones with bells of high resistance (at least 1,000 ohms) permanently connected across the two line wires, should be used. *N* represents a manual or automatic device that normally keeps the generator circuit open. When the generator handle is turned, the circuit must be closed at *N*, either automatically or by hand. *T* and B_1 represent the telephone transmitter and battery, respectively, and *p* and *s* the primary and secondary winding, respectively, of a telephone induction coil. If care is taken that the two halves *D* and *E* of the coil have exactly the same resistance and number of turns and that the two line wires are reasonably equal in resistance, clicks in the telephone will not seriously interfere with talking, although they may sometimes be heard. However, if the clicking is found to be objectionable, it may be almost, if not entirely, obliterated by connecting a condenser *C* of one or two microfarad capacity around the telegraph relay and key at each station. This system has been quite extensively used in France. The fundamental principle on which this method depends is also used in the two following systems.

SYSTEM USED BY TELEPHONE COMPANIES.

67. The Pacific States Telephone and Telegraph Company as well as other telephone companies use a simultaneous telegraph and telephone system quite extensively between important long-distance telephone exchanges. One operator signals another by telegraph to answer on that particular telephone line and again "rings off," that is, notifies the other operator when the subscribers have finished their conversation, without ringing any of the subscribers' telephone bells. This plan avoids ringing a subscriber's bell when he is not wanted and without the use of an extra wire for that purpose alone.

This company uses 600-ohm *retardation*, or *choke*, coils, as they are also called, for the coils D and E in Fig. 27, but no condenser at C. They arrange intermediate stations as shown in Fig. 28, in which I, I, I, I are 600-ohm retardation coils. In each line is inserted a condenser C, C'; an ordinary bridging telephone is connected across the two line wires. It will be noticed that, except where an intermediate telegraph instrument is cut in, the four retardation coils are the only pieces of apparatus that are required, besides the regular telephone and telegraph instruments. Even for an intermediate station only two condensers and four retardation coils are necessary. The arrangement of the intermediate telegraph station, as shown in the Pfund method, is probably superior to the arrangement shown here.

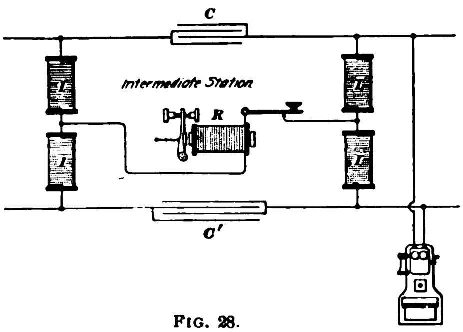


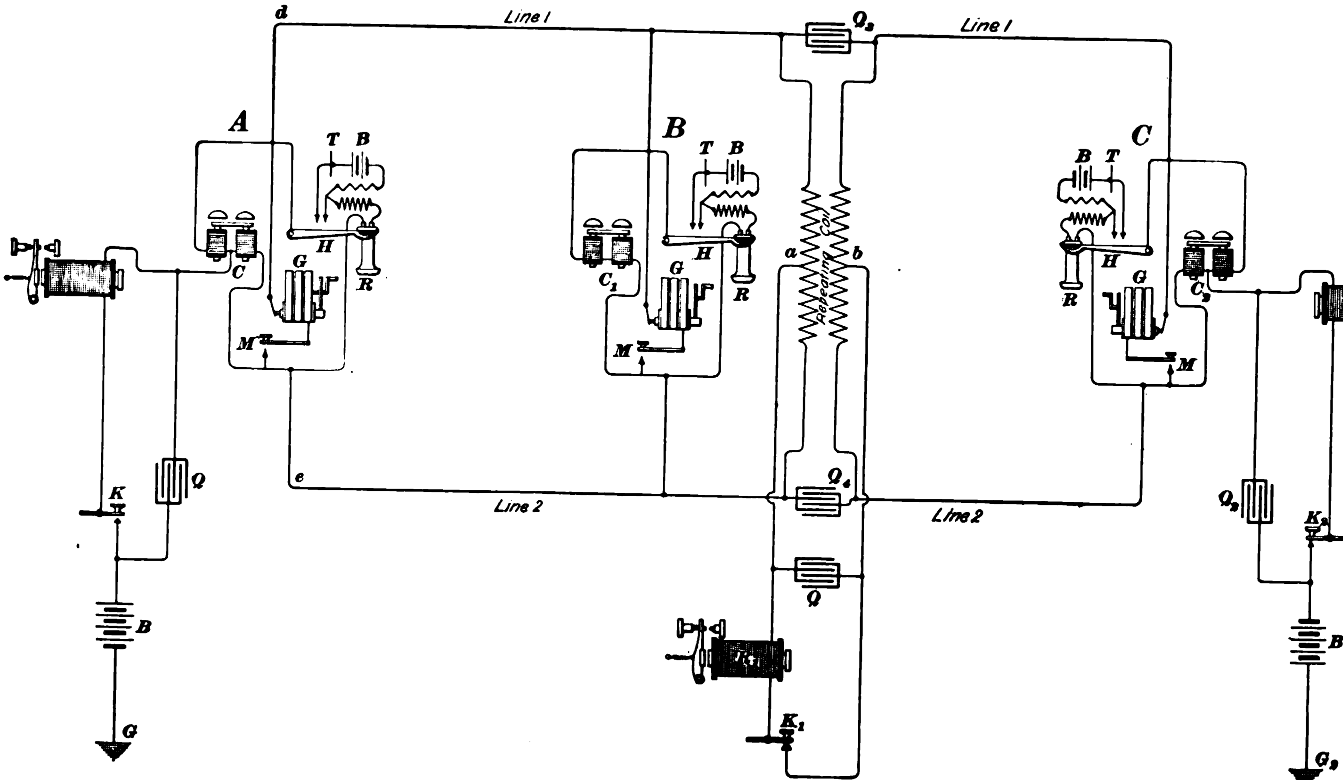
FIG. 28.

68. Dimensions of Choke Coils.—Two or three different styles of choke coils are used. The one used the most has an iron core $\frac{5}{16}$ inch in diameter, a length between

heads of $3\frac{1}{16}$ inches, and is wound to a depth of about $\frac{1}{8}$ inch with No. 36 B. & S. copper wire, giving a resistance of 600 ohms. The whole is iron clad, that is, closed by an iron cylindrical shell $\frac{1}{16}$ inch thick and by two iron end plates. The iron parts are firmly fastened together by a screw at each end. The capacity of the various condensers does not exceed 3 or 4 microfarads each. The induction coil is the one generally used by this company in its bridging telephones having 1,000-ohm bells and solid-back transmitters. The secondary winding of the induction coil has a resistance of 14 ohms and the primary winding a resistance of $\frac{1}{2}$ ohm.

PFUND SYSTEM.

69. Pfund's method for telephoning and telegraphing over the same wires at the same time is shown in Fig. 29. The two line wires form the two sides of the telephone circuit. For telegraphing, however, the two line wires are used as one side and the earth as the return. Three stations *A*, *B*, *C* are shown, *A* and *C* being terminal stations and *B* an intermediate station anywhere between the other two. The arrangement of the telephone and telegraph apparatus is clearly shown. There are in addition to the usual apparatus, a number of condensers *Q*, and at the intermediate station a so-called *repeating coil.* The repeating coil is a form of telephone induction coil having the same number of turns in the primary and secondary windings and a closed magnetic circuit of iron. The polarized or *magneto* telephone bells C, C_1, C_2, as they are called, are wound so that they offer a very high impedance to rapidly alternating currents, such as generated in the telephone circuit; consequently, practically none of the telephone current will pass through these bells or through the relays. Bells wound to a resistance of at least 1,000 ohms should be used. The repeating coils and the condensers Q_3 and Q_4 are used only where it is necessary to insert an intermediate telegraph station.



d
Line 1
Q3
Line 1
A
B
C
T
B
H
G
R
C
M
e
Line 2
C1
Repeating Coil
a
b
Q4
Line 2
Q
K
K1
G
C3
Q3
K3
G3

FIG. 29.

The telephone current will pass from *A* to *C*, partially through the condenser Q_3 and Q_4 and partially by induction through the repeating coil. The telegraph current from *A* to *C* will pass from the battery *B*, through the key and relay, to the middle of the winding of the bell *C*. There it will divide equally, one half passing through line *1* and the other through line *2* to the point *a*, where the two halves unite and pass through the relay R_1 and the key K_1 to the point *b*, where the current again divides equally, half flowing through line *1* and half through line *2* to the center of the bell C_2. They again unite at this point and flow through the relay R_2, the key K_2, and the battery B_2, to the ground G_2, returning through the ground to station *A*. Since this telegraph current flows equally through lines *1* and *2*, it will produce no difference of potential between such points as *d*, *e*, and consequently no disturbance will be produced in the telephones connected across these points; thus none of the telephone instruments will be disturbed by the telegraph currents. Moreover, the telephone current is not large enough to cause any trouble in the relays, even if it could go through them. The telephone current will be confined to the two line wires and will not flow through the relays and the ground, because the bells and relays offer a much greater impedance to the talking current on account of its fluctuating character than do the line wires, the condensers Q_3 and Q_4, or the repeating coil.

The condensers that are connected across the keys and relays not only reduce sparking at the keys, but also prevent a very rapid rise or fall in the strength of the telegraph current in the line wire. The inductance of the bell *C* also tends to reduce the rapid rise or fall in the strength of the telegraph current. In this system we are able to carry on conversation over two line wires between any of the stations connected by them, and at the same time to telegraph over the same circuit, using for the latter purpose the two line wires as one conductor and the earth as the return. No special apparatus is required; the repeating

coil and the high impedance bells are the same as regularly used in telephone systems.

70. In Van Rysselberghe's method, one telephone and two telegraph messages can be sent simultaneously over one pair of line wires, using the earth as a return path only for the two telegraph currents; or, by using the earth as a return for the telephone as well as for the telegraph current, then over a single wire one telephone and one telegraph message may be transmitted simultaneously. In Cailho's and Pfund's methods, however, two line wires are required for one side of one telegraph circuit, and hence only one telegraph and one telephone message can be transmitted simultaneously over two line wires, using the ground as a return for the telegraph current only. In these systems, high-resistance relays (150 ohms) should be used, and half the total number of cells necessary for operating the telegraph instruments had better be placed at each end, the two batteries being in series, of course, with each other.

EDISON PHONOPLEX.

71. The **Edison phonoplex system** is a well-known method of transforming a single Morse wire into a duplex circuit on which it is possible to send two separate messages from one station, or to send one message and receive another at the same time. It is thus an excellent emergency system, meeting the requirements of special occasions and doubling the number of circuits where wires are scarce. It is especially invaluable to the railroad service, where the number of wires is usually limited, since it provides an extra circuit that is available at all times.

72. The **principle** of the phonoplex system may be readily understood by the aid of Fig. 30. Two end stations are here represented as equipped with a Morse and phonoplex

set. The Morse relays and keys are bridged by condensers. A coil of wire *M*, wound on an iron core so as to have a high inductance, is called the *magnetic coil.* *C* is a condenser of small capacity bridged around the magnetic coil *M.* Its purpose is to quicken the impulses sent out over the line.

In order to explain the principle on which the phonoplex works, an ordinary walking-beam pole changer *Pt* is shown here. A resistance *d* of about 10 ohms is connected between the battery *Pb*, which we will call the phonoplex battery, and the contact *p*. The pole changer itself is operated by the local battery *L B* and the key *Pk* in the usual manner. The receiving instrument, or *phone*, as it is called, consists of an elongated horseshoe magnet, having wound on each of its terminals a small coil of insulated copper wire. Above the poles is a large diaphragm. So far the phone resembles a double-pole telephone receiver. In addition, however, there is a split steel ring *n* resting on the diaphragm, but so arranged that it can move freely up and down on a vertical pin *m*. Each agitation of the diaphragm causes the steel ring to be thrown against the nut, producing an excellent imitation of the tone of a telegraph sounder.

73. Operation.—To comprehend the working of the apparatus, it will be necessary to bear in mind that the transmitter produces the effect of dots and dashes by opening circuits and not by closing them. Suppose that the key *Pk* is open; then a steady current of considerable strength will be flowing from the phonoplex battery *Pb* through the magnetic coil (which has a resistance of a few ohms only) and the stop *o*.

If the key *Pk* is now closed, this current will be abruptly broken at *o*, causing quite a high counter electromotive force to be developed in the magnetic coil, due to its high self-induction; and since the circuit is open at *o* and *p*, there is no other outlet except along the line for the electrical impulses at this instant; they must, therefore, travel along

the line. The phone at the distant end responds to these impulses, but the impulses are comparatively feeble in

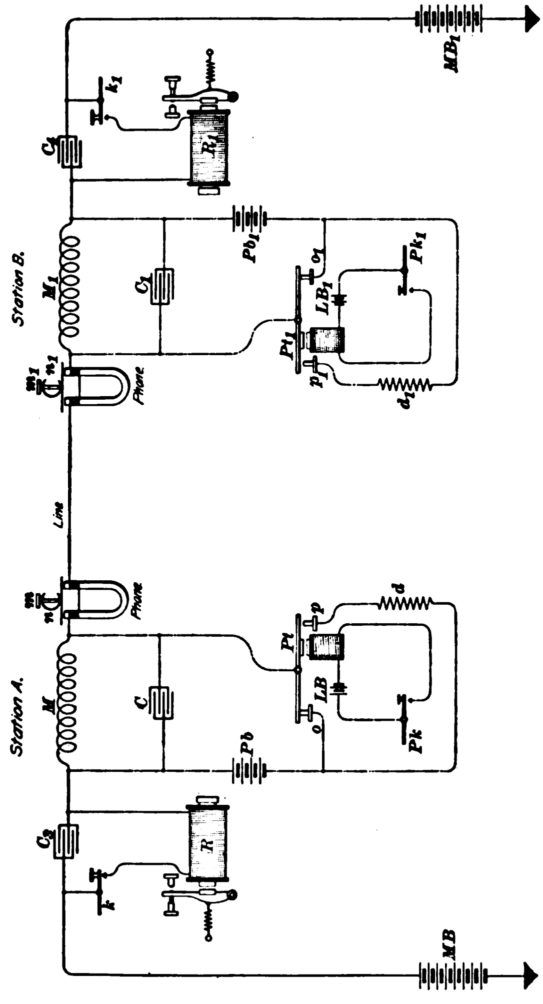


FIG. 30.

comparison with the Morse current; moreover, they are changing very rapidly in strength and hence will pass through the condenser C_1, around the magnetic coil M_1, and

through the condensers C_3 and C_4 instead of the relays R and R_1, and thus will not operate the relays. The sound made by the phone corresponds to the down or front stroke of an ordinary sounder. A moment later the circuit is closed at p, and although impulses are doubtless set up again in the magnetic coil, they can now expend themselves in the closed local circuit and do not produce any impulses of appreciable strength in the line circuit. The current flowing is not as strong, on account of the extra resistance d which is now included in the circuit with the phonoplex battery, as the current that flowed when the lever touched o.

When the key is released, this smaller current will be abruptly broken at p, and will develop in the magnetic coil a counter electromotive force of somewhat less intensity than when the key was closed. These impulses, for the same reason as given before, will travel along the main line, but will produce a sound less intense, however, than before, and so will resemble the sound produced by the back stroke of an ordinary sounder.

A moment later the circuit will again be closed at o, but the impulses that are developed in the magnetic coil will not flow out over the main line, but will expend themselves in the closed local circuit. Thus the down and up, or front and back, strokes of an ordinary sounder have been closely imitated and the system is ready for the production of another signal.

74. The resistance of the extra coil d—which is included in the battery circuit in one position of the transmitter Pt in order to produce an effect in the phone resembling the up and down stroke of an ordinary sounder—is not more than 10 ohms. The condenser C intensifies the impulses sent out by the coil M. The key Pk is not intended to merely open and close the circuit of the battery Pb through the coil M, but rather to cause impulses of two different intensities to be sent through the main line. Since the phone is an instrument that produces a sound only when

the current passing through it is rapidly changing in strength, the slowly changing Morse current will not operate it. The phone is adjusted by means of the screw *a*,

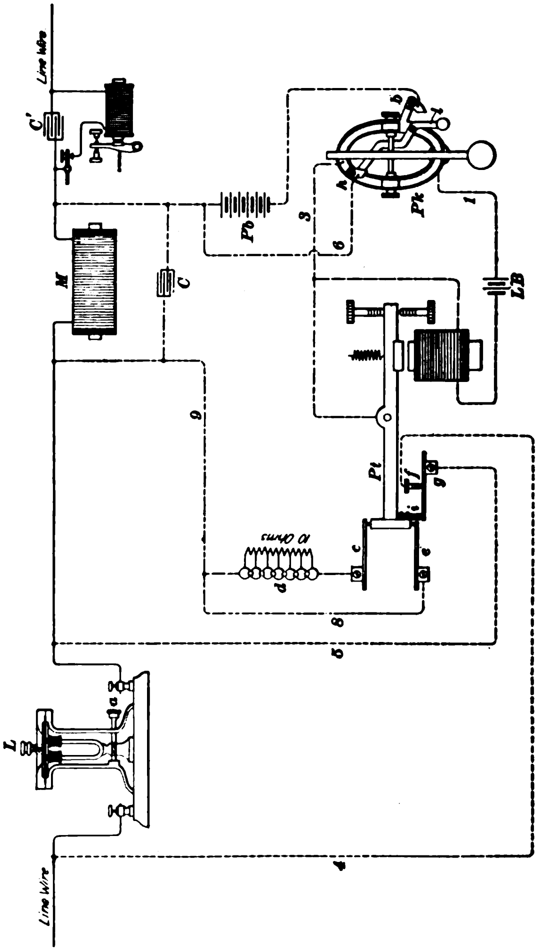


FIG. 31.

Fig. 31, so that the diaphragm is beyond the influence of the comparatively steady Morse currents, but is still within the influence of a rapidly changing current.

75. Practical Arrangement.—In Fig. 31, the complete and practical arrangement at an intermediate station is shown. The connection at the terminal station will be practically the same. This figure is lettered as far as possible like the preceding one.

The key *Pk* is slightly different from the ordinary key. The contacts *b* and *h* are insulated from the base or framework of the key. The bent lever *l* is permanently connected with the base and, consequently, to the wire *3*, which is also permanently connected to the base of the key. The wire *1* is connected, as usual, to a platinum point that is insulated from the base. When the bent lever *l* is turned to the left, which is called the *closed position*, the phonoplex battery *Pb* is left open at the point *b* and the magnetic coil *M* is short-circuited through the wires *9*, *8*, spring *e*, transmitter lever, wire *3*, base of key, the bent lever *l*, and wire *6*. Thus, in this position of the bent lever, the phonoplex transmitting apparatus is practically cut out of the circuit. The phonoplex battery is left open for the reason that it is of low resistance and depreciates rapidly when left on closed circuit. The magnetic coil *M* is short-circuited when not in use, so as to keep its resistance out of the main line.

76. Transmitting Position of Key Lever.—When the key is opened, that is, when the bent lever *l* is pushed to the right so as to come into contact with *b*, the phonoplex battery is connected through *b*, the bent lever *l*, base of key, wire *3*, through the transmitter spring *e* or *c*, and the magnetic coil *M*. This position of the lever *l* opens the short circuit around the magnetic coil and throws it into the line circuit, and furthermore closes the circuit of the phonoplex battery *Pb* through the magnetic coil and the transmitter springs. This is done when the operator desires to send a message. If the key is now manipulated, the transmitter will make and break the current through the magnetic coil. The key has no ordinary circuit closer; consequently, the circuit through the local battery *L B* and the

transmitter magnet is open at all times, except when a dot or dash is being made.

77. Receiving Position of Key Lever.—When the operator wishes to receive, he throws the lever *l* to the left, which act corresponds to closing the ordinary key, but in this system the movement disconnects the local battery *L B* from the transmitter, leaves the phonoplex battery *Pb* on open circuit, and short-circuits the magnetic coil, thus allowing the phone to be more readily affected by the discharge from the distant magnetic coil. The same result could, of course, be obtained with an ordinary key and a pole-changing switch.

When the key *Pk* is depressed while the lever *l* is turned to the right, the local circuit is closed and the armature of the transmitter is attracted, thereby breaking contact at spring *e* and sending an impulse from the magnetic coil into the line. When the key is released, the armature of the transmitter is also released and the circuit is broken at the point *e*, thus sending another but weaker impulse into the line. This time, however, the impulse produces a less intense sound that corresponds to the back stroke of an ordinary sounder, thereby enabling the operator to distinguish the difference between the two and thus avoid getting a back-stroke effect. Wires *4* and *5* connected to the points *f* and *g*, respectively, short-circuit the phone when the circuit containing the transmitter magnet is closed.

78. An insulated piece *i* attached to the lower part of the lever of the transmitter permits the spring *g* to make contact with the screw *f* just before the circuit is broken at *e* as the armature lever of the transmitter is attracted, and then breaking contact at *f* after the circuit has been broken at *e* as the armature is released. The phone at the home office is thus silenced while the home office is working. It is arranged this way because the response of the home phone to local impulses would be very loud if it were permitted to work, and some difficulty would be met with when

the receiving operator desired to break. The small condenser *C* not only quickens the impulses and helps the incoming signals, but also prevents excessive sparking at the contact points of the springs *c* and *e*. The Gordon, Edison-Lalande, bichromate of potassium, or other good closed-circuit, low-internal-resistance battery should be used for operating the phonoplex and only 10 or 12 volts are required.

79. One advantage of this system over the Morse is that it is less likely to be affected by ordinary trouble on the wire. It will work readily across heavy escapes or when the phonoplex wire is grounded or crossed with some other wire. Even bad weather fails to affect the signals to any great extent. All Morse sets in intermediate offices are bridged with condensers and the operation of the relays does not interfere in any manner with the working of the phonoplex. It is adapted for use between intermediate stations or between terminal stations.

A serious objection to the system is the fact that only one circuit can be worked successfully on the same line of poles carrying a number of wires, such as is usually strung along a railroad. A companion phonoplex on a line of poles on the opposite side of the track is even impracticable, for the reason that the phonoplex impulses are so penetrating that their inductive effects extend far into the space around the wire; hence it is much better to arrange only one phonoplex circuit along a line of wires in any one given direction. The phonoplex system at least duplexes the capacity of the line, as it may be used between any number of intermediate stations, any two of which may carry on telegraphic communications independently of the Morse system. It has been successfully worked on wires already duplexed or quadruplexed. The construction and operation of this system is simple, and the ease with which it can be adjusted places it within control of an ordinary operator.

SUBMARINE TELEGRAPHY.

INSTRUMENTS.

80. Cable Transmitting Key.—In submarine-cable telegraphy, the double-current system—a current in one direction to indicate a dot, and a current in the opposite direction to indicate a dash—is invariably used. Cablegrams are now transmitted both by hand and by automatic transmitters. The hand key is shown at *K* in Fig. 37. It consists of two long spring levers, or keys, *a* and *b*; one is operated by the index finger and the other by the second finger of the right hand. One lever *b* is connected to the cable conductor or apparatus, the other lever *a* is connected to the ground *G*. The two levers normally press against the strip *z* which is connected to the zinc pole of the battery. The under strip *c* is connected with the copper pole of the battery. When the lever *b* is pressed down, it leaves the strip *z* and touches the strip *c*. The circuit may then be traced from the ground *G*, to lever *a*, strip *z*, negative pole of the battery *B*, through the battery to the strip *c*, lever *b*, and to the cable conductor or apparatus. Thus the copper, or positive, pole is connected toward the cable and the zinc or negative pole to earth; hence a positive current flows toward the cable. When the other lever *a* is pressed down, a negative current will flow toward the cable, and the student should now be able to trace out the circuit for himself. When both keys are pressing against the strip *z*, the line is connected directly to earth. This is a good feature, for it allows the cable to wholly or partially discharge whenever, in making a space between two succeeding signals, both keys touch the top strip at the same time. The rate of signaling is not over 20 to 30 words a minute where this key is used, because its manipulation is not so simple as that of the ordinary key used on land lines in the United States.

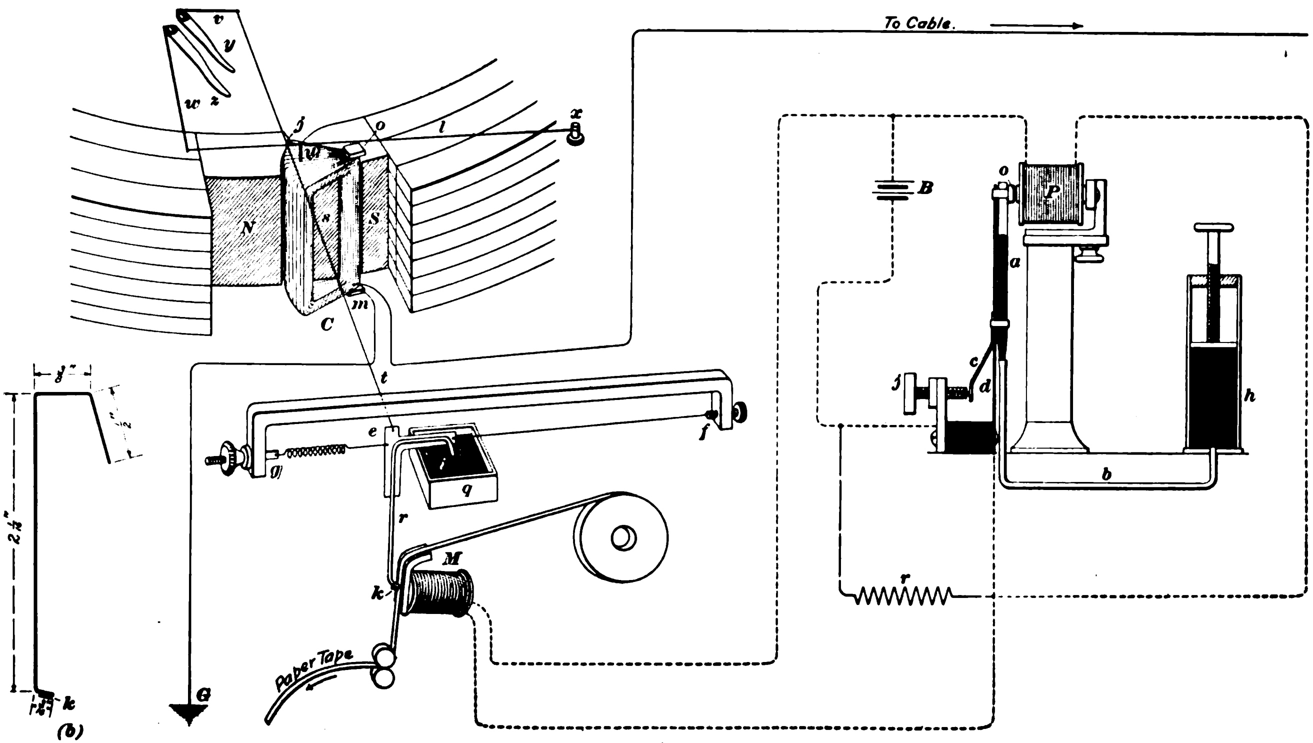
81. Very Sensitive Receivers Necessary.—In order to avoid the danger of injuring the insulating material

of a submarine cable, an electromotive force exceeding 40 or 50 volts is seldom, if ever, used. For this reason, and also on account of the large distributed electrostatic capacity of a long submarine cable, the current at the receiving end is very small, too small to operate any kind of electromagnetic relay. Consequently a more delicate receiving apparatus is necessary. Since it requires some time after the closing of the key at the transmitting end before the current at the receiving end has increased so as to have an appreciable strength, it is evident that the smaller the current that can be detected by the receiving instrument, the higher can be the speed of signaling.

At first reflecting galvanometers were used, the signals being read by the right and left deflections of the spot of light, a movement in one direction indicating a dot, and a movement in the opposite direction a dash. One man observed the deflections, and called them out, while another wrote the message upon paper. Then the siphon recorder, invented by Sir William Thomson, now Lord Kelvin, was used.

THOMSON SIPHON RECORDER.

82. The **Thomson siphon recorder** consists of a coil of wire suspended by a silk fiber between the poles of a magnet. The current passes through this coil and causes it to swing in one direction or the reverse, according to the direction of the current. This coil is attached to a glass siphon by a thread, thereby moving the recording end of the siphon across a paper tape as the latter moves along uniformly under the siphon. The upper end of this siphon dips into a vessel containing ink, and the lower end spurts the ink upon the paper that is drawn past the end of the siphon. The ink is charged positively, while the plate over which the paper passes is given a negative charge. Consequently, the ink is splashed upon the paper in a very fine stream of dots and a record is thus obtained of the movements of the coil.



(a)

FIG. 32.

83. Mouse Mill.—The electrostatic machine used for charging the ink is called the **mouse mill.** At times there is sufficient moisture in the atmosphere to seriously interfere with the electrostatic charging devices; and for this reason the improved recorders now used, and which do not depend on the attraction of a positive charge for a negative charge of electricity to cause the ink to flow, but on a mechanical vibration of the siphon tube, are much preferable.

CUTTRISS RECORDER.

84. The principle of the **Cuttriss recorder** is shown in Fig. 32. *N* and *S* are the north and south poles of a powerful, compound, permanent magnet made up of a number of separate permanent magnets. The magnet maintains a strong field in the space between the poles *N* and *S*.

The pole piece *s* is curved outwardly at the end facing the pole *N* and the pole *N* is cut away, or hollowed out, to correspond, thus forming one convex and one concave cylindrical surface about *o m* as an axis. A narrow space is left between these two cylindrical surfaces on *N* and *s* and there is also an opening, or slot, between *S* and *s* from the front to a point slightly beyond the central line, in order that the coil *C* of fine wire may be put in place. The pole piece *s* extends through the coil *C* and one vertical side of the coil is free to revolve in the strong field between *N* and *s* about the vertical side *o m* as an axis.

The movable galvanometer coil *C* is very delicately pivoted and supported by means of jewel bearings at *m* and *o*, and above the coil is a plate or piece of iron (not shown in the figure) so disposed that, by attracting a small iron pin fastened to the coil, it reduces the pressure and, therefore, the friction at the bearings and causes the coil to apparently float in the magnetic field.

85. Glass Siphon and Support.—The fine glass siphon, which has an outside diameter of $\frac{1}{64}$ to $\frac{1}{100}$ inch, is

shown in Fig. 32 (*b*), the actual dimensions of one form being given. On the lower end of the siphon is fastened a small piece of iron *k* about $\frac{1}{8}$ inch long. This siphon *k i* is fastened, Fig. 32 (*a*), by wax or paraffin to a delicate holder *e* that is attached to the fine wire *g f*. By means of the screws *g* and *f*, between which the wire is stretched, not only can the right tension be given to the wire but also the right torsion for the siphon holder. To the top of the siphon holder *e* is fastened one end of a fine thread *t*, the other end being fastened to one end of a delicate spring *v*. At right angles to this thread is another thread *l* that is fastened rigidly at *x* to an adjusting screw and at the other end to a delicate spring *w*. The "tension fingers" *y* and *z*, as they are called, press with sufficient force ordinarily to hold them in place against the top of the plate upon which the device is mounted. They may be independently adjusted and made to exert whatever stress is required upon their respective threads.

The thread *l* passes through a slot or fork in a projecting piece *u* that is fastened to and moves with the coil *C*, the other thread *t* is fastened to the thread *l* at the point *j* where they cross each other. When the coil is deflected in the direction of the hands of a watch, it moves the thread *l*; this pulls on the thread *t*, and the spring *v* takes up the slack in the thread *t*. This causes the lower end *k* of the siphon to move toward the reader. The tendency of the torsion in the wire *g f* is to oppose the pull of the thread *t* and to move the lower end of the siphon away from the reader. When no current flows through the coil *C*, these threads, wires, and springs are in equilibrium and keep the end *k* of the siphon in its middle, or zero, position.

The higher leg of the siphon dips into a small trough *i* of specially prepared ink. Between its lower end and the pole of the electromagnet *M*, there is uniformly drawn by a suitable motor a continuous tape of white paper along whose middle, when the siphon is at rest, is traced a fine ink line, which may be called the "zero" line. The force tending to deflect the coil helps one or the other of the two

forces that were previously in equilibrium and consequently the end *k* of the siphon is moved across the paper tape; the direction in which the siphon moves depends on the direction of the current through the coil *C*.

86. Vibration of the Siphon.—The siphon is made to vibrate to and from the paper, as will be explained elsewhere, in order to avoid the friction between the end of the siphon and the paper tape, which would impede the movement of the delicately suspended coil. Thus the siphon traces a dotted instead of an absolute continuous line. This is necessary because otherwise the ink is liable to gather upon the end of the siphon in globular form, and either blur the record or cause it to stop recording. The ink well also is adjustable, and may be readily lowered in order that it may be removed.

87. Magnetic Vibrator.—The apparatus shown in Fig. 32 and used with the Cuttriss recorder to make the siphon vibrate may be called a **magnetic vibrator.** It consists of an arrangement of apparatus that will send pulsatory currents through the electromagnet *M*, the frequency of these pulsations being so regulated as to correspond with the natural rate of vibration of the siphon. Almost every vibrating body has a particular rate of vibration, depending on its length and various other conditions, at which it will vibrate most easily and freely. For instance, a tuning fork or reed of a certain length and having a certain pitch will vibrate readily at a certain rate, but it cannot be made to vibrate uniformly nor continuously at any other rate without the expenditure of considerable more energy. A glass tube *a* fastened to a spring or reed *d* has its lower end connected by a rubber tube with the cylinder *h* containing mercury. By means of a piston, the mercury can be forced to any desired height in the tube *a*, and thus the natural rate of vibration of the tube and spring may be varied as required. When a new glass siphon is adjusted on the apparatus, it is frequently necessary to change the

natural rate of vibration of the spring *d* and the glass tube *a* to correspond to the natural rate of vibration of the new siphon.

When the contact spring *c*, which is attached to *d*, bears against the screw *j*, the circuit containing the battery *B* and electromagnet *P* is closed and the magnet is energized. It then attracts the armature *o* fastened to the tube *a* and opens the circuit between *c* and *j*. The very high non-inductive resistance *r* which is connected between *c* and *j* neutralizes, or at least reduces, the sparking when the circuit is broken between *c* and *j*; but its resistance is so high that it does not allow enough current to flow through *P* to cause the latter to attract or to hold its armature *o*. Consequently the armature is released, the circuit again closed between *c* and *j*, and the magnet *P* again energized. Thus *a* is kept vibrating uniformly and continuously, the principle being exactly the same as that used in buzzers and vibrating bells, and the circuit between *c* and *j* is thus opened and closed many times a second.

The opening and closing of the circuit containing the battery *B* and magnet *M* between *c* and *j* causes a rapidly pulsating current to flow from the battery *B* through the electromagnet *M*, causing it also to alternately attract and release the small piece of iron *k* fastened to the lower end of the glass siphon. Evidently the electromagnet *M* will have its circuit made and broken at the same rate as that of *P*.

88. Adjustments of Electromagnet.—The electromagnet *M* has an adjustable pole face constituting a table on which the paper rests as it passes beneath the recording point. As it is sometimes difficult to grind the recording end of the siphon so that its end will be exactly parallel with the face of the magnet, the pole piece of the magnet is made adjustable so that it may be turned until its face is parallel with the recording end of the siphon. The entire magnet *M* is supported so that it may be raised or lowered by means of an adjustable screw.

89. The general appearance of the Cuttriss recorder is shown in Fig. 33. It is practically the same as the figure already described, except that the wire *f g* which supports

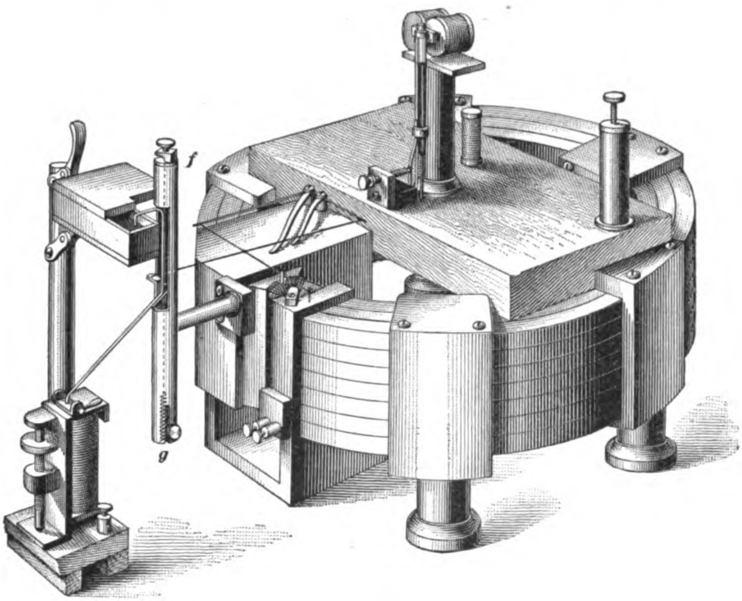
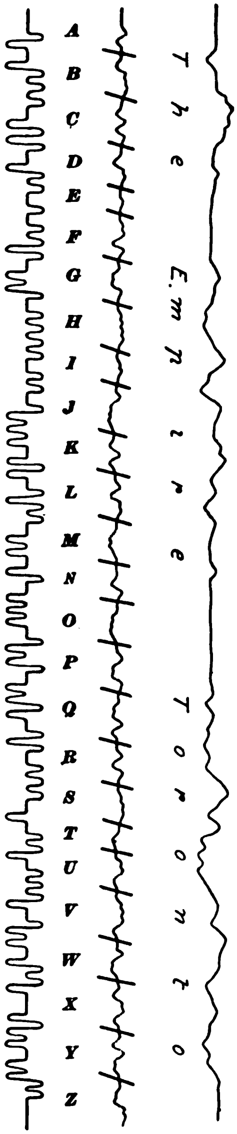


FIG. 33.

the siphon holder is vertical in this figure instead of horizontal, as shown in Fig. 32, and the siphon is necessarily shaped a little different to suit this construction.

CABLE ALPHABET.

90. The letters of the alphabet, figures, and other characters are formed by prearranged combinations of positive and negative currents that cause corresponding right and left movements of the recording end of the siphon. The letter "a" consists of one positive and one negative impulse, thus producing, to one facing the tape as it comes from under the siphon, one movement of the siphon to the left and one to the right; "b" consists of one negative and



(b) (c) (d)

FIG. 34.

three positive impulses, producing one movement of the siphon to the right and three to the left; and so on. On the paper tape these signals appear as being above or below the zero line which the siphon, when at rest, traces along the center of the tape. There is necessarily no return of the siphon to its zero line every time between impulses. In the case of impulses of opposite polarity, the siphon will usually cross the zero position or line, but in the case of several impulses of the same polarity, the curve will merely fall back a little and move a little farther away each time from the zero line.

The continental code is used on all submarine cables. If this alphabet is deliberately sent over a very short cable, it will be traced by a siphon recorder about as shown in Fig. 34 (*b*). If the letters are sent continuously one after another, the actual record made by the siphon recorder connected to a long submarine cable is shown in Fig. 34 (*c*). Fig. 34 (*d*), which is an accurate reproduction of a portion of a message actually transmitted over a transatlantic cable with the accompanying translation, will more clearly convey the character of the recorder signals. The message is translated and written down by the operator as the tape glides along in front of him.

91. Automatic Submarine-Cable Transmitters.—Sending by means of the hand key is the method

most generally used on submarine cables, but it is now being superseded by the automatic transmitter. The accuracy and speed of the working is thus greatly improved, for by this mechanism is obtained the utmost uniformity of signal with a speed and tirelessness unattainable by hand. By the use of the automatic transmitters, a speed of 40 or 50 words a minute may be reached on transatlantic cables. The Cuttriss, Willmot, and Muirhead automatic transmitters are used by the various cable companies. The Cuttriss is used in the United States. The Crehore and Squier sine-wave transmitter, which is suitable for use on submarine cables, as well as on land lines, will be described in connection with the sine-wave system.

CUTTRISS AUTOMATIC TRANSMITTER.

92. The principle of the **Cuttriss automatic transmitter,** whereby the positive and the negative impulses that are sent to the line or cable are controlled, may be explained by means of the diagram of connections shown in Fig. 35. *C*, *D*, *E*, *F*, and *B* show the ordinary arrangement of a cable key and the main battery. *G*, *H* are electromagnets, normally on open circuit, for operating the levers *C*, *D*. The so-called "trailers" *o* and *p*, under which a punched paper tape is drawn, are necessarily light and delicate; in order to keep their contacts in good condition by preventing the occurrence of sparks at *m* and *n*, the circuit is broken at *h* by means of the spring bar *j* and a cam *i* before the trailers open the circuit at *m* or *n*. The sparking is thus confined to the single contact at *h*, which may be made of substantial form and easily renewed and repaired. The spark may also be reduced by the use of a high non-inductive resistance *r*, which forms a shunt around the contact points.

93. A view of the Cuttriss transmitter is shown in Fig. 36. It is lettered the same as Fig. 35. On the shaft

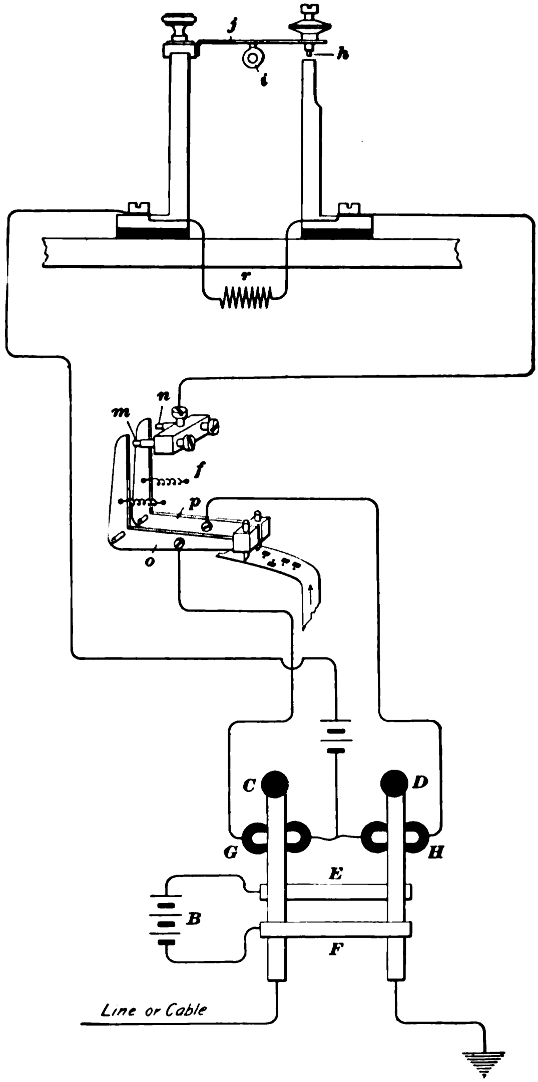


FIG. 35.

of an electric motor there is a worm-thread, or cam *v*, that engages with a wheel *W*, provided with projecting pins in such a manner that every revolution of the shaft causes the wheel *W* to revolve through a space of one tooth, allowing it to remain stationary, however, during a portion of the period of each revolution.

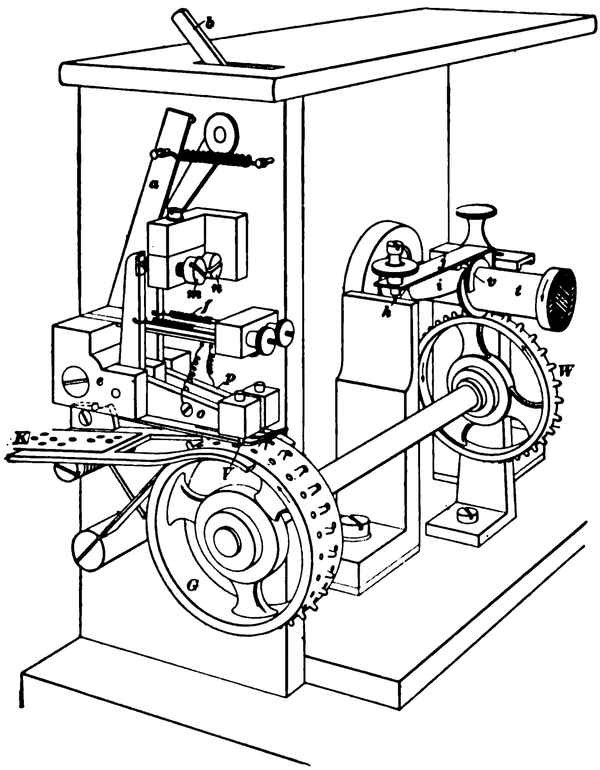


FIG. 36.

On the same shaft with the wheel *W*, but outside the case of the instrument, is fixed another wheel *G* provided with a like number of projecting pins and also having indentations on each side of each pin. The trailers *o* and *p*, which are the same as those shown in Fig. 35, are right-angled metallic

levers, pivoted side by side in an insulating block *e*, and having in their ends pins with points beveled on the under side, as shown, and lying directly over the lines of perforations in the wheel *G*. There are several springs to keep the paper tape that runs over the wheel *G* pressed against the surface of the wheel, and to furnish guides through which the pins on the ends of the trailers may readily move up and down, but cannot move sidewise out of line of the holes. Each trailer has a spiral spring *f*, which tends to make the pin enter the indentations on the surface of the wheel *G*. The paper tape *K* is made with a central line of equidistant perforations. It is prepared for the transmitter by a suitable perforating machine that makes two lines of perforations on opposite sides of the central lines of perforations. The Wheatstone perforator, which will be described in connection with the Wheatstone automatic system, may be used by merely replacing certain round punches with square punches. The side on which the perforations are made depends on the direction or polarity of the impulses that they are designed to transmit, but every perforation is exactly in line with one of the central perforations. The pins in the wheel *G* enter the perforations in the center line of the tape and so draw along the tape when the wheel rotates.

94. When the motor that revolves the shaft *t* continuously and uniformly is started, both wheels *W* and *G* are rotated intermittently, the period of rest being so timed as to occur when the pins on the lower ends of the trailers are opposite, that is, in line with the pins projecting from the surface of the wheel *G*. If there is no perforation in the paper under either pin, they are prevented from dropping down ; but whenever a perforation comes under one of the pins, it passes through the paper and causes its lever to make contact with *m* or *n*. On the shaft *t* is fixed a sleeve *i* having a raised portion that serves as a cam to raise the bar *j*, thus causing *j* to open the circuit at *h* (see Fig. 35) while the wheel *G* and the tape are at rest, and prior to the time when either trailer, if it is in contact with its back

stop, can be separated therefrom by the advance of the tape. The opening of the circuit, therefore, always precedes the separation of the trailers from their contacts.

95. The collar *i* is quite long in the direction of the axis of the shaft *t*. The edge of the projection on the surface of the collar, which raises the bar *j*, is oblique to the axis of the shaft, while the other edge of the collar, which allows the bar *j* to drop down again and close the circuit, is straight or parallel to the axis, so that by adjusting the bar *j* bodily at right angles to the axis of the shaft, the period of engagement between a lug on the under side of the bar *j* and the projection on the collar may be varied, according as the lug on the under side of the bar *j* passes over a narrower or wider part of the projection on the collar. Furthermore, the collar may be turned around on the shaft and fastened in any position desired.

96. Since the magnets *C* and *D*, Fig. 35, are only energized when the circuit is closed at *h*, it will be noticed that the cable is connected directly to the ground at all times, except when the circuit is closed by the bar *j*. The circuit may be closed at the contact *h* at a time that is adjustable within limits during each revolution of the motor shaft, and then opened at *h* after an interval of time during which the tape wheel and trailers are absolutely at rest. Moreover this interval of time during which the tape wheel and trailers are at rest may be varied by means of a speed governor on the electric motor that drives the transmitter, and thus the relative lengths of the impulses and of the intervening spaces, during which the cable is directly grounded, and the speed of transmission may be varied to suit the requirements of working at any time or through any cable.

The tape may be stopped without stopping the motor, by moving the handle *b* to the right, thus forcing the lever *a* to the left and raising both trailers and the springs that press the paper against the wheel away from the wheel. The forked spring, on which the paper tape *K* is resting in

the figure, then lifts the tape above and free from the pins on the wheel *G*.

In connection with the electric motor, there is a speed regulator and indicator that is not shown in the figure. By means of the regulator, the speed may be adjusted as desired, and the divisions on a graduated dial will indicate the number of turns of the shaft per unit of time, and, hence, the average number of letters being sent per minute, or the rate of transmission.

EARTH CURRENTS.

97. The operation of submarine cables is interfered with by earth currents more than are land lines. This is due to the differences of potential at the two ends of a long cable, which cause a more or less steady flow of current, if means are not taken to prevent it. During electric or magnetic storms, temporary currents are induced in a long cable that are sometimes very troublesome, because the delicate instruments used on submarine cables are very readily affected by them. Such disturbances, however, are so uncertain both in intensity and time of occurrence that nothing is usually done to eliminate them. It is a well-known fact that the flow of a steady current can be prevented by the introduction of a condenser in the circuit; hence, steady earth currents are avoided in cables by the use of a condenser somewhere in the circuit between the ground and the cable. While a constant difference of potential between the two ends of the cable will charge such a condenser, there will be no steady flow of current through the cable or receiving instruments after the condenser is fully charged.

98. The electromotive force due to the earth is fairly constant and changes direction but seldom, while the direction of the electromotive force due to the transmitting battery is being constantly changed by the operation of the transmitting keys; hence, the earth potential alternately helps and opposes the battery potential. This may be obviated in two ways. A condenser may be inserted in the circuit

between the cable and the ground connection, and the potential of the battery increased until the potential due to the earth is insignificant compared with it. This will evidently make the component of the signaling currents due to the earth potential negligible in comparison with the component due to the transmitting battery. In order that the charging and discharging currents may not now be too large, they can easily be reduced in volume by decreasing the capacity of the condensers (as *C* in Figs. 37 and 38). Thus one way is to diminish the capacity of the condensers and to then increase the electromotive force of the battery until the disturbing effects of the earth currents are eliminated. This is the method adopted in practice.

99. When a condenser is inserted in series with the cable, the combined capacity will be less than that of either the condenser or the cable alone, because the capacity of condensers joined in series follows a law exactly similar to that for resistances joined in parallel. Hence, to give the same charging current, a higher voltage battery will be required with condensers than without. However, the potential of the batteries must not be increased too much, for there is danger of injuring the insulation of the cables. Fifty volts is about the highest electromotive force that can be safely used. Low internal resistance batteries, such as Fuller bichromate and storage batteries, having an electromotive force from 30 to 40 volts, are commonly used on submarine cables.

On transatlantic cables, the capacity of the condenser used for minimizing the disturbing effects of earth currents is about 50 microfarads.

100. The second way to eliminate earth currents is to determine at each end, by measurement or experimental trials, the intensity and direction of the potential between the ground and the cable conductor, due to the earth, and then to insert a battery of this potential in the ground wire so as to oppose it. An objection to this method is the fact that the battery potential will be constant, while the earth potential will vary more or less.

TERMINAL CONNECTIONS.

101. Submarine cables are worked both simplex and duplex. When sending, the cable is connected through a condenser, switches, ordinary cable key, and the battery to the ground. When receiving, the cable key and battery are switched out and the siphon recorder connected in their place. A condenser is connected in series with the receiving instrument because this arrangement increases the sharpness of the signals.

SIMPLEX CABLE CONNECTIONS.

102. Position of Switches for Transmitting.—When cables are worked simplex, they are often connected

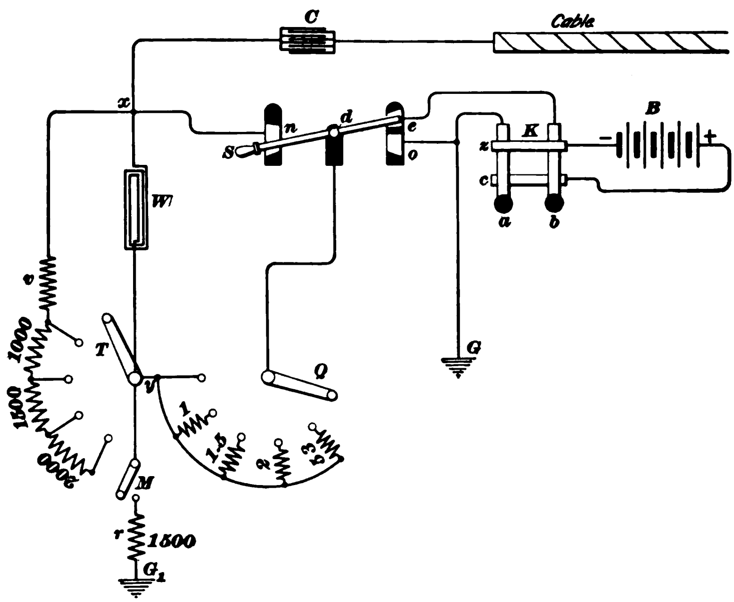


FIG. 37.

as shown in Fig. 37. Ordinarily, when transmitting, the switches will be placed in the positions shown. In this

position of the switches, the transmitting key K, battery B, and condenser C are connected directly in series between the cable and ground G; all the current is then utilized to charge the condenser and cable. The condenser C is used to eliminate earth currents and to increase the speed of signaling.

103. To Record Signals Sent From Home Office. If it is desirable to record the signals to see whether they are being properly transmitted or to preserve a record for future reference, the switches Q, T, and M are closed. The resistance r is usually as high as the resistance of the cable itself. When the two switches Q and M only are closed, there are two paths for the current that comes from the battery B; one is by way of d–Q–y–M to the ground G_1; the other by way of d–n–x–C and cable, to the ground at the distant station. Hence, if x and y have any difference of potential, some current will flow through W. This current may be increased by turning Q so as to increase the resistance between d and y, because this increases the difference of potential between x and y; or, it may be looked at in this way: The greater the resistance from d through Q to y, the greater will be the portion of the current flowing from d through n–x–W–y, and the smaller will be the portion flowing through the parallel path d–Q–y. The current through W may be decreased by closing the switch T. The more T is turned so as to increase the resistance from x to y, through x–v–T, which forms a shunt circuit around the coil W, the larger will be the portion of the current through W, and the smaller the portion through x–v–T–y. By adjusting the switches Q and T, the proper current may be obtained through W.

104. Position of Switches for Receiving.—When it is desirable to receive, the switch S is raised. This switch is so constructed that when this is done, the rear end of the lever touches the segment o before the front of the lever leaves the segment n. This is very necessary because it allows the cable to discharge to earth through n–d–o–G,

instead of through the coil *W*, as it would do if the switch lever left *n* before touching *o*. When the handle of the

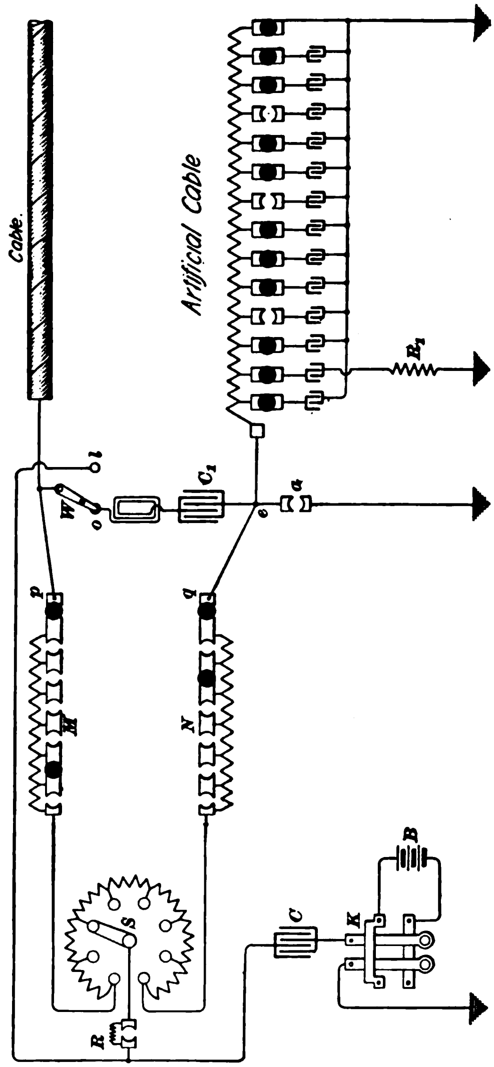


FIG. 38.

lever is up as high as it will go, contact between *d* and *n* is broken. The current from the cable then divides at *x*, part

passing through *W* and the rest through *v* and *T* to *y*, where the currents reunite and pass through *Q–d–o* to the ground *G*. When receiving, it is evidently immaterial whether *M* is closed or open.

CABLE DUPLEX.

105. When submarine cables are duplexed, the bridge method is generally used. One arrangement is shown in Fig. 38. *M*, *N*, and *S* are adjustable resistances forming two arms of the bridge, the cable and the artificial cable forming the other two arms. The artificial cable corresponds to the artificial line in the bridge duplex that has already been explained.

There are usually from 1,000 to 3,000 ohms in each of the boxes *M* and *N*, while *S* contains about forty ¼-ohm coils. *C* and C_1 are condensers of about 50 microfarads each. *C* is used to diminish the trouble due to earth currents and C_1 to make the signals sharper. *R* is a 10-ohm resistance coil that may or may not be connected in the transmitting circuit.

When one of the levers of the key *K* is depressed, one pole of the battery is connected to the condenser *C*, causing the latter to be charged. This will send charging currents which divide in such a manner through the arms of the bridge that there is no difference of potential between the points *e* and *W*; hence the receiving instrument connected between the condenser C_1 and the point *o* is not affected by the operation of the home key *K*.

106. The **Stearns artifical cable,** as the arrangement of the artificial cable here shown is called, consists of a large number of condensers and resistance coils put up in boxes. The coils and condensers are joined to terminals on the outside of the boxes, so that they may be connected together and to the ground in the way that will best resemble the real cable both in resistance and capacity. By connecting a condenser to the ground through a high resistance R_1, the discharge from that portion of the cable is retarded.

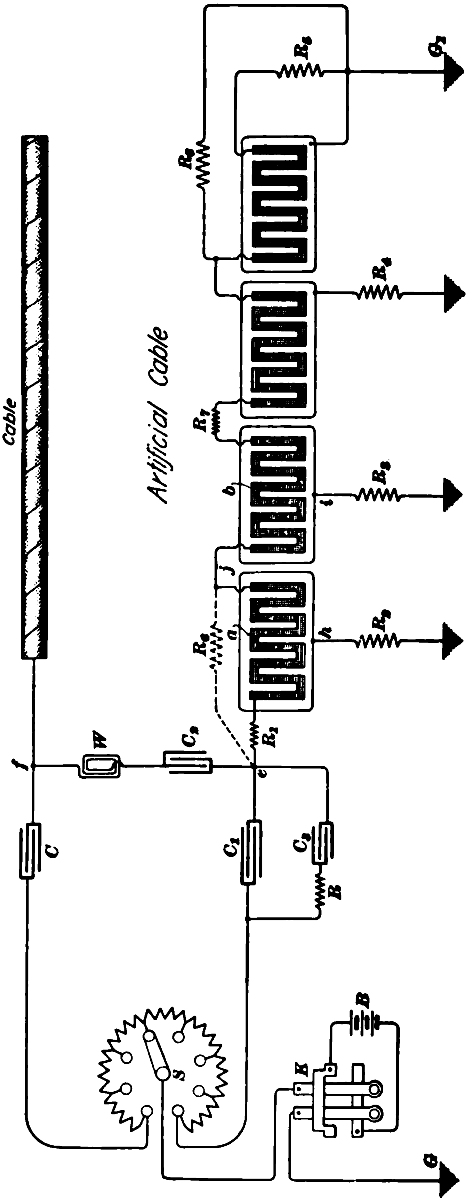


FIG. 39.

Hence the charge and discharge of the artificial cable may be accelerated or retarded to correspond to that of the real cable by connecting proper resistances between the ground and condensers at proper points in the artificial cable. Connecting resistances between the ground and condensers in the home end of the artificial cable will delay the discharge of the home end; and connecting resistances between the ground and condensers in other parts of the artificial cable will delay the discharge from those parts of the artificial cable. The more condensers that are connected to the artificial cable, the longer will it take to charge and discharge.

107. To Change From Duplex to Simplex.—When it is desired, as is often the case, to work the cable simplex, a plug is inserted at *a*, and the plugs at *p* and *q* are removed. When receiving, the switch *W* remains on contact button *o*, but when transmitting, it is shifted to the contact button *l*.

MUIRHEAD CABLE DUPLEX.

108. In the **Muirhead cable duplex,** shown in Fig. 39, the condensers C and C_1 are used in place of the resistances M and N shown in Fig. 38. A condenser C_2 is also connected in the bridge circuit *e f*. For the present suppose C_2 and R to be entirely disconnected. The condensers C and C_1 act in the same way as the resistances in a Wheatstone bridge. When connection is made at K with one pole or the other of the battery B, the condensers C and C_1, the cable, and the artificial cable are charged. A charge is given to the condenser at the distant station corresponding to C_2; but *if the charge of C is to the charge of C_1 as the charge of the cable is to the charge of the artificial cable, there will be no charge given to C_2*, because there is no difference of potential between the two points *e* and *f* to which the receiving circuit, containing W and C_2, is connected, and consequently the receiving instrument W is not affected.

The condensers and cable may evidently be charged in either direction by means of the key *K*.

109. As it is practically impossible to construct or build a number of large condensers, even out of exactly the same material, so that the rates of absorption of each will be the same, a supplementary condenser C_2 and an adjustable resistance *R* are often connected, as shown, in parallel with the condenser C_1. The resistance *R* is usually non-inductive, but there may also be included an inductive resistance so arranged that, by sliding a V-shaped iron bar in and out of the coil, its inductance may be varied. The condenser C_2, which is adjustable by steps of .01 microfarad, has usually a maximum capacity of 5 microfarads. The resistance *R* usually contains from 1,000 to 100,000 ohms. *S* is an adjustable rheostat of low resistance, containing about forty ¼-ohm coils and sometimes one or two 10-ohm coils. The receiving instrument at *W* is usually a siphon recorder. The arrangement of the artificial cable, condensers, and resistances shown in this figure is known as the **Muirhead double-block system.** Mr. Muirhead gave the following values as those required for balancing one of the Mackey-Bennett cables: *C* and C_1 120 microfarads, C_2 .15 microfarad, and R_2 100,000 ohms.

110. Muirhead Artificial Cable.—The artificial cable shown in Fig. 39 is known as **Muirhead's artificial cable.** It consists of a very large number of sections, only four of which are shown in this figure. Each section consists of a thin sheet of insulating material, such as paraffined paper, on one side of which is placed a plain rectangular sheet of tin-foil, and on the other side a piece of tin-foil *a* of about the same outside dimensions, but cut as shown, so as to form a long zigzag conductor. These are piled up, but are separated from one another by more sheets of paraffined paper. The rectangular tin-foil sheets in one pile are connected together, and the zigzag sheets are connected in series, so as to form one long conductor. By means of the terminals on the outside of the box to which the two ends of

the zigzag conducting strips in each pile are connected, the zigzag strips in each pile as a whole may be joined to any other pile in any manner required. The strips are generally joined directly in series, but sometimes a resistance, as shown at R_7, is included. Enough of these zigzag strips of tin-foil are used to give a resistance equal to that of the real cable. The tin-foil being extremely thin and cut into quite narrow strips ($\frac{2}{5}$ to $\frac{3}{5}$ inch in width), has quite an appreciable resistance, and it is evident that sufficient resistance can be obtained by using enough sections. The sheets of tin-foil and insulating material can be pressed and packed very closely together; nevertheless, so many are required that the boxes containing them often measure several feet in each direction.

111. Terminals are also brought to the outside of the box from the rectangular sheets of tin-foil that are on the opposite sides of the insulation to the zigzag sheets. Some of these are joined together and to the ground, and some are connected through resistances, as at R_2, R_3, R_4, to the ground. R_1 is a resistance representing that of the land line from the cable station to the cable itself, and it does not usually amount to very much. At the end of the cable, the zigzag sheets are connected through the resistance R_5 to the ground G_1. In order to represent the small amount of leakage that there may be in the real cable, a high resistance R_8 may be connected between one of the zigzag sheets and the ground. In some cases, a resistance R_6 is connected between the point e and some point in the artificial cable, as j. This resistance, which is generally 80,000 ohms, or more, represents the leakage paths from the land lines and the first part of the cable. Thus the artificial cable may be made to resemble the real cable by having the same resistance, due to the zigzag sheets joined in series; the same capacity, due to the proximity of the zigzag sheets to the grounded rectangular sheets of tin-foil; and the same amount of leakage, due to the high resistances that are connected between the zigzag sheets of tin-foil and the ground.

It is especially necessary to make the home ends of the real and artificial cable resemble each other very closely; and for this reason the home end of the artificial cable is subdivided into smaller sections than the remaining portion in order to permit a closer adjustment of these resistances and capacities.

112. The resistances in an artificial cable may have about the following values : R_2, 175 ohms; R_3, 1,400 ohms; R_1, 40 ohms; R_5, 175 ohms; R_8 and R_6, 90,000 or more ohms, or is infinite, that is, disconnected. In some cases a resistance of about 500 ohms is placed in each arm between the condenser C and the point f, and between C_1 and e.

On one of the cables of the United States Cable Company, the following are the capacities and resistances used at one time at Nova Scotia: C, 41 microfarads; C_1, 40 microfarads; C_2, 41 microfarads; C_3, .28 microfarad; R_1, 29 ohms; R_5, 860 ohms; R_6, 90,000 ohms; R, R_2, R_3, R_4, and R_7, 0 ohms; R_8, infinite, that is, disconnected.

The condensers C and C_1 are 50 microfarads each, and C_2, 30 microfarads in the duplex arrangement used in connection with the Coney Island cable of the Commercial Cable Company between New York and Nova Scotia. This cable has a total resistance of 13,700 ohms, a capacity of 231.4 microfarads at 75° F., and a length of 880.6 knots. The condensers C and C_1 upon the same company's No. 3 Atlantic cable between Nova Scotia and Waterville, Ireland, are each 80 microfarads capacity. This cable has a total resistance of 4,895 ohms, a capacity of 914 microfarads at 75° F., and a length of 2,164 knots.

113. Balancing Cable.—In effecting a balance of such a system as shown in Fig. 39, the artificial cable is first of all made equal in resistance, capacity, and leakage to the real cable; the condensers C, C_1, and C_2 are then inserted and their capacities and the resistance of S adjusted to give a close balance. Then a slight increase is made in the capacity of C_3—say by 1 microfarad—and by trials the right amount of resistance required in the various rheostats

is ascertained. If the artificial cables discharge too rapidly, more resistance must be inserted between the ground and the condenser plates. A sharp signal would indicate that the near end of the artificial cable was not properly adjusted; a faint signal, that the far end was not properly adjusted. When the home receiving instrument is not affected by the operation of the home key, the adjustment is correct. The artificial cable seldom needs adjustment more than twice a year and the bridge arrangement by means of the resistance *S* and condenser C_1, seldom oftener than once a day.

DUPLEX FOR A MIXED OVERHEAD AND CABLE LINE.

114. The arrangement shown in Fig. 40 is that used in some countries for automatic duplex systems over a circuit consisting of both land lines and underground, or short submarine, cables. *PC* represents a transmitting key or device,

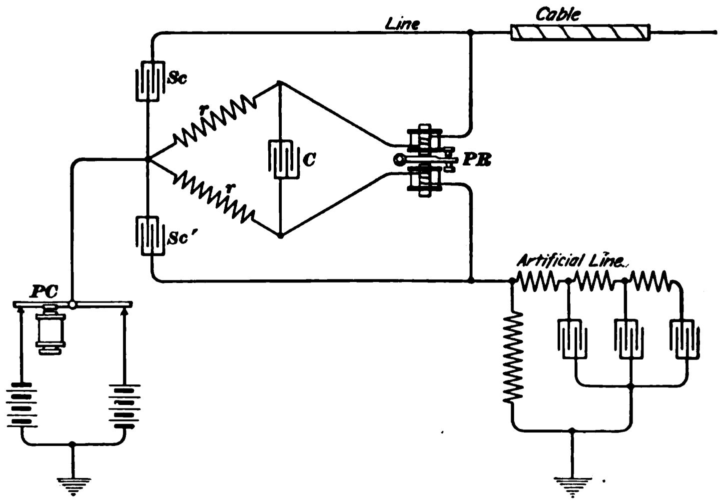


FIG. 40.

often the Wheatstone automatic transmitter; *PR* a differentially wound receiving device, often the polar relay of

the Wheatstone automatic recorder; *Sc* and *Sc'* so-called "signaling condensers"; and *C* another condenser connected across the polar relay and the ends of the adjustable resistances *r*, *r*. This is really a differential polar duplex. When the transmitter opens the circuit, the discharge from the condenser *C* tends to neutralize the extra current due to the inductance of the relay coils. The condensers *Sc* and *Sc'* shunt the discharging current from the cable and artificial line past the coils of the relay *PR*. Preece and Sivewright state that these signaling condensers have a disadvantageous effect upon the received signals, but that this may be compensated by using a condenser of larger capacity at *C*. They further state that the attainable speed on two circuits was doubled by adding the signaling condenser compensation illustrated in this figure. The speed on one circuit was increased from an average of 60 to 120 words per minute by using the connections shown in this figure with the Wheatstone automatic transmitters and receivers.

HIGH-SPEED TELEGRAPHY.

115. In telegraphy, as in nearly all other industries, there are two ways of working—by hand and by machine. Naturally the hand method comes first. Even now, probably 90 per cent. of the telegraph business of the world is done by hand. In America and England, it is done by hand and sound; in all other countries, by hand and sight, although Belgium is just beginning to use the sounder. France, Germany, Italy, Austria, Spain, Russia, and, in fact, the rest of the world, use the Morse key and a receiving instrument that records the dots and dashes in ink upon a paper tape. There are, however, a number of through circuits operated by the Hughes system. Transmission is by keyboard, and the message is received printed on a tape, similar to the type-printing system of Phelps, which is used to a small extent in this country.

England may be said to be the only country using machinery to any considerable extent for the operation of its telegraphs, having adopted the Wheatstone automatic telegraph system, which is an English invention.

WHEATSTONE AUTOMATIC SYSTEM.

116. The **Wheatstone automatic telegraphic system** is capable of transmitting and recording in ink signals at a rate of 500 or 600 words per minute, the speed below 600 depending on the electrical properties of the line. Over 225 words per minute can be transmitted between New York and Philadelphia, 190 words between New York and Chicago, and 110 words between Chicago and San Francisco. Between Calcutta and Bombay, which are 1,300 miles apart, 130 words per minute are transmitted without the use of repeaters. Where the line is long, repeaters are used. Between North Sidney and New York, over land lines, the Wheatstone is worked duplex, having a speed of about 100 words per minute. The Wheatstone system is extensively used in Great Britain, where it has given better results than in the United States, since in the latter country it is used on comparatively few circuits.

This system consists of a perforator that punches holes in a paper tape to represent dots and dashes; a transmitter, through which the paper tape is fed and by means of which electrical impulses are sent into the lines; and a receiver that records in ink the electrical impulses as dots and dashes upon a paper tape that is drawn through the receiver.

PERFORATOR.

117. The **perforator,** or punching apparatus, is shown in Fig. 41. It has three keys and five punches so arranged that pressing key *A* makes perforations in the paper tape *D* corresponding to a dot, pressing down *C*

makes perforations corresponding to a dash, and pressing down *B* makes one perforation corresponding to a space and is also necessary for advancing the paper tape. The paper tape passes behind a punching plate *G* containing 5 holes into which the ends of the punches enter in the act of punching corresponding holes in the paper tape. When the key *A* is depressed, three holes corresponding to *m*, *n*, and *o* are simultaneously punched in the paper, as shown at A_1; when the key is released, the wheel *F* revolves and teeth on its surface engage the center line of holes made in the paper and so advance the paper a distance equal to the proper distance between two center holes. When the key *B*

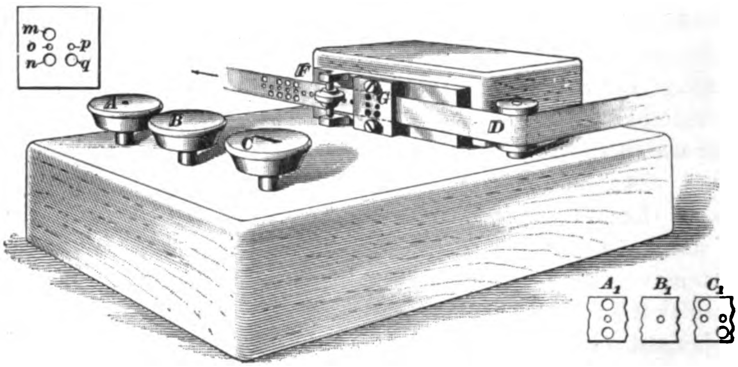


FIG. 41.

is depressed, one center hole is made by the punch at *o* in the paper, as shown at B_1; and the releasing of the key again advances the paper the same distance as before. When the key *C* is depressed, four holes corresponding to *m*, *o*, *p*, and *q* are simultaneously punched in the paper, as shown at C_1, and the releasing of the key advances the paper double the distance that is accomplished by the release of either of the other keys *A* or *B*. The double advance in this case is evidently necessary; for, otherwise, if *A* or *B* were depressed after *C*, some of the punches would enter holes already made in the paper by the depression of *C*.

The perforations A_1 made by the left-hand key *A*, when passing through the transmitter, cause a dot; the perforation B_1 made by the center key *B* causes a space, and the perforations C_1 made by the right-hand key *C* cause a dash to be printed on the tape at the receiver.

118. The student will understand this better when the transmitter and receiver have been described. The operator manipulates these three keys *A*, *B*, and *C* by pounding, or striking, them with rubber-tipped pieces of wood, one held in each hand. As this is laborious, they are sometimes arranged so that a key, which is very easily depressed, will operate the punches by pneumatic pressure. The pneumatic pressure is sufficient to punch from 4 to 8 tapes simultaneously at the rate of 40 words per minute. Although about 45 words per minute can be punched by pounding or pneumatic pressure by an expert operator, 40 words is considered a very good average speed.

NOTE.—Mr. J. Willmot (see "Electricity," March 28, 1900) has recently made some improvements in the steel punches used in the Wheatstone perforator, and has also improved the Wheatstone transmitter.

TRANSMITTER.

119. The object of the transmitter is to transmit the dot-and-dash alphabet by means of positive and negative currents. These currents are transmitted alternately in opposite directions; the arrangement of the transmitter and receiver is such that the current, whether positive or negative, continues to flow and produce a mark whose length varies according to the time that elapses before the current is reversed—such reversal producing an interval or space, whose length continues to increase until the current is again reversed in direction. Since alternate currents flowing in opposite directions produce the to-and-fro motions of the ink wheel in the receiver, lines of various lengths, that is, dots or dashes, may be printed. Hence it is necessary to send a current in the opposite direction through the line

and receiver before a mark or a space that has once been started can be terminated. The contact device in the transmitter exists in several slightly different forms, the result of improvements made from time to time. In this Course the latest arrangements will be shown.

120. Inside of a case is placed suitable clockwork and gearing for operating the transmitting mechanism, which is supported on the side of the case. This transmitting mechanism is shown in Fig. 42. The wheel *l*, which is driven by the clockwork, has teeth upon its surface suitably

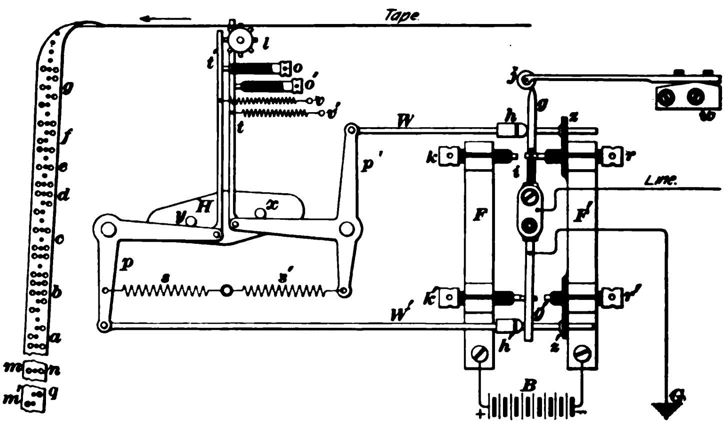


FIG. 42.

spaced to enter the holes along the center line of the previously punched transmitting tape and to draw it along at a steady desirable rate. This rate can be varied by an ingenious speed regulator to suit the conditions of the line circuit. The greater the *K R* of the line, the slower must be the speed of transmission.

The rocking beam *H*, as its name implies, has a rocking motion given to it by a shaft to which it is rigidly fastened at the center. This shaft is operated by the same clockwork that rotates the wheel *l*, and, hence, its rate of oscillation corresponds with the rate of rotation of the wheel *l* whether the transmitter is running fast or slowly. On the rocking beam

are two pins *x* and *y* against which the levers *p* and *p'* are pressed by the springs *s* and *s'*. Hence the rods *t* and *t'* move up and down as the two pins *x* and *y* on the beam *H* move up and down. Now *t* and *t'* are so adjusted by the screws *o* and *o'*, against which they are held by the springs *v* and *v'*, that the horizontal distance between them is exactly equal to the distance between the centers of the two holes *o* and *p* in Fig. 41. Moreover the distance between the two rods at right angles to the plane of the figure is exactly equal to the distance between the centers of the holes *m* and *n* in Fig. 41. Hence the rod *t* is directly below whatever holes may have been punched on one side of the center line of holes and the rod *t'* is directly below whatever holes may have been punched on the other side of the center line of holes. The springs *s* and *s'* always tend to force the rods *t* and *t'* upwards and to push the rods *W* and *W'* to the right.

121. The apparatus at the right constitutes a pole changer. The lever *gg'* is pivoted at the center and has attached to, but entirely insulated from, it a contact piece *i*, to which the line wire is connected. The metal piece *F*, to which is attached the positive pole of the battery *B*, has two contact screws *k* and *k'*; and the metal piece *F'*, to which is attached the negative pole of the same battery, has the two contact screws *r* and *r'*. The insulated piece *i* moves between the two contact screws *k* and *r*, and the lower end of the lever *gg'* moves between the two contact screws *k'* and *r'*. *W* and *W'* are two rods having fastened to them the collars *h* and *h'*, respectively, which are called *collets*. The rods pass freely through the lever *gg'* without touching it, and have bearings in the pieces *z* and *z'*, which are insulated from the metal piece *F'*. The rod *W* pushes the lever to the position shown in the figure, and *W'* pushes it over so that *i* rests against the screw *k* and *g'* against the screw *r'*. Neither rod, when moving to the left, can move the lever. The wheel *j*, termed the *jockey wheel*, is fastened on the end of a flat spring that is adjustable at *w*. It is used to help move the lever *gg'* sharply to one side or

the other, to prevent the lever from remaining in an intermediate position, and to hold it against whichever side it may have been pushed by the rods *W* and *W'*.

122. When the pin *x* moves upwards, the rod *t* will move upwards; and if there is a hole directly above it, the rod *t* will enter the hole and continue to move upwards as far as the pin *x* will allow it. On the other hand, if there is no hole directly above it, the upper end will come against the paper tape, and although the pin *x* continues to move upwards to the end of its stroke, the rod *t* can go no farther. Similarly the rod *t'* will move upwards as far as the pin *y* will allow, provided there is a hole in the tape directly above it; otherwise it is arrested in its upward movement by the tape. If the tape contained a series of holes, like those at A_1 in Fig. 41, representing a series of dots, there would be a hole directly above both *t* and *t'* every time these rods came up and this would transmit, as we shall see, a succession of negative, or marking, currents the proper length for dots, and a succession of positive currents, producing the break or space between the dots. The motion of the wheel *l* and the rocking beam *H* is such that the tape is advanced exactly the distance between two center holes while the rod *t* or *t'* moves once down and up. Hence these rods will pass through every hole that is punched on either side of the center line of holes.

123. For instance, assume that the rod *t* projects through the hole *m*. When the rod *t* is drawn down by the downward movement of the pin *x*, the paper will be moved forwards the proper distance to allow the rod *t'*, as it moves up, to enter the hole *n*. At the start, when the rod *t* moved up through the hole *m* in the tape, the rod *W* would push the collet *h*, and with it the lever *g*, over to the right so far that the jockey wheel *j* would slip down and press on the left side of the lever *g* and so hold *i* against the contact *r* and *g'* against the contact *k'*, causing the negative pole of the battery *B* to be connected to the line and the positive pole to the ground *G*. This state will continue, in

spite of the fact that *W* moves to the left, until the rod *t'* can enter a hole in the tape. Then the rod *W'* will push *g'* over until the jockey wheel *j* slips down on the right of *g*, and so holds *g'* against *r'* and *i* against *k*. This will reverse the battery *B*, connecting the positive pole to the line and the negative pole to the ground.

Suppose the rod *t* is in the hole *m'* and the negative pole of the battery connected to the line. As the rod *t* moves down and the pin *y* moves up, the paper will advance, but *t'* can move up but little, if at all, because it comes up against the paper opposite the hole *m'* where there is no hole. Consequently the lever *g g'* is not disturbed and the negative pole of the battery *B* remains connected to the line. When *y* moves down and *x* moves up, the rod *t* comes against the paper opposite the hole *q*, where there is no hole, and again the lever *g g'* is not disturbed. When *y* moves up again, however, the hole *q* will be in line with *t'*; hence the rod *W'* will push *g'* to the right and, by aid of the jockey wheel *j*, will reverse the battery, causing the positive pole to be now joined to the line. The time between reversals, in this case, when a dash is made, is three times (two dots and one space) as long as it was when a dot was made. A space is evidently started by a hole on the lower or right-hand side of the tape, and the space will continue until a hole on the upper or left-hand side of the tape comes opposite the rod *t*, thereby pushing *W* and *g* to the right and so starting a dot or a dash. Thus dots and dashes are transmitted by currents in one direction and spaces by currents in the opposite direction; a reversal of current is necessary in any case to terminate a signal, be it a dot, dash, or space.

124. Improvements Made by Willmot.—An improvement of the transmitter just described has been made recently by Mr. J. Willmot, of England. He has substituted a permanent magnet and a soft-iron tongue in place of the jockey wheel, and has made quite a number of improvements in the details of construction that reduce the

wear and tear to which high-speed apparatus is especially subject. The arrangement of the improved transmitter is shown in Fig. 43. The lever *g*, which is made of soft iron, vibrates between the poles *N* and *S* of a permanent magnet. The soft-iron piece *g* will, of course, be attracted by both the north and south pole of the permanent magnet and it will move rapidly toward and remain firmly against

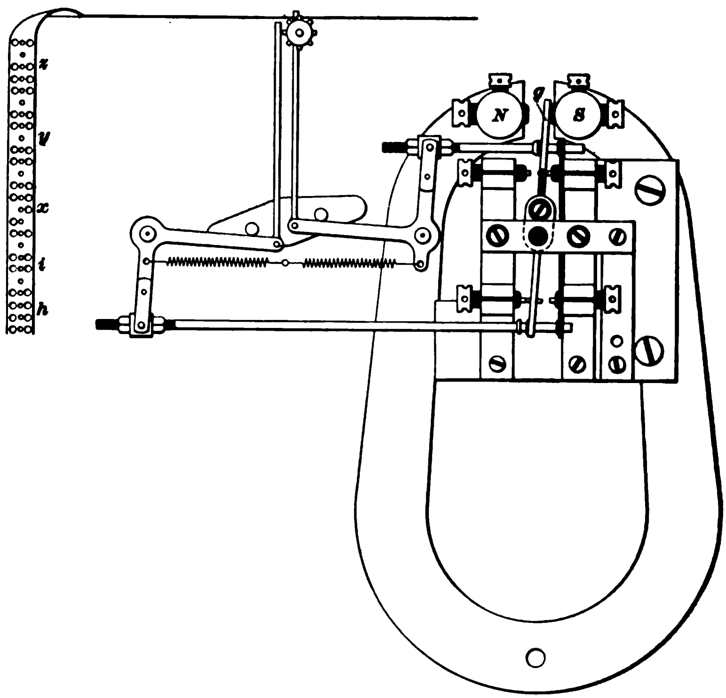


FIG. 43.

whichever pole it happens to be nearest. The use of magnetic attraction in place of the jockey wheel entirely removes the downward pressure of the jockey spring, and greatly increases the holding-over force operating upon the lever, thereby causing a better contact between the contact points. The force necessary to drive the instrument when fitted with the magnetic arrangement is considerably less

than with the jockey roller, due to the fact that the downward pressure on the pivots is entirely removed. Furthermore, the laws of magnetism hold, and no sooner does the lever commence to move from the pole of the permanent magnet to which it is nearest than the attractive force of that pole from which it is receding diminishes inversely as the square of the distance, while the attractive force of the pole that it is approaching increases inversely as the square of the distance—a condition most favorable to the object in view.

RECEIVER.

125. The **Wheatstone receiver,** or **ink recorder,** as it is also called, consists of clockwork operated by a weight and a very sensitive polarized relay. It is shown in Fig. 44. Inside the case is placed the polarized relay and also the clockwork that revolves the wheel *c*, the ink disk *i*, and the ink-supply wheel *b*. The paper tape on which the ink records are made by the ink disk *i* is drawn by the roller *c* from the base of the instrument, where it is coiled away. The speed of the clockwork, and hence the speed of the tape, can be regulated by means of the handle *f* to suit recording at any speed from about 25 to 600 words per minute. The ink wheel *b*, which dips into a covered ink well *g*, has a V-shaped groove around its periphery. This is shown better in Fig. 45. The edge of the revolving ink disk *i* enters this hollow in the periphery of the wheel *b*, but it never actually touches the wheel. Thus there is no friction between the revolving disk and wheel. During the revolution of the ink wheel *b*, capillary attraction keeps the hollow full of ink, and a constant and uniform quantity is supplied to the ink disk *i*. The clockwork is started and stopped by means of the handle *a* and wound up by the handle *Q* in Fig. 44.

126. The **Wheatstone polarized relay** that moves the ink disk *i* against the paper tape as it is drawn along is shown in Fig. 45. The relay consists of a permanent

magnet *P* across whose ends is a vertical shaft *h* to which is rigidly fastened the soft-iron armatures *n* and *s* and the arms *j* and *k*. The soft-iron armatures are permanently polarized by the permanent magnet *P*.

Two vertical electromagnets *m* and *m'* have polar extensions opposite each other and between which the soft-iron armatures *s* and *n* can move. These two soft-iron armatures

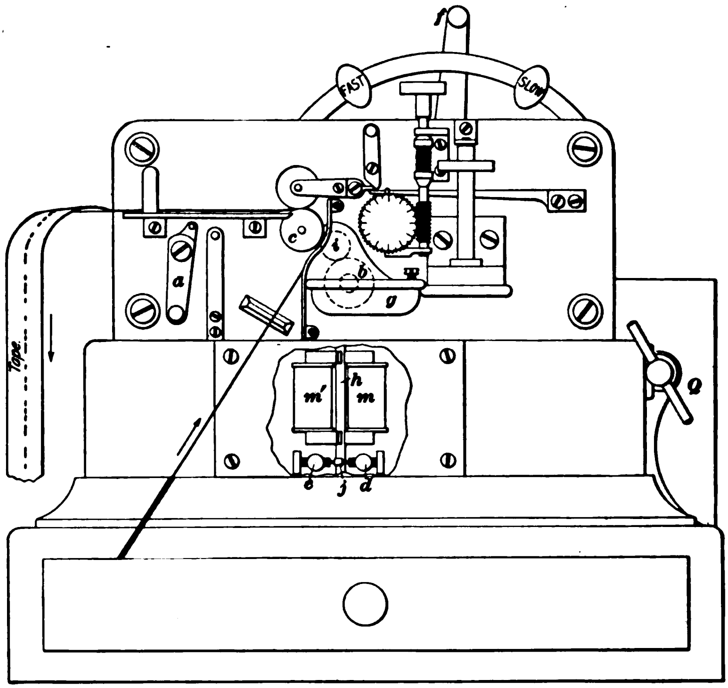


FIG. 44.

are rigidly fastened to the shaft *h*; but their motion, which is exceedingly small (about one-fourth degree), is limited and adjusted by the stop-screws *d* and *e*. When the magnets are energized by a current, the polar extensions opposite each other are oppositely magnetized; hence each armature *s* and *n* is repelled by one and attracted by the opposite polar extension, and the polarities of the four polar extensions are always such that they all tend to move both armatures

toward the same side. When the current is reversed, the polarities of the four polar extensions are reversed and both armatures move toward the other side.

The shaft *l*, which is pivoted at the end *o* and caused to revolve by the wheel *o*, rests lightly in a cavity at *r* in the arm *k*. When the armatures move away from the reader, the arm *k* moves the ink disk *i* toward the moving tape, on which it makes a dot or dash, depending on the length of time that the marking current lasts. When the current is reversed, the armatures move toward, the reader and the ink disk away

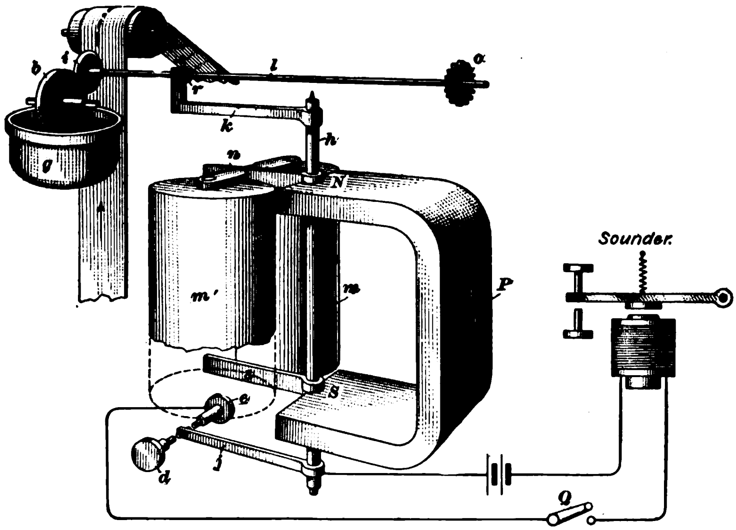


FIG. 45.

from the tape, making a space that lasts until the current is again reversed. Hence a series of instantaneous, alternately positive and negative currents passing through the electromagnet will cause a to-and-fro motion of the marking disk *i*, a current in one direction pressing the marking disk against the paper, where it will remain until withdrawn by a current in the opposite direction.

127. The motion of the armature is limited by the screws *d* and *e*, which are shown in both figures; one may be

used as a contact screw at which is opened and closed the circuit of a local sounder that is used to attract the attention of the operator, and also for reading messages when the line is being operated manually by a key.

In the base of the transmitter is placed a triple switch, by means of which the automatic transmitting apparatus may be cut out and the battery connected to a hand transmitting key. This switch is worked by the lever used for starting and stopping the clockwork. By this arrangement, messages may be transmitted by hand. On the transmitting key there are also switches enabling the operator to cut the key and batteries out of the circuit when he is receiving messages by means of a local sounder controlled by the polarized relay of the automatic receiver.

128. Resistance and Inductance of Wheatstone Relay.—The relay used in the Wheatstone receiver is generally wound differentially, so that the system may be worked duplex. To give the two coils exactly opposite magnetic effects for duplex working, the two wires are wound together as one upon the spool; the resistance of each coil is made equal to 100 ohms in the British service. The inductance of a 200-ohm Wheatstone receiver, with the two coils of the relay connected in series, is about 3.46 henrys; with the two coils in parallel, about .875 henry. When the two coils are differentially connected and the current flows in the proper direction to create an equal but opposing magnetization, the inductance is about .187 henry.

129. Non-Inductive Resistances and Condensers in Wheatstone System.—In practice it is found that when the Wheatstone receiver is connected directly in the line and is operated by the Wheatstone transmitter, the speed obtainable over most lines can be increased by the use of condensers properly arranged. The arrangement of condensers and resistances in actual use in England is indicated in Fig. 46. Common values of the resistance and capacity are about 8,000 ohms and 10 to 20 microfarads,

increased the speed from 100 or 200 to 600 words per minute. The Wheatstone system has been in commercial operation in England for so long a period that the speed expected on any given line is accurately known, and may be represented closely by an equation of the form

$$W = \frac{a}{KR}, \qquad (1.)$$

where K denotes the total distributed capacity of the line, R the total resistance, W the number of words per minute, and a a constant. The constant a depends on the kind of line used, and differs for iron and copper wire and for cables. The values of the constant a determined by a series of experiments extending over a long period are as follows:

10×10^6 for aerial line of iron wire.
12×10^6 for aerial line of copper wire.
15×10^6 for submarine cable with condenser at one end.
18×10^6 for submarine cable with condensers at both ends.

A copper aerial line having a KR equal to about 30,000 will reduce the Wheatstone speed to about 400 words per minute; when a line exceeds this it is customary to insert an automatic repeater, by which the speed is maintained over longer distances. Speeds of 400 words per minute are regularly maintained in England in commercial working, while the limit of the commercial working in the United States is considerably lower, about 200 words per minute.

WHEATSTONE DUPLEX.

132. The arrangement of the Wheatstone apparatus when worked as a polar duplex with dynamos as a source of current is about as shown in Fig. 47. The polar relay is wound differentially and the line and artificial-line circuits run through separate coils of the differential galvanometer $D\,G$. The two coils of this galvanometer have the same resistance and the same number of turns and are wound in such a direction that equal currents through the

changer *PC*; when the switch rests on *b*, the automatic transmitter may be used. The latter instrument is somewhat altered when used with dynamos so that it resembles the ordinary walking-beam pole changer, $g g_1$ representing the beam or armature lever, and *r* and *k* the positive and negative contact stops, respectively. The lever $g g_1$ is joined to the point *b*.

For a high-speed duplex system, the line must be much more carefully balanced than for a manual duplex system. For this reason three retarding coils are required: one *cde* in series with the condenser *C*; a larger resistance *cdfh* in series with the condenser C_1; and a still larger resistance *cdfij* in series with C_2. The condenser *C* must have the largest and C_2 the smallest capacity; the rheostat consists of the coils in the circuit *c–m–n–o–p*.

134. Balancing.—The system is **balanced** by asking the distant operator to run his transmitter while the home artificial line is adjusted in the usual manner. If balanced properly, the galvanometer should give no deflection when the switch *Q* is placed on *a* and the key *Pk* is operated.

To further eliminate the disturbing effects of the static line charges, the home transmitter should be run and the condensers and the retarding coils adjusted until the incoming signals made by the receiver are clear and distinct.

WHEATSTONE REPEATER.

135. Repeaters known in Great Britain as "fast-speed" repeaters are used in connection with the Wheatstone apparatus when the latter must be worked over long circuits. The value of the repeaters for speed purposes may be illustrated by the fact that direct working between London and Aberdeen (560 miles) would not be possible at a higher speed than 40 words per minute, whereas with repeaters at Leeds and Edinburgh, the practical working speed is increased to 350 words. These repeaters in their

present efficient form have been introduced within the last 25 years and are marvelous examples of ingenuity. The present form of this apparatus, for use on cable circuits, comprises 41 instruments of 26 different forms; it is arranged to work bridge duplex on the cable side and differential duplex on the land side of the circuit.

DELANY SYNCHRONOUS MULTIPLEX TELEGRAPH SYSTEM.

136. The system devised by P. B. Delany, of South Orange, New Jersey, is based on two main principles: *first*, that of synchronism, or the simultaneous motion of similar pieces of apparatus at two different places; *second*, that of distributing to several telegraph operators the use of a wire for very short equal periods of time, so that practically each operator has the line to himself during these periods.

137. As Delany's system is so entirely different from the duplex and quadruplex systems, it is proposed for clearer definition to give to the modes of working his system names based on the Greek word *hodos* (a way). Thus a two-way mode of working, or a mode by which two messages are practically sent at the same time, will be *diode* working; three-way, *triode;* four-way, *tetrode;* five-way, *penthode;* and six-way, *hexode*.

Duplex and quadruplex are such well-rooted and explicit terms defining particular modes of working by compensation, that their application to different modes of working based on a different idea may lead to confusion, while new and distinct terms will confine the attention to a new and distinct system.

138. In Fig. 48 (*x*), *A* and *B* are two separate offices connected together by a line wire *L*. If the arms *a* and *b*, which are in electrical connection with the line wire *L* at *A* and *B*, respectively, rotate simultaneously around the circles *1–2–3–4* at each station in the direction of the arrows,

making contact upon the segments as they pass, then, when *a* touches *A–1*, *b* will touch *B–1*; when *a* touches *A–2*, *b* will touch *B–2*; and similarly for *3* and *4*. If *1*, *2*, *3*, and *4* at each office are each in connection with a set of similar telegraphic apparatus, the four sets at one office will be in

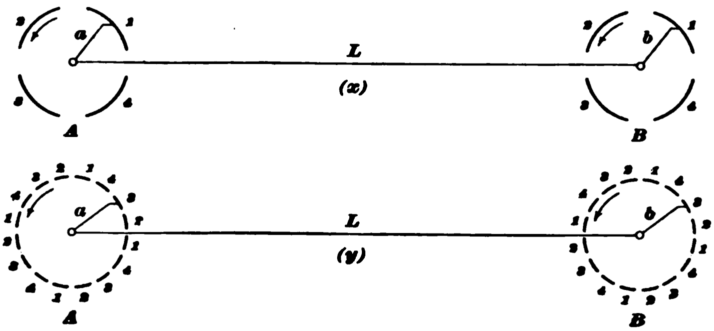


FIG. 48.

direct communication with the four sets at the other office as the arms *a* and *b* touch their corresponding segments. Thus, for each rotation of the arms, the instruments connected to *A–1* and *B–1* will be in direct communication with each other once; and so on with those connected to *A–2* and *B–2*, etc.

139. If each segment be divided into four segments as shown in Fig. 48 (*y*), and every fourth one of these smaller segments is connected with one of the four instruments instead of one large segment being connected with only one of them, as in (*x*), then, during one complete rotation, each arm will place corresponding instruments, one at each end, in communication with one another 4 times. Or, if each circle be divided into 40 segments and each of these 40 into four segments, then corresponding instruments will be in communication with each other 40 times during each complete rotation of the arms *a* and *b*. In Delany's apparatus there are 84 segments in the whole circle, and these are grouped according to the number of ways of working. Hexode working requires one grouping, triode another, diode another, and so on.

140. To Maintain Synchronism. — Two tuning forks pitched to absolutely the same note and set in vibration by currents like an electric trembling bell, will move in synchronism, but the synchronism cannot be maintained. The deposition of dirt, dust, or moisture, changes of temperature, and variation of current produce changes that affect the rate of motion.

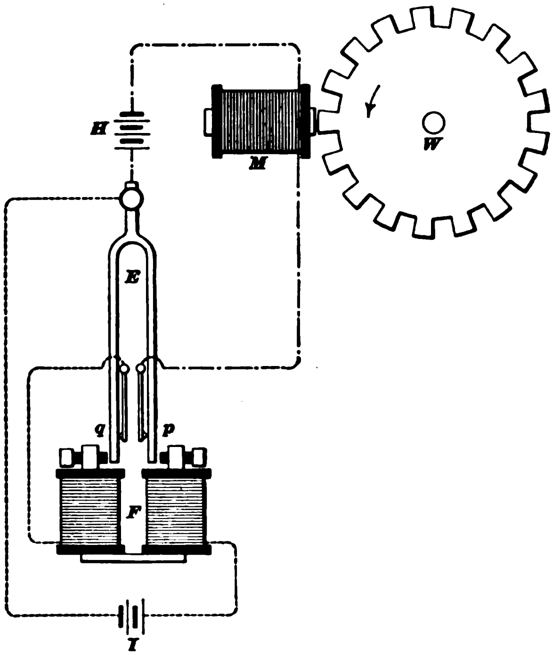


FIG. 49.

Paul la Cour, of Copenhagen, invented an ingenious way to maintain synchronism. In Fig. 49, *E* is a tuning fork vibrating between the poles of the magnet *F*. There are two contact points *p*, *q*. At *p* is completed a circuit containing the battery *H* and an electromagnet *M*. The other contact *q* completes the circuit containing the battery *I* and the electromagnet *F*. Every time the tuning fork touches the contact point *p* a current is sent through the electromagnet *M* which, therefore, is magnetized once for every movement to

and fro of the fork. In front of the magnet M is a wheel W having iron teeth, and every time the magnet M is excited.

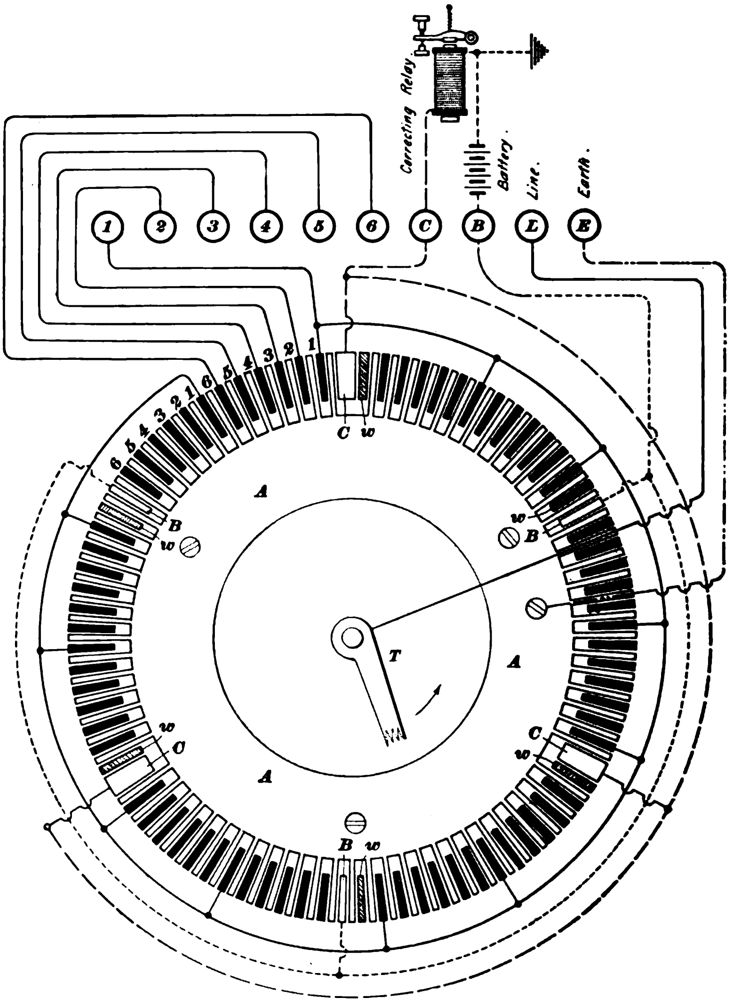


FIG. 50.

attraction is momentarily exerted on the nearest tooth. If the tooth is approaching the pole, it is urged forwards, and if it is moving away from the pole, it is retarded; hence, the wheel

can be propelled with wonderful uniformity and with considerable force. The electromagnet *F* is similarly excited, and it keeps the fork in constant vibration. The wheels must be started by giving them a turn by hand, as they will not start otherwise. Delany uses this *phonic wheel*, as it is called, in connection with a *distributor*, but he has adopted a reed instead of a tuning fork.

141. The **distributor,** as arranged for hexode working, is shown in Fig. 50. The circle is divided into 6 groups, each group having 12 platinum-faced brass segments insulated from one another, and being separated from the next group by what are called the two *correcting segments*, one (shaded and marked *w*) called a "dead" segment, and the other (clear and marked *B* or *C*) called a "live" segment. The dead segments *w* are entirely insulated, the live segments *B* are connected through the binding post *B* to the battery, and the live segments *C* to the correcting relay. All the segments are not only insulated but are also separated from one another by the spokes of the brass ring *A*, which is connected with the earth. Each group of 12 segments is further subdivided into 2 subgroups of 6 segments each, in which the corresponding segments are connected, so that *1* and *1*, *2* and *2*, *3* and *3*, and so on are electrically joined together. Not only so, but they are connected to every corresponding number in the other groups around the circle. In Fig. 50, the segments in only 2 of the subgroups are numbered, but the remaining 10 subgroups must be understood as being numbered in the same way. The 12 segments numbered *1* are electrically connected through the binding post *1* to the telegraph instrument numbered *1*; the 12 segments numbered *2* are connected through the binding post *2* to the instrument numbered *2*; and so on. The first, third, and fifth live segments, that is, the *C* segments, are connected together and to a so-called correcting relay; they are intended to receive currents from the distant station. The second, fourth, and sixth live segments, that is, the *B* segments, are also connected together and to a battery, and so

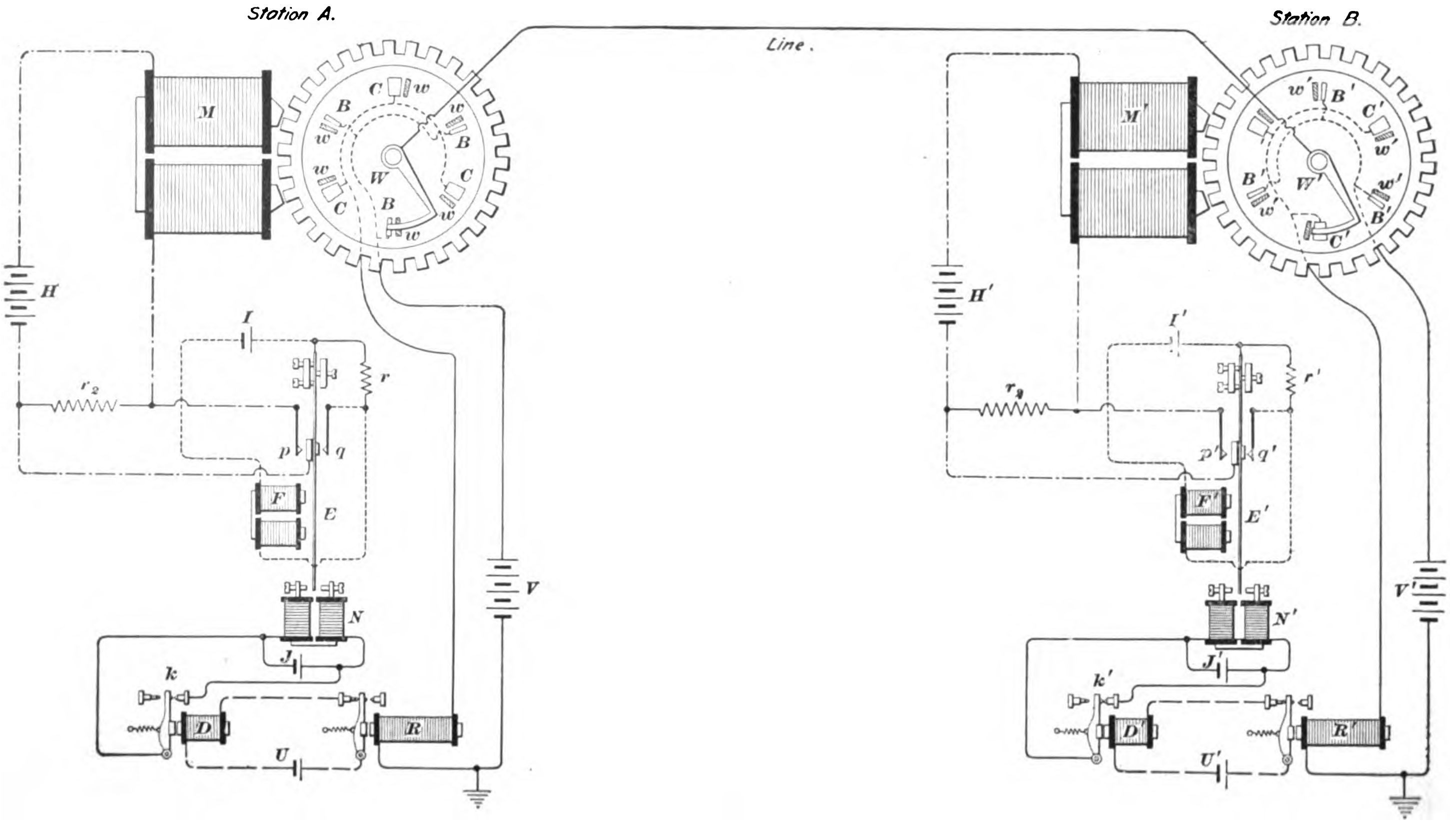


FIG. 51.

can send currents to the distant station. The "dead" segments are so arranged that one is fixed before each receiving "live" segment *C*, and one after each sending "live" segment *B*.

142. Correcting Segments on Lines Having Large Capacity.—The correcting segments are connected in the manner just described for lines whose electrostatic capacity is small, and where the retarding effect on the current is, consequently, slight; but when the capacity is considerable, the segments that are called "dead" are brought into use. A correcting battery is then connected to the "dead" segments immediately in front of the broad "live" *C* segments, and a receiving correcting relay is connected to the "dead" segments immediately following the narrower "live" *B* segments. This arrangement gives a space of one segment to allow for retardation of the current when the capacity of the line exceeds 3 microfarads. When, however, the capacity is within that amount, this space is not required; indeed, it would be disadvantageous, because there is then a very slight loss of time in the transmission of the signal. The receiving correcting segment is, therefore, extended in such a manner as to meet the trailer, and so receive the correction almost as soon as it is sent. It is not really necessary that the segment should be made broad, but only that it should be moved in the direction indicated—it is only made broad to fill up the space.

143. The arm or trailer *T* presses lightly upon the surface, and moves continuously around the circle, coming successively in contact with every segment. It moves in the opposite direction to that of the hands of a watch, and is electrically connected to the line wire *L*. In every rotation it makes 84 electrical contacts, 72 of which are for telegraphing, while the others are for maintaining synchronism.

The function of the trailer is to place the line wire successively in connection with the segments in the different groups. The currents of electricity that flow through the

line wire are dependent on the operations performed on the telegraphic apparatus, and are broken up into short rapid pulsations or impulses by the momentary contacts made by the trailer. The uniform rotation of the trailer is produced by La Cour's wheel, shown in Fig. 49.

144. Fig. 51 shows the La Cour wheel in connection with Delany's actuating, correcting, and synchronizing devices. The iron-toothed wheel *W* is placed before the poles of the electromagnet *M*, which is magnetized periodically and regularly by currents from the battery *H* sent at each vibration of the reed *E* against *p*. It propels with great uniformity the toothed wheel, to whose axle the trailer is attached. Momentum carries the wheel until the next tooth approaches, when the next impulse is given. As the impulses are due to the vibration of the reed, the motion of the wheel follows these vibrations, which are maintained by the electromagnet *F*, which is excited by the battery *I* every time contact is made at *q*.

145. Non-inductive resistances r and r_1 are placed as shunts around each of the contacts *q* and *p* to prevent sparking. A resistance of 100 ohms in series with a condenser of ½ microfarad capacity may also be used as a shunt around the magnet *M*, instead of the resistance r_1 as shown in this figure. Furthermore, it is sometimes advantageous to connect a condenser in a shunt circuit around the relay *R*.

146. The end of the iron reed *E* vibrates between the extended pole pieces of the electromagnet *N* and, consequently, vibrates in a magnetic field. This magnet is excited by the battery *J* whenever contact is broken at *k*, and this contact at *k* is broken whenever the current from battery *U* ceases to flow in *D*. The interruption of the current from *U* through *D* depends on the action of the relay *R*, which is excited by currents sent from the distant station coming through the live correcting segments *B'* of the "distributor" there, and received through the live

correcting segments *C* at the home station. When the armature of the relay *R* is attracted, it breaks the local current flowing through *D* and opens a short circuit around the battery *J* at *k*. When the magnet *N* is excited by the opening of the short circuit at *k*, the magnetic field in which the iron reed vibrates tends to retard the rate of vibration by attraction, so that if the reed vibrates too frequently its rate is checked. The normal rate of vibration may be adjusted by a sliding weight, or in various other ways not shown in the figure.

147. The manner in which each set of apparatus is connected is shown by Fig. 52. The segments of the "distributor" at each station are indicated, and the trailers are shown in contact with corresponding segments that direct the current to the No. 1 telegraph set. The relay *R*, by its form, is rendered sluggish, so that the sharp rapid currents collected by the trailer are practically made continuous in their action on the armature of the relay. The currents flowing through the line wire are short, sharp, rapid impulses, or waves, of electricity, and to convert these waves into telegraphic symbols, such as Morse characters, some such method is needed to render them practically continuous for the duration of a dot or a dash.

148. The **relay** has a condenser *C* connected around it and a permanent horseshoe magnet *O* fixed below the coils. The cores are thus polarized more or less. The result is that the self-induction of the coils, assisted by the charge and discharge of the condenser, retards the demagnetization of the core, so that the effect of the rapid succession of short currents is made continuous upon the armature of the relay, and the marks are made as though they were produced by continuous currents. Dots and dashes are thus recorded without breaks. The relay *R* operates a repeating sounder or relay *R S*, which, in turn, operates the sounder *S*. This arrangement is introduced because in the ordinary method of completing the local circuit, the contacts are not firm enough.

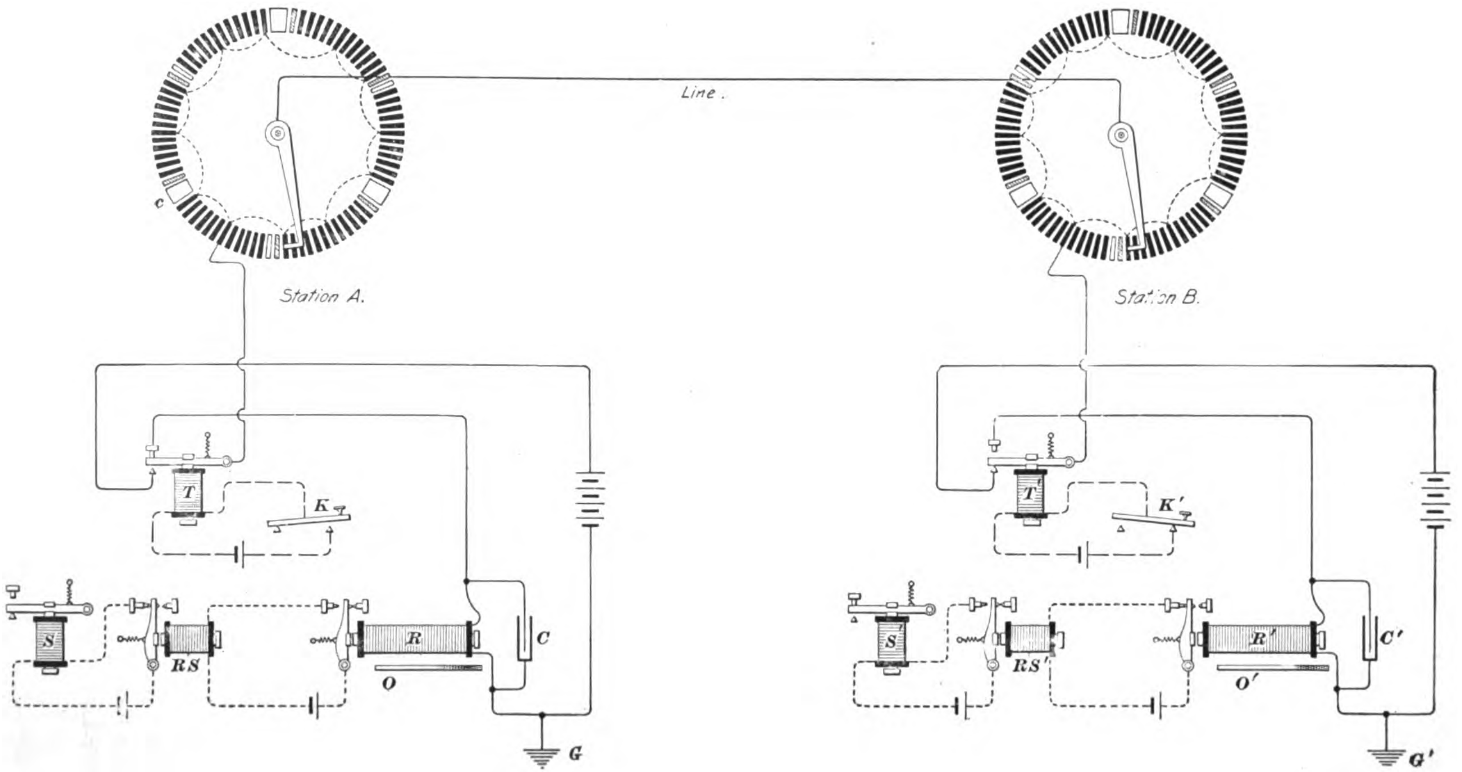


FIG. 52.

149. Line Grounded Between Each Current Impulse.—It has been mentioned that each segment is separated by an earth contact—a spoke of the brass rim. This is done to favor the rapid discharge of the static charge to earth between each electrical impulse or current. The apparatus being ready, six pairs of operators are placed in communication and each pair has virtually a circuit to itself.

150. In Fig. 51 only the correcting "live" and "dead" segments are shown. Of the "live" segments, those in connection with the battery are of the usual dimensions, while those in connection with the correcting relay and the reed apparatus are broad. This is to admit of corrections being made *before* the working segments are effected. Want of synchronism is thus prevented. When the trailer at station *A* is on the narrow live segment *B*, the trailer at station *B* is on or near the broad live segment *C'*. If the wheels are in perfect synchronism, the trailer at station *B* is on the dead segment *W'* when the trailer at station *A* is on the sending live segment *B*, and *vice versa*, hence no current flows. But when the wheel at station *B* is in the least degree in advance of that at station *A*, then the trailer at station *B* is on the receiving live segments *C'*, while the trailer at station *A* is on the sending live segments *B'*. Hence current flows and excites the relay *R'*; the electromagnet *D'* releases its armature, thus opening the shunt around *N'*; hence *N'* is magnetized and the vibration of the reed *E'* is retarded. Perfect synchronism is again obtained and the correcting current ceases to flow. Six correcting currents can be sent at each revolution, three in one direction and three in the other. Thus a deviation of a thousandth of an inch can be speedily rectified.

151. The method of Mr. Delany is perfectly automatic in its action, practical and successful. The "distributor" rotates nearly 3 times in 1 second, hence 252 contacts are made each second in hexode working. The distance to which the system can be worked hexode is limited; for,

owing to the retarding effect of static induction, the number of currents that can be sent per second is limited by the static capacity of the line. Now as the static capacity of the line has the effect of retarding the speed of a signal, it follows that the limit of working is dependent on the magnitude of the static capacity, for if the signaling current be late, it will enter the wrong segments, and confusion of signals will result.

The retarding effect of static capacity can be met by making each group of a greater number of segments, or by making the segments of greater breadth; but this has the effect of reducing the number of ways of working. Either plan will reduce the hexode to tetrode or triode working.

152. Working in One Direction Only.—So far, it should be understood, the system has been described as one for working in either direction (not simultaneously as in duplex, but alternately), as in ordinary simplex working. If, however, it is used for working in one direction only, distance has not the same effect upon it. If the static capacity so reduces the speed of the signaling current that, while it leaves segments *1* at station *A*, it enters segments *2* at station *B*, then it is possible to still work five ways *in one direction*, for every segment at one end will be advanced one segment, or the distance of one segment. For this mode of working two wires are necessary, one for sending and the other for receiving; but it has this advantage, that two wires can be converted into ten circuits. Segment *6* is rendered useless in consequence of the current arriving at station *B* when the trailer is on the correcting segments.

Working hexode in either direction is feasible between London and Brighton, but tetrode is the limit to Bristol and Manchester. In one direction, however, to Bristol and Manchester even six circuits have been operated, so that with two wires 12 circuits might be worked, 6 in each direction. It is more difficult to adjust the system for working in both directions than for one direction only.

153. Advantages of This System.—The Delany system, somewhat modified and improved, is now being successfully used in England. Its great advantage over other systems is that it does not disturb the general mode of working. The sounder, relay, and key system is retained. All initial delay due to punching, as in automatic systems, is avoided. The skill of able operators is fully utilized and each operator has practically an independent circuit. When there is a rush of traffic in one direction, the system can be worked all in one direction, and not only half of it as in the quadruplex.

TELEGRAPHY.

(PART 6.)

CHEMICAL TELEGRAPH SYSTEMS.

154. Higher speed than the Wheatstone system will give at the receiving end of a line may be obtained by electrolysis. It is at least 10 times quicker than the fastest electromagnet that is found in the latest Wheatstone receiver. Receiving instruments all require a certain amount of energy to operate them, and, in addition, most of them have inertia in the moving parts. The Wheatstone receiver, which has come into successful operation, may be taken as representative of a type of receiver possessing inertia in the moving parts. As a type of instrument having no inertia in the recording mechanism may be mentioned the various forms of chemical receivers acting by electrolysis.

155. A simple method of obtaining records of transmitted currents is to place chemically prepared tape upon a smooth metal surface, which serves as one electrode, and to draw over it a steel needle that acts as the other electrode. If a direct current is used, no record appears when the current is in one direction, but it does appear when the current is reversed. If two needle electrodes are placed side by side upon the tape, a record will appear at one needle for a direct current, and at the other for the reversed current.

With the exception of the Wheatstone transmitter, which is entirely too slow for chemical telegraphy, all mechanical transmitters used or proposed have heretofore consisted of

a revolving wheel over which the perforated tape was drawn. This wheel was connected to the transmitting battery. On top of the tape pressed a scraping finger, which was connected to the line. When a hole in the paper came between the line and the wheel, an impulse was transmitted. Contacts made in this way were rather imperfect, and frequently missed altogether, on account of the collection of dirt and dust on the face of the wheel.

156. Tailing.—Suppose that the electromotive force has acted long enough for the current at the receiver to reach its steady value, and then that the circuit is suddenly broken at the transmitter. Some time will elapse before the current in the receiver is reduced to zero. The manner in which the break is made must be considered. A slow break when there is an arc, or a spark, is different from a rapid one. The whole line has been charged to the limit of the electromotive force used and must become sufficiently discharged before the next wave can be received. This produces the effect commonly known as **tailing,** which means that a signal becomes so drawn out at the receiver that it interferes with the following signal.

Mr. Delany uses impulses of equal duration and indicates the directions of these impulses, whether positive or negative, by a chemical receiver. If impulses, or waves, of equal duration are used, evidently more of them may be received in a given time than of any other combination of waves—for the shortest wave that will operate the receiver may be used. With this plan the effect of tailing is reduced.

157. Reversed Currents of Equal Duration.—A system using current waves of different duration, as sent out by a Wheatstone transmitter, is not as simple as one that uses current waves of equal duration, because in very high-speed systems a long line receives a larger charge when the current flows longer in one direction than in the reverse direction. Hence, a shorter current following a longer current in the reverse direction leaves the line partially charged. Consequently a signal will depend on the length

of preceding signals. The difficulties become apparent only when it is attempted to send waves of unequal duration at a very rapid rate, which is desirable in machine telegraphy. The current requires time to become established at the receiving end of the line after the electromotive force is introduced at the sending end. There is evidently a practical limit to the shortness of the time that the electromotive force must remain applied, which is determined by the smallest current that the receiver is capable of recording. If the potential between the terminals of the receiver is increased, the time required to make a given record is correspondingly reduced.

158. Chemical receivers possess many advantages, perhaps chief among them being the fact that a large part of the energy received is brought to bear directly upon making the record. Another feature is the simplicity of the essential mechanism involved, as no intermediate steps are used after the impulse is received from the line before the record is made. These qualities alone imply rapidity, and the chemical receiver is one of the most rapid known.

DELANY CHEMICAL TELEGRAPH SYSTEM.

159. Most of the above obstacles to high-speed telegraphy by chemical recording apparatus and automatic transmitters have been overcome by P. B. Delany's system for machine telegraphy. The three principal features of machine telegraphy are the perforator, transmitter, and receiver. The following description of this system has been taken from a paper that Mr. Delany presented to the Franklin Institute in 1895.

THE PERFORATOR.

160. The perforating machine, as shown in Fig. 53 (x), comprises three keys—one dot, one dash, and one space key; two electromagnets C and B, for forcing the punches

through the tape; and a step-by-step tape-feeding device *m*, *n*, *o* controlled by an electromagnet *A*.

The operation is as follows: The ribbon is perforated in two lines, the holes in the top line representing dots; those in the lower line, dashes. The letters are made of combinations of dots and dashes, preferably according to the Continental code. The lower contacts of the three keys are connected to one pole of the battery *L B*. The dot-key lever is connected to the punch magnet *C*, the dash lever to punch magnet *B*, and the space lever to space magnet *A*.

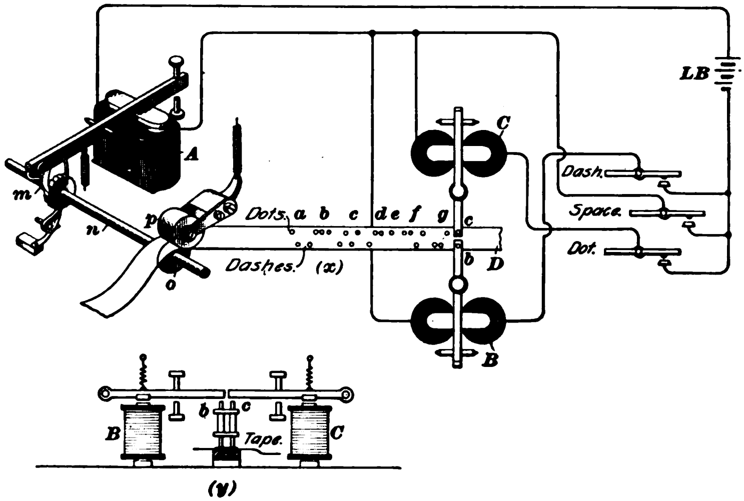


FIG. 53.

Obviously, but one key is pressed down at a time. The spacing magnet is in series with the dot and the dash magnets. To punch the letter *A*, the dot key is pressed down, magnet *C* forces its punch through the paper, and, at the same time, the lever of the space magnet is drawn downwards, and pawl *m* takes a new tooth in the ratchet wheel on shaft *n*. When the key is released and the circuit broken, the punch is raised out of the die and the strip is drawn forwards a definite length by the saw-tooth wheel *o* and pressure wheel *p*. Then the dash key is operated in the

same way, after which the space key is touched, which provides a space between the letter punched and the one that is to follow. Thus, the space key is pressed down once after each letter, and three times after each word.

Perforating is no more laborious than working an ordinary Morse key, and the speed, with a little practice, will be fully up to the average of Morse transmission.

A side view of the punch magnets, their levers, and punches is shown in Fig. 53 (*y*).

THE TRANSMITTER.

161. The **transmitter,** as shown in Fig. 54, consists of a paper-pulling device, represented by roller *R*, and the two pairs of wire brushes pressing toward each other above and below the tape. The top brushes are electrically one, and are connected to the line. The two bottom brushes are insulated from each other, one being connected to the

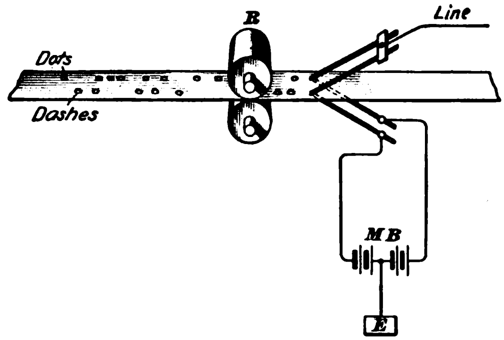


FIG. 54.

positive, the other to the negative pole of the main transmitting battery *M B*. This battery is connected to earth at its middle.

The paper tape usually separates the brushes. However, when a hole in the top line is drawn between the brushes, a positive impulse, representing a dot, is sent into the line,

and when a hole in the lower line is drawn between the other brushes, a negative current, representing a dash, is sent into the line. In this manner all the dots and dashes on the tape are transmitted.

162. The brushes are made up of six wires each, so that six contact points come together at each perforation, rendering failure impossible and insuring perfect uniformity in the quality of the impulses. The ends of the brushes are kept bright and clean by the edges of the holes, and a pressure may be put upon them that will insure electrical contact with the tape moving 30 feet per second, or at the rate of 8,000 words per minute, or over 2,500 impulses per second.

In this form of transmitter, there are no movable or adjustable parts, no circuit wheels to get dirty, no loose or lubricated contacts. An electric motor is used to pull the perforated tape.

163. It will be seen that as no dashes are sent, but only dots, some of which, owing to their position on the tape, *represent* dashes, the impulses are of uniform duration, and the line is not more heavily charged at one time than another; and consequently the discharge is also uniform, and the signals on the receiving tape are correspondingly regular.

THE CHEMICAL RECEIVER.

164. The **receiver** is shown in Fig. 55. It comprises a wheel over which the chemically moistened tape is drawn under three thin iron wires that press lightly upon its top. The two outside wires are electrically one, and are connected to earth *E*. The middle wire is insulated from the others and is connected to the line.

When the brushes of the transmitter drop into a hole in the dot line, a positive current is sent, and a dot is marked in the track of the middle wire of the receiver. When the transmitter brushes drop into a hole in the lower, or dash, line of perforations, a negative current is sent, and a dot is

marked in duplicate on the receiving tape, one in the track of each of the outside wires. This impulse is but a dot in duration; but as it is meant to represent a dash, it must have something to distinguish it from the dot signal; therefore, the current is forked or divided on the receiving tape, so that all dashes are in the form of double parallel dots, while the dots proper are single, and occupy the center line on the

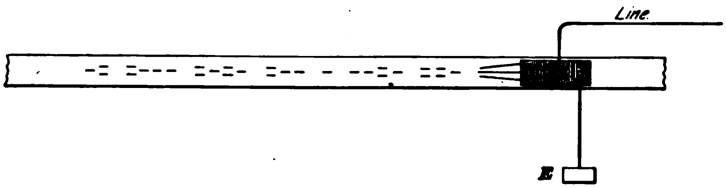


FIG. 55.

tape. It will be understood that the chemically moistened tape forms the circuit between the center wire and the outer wires of the receiver, or between the line and earth; and that all positive currents come over the line and mark in the track of the middle wire, while negative currents come from the earth and mark in the track of the two outside wires, forming double dots, which are recognized as dashes.

165. In this way, no matter how bad the "tailing" may be, it is impossible to mistake a dot for a dash, or to connect them together erroneously; neither is it necessary to have definition between successive dots or dashes. The length of the composite, single or double mark, determines at once the number of distinctive marks intended.

In this system of perfectly straight marks in distinctly different lines, translation is much easier than in submarine-cable signaling where a change in the direction and amplitude of a very irregular curve distinguishes dots from dashes.

166. The specimens of record *A* and *B* seen in Fig. 56 illustrate this most important feature. *B* shows the word "telegraphy" with clearly defined individuality of each dot and dash. *A* shows the same word without any definition

whatever, but, notwithstanding, the word to a practiced eye is just as plain in this form as the other. It is safe to say that, with a few weeks' practice, the transcriber would not look for definition in signals.

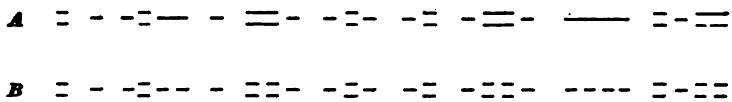


FIG. 56.

It will be clear, then, that a length of line or rate of speed that would render signals by the ordinary dot-and-dash method utterly illegible would be perfectly practicable with this method.

167. Specimen Transmitting and Receiving Tape.—In Fig. 57 is shown a portion of a message as it was actually punched in the tape for the transmitter, and the same message as actually recorded by the receiving instrument on the chemically prepared tape. These are reproductions of the sending and receiving tapes of a portion of

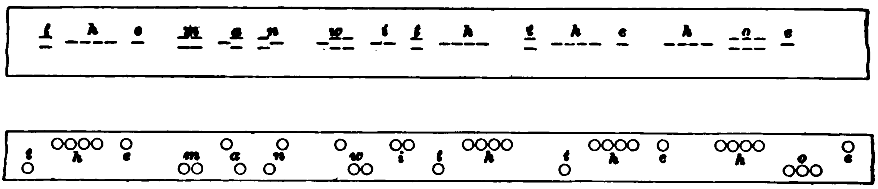


FIG. 57.

a message actually transmitted at the rate of 2,000 words per minute. The Continental code was used. The relative lengths and appearance of the two tapes have been reproduced as accurately as possible.

168. Speed of Transmission.—A perforator will prepare messages as fast as a Morse operator will transmit by hand. The machine transmitter will send, between New York and Philadelphia, over a common iron wire, at least 1,000 words a minute, or as much as can be sent over 50 wires by hand, simplex. If quadruplex is used, 15 wires

will be required to compete with this machine system on one wire. With a copper wire of 500 pounds to the mile, the machine system will carry 2,000 words per minute, or as much as can be carried by 30 wires worked quadruplex.

169. Trial Results.—On October 13, 1895, a trial was made over a wire from Philadelphia to Harrisburg and return, 216 miles, principally of No. 11 copper wire, 130 pounds per mile, and about 25 miles of ordinary iron wire. The speed reached was 940 words per minute, perfect record. The weather on that occasion was very stormy and the leakage of current very great. So far as resistance is concerned, this circuit was about twice as long as a line of 850 pounds per mile of copper would be from New York to Chicago, but the electrostatic capacity was very much less. The electromotive force used was 120 volts, or about one-half the pressure used for quadruplex (Morse) working.

170. Solutions for Chemical Receiving Tape.—The solution for saturating the paper tapes used in chemical telegraph receivers should be one that is easily decomposed; it should contain some so-called deliquescent chemical, that is, a chemical that does not dry out, but rather absorbs moisture from the air; the record made should be permanent; and the resistance of the moistened paper should not be too high. The resistance may be reduced by putting a little sulphuric acid in the solution; not enough, however, to act upon and corrode the marking styles. A good chemically sensitized paper will have a resistance of about 275 ohms between the marking style and the metal roller beneath it.

171. A chemical solution may be made as follows:

1 part of potassium ferricyanide;
30 parts nitrate of ammonium;
2 parts of water.

The following solutions for chemically sensitizing the paper tape for use in chemical telegraph receivers are given by Mr. G. B. Prescott in "Electricity and the Electric Telegraph":

Solution No. 1, nitrate of ammonia, 4 pounds; ferricyanide of potassium, 1 ounce; gum tragacanth, 4 ounces; glycerine, 4 ounces; water, 1 gallon.

Solution No. 2, nitrate of ammonium, 2 pounds; chloride of ammonium, 2 pounds; ferricyanide of potassium, 1 ounce; water, 1 gallon.

Solution No. 3, iodide of potassium, ½ pound; bromide of potassium, 2 pounds; dextrine or starch, 1 ounce; water, distilled, 1 gallon.

"Of the above solutions, No. 1 may be considered best for steady work on short circuits, and being also of comparatively high resistance, it is least affected by leakage from other lines. No. 2 is much more sensitive and can be made to record with the faintest trace of current; it is therefore well adapted for long circuits. No. 3 is highly sensitive and capable of the most perfect and beautiful work at an extremely high rate of speed."

CREHORE AND SQUIER SINE-WAVE SYSTEM.

172. Let the sine curve, Fig. 58 (*a*), represent a regular succession of simple alternating-current waves given to

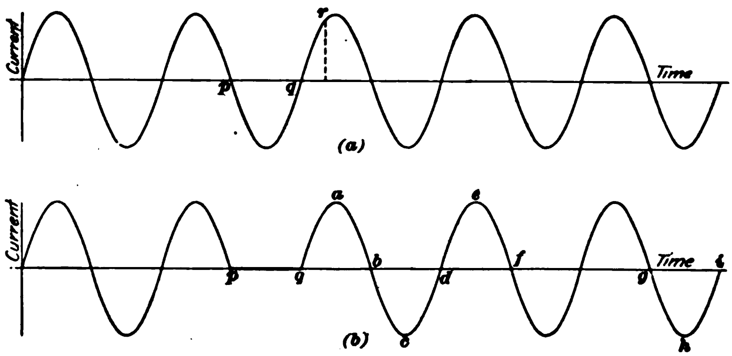


FIG. 58.

the line by an alternating-current generator. If the current passes through a key that may be opened or closed at

pleasure, then, provided the key previously closed is opened at a time corresponding to the point *p* of the wave upon the horizontal axis, the current that was zero at the instant the key was opened will remain zero in circuits that have resistance and inductance alone; again, if the key could be closed exactly at a time corresponding to the point *q* on the curve, also upon the axis, the current would resume its flow undisturbed according to the sine curve. The true current obtained by opening the key at *p* and closing it at *q* is shown in Fig. 58 (*b*), where the current remains at zero between these two points.

If the key had been closed at any other point than *q*, as at *r*, the current would not have resumed its flow according to the simple sine wave, but would give a succession of waves alternately smaller and larger than the normal sine wave for a very few alternations, after which it would practically coincide with the sine wave. Furthermore, if the key is opened at some other point than *p*, when, therefore, the current is not zero, a spark may be observed at the break, and it requires time for the current to fall to zero.

NOTE.—This description of the sine-wave system is taken from a paper presented by Messrs. Crehore and Squier to the American Institute of Electrical Engineers.

No spark is made in a transmitter adjusted to break the circuit at the exact times when the current is naturally zero. This makes it possible, if it is found desirable, to use comparatively large electromotive forces and currents on the line, for no matter what the maximum value of the current, it is made and broken by this plan with no sparking. It is also possible to use waves of high frequency upon the line, the upper limit obtainable from an ordinary alternator being probably much higher than can be utilized for telegraphic purposes.

173. If a receiver were used that could reproduce an exact trace of the actual waves sent over the line, the curve traced would resemble that represented by the heavy curve in Fig. 59. The sine wave continues uninterrupted to the

point *p*, when the key is opened and held open for one complete wave length *p q*, when it is again closed for a wave length *q r*, then opened for one-half a wave length *r s*, closed for a wave length *s t*, opened for a wave length *t u*, closed for half a wave length *u v*, opened for half a wave length *v w*, and finally closed. By this plan it is possible to use the ordinary Continental telegraph code, a dash being indicated when two successive waves, a positive and a negative one, are omitted by keeping the key open, and a dot when a single half-wave is omitted. The space between

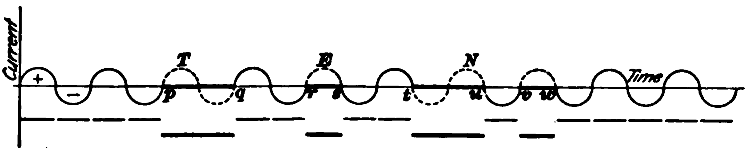


FIG. 59.

parts of letters, as between the dot and dash of the letter *n*, is indicated by the presence of one-half a wave length, and the space between letters, as between *t* and *e* in the word "ten," by the presence of two half-waves, while the space between words may be represented by the presence of three half-waves, and between sentences of four half-waves, or more. The above is a single example, of which there are many, of a method of using alternating-current waves and shows how these signals may be interpreted by a fixed code.

174. A consideration of the time required to send the word "ten" by the above plan shows that it corresponds to the time of eleven half-waves of current. If we suppose that the frequency is an ordinary one used in alternating-current work, viz., 140 complete waves per second, the time required to send the word "ten" is .0394 of a second, or, by allowing three additional half-waves for the space between the words, the word "ten" would be sent just 1,200 times in 1 minute. There is no difficulty in using over some lines a frequency as high as 560 or even 600 periods per second. This would correspond to sending the word "ten" 4,800 and 5,143 times per minute, respeectively. This limit in each

instance is only determined by the particular line used. (It is doubtful if these very high speeds could be obtained in practice even on short lines.)

175. It will be sufficient to show how any single half-wave may be omitted; for obviously any word or sentence may be formed by a repetition of this operation. Imagine one metallic brush bearing upon the smooth circumference of a metallic wheel and another metallic brush bearing upon the axle. One brush is connected through the armature of an alternating-current dynamo to the ground, and the other brush is connected to a line wire. The wheel and axle upon which the brushes bear are geared to the axle of an alternating-current dynamo and hence revolve in synchronism with it. If the periphery of the wheel is divided, for example, into 40 equal parts, and it is geared to run at one-fourth the speed of an armature that revolves in a field having 10 poles, each division thereof corresponds to one semicycle of the electromotive force produced by the generator. If both brushes remain continually in contact with the wheel and axle, the current transmitted will have the regular sine form represented in Fig. 58 (*a*); and for each revolution of the wheel there will be 40 half-waves, or 20 complete waves, transmitted. If one-fortieth of the circumference of the wheel is covered by paper or other insulating material, and the brush bearing on the circumference of the wheel is adjusted to ride on to and off this insulation just as the current is changing from one semicycle to the next, that is, changing its sign, while the other brush is in continuous engagement with the axle, the semicycle represented by the section covered will be suppressed, and without any sparking, even if the potential used is high. In practice, the brush bearing upon the circumference of the wheel is easily adjusted to this point by moving it slightly backwards or forwards around the circumference of the wheel until the sparking ceases; this adjustment having been once made, the brush is fixed in position. In each succeeding revolution of the wheel, this cycle of operation is exactly

repeated, and the current sent over the line will resemble that shown in Fig. 58 (*b*), having every fortieth semicycle omitted. It is only necessary to cover other similar sections of the circumference of the wheel in a predetermined order according to a code, or to draw a properly punched tape over the wheel without allowing it to slip, in order to transmit intelligence over the line.

It is seen that by this method of operating upon the alternating current, there is complete control of the individual half-waves of the current, which may be changing direction thousands of times in a second, far beyond the range of possible control by hand.

176. It has been shown by Crehore and Squier that theoretically two messages may be sent simultaneously by this method in the same direction or one in each direction over the same line. If by means of the sine-wave transmitter and light-polarizing receiver, which will be referred to later, 3,000 words can be sent in one direction over one line, then theoretically by duplexing the line 6,000 words may be sent per minute.

SINE-WAVE TRANSMITTER.

177. Messrs. Crehore and Squier have perfected a practical telegraph transmitter using an alternating sine-wave current, which is suitable for cable and land lines. It will operate their chemical receiver, the Wheatstone receiver, or a siphon recorder. The transmitting tape, however, is punched somewhat differently in each case. The following description is an abstract of a paper presented by them to the American Institute of Electrical Engineers in May, 1900.

178. In the present method of operating long cables, a dot is transmitted by a positive current obtained by connecting one pole of the battery to the cable and the other to the earth, and a dash by a negative current obtained by

connecting the opposite pole to the cable; the time required for a dot and dash is the same.

Several letters of the alphabet require two or more consecutive signals in the same direction, and in order to separate these successive signals at the receiver, it is usual to connect the cable to the earth during the latter portion of each individual signal. The electromotive force used in transmitting the letters *A*, *B*, and *C* is shown in Fig. 60 (*a*), where it is seen that the cable is connected directly to the

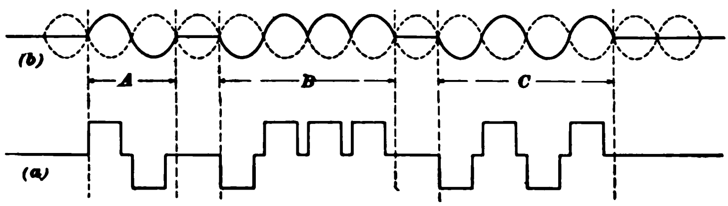


FIG. 60.

earth during one-fourth of each signal. This represents the form of electromotive force as furnished by the battery and transmitter; if no condensers were used, it would be the form of wave applied to the cable. But it is customary to use condensers at each end of the cable whether working simplex or duplex, and these condensers greatly modify the shape of the electromotive force that is applied to the cable itself.

179. It is important that a sine-wave transmitter should be used that will transmit to the cable the same combinations of impulses as those at present used in cable signaling, so that as far as the receiving station is concerned, no change whatever will be required, either in instruments or technical staff. In the sine-wave system, instead of the square-topped form of the electromotive force used for each individual signal at the transmitting end of the cable, as shown in Fig. 60 (*a*), each signal consists of a single sinus, or semiwave, of an alternating current, as represented in Fig. 60 (*b*).

180. The required combination of signals is produced by means of an alternating-current dynamo. A diagram of the alternator and cable transmitter is shown in Fig. 61. The armature rotates continuously, and a wheel *W*, geared to the alternator shaft, feeds the paper tape *T* in synchronism with

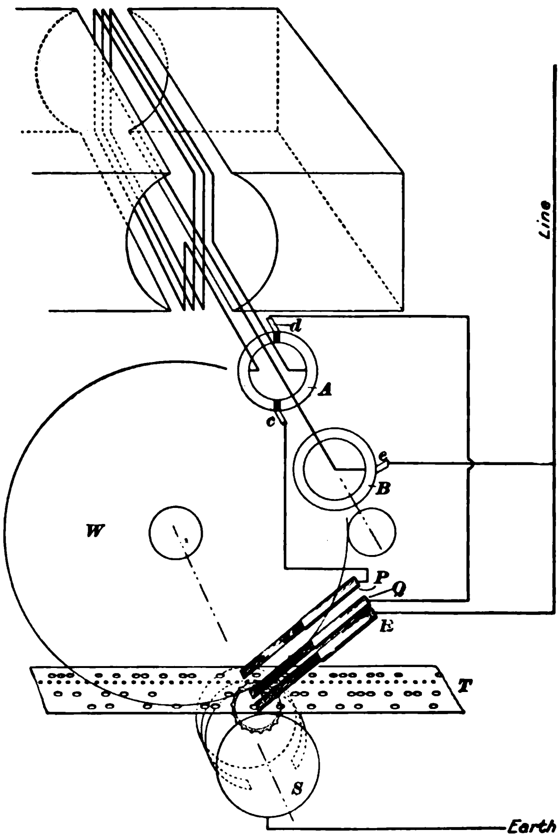


FIG. 61.

the electromotive force generated, so that one semiwave of electromotive force is generated during the time that the tape is advancing a distance equal to the distance between the centers of two consecutive feed-holes. The transmitting tape is similar to the ordinary tape, having a row of

perforations on one side of the feed-holes to transmit dots, and on the other side for dashes. Brushes are used for making contact through these perforations, and by making the holes a proper size, the duration of contact can be made equal to the whole or any portion of the semicycle desired. The two brushes for transmitting the signals are on the same line transversely across the tape, and each brush *P* and *Q* is connected to one terminal of the armature winding through the brushes *c* and *d* and a divided ring *A*, which causes pulsations of the electromotive force supplied to each transmitter brush *P* or *Q* to consist of successive semisinuses in the same direction. A continuous ring *B* is also supplied, which connects the middle of the armature winding by means of the brush *e* to the line. The contact roller *S*, upon which the three brushes *P*, *Q*, and *R* bear, is connected to the earth or to a return wire. Thus it appears that whenever contact is established on the dot side of the tape between *P* and *S*, a positive sinus is transmitted to the line; contact between the brush *Q* and the roller *S* on the dash side sends a negative sinus.

181. Perforated Tape.—Earth connection is provided between letters and words by adding to the tape another row of holes and supplying a third brush *R*, which connects the line directly to earth whenever a perforation

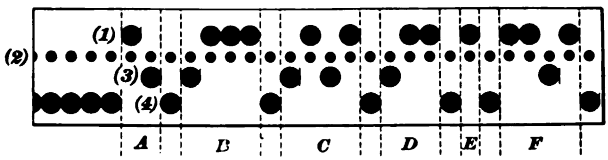


FIG. 62.—*Sample of transmitting tape, showing letters A, B, C, D, E, and F.* (1) *is the dot row.* (2) *is the feeding row.* (3) *is the dash row.* (4) *is the space row for earthing the cable between letters and words.*

occurs under this third brush. A sample of the transmitting tape is shown in Fig. 62, where the letters *A*, *B*, and *C* are represented. The three-hole tape, or four-hole tape counting the feeding row, is prepared on a perforator that differs from the ordinary form only in the arrangement of the

punches. The operator can detect no difference between its action and that of the ordinary Wheatstone perforator.

182. Adjustment of Brushes.—Evidently, to send a simple alternating current to line with this transmitter, it is not only necessary to perforate the tape properly for dots and dashes, but the brushes must be so placed that contact through the perforations will take place at the instants when the current is approximately zero, otherwise there will be a disturbance that will distort the wave from its true sine form. To adjust the brushes easily, they are both mounted upon the same carriage, which is adjustable along the tape by means of a micrometer screw. This adjustment should be made by receiving a current (sent by means of a tape properly perforated to transmit the full alternating current) on a local siphon recorder connected in a circuit with the cable to be used, and not merely in a local circuit. The brushes are properly adjusted when the record is a smooth sine wave.

183. One peculiarity met in designing an alternating-current dynamo for working long cables is the low frequency required, which, for an Atlantic cable, is as low as 3 or 4 per second, while the ordinary frequencies of alternators for lighting and power circuits vary from 25 to 150 per second.

One of the radical features of the transmitter is the use of small steel brushes that make contact through the perforations in the tape with a platinum cylinder having a corrugated surface. In using the alternating current, always interrupted at the zero point, there is not the same objection to the use of brushes due to sparking that is the case when a direct current is suddenly broken at a high voltage. Any system of levers, such as is used in the Wheatstone automatic transmitter, is impossible for very high-speed telegraphy.

184. A large number of experiments with this transmitter were performed upon the cables of the Commercial Cable Company. To make a comparison between the automatic battery transmitter of the Cuttriss pattern, as used

by the Commercial Cable Company, and the Crehore-Squier sine-wave transmitter, observations were taken with each instrument under the same conditions of the circuit, the recorder having the same adjustment in each case. The cable was used, as in regular working, with the duplex arrangement. The battery used consisted of Fuller primary cells, and measured 36 volts on open circuit.

185. Amplitude of Siphon Signals.—With this voltage the double amplitude of the excursions of the siphon were about .11 inch at a frequency of 3, and decreased to .015 when the frequency increased to 5.6 periods per second. Below a frequency of about 4.3 waves per second, the sine-wave transmitter produced siphon records having a smaller amplitude, and above 4.3 waves per second, a larger amplitude, than any other form of transmitter.

186. Influence of Electromotive Force on Speed of Signaling.—The speed of signaling or the number of letters per minute that can be transmitted and received by a given set of instruments on a submarine cable depends on the magnitude of the electromotive force as well as on the shape of the wave. The speed is not proportional to the voltage by either method, but the increment becomes less and less as the pressure is increased, until it may be necessary to double the voltage to gain a few letters per minute.

187. Limiting Electromotive Force.—There is a practical limit with any particular cable to the voltage, which it is not profitable to exceed, since the gain in speed is so slight. The limit of voltage that it is profitable to use is not the same for the sine wave as for the battery method. To obtain the best speed with either system it should be worked at this maximum voltage point, which limit can only be determined by experiment. Before such a limit is reached, however, there are often other causes that prevent the best voltage from being used. If a fault develops, a high potential at that point might effect the complete interruption of the cable. When the fault is discovered,

it is customary to reduce the voltage to prevent entire interruption. There is at present such a fear of using high voltage on submarine cables that a limit is set to the pressure at which cables may be operated, and this limit, for most of the cables of the world, is little more than 50 volts.

Since the voltage is limited upon a cable, it is evident that the system which can furnish the higher speed at the same pressure has the advantage, or that system which can furnish a given working speed with the lowest voltage is the safest one to use.

188. With battery transmitters, the maximum pressure to which the cable itself is subjected is approximately equal to the battery voltage, whether condensers are used or not. The difference is that with condensers this pressure is momentary, while without them it is more continuous. It should further be stated that a sine-wave electromotive force that has an amplitude of 1 gives a reading of only .707 on an electrostatic voltmeter. This reading is known as the *virtual* electromotive force. Hence, a sine wave that produces an electrostatic voltmeter reading of 35.4 volts between the cable and earth is equivalent to a battery of 50 volts, whether applied to the cable directly or through condensers, because the two have the same maximum values.

189. Gain in Speed at Same Voltage.—The received waves through a long submarine cable are approximately sine waves, whether true sine waves or merely battery reversals are used at the transmitting end. With the same maximum voltage at the transmitting end of the cable, however, the amplitude of the wave at the receiving end is greater when the sine wave is used, which means that more energy is transmitted by the cable. This is equivalent to attaining higher speed, since with the same speed as with the battery transmitter, the amplitude of motion and definition is greater; but by tightening the suspensions and quickening the natural period of the recorder, the same definition and amplitude is obtained at a higher speed.

190. The **advantage** of this transmitter is therefore the increase in speed that may be obtained with its aid over cables, and especially over long lines where higher frequencies may be used on account of the smaller electrostatic capacity. This increase in speed is partly due to the use of a higher voltage, since with a battery transmitter like the Wheatstone or Cuttriss, voltages over a certain value are impossible owing to the sparking at the contacts, the line currents being interrupted at full strength; whereas, the sine-wave transmitter uses alternating currents that are interrupted only at the zero instants, whatever electromotive force is used. A trial made between London and Aberdeen without repeaters showed that the limiting speed was 107 words per minute with the ordinary Wheatstone transmitter, and 195 words per minute with the sine-wave transmitter, using an electromotive force of only 230 volts.

191. In telegraph stations where a number of sine-wave transmitters are used simultaneously, there need be but a single alternating-current dynamo for the whole station, and a separate small synchronous alternating-current motor at each desk, the sole duty of which is to draw a paper tape under contact brushes in step with the impulses of the generator. The single alternator not only drives the synchronous motors, but also supplies the line with alternating currents through the contact brushes. The present tendency in telegraphic engineering is to remove all forms of primary batteries as a source of power, and the sine-wave alternator combines this advantage with the most efficient form of wave for signaling.

CREHORE AND SQUIER CHEMICAL RECEIVER.

192. According to Crehore and Squier, the use of a sine-wave alternating current permits of greater potentials being realized in a chemical receiver with less disturbing influence from the line than would be the case if a constant direct electromotive force was used. By using a sine-wave

alternating current with a single needle and a plate as electrodes, the record shows a regular succession of distinct marks separated from one another by equal intervals. Each mark exhibits an intensity varying approximately according to the sine curve. Since by this arrangement the current makes its record in one direction only, the result is that alternate semicycles of the current are suppressed and alternate ones are recorded.

By receiving with two needles side by side, all the alternations are recorded, those that were suppressed before now appearing at the second needle. The record then appears in two parallel lines of marks, marks appearing in one line opposite spaces in the other. The marks that appear in one line represent dots, those in the other line dashes. In their chemical receiver, the record is made in lines across a page instead of in one continous line, which requires a long tape that is inconvenient for some purposes.

193. The Crehore and Squier instrument may be used as a transmitter or as a receiver, and will transmit messages from sheets upon which they have been perforated in lines transversely on the sheet and also receive the messages in lines transversely on a sheet. The messages will then be in letter form. Another object of the invention was to construct a receiver that would be especially adapted to take messages sent by the alternating sine-wave current transmitters constructed by them. The receiver may not, however, be used only with the latter transmitters, since it may be readily adapted for use in the place of any chemical receiver.

194. In this receiver the styles, or contact points, are made to travel across the paper or message sheet, and the sheet is also made to travel under them. The paper may be in the form of sheets or in a continuous web. The message sheet may be made to travel step by step, being stationary, while the styles are making a trip across it and moving a line space between the trips of the styles, in which case the styles would move straight across the sheet; or the

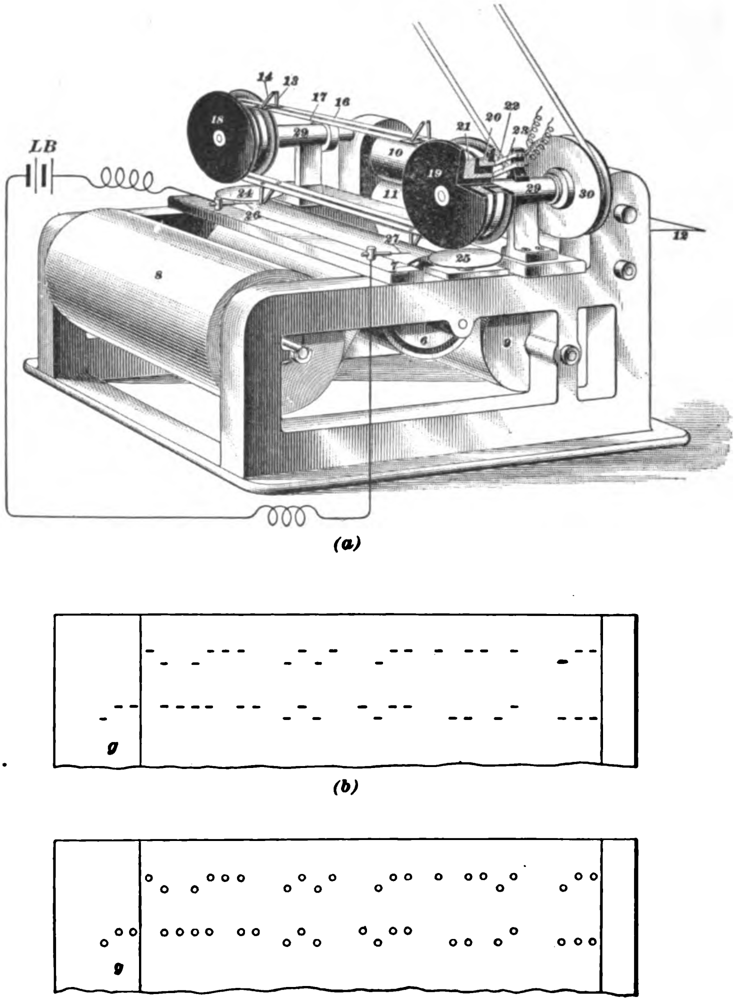
sheet may have a continuous movement, in which case the styles may be made to move obliquely across the machine, their speed with relation to that of the sheet being so timed that the paper will have advanced a line space between successive styles and the line of characters will be nearly straight across the sheet. This latter construction is the one preferred, and, therefore, the one illustrated.

This apparatus is shown in Fig. 63. In the frame of the instrument is a roller *6*, which is, in a sense, a "platen," and may be so termed. It is formed of a metal tube of tin or nickel, or plated therewith, and is mounted upon and suitably insulated from the frame in which the journals of the rollers are secured. When the platen is a conductor, the apparatus may be used either on an alternating-current circuit or on a direct-current circuit. When so used, the platen may be placed in circuit by a brush *7*. The chemically prepared or sensitized paper is made up in a roll and mounted in one end of the frame, as indicated at *8*. From this roll the paper is led over the cylinder *6*, around a suitable guide roll *9*, and out through feeding rolls *10* and *11*, the paper being shown at *12* as it comes out of the instrument.

195. In the form of instrument here shown—that is, one adapted to receive messages from an alternating-current transmitter—two styles, *13* and *14*, are secured to the conducting tapes *16* and *17*, respectively. The conducting tapes are in the form of endless bands and mounted upon rollers, or drums, *18* and *19* journaled in suitable brackets, or bearings, at either side of the apparatus. The metallic rings *20* and *21* are suitably constructed and insulated from one another, so that each may receive and be in electrical contact with one of the conducting tapes. These rings have flanges, or projections, extending to the face of the pulley, so that contacts, or brushes, *22* and *23* may bear thereon and convey the current through the rings *20* and *21* to the metallic bands and the styles while in motion.

Several pairs of styles *13* and *14*, mounted upon the same

bands, are placed equal distances apart, and these intervals are such that one pair will engage the message sheet just



(a)

(b)

(c)

Fig. 63.

before the preceding pair leaves it, whereby it will be impossible for the apparatus to omit any character. The

current flows from one style to the other through the message sheet, and as the alternations occur, a mark is made at one needle, then at the other, the cessation of current or the periods of zero current between alternations or semicycles producing no mark upon the sheet.

The styles are led on to and off the paper by means of disks *24* and *25* of insulating material. These disks insure a steady and perfect contact between the styles and the paper as they come upon the latter and, likewise, a smooth and steady movement upon leaving the paper, even when traveling at a high speed. These disks also serve to determine the margin of the sheet on which the messages are received.

196. In providing for the presence of two sets of brushes upon the paper just before the preceding set leaves the same, the repetition of a portion of a character or signal will frequently be produced. This repetition, however, is readily discernible; but for the purpose of making it absolutely clear where such repetition terminates, longitudinal lines may be produced upon the sensitized paper to indicate the actual limits of the lines of characters. These lines may be made by marking devices as the paper is passing through the apparatus. These marking devices consist of steel needles *26* and *27* in an electric circuit containing a battery *L B*. The needles are mounted upon the frame of the machine and bear upon the paper as it passes over the platen *6*. These marginal lines are produced by electrolysis, and in this figure the character *g* is shown as repeated. This figure also illustrates the appearance of the characters upon sensitized paper.

The driving pulley *30* is driven by a belt from a suitable motor. The movement of the paper through the apparatus is accomplished by means of a worm (behind the pulley *30*, and therefore not shown in the figure) mounted, with the driving pulley *30*, upon the shaft *29*. The worm meshes with a worm-wheel mounted upon the shaft of the feeding roll *10*. The brackets supporting the shaft *29* are so

mounted that the styles *13* and *14* travel obliquely across the apparatus, and their point of leaving the paper is a line space from the point at which they engage the paper. The movement of the paper is so regulated with relation to the speed of and obliquity of movement of the styles that the lines of characters are parallel and extend across the sheet at right angles to its lateral edges.

197. In using this apparatus for receiving messages over a direct-current circuit, the marks will appear at one style, the current passing from one style through the paper to the other, or by the omission of one style it may be made to pass from the remaining style to the roller *6*. In each character represented on the message sheet in Fig. 63 (*b*), the upper dots or dashes are made by, say, the positive semicycles, while the lower ones are made by the negative semicycles, the intervals between dots or between dashes representing the brief periods of zero current, and the spaces between the characters or words representing the semicycles that have been suppressed by the transmitter plus the brief period of zero current between the end of one signal and the beginning of the next. Obviously, the apparatus described is not limited to the receipt of any particular style or character of signal, but may be used with any of the existing codes.

198. As a Transmitter.—To use this instrument as a transmitter, the messages are prepared as indicated in Fig. 63 (*c*), wherein perforations are made across a sheet of paper or other suitable non-conducting material, as shown. The message sheet thus prepared is fed over the platen, and as the styles ride across the sheet, they make circuit with the platen through the perforations, the circuit being interrupted as the styles ride over the portions of the sheet between the perforations.

To render a transmitting sheet operative with the alternating current, the brushes must move in synchronism with the alternations of the current, and the brushes or the parts carrying them must be made adjustable with respect

to the perforations in the message sheet, so that the makes and breaks in the current flowing over the line will occur at the zero points between the pulses or alternations of the current.

199. Messrs. Crehore and Squier, while working with their sine-wave transmission, developed an entirely new type of receiver, called a *light polarizing receiver*, having no inertia in the recording mechanism. No difficulty was experienced in sending and recording messages by the use of their sine-wave transmitter and light polarizing receiver at the rapid rate corresponding to between 3,000 and 4,000 words per minute. However, their elaborate light polarizing receiver is hardly a practical telegraph instrument, and hence will not be described here. A description of it, with interesting experiments relating to their system, will be found in Vol. XIV of the Transactions of the American Institute of Electrical Engineers.

200. Sine-Wave Transmitter and Wheatstone Receiver.—The sine-wave transmitter can operate the Wheatstone receiver approximately three times as fast as the Wheatstone transmitter on any line, provided the mechanical limit of the receiver, which is about 600 words per minute, is not already reached. Furthermore, it has been worked on circuits that ordinarily require two repeaters, without any repeaters, and at any speed up to the mechanical limit of the receiver. From the numerous experiments that have proved the foregoing statements, it seems probable that the sine wave possesses superiority over other forms of current wave for any speed, slow or fast. There are two causes that account for the slower speed of the Wheatstone transmitter, namely, the difference in wave lengths sent into the line by the transmitter and the departure from the sine form of wave. Another cause for gain in speed by the sine-wave transmitter is the fact that a higher voltage may be used with it than with the Wheatstone transmitter, although it is difficult to estimate the precise amount of gain due to this fact. The sine-wave transmitter and Wheatstone receiver will work

successfully on a line $1\frac{7}{10}$ times as long, at the same speed as the Wheatstone system, provided the mechanical limit of the receiver is not exceeded. With copper wire weighing 800 pounds to the mile, the sine-wave transmitter can operate to the limit of the Wheatstone receiver any distance less than 1,800 miles, while the Wheatstone system using the same wire can operate to the same limit any distance less than 1,260 miles.

201. Wheatstone Receiver Shunted by a Condenser.—When the Wheatstone receiver is used in connection with the sine-wave transmitter, it is possible to increase the receiver current materially, making it even larger than the line current, by connecting a condenser of proper capacity around the receiver. By knowing the inductance of the receiver and the frequency, the capacity of the condenser that should be used to give the best results can be calculated by the formula

$$Q = \frac{1}{L(2\pi n)^2}, \qquad (2.)$$

in which Q = capacity of condenser;
L = inductance of receiver;
n = frequency;
π = 3.1416.

From this it is seen that the capacity of the condenser should vary inversely as the square of the frequency n, although the value of the capacity for any frequency is not very critical; that is, a given condenser will improve the working for a considerable range of speed.

POLLAK-VIRAG TELEGRAPH SYSTEM.

202. The method of high-speed telegraphy devised by Pollak and Virag, of Austria, has excited considerable attention. Experiments made over a metallic circuit 400 miles long, having a resistance of 4,000 ohms, and using a battery

of 20 volts gave clear signals, both in wet and dry weather, at a speed of 70,000 words per hour, while with 25 volts a speed of 100,000 words per hour was attained. Other experiments on a metallic circuit of iron wire 210 miles long and of 6,000 ohms resistance was also successful, a speed of 54,000 words per hour being obtained with a 60-volt battery. Trials between Budapest and Berlin, in the fall of 1899, gave distinct and readable signals at speeds of from 1,300 to 1,500 words per minute.

203. Advantages and Disadvantages.—This gives of course a great improvement in speed over ordinary telegraphy, but it is likely to prove that while the actual sending of the electrical signals is much faster than the common methods, the advantage will be lost in a great measure, if not fully offset, by the time and complication of making the messages ready for the wire and of translating them into a written language at the receiving end. The telegram must first be changed into the characters of the Morse system and the tape perforated, as in the Wheatstone system. After reception, the photographed strips must be developed and then translated into ordinary language. It is thought that this complicated manipulation may lead to many errors in transmission. This has been found to be the great objection to many high-speed systems heretofore, and is the reason why the Wheatstone system is in comparatively restricted use in this country.

204. The following is an abstract of the descriptions of the Pollak-Virag systems and apparatus that appeared in the London "Electrician," during 1899 and 1900. The transmission is effected by a perforated strip of paper, as in the case of the Wheatstone automatic system, and a telephone fitted with a small concave mirror serves as the receiver, the diaphragm of the telephone being set into oscillation corresponding to the current impulses generated by the transmitter. These oscillations are made visible photographically. The dots and dashes of the Morse code

are represented by strokes on either side of the central line, as shown on the cylinder *H* in Fig. 64 (*x*), the strokes being produced by current impulses in reverse directions. The transmitting apparatus *T* consists of a roller *a* driven by a motor or clockwork. The perforated paper is drawn over the metal roller *a*, which is connected to one of the line wires. The strip of paper *b*, shown in (*z*), is perforated

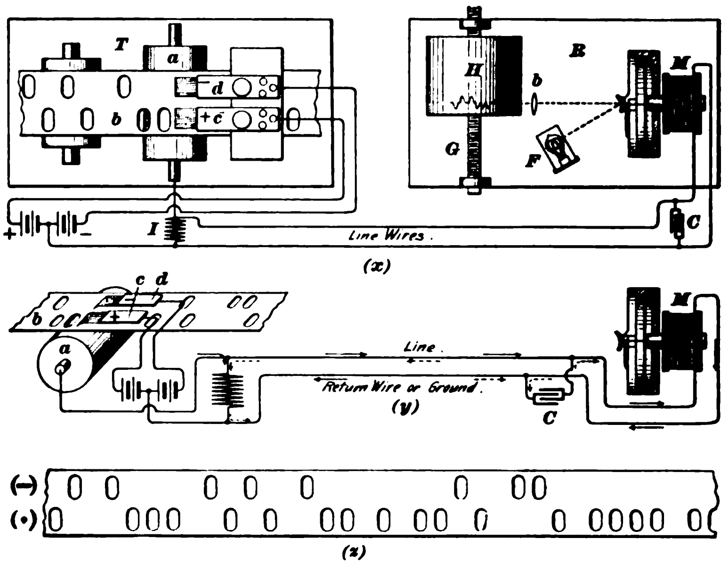


FIG. 64.

in two lines corresponding to the two directions of the current. Above the tape two brushes *c* and *d* are fixed, one connected to the positive pole and the other to the negative pole of the battery. The return wire or ground is connected to a point at the middle of the battery. Now, if in consequence of the perforations of the paper, either one of the two brushes comes into contact with the metal roller, either a positive or negative current flows through the roller to the line and thence to the receiving apparatus.

205. At the receiving station *R*, the currents pass through a telephone *M* whose diaphragm is moved in a direction determined by the direction of the current impulse. The movements of the diaphragm are transmitted to a small mirror with the assistance of a metal rod. It is necessary that the small movements of the diaphragm should occasion a relatively large displacement of the mirror. This is done by fastening to the mirror a small plate of soft iron, held in position by one pole of a permanent magnet, about as shown in Fig. 65. The pole *n* of the magnet ends in two points and holds the mirror in such a way that the line joining these two points is the axis about which the mirror turns. The other pole *s* of the magnet is provided with a weak spring *a*, which forms the third point of support for the mirror. This spring *a* is connected to the diaphragm by means of a small rod, so that the small movements of the diaphragm cause a motion of the mirror, which is relatively large, as the points of support of the mirror, the two on *n* and the one on *a*, are very near to one another. This method of magnifying the movements of the diaphragm has the advantage that, in consequence of the small weights of the moving parts, the velocity of vibration of the diaphragm is not lessened.

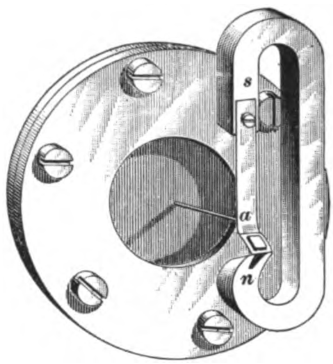


FIG. 65.

The light of a small incandescent lamp falls on the small concave mirror just mentioned, which throws the image of the filament on a piece of paper sensitive to light. In front of this sensitized paper, a cylindrical lens *b* is placed that focuses the reflected beam of light so as to produce a bright spot upon the paper. In consequence of the current impulses that move the diaphragm and mirror, the spot of light moves out of its original position in one direction or the other. In this way the up-and-down strokes, representing

letters, as shown in Fig. 66, are traced on the sensitized paper. The latter (see Fig. 64) passes over a drum *H* that moves horizontally on a screwed spindle, so that the line

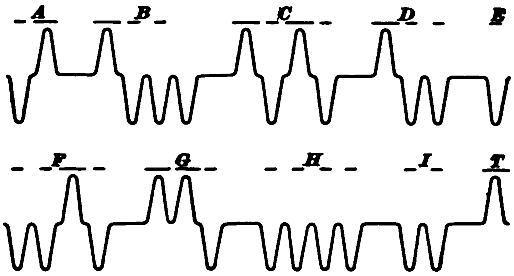


FIG. 66.

traced by the spot of light follows a continuous spiral route. The amplitudes of the movements of the spot of light are large enough to make the signals clearly legible.

206. Although this action appears simple enough, allowance has to be made for one important disturbing factor, viz., the natural period of oscillation of the diaphragm itself. This is done by making the duration of each current impulse equal to the natural period of the telephone diaphragm, so that the current always stops exactly at the moment when the diaphragm swings back to its original position. By suitably adjusting the velocity of the paper and the dimensions of the perforations, the duration of an impulse can be regulated and a perfect damping of the membrane so obtained. But in order not to be dependent in practice on the precision of the movement of the paper, another device has been added. In Fig. 64, the condenser *C*, which is connected in parallel with the telephone, will be charged as long as the current impulse lasts, but after the current ceases, the condenser will discharge into the telephone circuit. Hence, if the current impulse is shorter than the natural period of the vibration of the diaphragm, the discharge from the condenser will prolong the duration of the current, and *vice versa*. By using a condenser of suitable capacity, the diaphragm may be made to

return to its original position without first oscillating to and fro.

It appears that the inventors have not overlooked the fact that the properties of the line, independent of the apparatus, render high-speed telegraphy difficult. An endeavor is made to counteract this influence to some extent by connecting, parallel to the line at the transmitting station, a coil *I* having self-induction, whose dimensions are chosen according to the self-induction, capacity, and resistance of the line.

207. Fig. 65 shows the most recent type of diaphragm and mirror connection, while Fig. 67 gives a good idea of the arrangement of the parts of the complete receiving

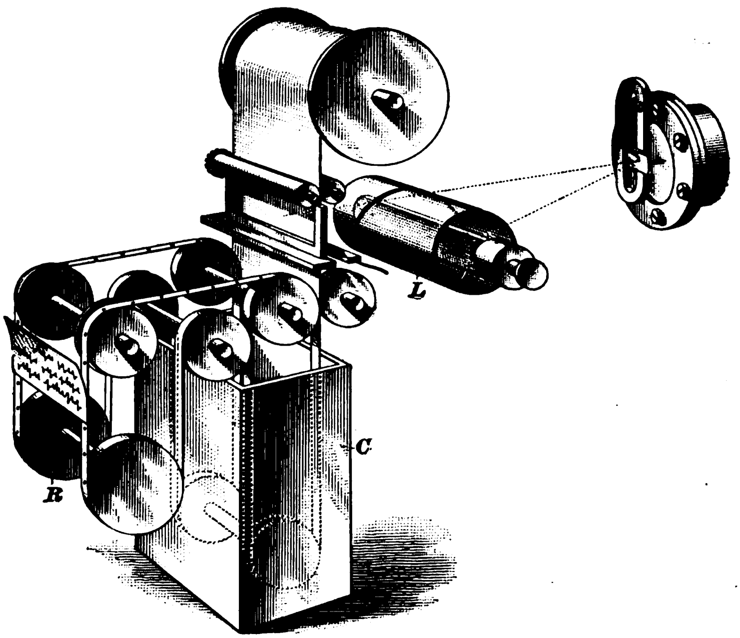


FIG. 67.

apparatus. By this apparatus, messages are received and recorded in zigzag lines running from left to right on a broad strip of sensitized paper. This left-to-right movement is produced as follows: The source of light is a

glowing filament that is surrounded by the cylindrical metal mantle *L*. In this mantle a helical slit is cut, the helix making one complete turn. In consequence, when the mantle is turned about its axis, the source of the light falling on the mirror moves uniformly from right to left, and, hence, the spot of light formed on the paper by reflection from the mirror moves uniformly from left to right. A series of motions of the mirror about a horizontal axis is recorded, therefore, on the paper as an up-and-down zigzag line running from left to right, and commencing at the left end of a new line upon the completion of every filled one. On the commencement of a message, the revolution of the helically slit mantle and of the sensitized paper feeder *R* is automatically started. At the close of the message, the paper strip is cut and the movement of the unexposed paper stopped, while the exposed strip is carried forwards by clockwork into the developing bath *C*, then into a neighboring fixing bath, and is finally pushed through a slot in the outer cover of the apparatus.

POLLAK-VIRAG WRITING TELEGRAPH.

208. The apparatus shown so far yields only the zigzag writing resembling that of a cable siphon recorder. For the recording of a message in the characters of ordinary handwriting, a double receiving apparatus, shown in Fig. 68, is necessary. This differs from the receiver already described in having two telephones and one concave mirror supported upon one fixed point and two movable points. One telephone

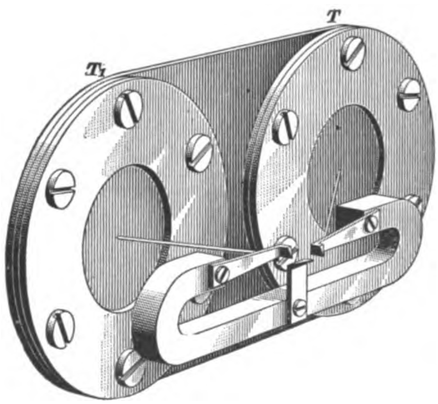


FIG. 68.

moves the mirror about a horizontal axis, the other about a vertical axis, so that by acting simultaneously the two telephones can cause the reflected spot of light to trace any desired curve. The arrangement of transmitting and receiving apparatus, which will be explained presently, is shown in Fig. 69. Two line wires L and L_1, in addition to an earth return, are now necessary. One telephone T_1 is connected in a loop with these two line wires, that is, in series with them; the other telephone T is connected between the loop and the earth. For producing horizontal

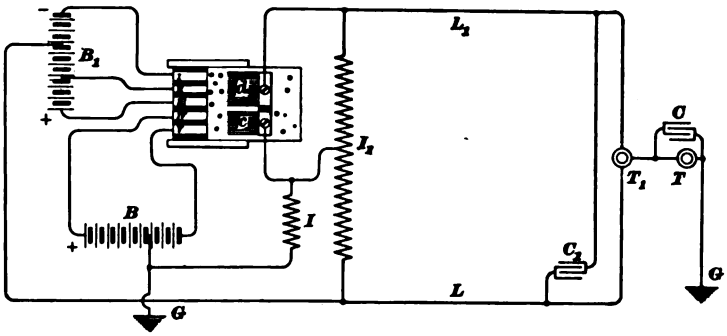


FIG. 69.

motions, a positive current and a negative current of approximately equal strength are required; for the vertical movements, a positive current, an equal negative current, and a positive current of double their strength are required. These current impulses produce motions to left and right and up-and-down motions of equal amplitude, and a downward motion of double this amplitude. Fractions of this amplitude are obtained by shortening the duration of the contact at the sending end.

209. The transmitting apparatus shown in Fig. 69 consists of a perforated paper strip, five slip rings connected to the batteries, and two brushes connected to the line. The size of the holes in the paper determines the duration of the contacts between the brushes and rings.

210. If the ordinary written Latin characters be dissected, it will be found that certain of them, such as *m*, *v*, *p*, as shown in Fig. 70, can be resolved into elements each consisting of a down and an up stroke commencing and ending at the same height above the line. The letter *m* consists, for example, of three such elements, the letters *v* and *p* each of two. In order to cause the receiver to write letters that can be analyzed in this way, the currents sent from the sending end to produce vertical movements in the receiver are regulated with respect to direction, intensity, and duration. This is done for these three letters by perforating the paper-transmitting strip with larger or smaller holes in two rows, as shown. The elements are so combined and spaced as to produce the letters distinctly and in the order desired.

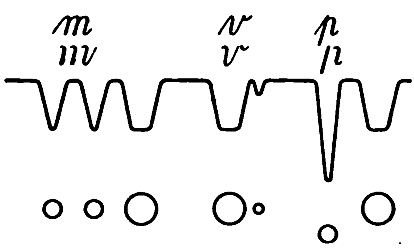


FIG. 70.

211. For letters extending above the top of an *m*, there are three rows, *I*, *II*, *III*, of holes, as shown in Fig. 71, corresponding to the three rings under one brush. A hole in row *I* exposes to the brush *d* (see Fig. 69) the ring *I*, supplying a negative current of known voltage, a hole in row *II* exposes ring *II*, supplying a positive current of equal voltage, and a hole in row *III* exposes ring *III*, supplying a positive current at double that voltage. The effect on the mirror of the receiver of holes punched as in Fig. 71 is shown directly above the plan of the perforations. It is a matter of trial to fix on that size of hole which

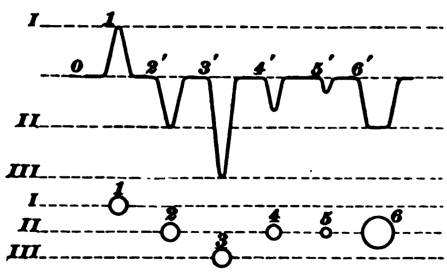


FIG. 71.

allows just sufficient time for the current to exercise its full effect on the telephone. A larger hole then merely broadens the loop that the spot of light traces on the moving sensitized paper; while a smaller hole displaces the spot of light a distance that is only a fraction of the full amplitude.

212. But the written Latin characters include many composed partly or wholly of closed curves, and these cannot be written by the mere up-and-down movements so far described; properly timed to-and-fro horizontal motions are necessary in addition. Such letters are therefore resolved into and compounded from vertical and horizontal components. The movements of the receiver corresponding to each of these components are each produced by separate current impulses, and the time intervals between these impulses are chosen and obtained by deciding on the spaces to separate consecutive holes in the perforated tape.

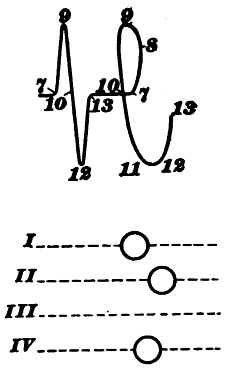


Fig. 72.

Take, for example, the letter *l*, which contains a closed curve, or loop. Its vertical components, merely, are written by the mirror as in the left-hand portion of the diagram in Fig. 72. This up-and-down zigzag is the result of impulses sent into the line through the perforations in the rows *I* and *II*, acting alone. The hole in row *I* would cause the **V**-curve *7–9–10* to be described on the moving paper; the hole in row *II* would produce the curve *10–12–13*. But when a hole, as shown in the figure, is punched in the row *IV*, so that a current deflecting the spot of light from right to left is sent into the line, as soon as the spot of light in its upward motion due to hole *I* reaches the place marked *8*, a deviation to the left is produced—in spite of the forward movement of the paper—which carries the spot of light to *9*. Here the current through the hole in row *I* ceases, and the spot of light returns to *10*, where it is immediately, in consequence of the coming of the hole in row *II*, given a

downward motion toward *11*. Here the effect of the hole in row *IV* dies out, and the mirror, in restoring itself to its normal position, then writes on the moving paper the broad loop *11–12–13*. Thus the second of the two telephones, by

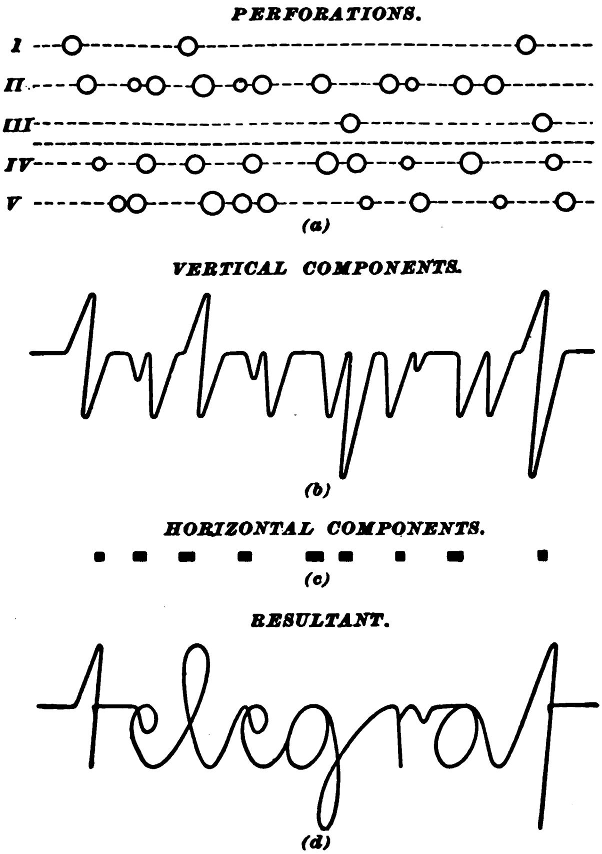


FIG. 73.

its production of horizontal to-and-fro motions of the mirror, makes it possible to write letters containing closed curves.

In this manner any character of the alphabet can be written. The character must be analyzed at the sending end into its horizontal and vertical components, as defined above, and compounded at the receiving end by the two

telephones. The telephone T_1, Fig. 69, gives the spot of light the vertical motions caused by holes in rows *I*, *II*, *III*; the telephone *T*, the horizontal motions demanded by the holes in rows *IV*, *V*. The construction of the complete word "telegraf" on these principles is shown in Fig. 73. Fig. 73 (*a*) gives a plan of the perforations in the sending strip; (*b*) gives the written record due to the telephone T_1 operated from the rows *I*, *II*, *III*; (*c*) represents the effect on the telephone *T* of the holes in rows *IV*, *V*; and (*d*) is the resultant of the vertical and horizontal components.

213. The sources of current are two comparatively small batteries connected to the rings, line, and earth, as shown in Fig. 69. From battery B_1 are taken equal negative and positive currents corresponding to rows *I* and *II* of the perforated paper, and also a positive current of double the value corresponding to row *III*. From battery *B* are taken a strong positive current for the leftward deflection of the spot of light and a weak negative current for the rightward deflection. It will be noticed from this diagram that, as before mentioned, only the telephone T_1 is included in the loop of the double line, the telephone *T* receiving its impulses after they have passed as two oppositely directed currents of equal strength through the telephone T_1; in other words, T_1 is differentially wound and is not affected at all by equal currents that flow in both line wires *L* and L_1 in the same direction and return through the earth to the sending station.

214. The self-induction and the capacity of the wires and the effects of the natural oscillation periods of the telephone diaphragms are compensated for by coils and condensers as shown in Fig. 69, where I_1 and *I* are inductance coils and C_1 and *C* are condensers. By modifying the condenser *C*, moreover, the difference between the horizontal and vertical motions can be adjusted to a certain extent. The perforating of the paper sending strip is accomplished by a simple machine that punches simultaneously all the holes corresponding to any required character.

There is in this system of telegraphy no need for the synchronizing of the sending and receiving apparatus, for variations in the speed at either end merely broaden or narrow the letters; and, therefore, the inventors claim that this system is simpler and considered more reliable merely from this point of view. With the aid of a distributor (such as Delany's) it is claimed that about 30 sets of apparatus could be arranged to work on one line. At a recent trial, allowed by the Hungarian Minister of Commerce, most excellent results were said to have been obtained over two pairs of telephone wires from Budapest to Pozsony and back, a distance of nearly 230 miles. The rate of transmission—at which rate very good writing was produced—reached 1,000 words per minute through a resistance of 2,000 ohms.

PRINTING TELEGRAPHS.

215. Telegraph systems that record the transmitted signals in plain Roman letters upon a moving tape or a sheet of paper are called **printing telegraphs.** The problem of automatically recording telegraph messages in Roman type is one that has fascinated inventors almost from the days of Morse. Printing telegraph systems have been used more or less since about 1856, and on account of constant improvements there are more of them than it is practical to describe. Mr. Royal E. House invented a type-printing telegraph that was in successful operation in this country in competition with the Morse and Bain systems prior to 1857. The systems that are used in the large cities for reporting stock quotations, race-track news, etc., are commonly known as *stock-ticker systems.* The Phelps printing telegraph is used on several main-line circuits by the Western Union Telegraph Company. In some of the European countries and on the English Channel cables, the Hughes type-printing telegraph, or modifications of it, and in France, the Baudot type-printing telegraph systems, are used.

The French system of Emile Baudot and the American system of Professor Rowland use an arrangement for dividing the use of the line among several operators, resembling in this respect the Delany multiplex system.

PRINCIPLE OF PRINTING TELEGRAPH SYSTEMS.

216. Almost all printing telegraphs depend on the synchronous rotation of the transmitting and receiving mechanism, but the methods used for accomplishing this vary considerably.

Imagine two toothed wheels synchronously propelled by clockwork or like those used in the Delany synchronous multiplex system, one at the transmitting station and one at the receiving station. Suppose there are as many teeth as characters, there being one character on the face of each tooth. In circuit with the magnet controlling these wheels is a key, the pressing down of which will not only stop the rotation of each wheel, but will also cause an electromagnet to press the tape upon which the characters are to be printed against the tooth that stops opposite it. When the two wheels start to rotate, similar letters upon the two wheels must occupy exactly similar positions; that is, if the letter A is opposite a certain point at the transmitting station, the letter A must be opposite a similar point at the receiving station. Then, if the operator is able to momentarily stop the wheel at his station when the letter he wishes to transmit comes into a certain position, that same letter will be opposite the tape in the receiving machine, and the tape being pressed against it when the wheel momentarily stops, the character will be printed. When the key is released, the wheels will immediately start to rotate again and the paper tape will also be moved along by clockwork or otherwise. In this way any character can be printed in succession at the will of the transmitting operator.

217. A number of receiving stations may be connected in series in the same line circuit. It is necessary to make all the wheels rotate synchronously, which would not be an easy matter merely with clockwork. To obtain the synchronous rotation of the type wheels, usually a step-by-step mechanism, controlled by the transmitting apparatus, is used. This may be done by sending into the line one brief current every time each character of the transmitting wheel passes a certain point, each one of these brief currents causing a properly arranged electromagnet in the receiving instruments either to release a clock-driven wheel one tooth at a time or to actually push the wheel around one tooth each time. Furthermore, it is usually necessary to have a correcting device that will bring all receiving wheels absolutely to the starting point, no matter what their position may be at the instant the correcting device operates. It may operate about every third revolution of the receiving wheels.

STOCK-TICKER SYSTEMS.

218. Stock-ticker telegraphs may be divided into the *single-wire single-wheel*, the *single-wire double-wheel*, and the *two-wire double-wheel systems.*

In the **single-wire single-wheel** system, there is only one line wire, and all the characters, both letters and figures, are placed in succession on the periphery of one printing wheel. While this is theoretically the simplest method, it is not as fast as the others, and is not used as extensively.

In the **single-wire double-wheel** system, there is one line wire and two printing wheels alongside each other, one usually for letters and another for figures and other characters. The two wheels usually rotate together, but the paper tape is pressed up against only one at a time.

In the **two-wire double-wheel** system, there are two line wires and two printing wheels. The two printing wheels are alongside each other and have the characters on

their periphery, as in the preceding system, but in this case a separate wire is used to merely shift a pad from one to the other type wheel as required. One wire governs the rotation of the printing wheels and causes the pad to be pressed against the type wheel opposite which an electromagnet connected in the other line wire has moved it.

PAGE-PRINTING TELEGRAPH SYSTEMS.

219. There are two page-printing telegraph systems now receiving attention that use a perforated transmitting tape: the Murray page-printing telegraph and that of Mr. C. L. Buckingham. The received record in the Buckingham printer is made on the ordinary telegraph blank, resembling the Murray printer in this respect. The Buckingham system, which has recently come into commercial use on some lines of the Western Union Telegraph Company, has a maximum speed of about 100 words a minute on the circuit between New York and Chicago. The circuit can be duplexed, giving about double the above capacity.

MURRAY PAGE-PRINTING TELEGRAPH.

TRANSMITTING ARRANGEMENT.

220. Mr. Murray uses a special alphabet, perforating the transmitting tape with a keyboard perforator, having a separate movable lever for each character. Each character occupies an unvarying linear space on the tape, and consists of five perforated and unperforated subdivisions of such space. The difference in the number and succession of these subdivisions or perforations imparts the designating characteristics. There are no spaces between successive letters or characters. Either makes and breaks or reversals can be used in transmitting. It is to this fundamental fact—

all letters of the same length—that the success of the system is due. Each letter occupies half an inch on the

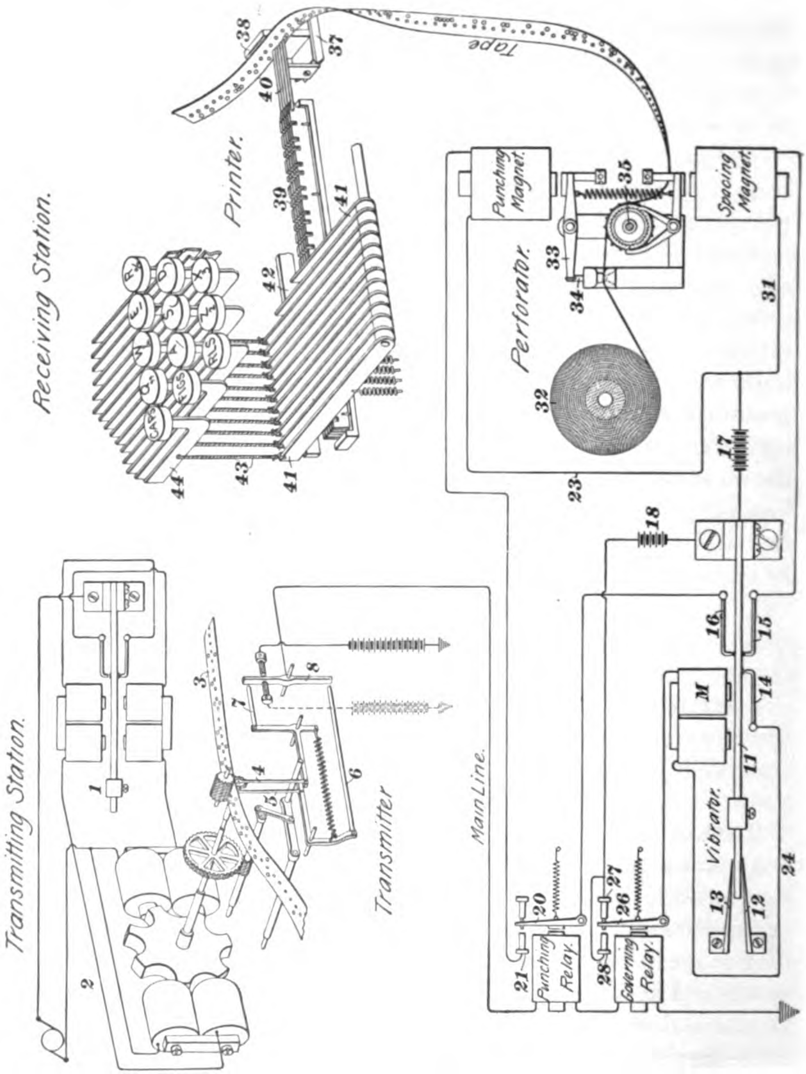


FIG. 74.

transmitting tape, and a similar length on the receiving tape. The result is that a comparatively simple transmitting-tape

perforator worked by an ordinary typewriter keyboard is rendered possible. In connection with the ordinary typewriter keyboard, there is a group of ten punches, one punching magnet, and one spacing magnet that controls a motor-driven escapement.

NOTE.—This description of the Murray page-printing telegraph is an abstract of a paper presented by Mr. W. B. Vansize to the American Institute of Electrical Engineers in January, 1901.

221. Receiving Apparatus.—At the receiving station there is an electromagnetic perforating device that accurately reproduces the transmitting tape by producing corresponding perforations and spaces. This receiving perforated tape passes from the receiving perforator into the typewriter-operating device. This typewriter-operating device consists of five longitudinally reciprocating bars or combs *39*, Fig. 74, presenting five pointed terminals *40*, to a perforated plate or die *38*. The perforated tape passes between the surface of the perforated plate and the pointed terminals of the bars. The pointed terminals of these bars register respectively with the five holes in the die. The tape is moved along between the die and the pointed ends of the bars step by step, the length of a letter or character at each step being, say, ½ inch. When perforations in the tape coincide with the pointed ends of the bars and corresponding perforations in the plate or die, and the plate is moved toward the pointed ends of the bars, the bars may be separated into two groups: one group is moved longitudinally, corresponding with the unperforated subdivisions of the tape; the other group projects through the perforations in the tape and in the die and is unmoved. Lying over the five bars or combs at right angles thereto are a series of thin metal strips *41*; each strip is mechanically connected with its individual key lever on the typewriter. The upper surface of the five bars first described are notched arbitrarily. These notches are caused to be alined below any one of the strips under the control of the perforated tape and die; when any one of the strips drops into a groove, a motor-driven cam engages it and produces a movement of the

typewriter lever. The movement of the die and paper tape and of the typewriter-key lever is produced by motor-driven cams. It will be seen that this mechanism will operate not only a typewriter, but any keyboard machine, such as a typesetting machine or linotype. The perforated receiving tape is, therefore, available for setting type automatically.

222. The Diagram.—In the diagram shown in Fig. 74, the apparatus at the transmitting station is connected by a single main line with the apparatus at the receiving station. The vibrating reed *1* at the transmitting station is in a local circuit with an electromagnetic motor *2*. The reed makes and breaks its own circuit, and is substantially like the well-known La Cour phonic-wheel device used in the Delany and other multiplex systems. The "prickers" *4* and *5*, familiar features in the Wheatstone transmitter, are located as usual in line with the advancing lines of perforations in the transmitting tape *3*; *6* and *7* are reciprocating rods engaging respectively with opposite ends of the centrally pivoted pole-changing switch arm *8*. The parts shown are all essential parts of the well-known Wheatstone transmitter, which is here used practically without alteration, except that the prickers *4* and *5* are arranged to move or reciprocate *together instead of alternately*, thereby enabling any multiple of a single impulse to be transmitted. The ordinary arrangement of the Wheatstone transmitter can only transmit unit signals or odd-number multiples thereof; it can transmit a dot or a dash equal to three or five dots, but cannot transmit a dash equal to two or four dots. Mr. Murray, to avoid this difficulty, arranges the prickers to reciprocate together instead of alternately. There is thus obtainable transmitted impulses or dashes equal to one, two, three, four, or five dots, with corresponding spaces.

223. In transmitting, the number of impulses thrown upon the main line is minimized by producing the impulses locally at the receiving station and using only sufficient main-line impulses to determine the action of the perforator

at the receiving station. At the receiving station there is, therefore, a main-line relay to determine the action of the punching magnet, and a governing relay that operates to maintain unison between the main-line impulses as they arrive and the corresponding impulses in the local circuit. For the purpose of creating these local uniform impulses, there is a vibrating reed *11* (see Fig. 74), operated by an electromagnet *M*. The circuit of this magnet extends from the local battery *18* through the reed *11*, contact point *14*, wire *24*, magnet *M*, armature *26* of the governing relay, and thence by way of the points *27* or *28* to the battery. The precise operation of the governing relay will be described presently. The receiving perforator is composed of a punching magnet and a spacing magnet; the punching magnet operates a spring-retracted pivoted armature bar *33*, mechanically connected with the punch *34*, reciprocating through a guide block and engaging the tape upon the surface of a suitable die, over which the tape passes. The tape is fed along by a star wheel located on a motor-driven shaft *35*, and upon this shaft is an anchor escapement under control of the spacing magnet. The vibrating reed *11* alternately makes and breaks the local circuit of the spacing magnet; this circuit extends from battery *17* to the reed *11*, contact spring *15*, through the spacing magnet and wire *31* to the battery *17*. The punching magnet is in a local circuit with a contact point *16* operated by the vibrating reed *11* and controlled by the contact points of the punching relay, so that while the reed is continually generating local circuit impulses, these impulses are effective to operate the punching magnet at only such times as the punching relay is closed upon its front contact *21*. This local circuit passes from the battery *17* through reed *11* to contact point *16*, thence by armature *20*, contact *21*, through the punching magnet, and wire *23*, to the battery. It will thus be seen that the reed *11* is continually making and breaking two circuits alternately; first, that of the spacing magnet, which is a continuous operation; and second, that of the punching magnet, which is an intermittent operation, rendered so by

the action of the punching relay. This punching relay and also the governing relay may be either neutral relays responsive to makes and breaks or they may be polarized relays responsive to reversals of current; in only the latter case would the battery that is shown dotted at the transmitter be used. As the reed *11* vibrates, the electric impulses in the spacing-magnet circuit permit a steady progressive movement of the tape. Upon the arrival of an impulse of current from the transmitting station, the contact points *20* and *21* of the punching relay are held closed for one, two, three, four, or five times the time interval of one dot length; and while this relay circuit-breaker is closed, the punch *34* operates to perforate the tape as many times successively as permitted by the time length or duration of the transmitted impulse upon the main line. Mr. Murray has thus avoided the necessity of transmitting over the main line all impulses necessary to produce spacing, and all but a fractional part of the impulses necessary to produce the perforations. It is of vital importance, however, to preserve unison between the arriving transmitted impulses in the main line and the local punching and spacing impulses at the receiving station. This is done in the following manner.

HOW UNISON IS MAINTAINED.

224. The governing relay operates a circuit-breaker *26*, moving between two fixed contacts *27* and *28*, electrically connected to the same circuit terminal, so that the moving contact in going from one to the other operates to open the circuit during its time of transit only. This break in the local-vibrator circuit takes place at the beginning and end of each main-line signal, and as the main-line signals arrive at a uniform rate and are of unit or multiple-unit duration, the governing relay operates its break point at uniform unit intervals or multiples of these intervals. In the same circuit in which this break point operates, there is also the

break point *14* of the motor magnet *M*, which works on the familiar buzzer, or vibrating bell, principle. There are thus two break points in the same circuit. If they open and close together, then full vibratory impulses flow through the magnet *M*. If, on the other hand, the rate of vibration of the reed tends to accelerate, or the rate of the arriving current signals tends to lag, then the two breaks occur more or less alternately, and, consequently, less current gets through—the impulses are clipped—and the rate of vibration of the reed is reduced. In practice, the receiving vibrator is set to go 1 or 2 per cent. faster than the rate of the arriving signals, and then the governing action of the two interfering break points in the same circuit results in the establishment of a steady balance between the accelerating tendency of the reed and the retarding tendency of the arriving main-line signals. By this arrangement, the necessity for sending correcting impulses over the main line to secure synchronism is avoided, the correcting impulses being obtained locally with the co-operation of the main-line signals themselves.

It is to be understood that movable weights are present upon each reed, that of the transmitting station and that of the receiving station, and by varying the position of the weight upon the reed, the rate of vibration and the rate of transmission may be changed. It is necessary in maintaining unison to have a considerable range of variation in the speed of the reed at the receiving station, such variation in speed to be attained in response to variation in the length of current impulses of uniform strength.

225. Constrained Vibration of the Reed.—To secure this result there is placed at or near the free end and upon the opposite sides of the reed, resilient stops, shown at *12* and *13*. These springs receive the reed on each side with a cushioning effect and impart an initial return movement. In explanation of this result it should be stated that the rate of vibration of a reed varies with its length, mass, and the distribution of such mass; increase of

current in the magnet M circuit increases the amplitude of vibration without varying the speed beyond a practically negligible amount due to a slight electromagnetic damping effect. Rigid limiting stops have not proved satisfactory. By the use of resilient stops, the movement of the reed is rendered smooth and uniform; it is freed from the interference due to an impact with a rigid stop, which would act to jar and disturb the normal rate of vibration; and its rate may be varied by varying the length of the current impulses.

226. Shape of Punch.—The shape of the punch for perforating the receiving tape is quite important. The punch shown in Fig. 75 has the best shape.

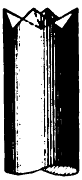


FIG. 75.

227. The Murray Alphabet.—Murray, by using multiple units of current and space (that is, by using several different time intervals instead of only one), has not found it necessary to use reversals. The Murray alphabet is shown in Fig. 76. It will be seen that the uniform time for each letter is divided into 5 equal units or subdivisions, one or more of these 5 subdivisions being a current impulse, so that we get current impulses or spaces of 1, 2, 3, 4, or 5 units duration. Thirty-two possible combinations are obtained in this manner, and by using two of these letter signals as prefixes to the others for capitals, figures, and lower-case letters, about 87 characters may be transmitted. Makes and breaks or reversals may be used, therefore, adapting the system for use in quadruplex transmission, a use not practicable with an alphabet using both makes and breaks and reversals as in Baudot's alphabet. The alphabet, however, is only avaible for machine telegraphy, as it is practically impossible to observe five different time intervals with sufficient accuracy in manual transmission. No space is required between letters in the Murray alphabet, whereas in the Morse a 3-unit space follows each letter. It will be seen upon examination of Fig. 76, that the maximum number of impulses required is 3 for the letter y, and the average number reckoned according to the frequency of the

letters is 1.25 impulses per letter as against 2.59 for International Morse and 5 for the Baudot alphabet, in addition to the necessary correcting impulses to secure or maintain

TABLE OF ALPHABETS

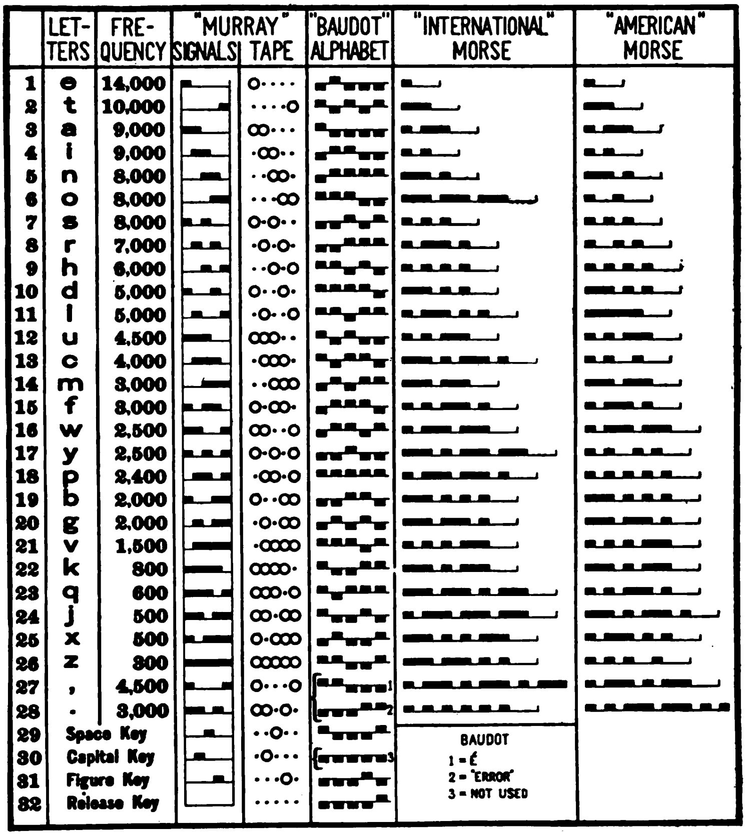


FIG. 76.

synchronism. Murray has the shortest alphabet possible to be constructed from reliable signaling material, and by combining it with machine transmission, the entire time of the line is used in the most advantageous manner possible.

COMPARISON OF ALPHABETS.

228. Referring to Fig. 77, it will be seen that the Murray word is shorter than the Morse in the ratio of 30 to 51, or 41.18 per cent. This is borne out by a comparison made with an actual word, such as Paris. This comparison is made on lines *13* and *14*. It will be observed that in this case the Murray alphabet is shorter than the Morse in the ratio of 30 to 49, or 38.78 per cent. Practically, the two alphabets are in the ratio of 3 to 5. Hence, using the same number and length of current impulses in each case, a speed

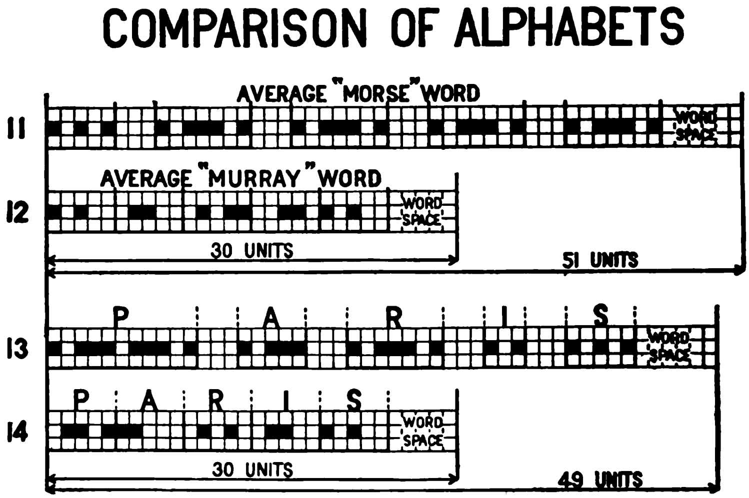


FIG. 77.

of 100 words a minute with the Murray alphabet would not be more than about 60 words a minute in Morse. . The saving in the Murray alphabet lies chiefly in the fact that there is no space between the letters. Indeed, signals in adjoining letters not unfrequently coalesce, as will be seen in the case of the letters p and a in the word Paris, where one current impulse is actually shared by the two letters, and five letters are transmitted by 7 impulses, whereas in the Morse representation of the same word no less than 14 impulses are required.

TESTS OF THE SYSTEM.

229. Speed.—From time to time, as the system developed, careful tests were made of its capacity, both on loops of varying lengths and on circuits between cities. The speeds mentioned below were calculated on the basis of 5 letters to the word and a word space equal to 1 letter. That is to say, the receiving tape fed through the perforator in 1 minute was measured to find the number of letters it contained, and this number was divided by 6. In April and May, 1900, a series of tests were made between New York and Chicago. Working direct from Chicago to New York via Meadville without a repeater, a distance of 1,050 miles by the route of the wire, the best speed attained was 77 words a minute. Working with a repeater at Meadville, much better results were achieved, 102 words a minute being easily attained. The wire used was copper, 208 pounds and 4.5 ohms per mile. Duplex working was readily secured. Attempts were made to reach a speed of 114 words a minute. These were only partially successful, but the results gave promise of a speed of at least 120 words a minute in the future.

The most exhaustive tests of the system were made from October 17 to November 3, 1900, between Boston and New York. Two hundred ordinary commercial messages were transmitted, consisting of 160 business telegrams (including 18 in cipher) and 40 domestic and social. They averaged 10.8 words in the paid portion of each message. Following the usual practice of counting single figures as words, they averaged about the usual rate of 30 words per message; but, counting figures as single letters, and counting all letters by measuring the transmitting tape and dividing by 6, the average was about 26 words per message. These 200 messages were perforated in Wheatstone tape. A column press despatch from the New York "Herald," containing 5,988 letters and 1,261 words, or an average of 4.75 letters per word, was also prepared in Wheatstone tape. This press despatch and the 200 commercial messages were transmitted from Boston to New York day after day at speeds

varying from 60 to 96 words per minute. It was found that the apparatus worked with great accuracy, the whole 200 messages frequently coming through without error. At other times occasional errors occurred, owing to swinging wires and other familiar line troubles common to all telegraph systems.

230. In regard to the number of messages transmitted per hour, in tests made when the apparatus was running at 61 words per minute, the 200 messages came through to New York in 1 hour 23 minutes. This is a speed of about 144 messages per hour, or more than three times the average rate of transmission by the Morse key, 40 messages per hour being regarded as a fair day's work for an average operator. At the 96-word rate the messages came through at about 230 per hour.

The length of the Postal Telegraph Company's lines from New York to Boston is about 290 miles, and the lines include from 20 to 30 miles of cable. Over this comparatively short line the system did not require any readjustment for weather, which varied during the tests from clear and cold to dense fog and rain all the way between the two cities. Duplex working was perfect.

231. It will be seen from the foregoing tests that this system, working at the 60-word rate, has a capacity of 140 messages per hour. Cutting this down to 120 messages per hour to allow for corrections and delays, and working duplex, there is an output of 240 messages per hour, or 50 per cent. more than the Morse quadruplex can achieve.

The tests have shown that, owing to the characteristic alphabet, distances of 1,000 miles are not an obstacle, and the inventor is sanguine enough to believe that it will be possible, though not at present commercially practicable, to work between New York and San Francisco, a distance of 3,000 miles, at a speed of at least 40 words a minute, or double the rate of manual transmission.

AUTOMATIC FACSIMILE TELEGRAPH SYSTEMS.

232. The **facsimile telegraph system** is one that transmits the facsimile of a drawing or writing that has been previously prepared upon a flat or smooth surface. The methods usually employed involve a synchronous rotation of two metallic cylinders, one at the transmitting end and the other at the receiving end.

HUMMELL FACSIMILE TELEGRAPH.

233. In 1898 the New York "Herald" experimented with the **Hummell** system of picture telegraphy, and since then the same journal has been making experiments with an improved form of the Hummell apparatus in connection with the Chicago "Times-Herald," St. Louis "Republic," Philadelphia "Inquirer," and Boston "Herald."

234. The apparatus, as described in the "Telegraph Age," consists of a receiver and transmitter, which are similar in appearance and mechanism. The picture to be transmitted is drawn on a heavy piece of metal foil, the lines of the drawing being made with an insulating ink. The foil is then secured on the circumference of a horizontal cylinder on the transmitter, the cylinder being about the size of a typewriter rubber roller. There is a similar cylinder on the receiver, upon whose surface is clamped the paper on which the drawing is to be produced; over this is superposed carbon paper, which is covered in turn by a sheet of thin paper. A style actuated by an electromagnet is adjusted close to the surface of the latter, and each time a current is passed through the electromagnet the style is forcibly pressed against the moving surface of the cylinder and a corresponding mark is made on the two sheets in contact with the carbon paper; the outer sheet serves merely to form a smooth surface for the style and to enable

the operator to see that the picture is being properly produced.

235. The transmitting cylinder passes under a similar style that closes the circuit between the receiving and transmitting ends when it rests upon the foil, and opens the circuit when it passes over the lines drawn with insulating ink, in the latter case causing the style magnet at the receiving end to leave a mark on the paper on the receiving cylinder in the form of a line corresponding to the width of the insulation over which the transmitting style passes. The style at each station is simultaneously advanced at the end of each revolution of the cylinders by a screw of small pitch. If the surface of the foil on the transmitting cylinder were entirely insulated, the receiving style would merely draw a number of parallel lines on the paper corresponding to the turns of the screw, and separated a distance corresponding to the pitch of the screw and the angle through which it is turned at each operation. Four different rates of advance may be given the style, corresponding to as many different angles of advance that may, by appropriate mechanism, be given the screw.

236. The two cylinders have synchronous motion, so that all the marks or lines on the receiving cylinder correspond to widths of insulating ink marks on the transmitting cylinder. Synchronism is obtained as follows: Connected with both receiver and transmitter is an electric motor that, at the end of every revolution of the cylinder, raises a weight that acts upon a clock train when falling and thus gives motion to the cylinder. At the end of each revolution of the transmitting cylinder, a contact is made that locks for an instant the receiving cylinder when it arrives in a position corresponding to a similar position of the transmitting cylinder. Thus it will be seen that each cylinder begins its revolution from identical positions and at the same instant, and as the clockwork of both receiver and transmitter are duplicates, approximate synchronism is maintained during a revolution. Owing to the use of carbon

paper, the lines made by the receiver are of considerable width, and in consequence the resulting picture has but slightly the appearance of being made up of parallel lines.

237. The Hummell apparatus appears to be entirely practicable, and its synchronizing mechanism is quite simple. The apparatus has been worked duplex with success. In one instance, a picture was sent from New York to St. Louis, while one sent from St. Louis was being received in New York, the latter picture, in addition, being received simultaneously at Boston.

DUN LANY FACSIMILE TELEGRAPH.

238. The International Facsimilegraph Company, in which the managers of the Associated Press take an interest, have been developing the facsimile telegraph system patented on August 22, 1899, by P. Dun Lany and Thomas Mills. In transmitting a picture or drawing by this system, it is first stereotyped on a flexible metal plate. The outlines of the picture are exposed, while the remainder of the surface of the plate is covered with a non-conducting paint. The plate is then placed around a brass cylinder 5 inches long and 2 inches in diameter, and the machine, which is operated by an electric motor, is started. An arm bearing a tracer has its base upon a very finely threaded rod. The arm is gradually moved to the left, until the entire picture has been covered by the tracer. Both sending and receiving machines are governed by a simple synchronizing arrangement, so that both machines are automatically regulated in their speed and run exactly together. The tracer at the sending point controls the current on the wire and closes the circuit whenever it comes in contact with the exposed lines of the picture.

239. At the receiving end, the apparatus is similar to that at the transmitting point. The arm projecting over the cylinder, however, is provided with a style controlled

by an ordinary telegraph sounder. Around the cylinder is wrapped several sheets of paper having carbon copying sheets between them. The sounder operating the style causes the latter to bear down upon the cylinder and copying paper, recording the most minute lines in the original picture as the tracer at the sending point passes over them. A portrait was successfully transmitted by this method over a 650-mile circuit between Cleveland and St. Louis.

240. In transmitting written or printed matter, the process is the same, except that the copy is either written or copied on a flexible metal plate, the circuit being broken whenever the tracer strikes the non-conducting ink. In this case the receiving instrument is reversed, so that it records on the paper the opening instead of the closing of the circuit. The synchronizing arrangement is very ingenious. It is said that the operator at the transmitting point, no matter how many receiving machines there may be cut in along the line, can easily correct or regulate the speed of all.

It is claimed that by using an enlarged cylinder, a half or even a full newspaper page, in matrix form, can be placed in a transmitting machine, operated, say, in New York or Chicago, and reproduced simultaneously in practically all the leading cities of the country within a very few minutes.

AMERICAN DISTRICT TELEGRAPH SERVICE.

241. In all large cities there are companies with some such title as in the above heading that enable a subscriber to notify them that a messenger, hack, policeman, fireman, doctor, or some other service is desired at once. The subscriber, by turning the crank on a small *call box* placed in his office, causes a certain special signal or number to be sent to the central office, thereby notifying the central

office exactly what subscriber is calling. The majority of call boxes in use are of this type and are used merely to call for a messenger. However, call boxes are also used that enable the subscriber to notify the central office whether a messenger, doctor, policeman, fire department, or other service is desired. Furthermore, all types of call boxes may be fitted with a return signal whereby the subscriber is notified by the ringing of a bell or by some other signal that his call has been properly received. Lately the telephone is being adapted by some district telegraph companies. A telephone specially connected is installed in each subscriber's office to enable the subscriber to call up the central office and make his wants known. However, the central office cannot usually call up the subscriber nor can one subscriber be furnished with connection to any other subscriber. In other words, there is no provision or intention whatever to enter the telephone-exchange business.

242. Call boxes are made in an almost infinite number of different ways and for various purposes. However, they are invariably connected in series in a circuit that does not normally use the ground as a return conductor. Morse ink or embossing registers are invariably used at the central office to record the calls sent in by the subscribers, and, in addition, a bell or gong is generally used to notify the central-office attendant that a call is coming in.

243. A diagram of connections used in the district telegraph service is shown in Fig. 78, in which the central office and four subscribers' call boxes *A*, *B*, *C*, and *D* are included. At the central office, the line circuit normally includes the key *k*, battery *B*, and relay *R*. If call box No. 42 is properly operated, the line circuit, which is normally closed, will be opened 4 times, and after a proper interval 2 times, thus causing the armature of the relay to close, on its back stop, a circuit containing a local battery *L B*, a Morse ink or embossing register *E*, and a gong *S* 4 and 2 times. Thus a record of the signal 42 is made on the register *E* and at the same time an audible signal is

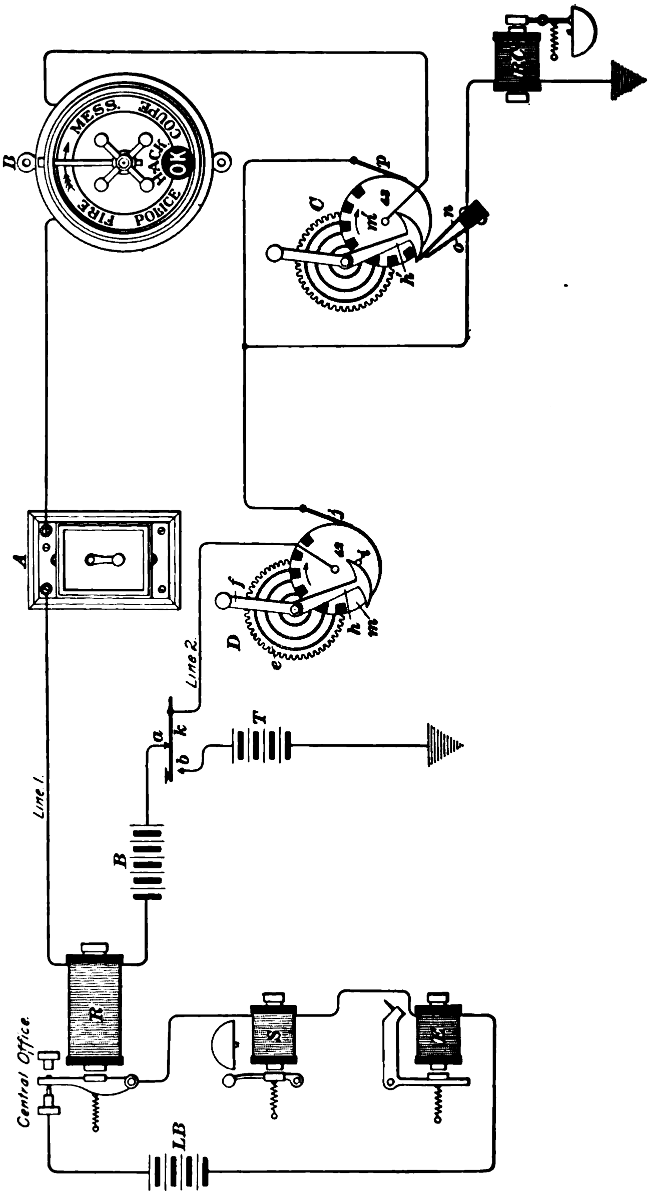

Central Office.
Line 1.
Line 2.
MESS.
COUPE
HACK
OK
POLICE
FIRE
LB

FIG. 78.

made by means of the single-stroke gong or bell *S*. If return-call boxes are used on this circuit at the subscribers' station, the attendant presses the key *k* immediately after receiving the signal, thus sending a current from the return-call battery *T* over the line to the box that has been operated, where a momentary connection to earth affords a return circuit. The batteries *L B* and *T* usually consist of Leclanché cells, and *B* of some form of closed-circuit cells, such as gravity, Gordon, Edison-Lalande, or storage cells, or a converter or motor dynamo may be used. *A* and *D* represent ordinary single-call boxes, *B* and *C* return-signal boxes, *B*, as indicated, having five distinct calls.

244. The mechanism at *D* consists of a gear-wheel *e*, having a spiral spring that is wound up whenever the crank *f* is turned in the act of calling for a messenger. When the crank is released, it returns to its normal position. When the handle *f* is turned, the stop *h* moves out of the path of the pin *i* and the spring propels the mechanism, causing the break wheel *m* to make 1 revolution in the direction of the arrow; the lever *h* coming in the path of the pin *i* stops the wheel at exactly the same place every time. As the wheel revolves, the circuit between the wheel and the brush *j* is broken every time an insulated segment on the periphery of the wheel comes under the brush. Thus at station *D*, the circuit is broken 4 times, and then 2 times, causing the signal 42 to be sent into the central office.

245. Multiple-Call Box.—In a call box such as shown at *B*, by means of which several different calls may be made, the circuit would be interrupted, after the box number would have been sent in, once for a messenger, twice for a coupe, three times for a hack, etc. Upon the periphery of the break wheel there would be, besides those necessary for sending in the box number, such additional insulated segments as are required for the various calls.

246. Return-Call Box.—At *C* in the figure is shown the mechanism of a return-call box. It has two springs *o*

and n that are normally insulated from each other, and also from the break wheel m'. The break wheel when released makes 2 complete revolutions. Upon making the second revolution, the arm h' comes into such a position as to press the two springs n and o together, for a short time only, however. If, while these two springs are in contact, the attendant depresses the key k, a current from the return-call battery T will pass out over line 2, through the springs o and n and the magnet $R C$ of the return-call bell, and returns through the ground. It is necessary with this type of box for the attendant to depress the return-call key as soon as the whole signal is received, otherwise he cannot give the return signal. Return-call boxes may be manual or automatic. In one form of the manual return-call box, the subscriber, after calling, must press his finger on a knob, or push button, in order that the office may signal back. This is done by causing a little ball to tap against a glass disk, thus informing the subscriber that his call has been received.

247. Automatic Return-Call Boxes.—Box B in this figure is an automatic return-call signal box made by the Viaduct Manufacturing Company. When the subscriber calls, the O K disappears and when the office signals back, the O K drops into view, signifying that the call has been received. The return-call magnet has a resistance of about 13 ohms and the normal current due to the battery B is not sufficient to operate it.

248. The **Field and Fireman** return-call box made by the Western Electric Company has provision for sending in as many as 11 different calls. When primary batteries are used with this call box, the arrangement is generally as shown in Fig. 79. At C enough of the box mechanism is shown to enable the student to understand the method of giving the return signal. Normally, the gravity battery B, containing about 14 cells, sends enough current through the circuit to keep the relay energized; and the magnet Rs,

which gives the return signal, is short-circuited by the connection between the spring *b* and the piece *a*. When a call is made by moving the lever *f*, the piece *a* is moved so that

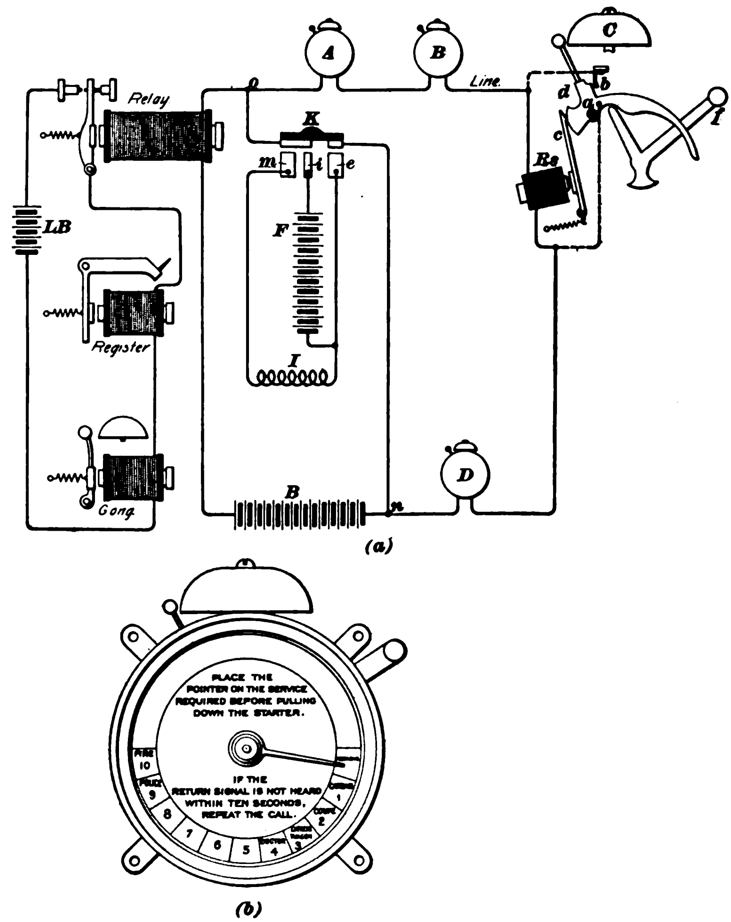


FIG. 79.

the spring *b* is separated from *a*, thus opening the short circuit around *Rs*, and, furthermore, the hook *c* catches at *d* and holds the circuit open between *a* and *b*. The magnet *Rs* is then directly in the line circuit. While the box is in this

condition, just after a call has been completed, the attendant presses a special push-button key *K*, which connects *e* to the line at *n*, and *i* to the other line at *o*. This connects the battery *F* of about 12 Leclanché cells and the large spark coil *I* between *n* and *o*. On account of the high inductance of the coil *I*, almost all of the rapidly increasing initial current from *F* will pass over the line, momentarily energize the return-signal magnet *Rs*, cause its armature to release *a*, the hammer attached to which strikes the gong, and the circuit around *Rs* is closed at *b*. The current is only on a moment while the key *K* is depressed.

249. Many boxes have a provision for temporarily or permanently grounding the circuit in case of a break somewhere in the circuit. By also grounding both sides at the central office, all boxes are still in working condition, but with a ground return, instead of a complete metallic circuit. With metallic circuits, which are the ones generally used, one accidental ground on a circuit does not interfere with the operation of the system. In the case of two grounds on the same circuit, only the call boxes between the two grounds are rendered useless until one or both grounds are removed. It is customary to make regular tests at the central office of every call box about once an hour, in order that grounds and breaks may be detected and removed. It is further customary to have extra relays at the central office that may be instantly cut in the circuit in place of the regular relays, in case any of the latter fail to work. All possible precautions are taken to keep all circuits always in working order.

Switchboards resembling those in telegraph offices are used for connecting the central-office relays, batteries, and test instruments with the various circuits. Although as many as 100 call boxes may be operated in one circuit, it is not customary to connect over 50 in the same circuit. With such a large number there is so much more danger of signals from more than one box being sent in at the same time. In district telegraph systems, usually no provision is made to avoid the interference of one signal with another.

In case it happens and the attendant is unable to recognize one or both signals, there is no remedy, and one or both subscribers must repeat their calls. In case the subscriber has a return-call box, he will know from the absence of a return signal, that he should repeat his call.

M'CULLOH DISTRICT TELEGRAPH SYSTEM.

250. Ordinarily, a break in the line might result either in the cutting out of all call-box stations beyond the break or in making the entire circuit inoperative until the break is located and repaired. To avoid this defect, the arrangement shown in Fig. 80 was devised by Mr. C. F. McCulloh. The boxes have ground connections that are normally open, but the ground connections are closed temporarily when the boxes are operated, and the ground at the central office may be connected to the circuit at any time by the attendant. The boxes are provided with a device for simultaneously making and breaking connections with the main line and with the ground, so that while the line is intact, the current returns over the line wire, but in the event of a break, the return is through the ground. Nothing short of two simultaneous breaks, one on each side of the station, can throw a box out of communication with the central office and even then the other stations on the same circuit are not affected.

251. Operation. — Ordinarily, common pin plugs would be placed in the holes a, b, c, and d, and the switches s_1 and s_2 would be turned to the left so as to connect with the two grounded buttons e_1 and e_2, as shown here for the call-box circuit No. 1 (*C. B. C., No. 1*). The current may be traced from G_1, through e_1, s_1, R_1, t, b, u, call-box circuit No. 1, v, a, w, B_1, G, and finally back to G_1. This is shown in the small detached diagram (z), which is lettered the same as the other part of the figure. The central office is immediately notified if a break occurs on a circuit, because the

current through the relay in that circuit will cease and hence the gong will ring once.

In case there is a break somewhere, as at *y* on the No. 2 circuit, the switch s_2 should be turned to the right in contact

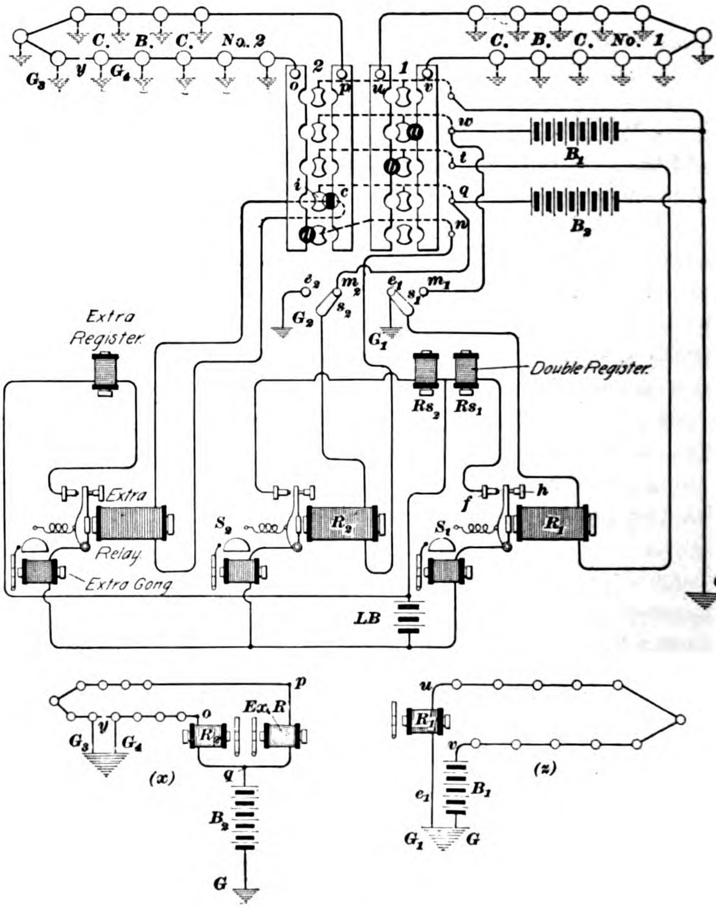


Fig. 80.

with the button m_2. A split wedge, containing the extra relay in circuit with it, should be inserted in the hole *c*, as indicated. This will make two outgoing parallel circuits

worked with the same battery B_2 and a ground return whenever a call box on this circuit is operated. This is clearly shown in the detached small diagram (x), in which the circuit is lettered the same as in the other part of the figure. One circuit may be traced from the battery B_2 through q, i, extra relay, c, p, call-box circuit No. 2, to a ground, as at G_3, at some box from which a signal is being sent and back through the ground to G and the battery B_2. The other circuit from the battery B_2 passes through q, m_2, s_2, R_2, n, d, o, call-box circuit No. 2, to a ground, as at G_4, at some box from which a signal is being sent and back through the ground to G and the battery B_2. Thus stations on both sides of the break can signal the central office.

252. Breaks and Grounds on Line.—The central office is notified immediately a break or ground occurs on an otherwise good circuit. For, suppose a break occurs on circuit No. 1, and that the wire on the side of the break connected to v becomes grounded. When the break occurs, all current will be cut from the relay R_1, the gong S_1 will sound, and the register Rs_1 start. The attendant recognizes that the one side is open and can test to determine whether the other side is grounded or open by inserting in the hole a a split wedge, containing in circuit with it an extra relay.

If the No. 1 circuit is grounded on the v side of the open circuit, the extra relay will be energized; if open, it will not be energized. If the side connected to u [see diagram (z)] becomes grounded and the other side opens, there will be no current in either R_1 or in the extra relay, because now no current flows from B_1 in either side of the No. 1 circuit. In this case, the register Rs_1 and the extra register will run until stopped. In case of an open circuit and the registers start, the local circuit should be transferred from the back stop f to the front stop h of the relay to stop the register and also in order that the gong will sound when the break is repaired and the relay is again energized.

253. Double-pen ink registers are commonly used in district telegraph offices. The one local battery $L\ B$

supplies current for the three local circuits. A good form of open-circuit cell, storage batteries, or converters may be used at *L B*. B_1 and B_2 should be closed-circuit cells, storage batteries, or converters. Whenever storage batteries or generators are used, resistances and fuses to limit the current to a safe strength should be connected in each circuit.

M'CULLOH SYSTEM WITH DYNAMOS.

254. The connections of the McCulloh system, as used in Denver, where dynamos are used, replacing 175 gravity and Leclanché cells, is shown in Fig. 81 (*a*). The momentary grounding of each call box when operated made it necessary to place the 400-ohm relay that controls the register recording the call on the same end of the circuit with the generator. On this account the arrangement shown here was made to enable the operator to at once detect a ground, heavy escape, or break in the circuit. There is a 400-ohm relay that controls the register on the dynamo end and a 150-ohm relay that controls a vibrating bell on the ground end of each circuit. Both the register and vibrating bell are normally connected to the back contact stops of their respective relays, enough current being used to keep both the relays closed. However, the local contact stops of the relays are so connected that either the front or back stop may readily be used as the occasion demands.

255. There are fourteen circuits in the Denver system; the current for all of them is supplied by a motor dynamo giving 24 volts, the positive brush being connected toward the line. The current is reduced by means of resistance lamps to such a strength that it will not magnetize the 13-ohm coil of the answer-back signal magnet in the subscriber's box sufficiently to cause the O K sign (see *B*, Fig. 78) to drop into view.

The answer-back push button when pressed down grounds the end of the circuit just outside of the 150-ohm relay, and at the same time connects 170 volts positive to the other

end of the line just outside the 400-ohm relay. Enough current is thus forced through the circuit containing the

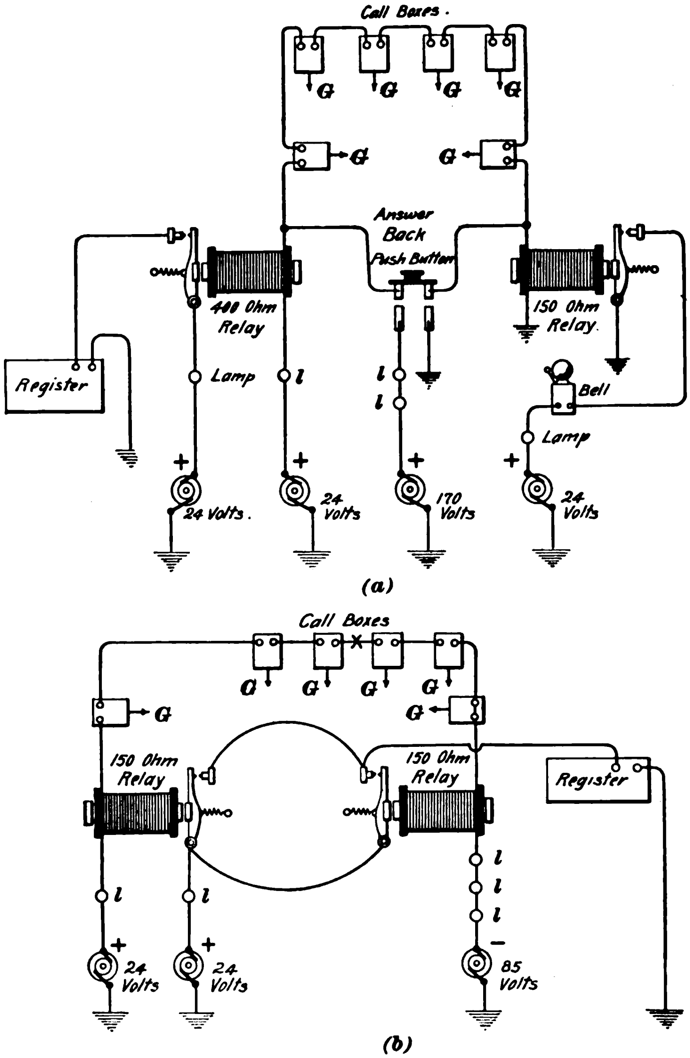
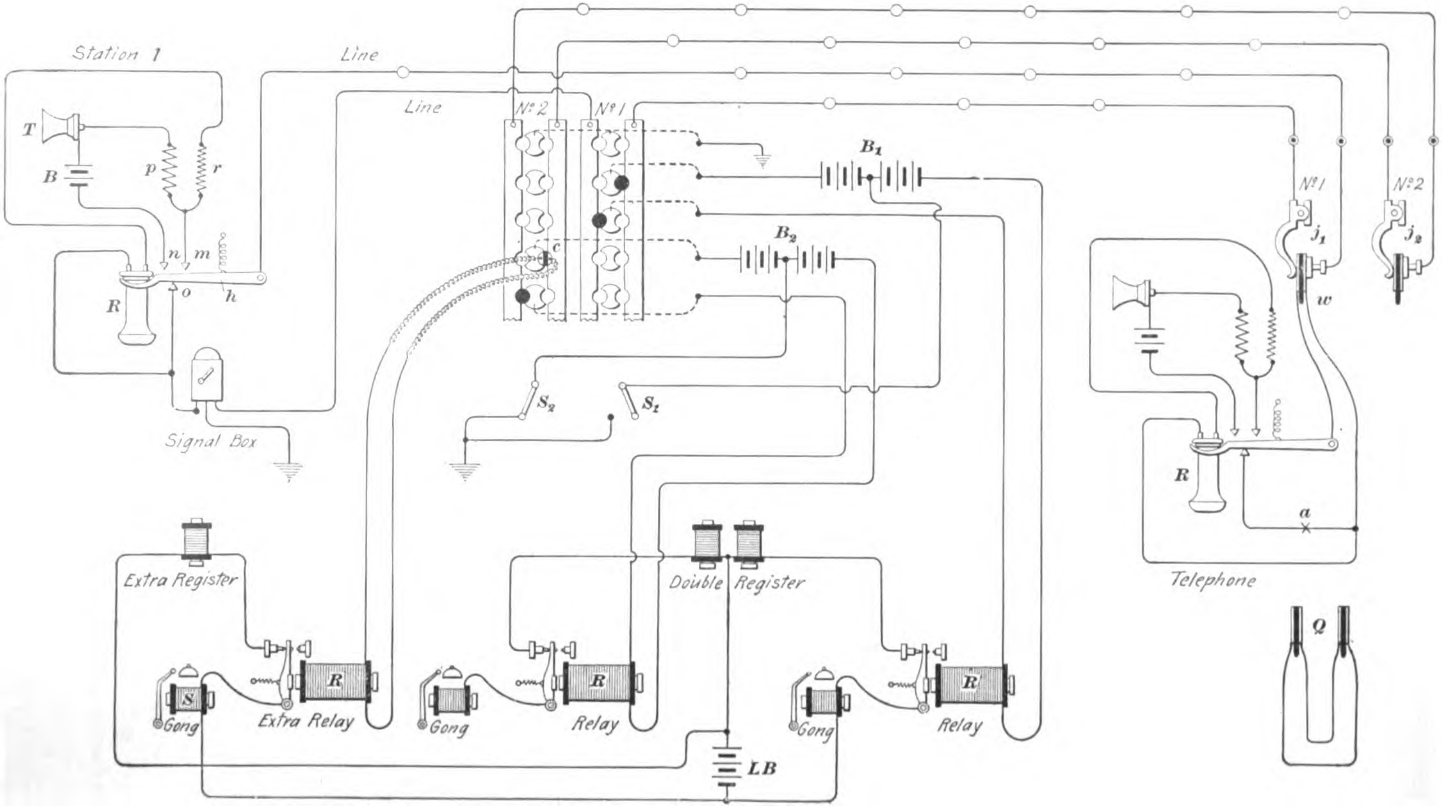


FIG. 81.

13-ohm coil of the answer-back signal in the call box to release the catch and drop the O K sign into view.



Station 1
T
B
p
r
n
m
h
o
R
Signal Box
Line
Line
N° 2
N° 1
c
B_1
B_2
S_2
S_1
N° 1
N° 2
j_1
j_2
w
R
a
Telephone
Q
Extra Register
S
R
Gong
Extra Relay
Gong
R
Relay
Double
Register
Gong
R
Relay
LB

FIG. 82.

256. In case of a ground, escape, or opening of a circuit, the current being cut off from the 150-ohm relay causes the relay to open, thereby closing the local circuit and ringing the bell. The operator at once switches the circuit to a set of so-called McCulloh relays, as shown at (*b*), so that no call will be lost, unless more than one break or ground occurs at the same time on the same circuit. A break is represented in this figure by the cross on the line wire. One of the relays being connected to the 24-volt positive dynamo, the other had to be connected to the 85-volt negative dynamo, no smaller negative voltage being available, and opposite polarities being desirable, so that the two relays will close when a break on the circuit is repaired. The operation of either relay will work the register. The switchboard, which is a collection of small spring jacks, having 14 jacks for each circuit, was made expressly for these circuits, and is so wired that changes may be rapidly made from the regular relays to McCulloh sets, making it almost impossible for a call to be lost.

TELEPHONE IN DISTRICT TELEGRAPH SYSTEM.

257. The telephone is coming more and more into use every day in district telegraph, police, fire-alarm, and railroad systems. In Fig. 82 is shown an arrangement introduced by the Viaduct Manufacturing Company for the use of the telephone in the district-telegraph service. The circles in the line circuits represent subscribers' stations. The connections at one subscriber's station are shown in full at the left. Besides the usual strap switchboard, relays, registers, gongs, and batteries at the central office, there is also a spring jack in each loop circuit and a few telephones connected, as shown at the right side of the figure, to wedges or plugs *w*, and a number of plugs connected in pairs, as at *Q*. Normally, there is no wedge in the jack and the receiver *R* rests on the regular telephone hook switch. In this state of affairs any subscriber can call up the central office by turning the handle of an ordinary single-call signal

box in the usual manner. As soon as the call is received on the register in the No. 1 circuit, for instance, the operator inserts a double wedge *w*, to which a telephone is connected, into the jack j_1. Both subscriber and operator put their receivers to their ears and can then communicate with each other. The subscriber makes his wants known and the operator attends to them. When the receiver *R* is removed from the hook, the lever *h* makes contact with *m* and *n* and parts from *o*. This closes a local circuit containing the battery *B*, the telephone transmitter *T*, and the primary winding *p* of an induction coil. It also connects the receiver *R* and the secondary winding *r* of the induction coil in series in the line circuit.

258. No method is here shown by which the central office can call up a subscriber. If this is done, it requires either an answering battery and key of some kind at *a* and a gong at the signal box or a magneto generator at *a* and a magneto, or polarized, bell at the subscriber's station. It is not absolutely necessary or advisable in some cases to use a hook switch in the telephone at the central office. The telephone-transmitter circuit may be closed permanently during the busy part of the day and the receiver and secondary winding of the induction coil permanently connected to the two sides of the wedge *w*. Plugs, connected together as at *Q*, may be used, by inserting each in a different jack, to interchange the grouping of the call-box circuits. A simple telephone switchboard could be used in place of the jacks and plug circuits shown here.

259. Signaling in Case of a Fault.—Suppose there is an open circuit, or ground, at some point on the No. 2 circuit. By turning the switch S_2 to the left and inserting a split plug, connected to an extra relay, in the switchboard at *c*, subscribers on both sides of the trouble can still signal the exchange. This will put half the battery B_2 and a relay in circuit with each portion of the circuit. A signaling box, such as that made by the Viaduct Manufacturing Company, which makes connection alternately with one line and the

ground when operated, must be used at each station. B_1 and B_2 are main-line closed-circuit batteries; all the other batteries usually consist of Leclanché cells. When this arrangement is equipped to send in fire-alarms, a so-called *slow-motion fire-alarm box* will be used. The mechanism of such a box is constructed so that the signals follow one another slowly, thus allowing the gongs to strike slowly. Fire-alarm boxes usually repeat the number of the box three to five times.

260. The American District Telegraph Company in New York City has introduced on some of its circuits a compact signal and telephone instrument. The telephones are worked upon a common-battery system, there being no battery for the telephone transmitter at the subscriber's station, all batteries being located at the central office. On each box are two push buttons, one on each side of the instrument for connecting either side of the line to the ground. By pushing one or the other of these buttons in case of an open circuit on the loop, communication may still be maintained with the central office.

TESTING.

ROUGH TESTS.

261. The testing of circuits and apparatus is an important matter in all branches of electrical work. The general methods described in *Electrical Measurements* are, as a rule, directly applicable to telegraph work, but more specific directions will be given here. In testing either lines or apparatus, it is frequently necessary to make rough tests to show whether or not circuits are continuous or broken, or whether they are crossed, grounded, or properly insulated. These tests do not require accurate measurement, they being merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

MAGNETO TESTING SET.

262. A very common and useful form of testing instrument is that consisting of a magneto generator and polarized bell, together with some simple form of telephone, all mounted compactly in a box provided with a strap for convenience in carrying. Such an outfit is shown in Fig. 83. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt. The circuits of a convenient form of magneto-testing set having an automatic shunt are shown in Fig. 84.

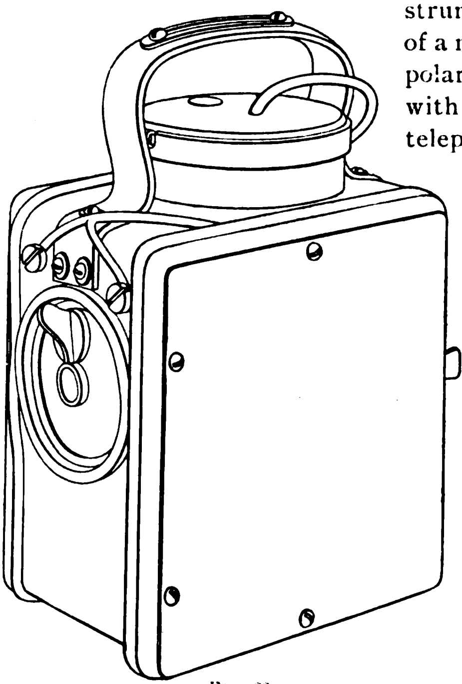


FIG. 83.

263. The polarized bell *R* is here connected in series with the generator *G* when the small switch *S* is in contact with the center button. When the switch is thrown to the left, the call bell is cut out of circuit and the generator only is connected across the line terminals, this condition being advantageous when it is necessary to signal a distant station over a line that may be partially grounded or crossed. When the generator is at rest and the switch thrown to the right, only the telephone *T* is connected in the circuit between the binding posts *L*, *L'*, the generator being short-circuited by the automatic device. The telephone *T* may then be used either as a transmitter or as a receiver for communicating with another party on the line.

When the handle of the generator is turned, the short circuit around the armature winding is opened and the current from the generator, if the switch is turned to the right, will pass through the telephone and to line, thus producing a buzz in the telephone. By means of this, the party testing can often form some idea of the resistance or capacity of a circuit by the loudness of the buzz produced when ringing through the telephone.

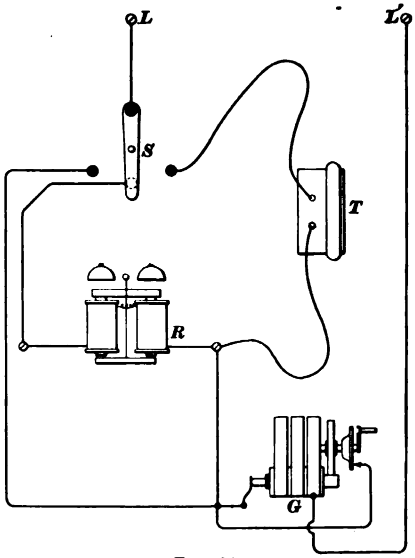


FIG. 84.

264. Continuity Tests.—In testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire and the generator operated, the switch of the testing set being thrown so as to include the bell and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and cables, because it may be that the capacity of the line wires themselves will be sufficient to allow enough current to flow through the bell to operate it even though the line or lines are open at some distant point.

265. Testing for Crosses.—In testing a line for crosses, either with the earth or with other conductors, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under

these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross.

266. An experienced telephone lineman can often tell with considerable accuracy the approximate location of a cross on a line by the sound produced by the bell or by the pull of the generator crank when the generator alone is thrown on the circuit. Here again, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists if the line under test is a very long one. The insulation may be perfect and yet a sufficient current may pass to and from the line, through the bell, to cause it to sound, these currents of course being due to the static capacity of the line itself.

267. In testing very long lines or comparatively short lines of cable, the magneto set must be used with caution and intelligence, on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied on as being accurate. Magneto testing sets are commonly wound in such manner that the generator will ring its own bell through a resistance of about 25,000 ohms. They may, however, be arranged to ring only through 10,000 ohms, or, where especially desired, through from 50,000 to 75,000 ohms. The first figure mentioned—25,000 ohms—is probably best adapted for all-around testing work.

CURRENT-DETECTOR GALVANOMETER.

268. In order to test for grounds, crosses, or open circuits on long lines or on cables without the liability to error that is likely to arise in testing with a magneto set, a cheap form of galvanometer for detecting currents may be used. In testing for grounds or crosses, the galvanometer should be connected in series with several cells of battery, and one

terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the galvanometer needle may take place whenever the circuit is first closed, this being due to the rush of current into the wire necessary to charge it. If the insulation is good, then the needle of the galvanometer will soon return to zero, but if a leak exists from a line to ground or to the other wire with which it is being tested, the galvanometer needle will remain permanently deflected.

Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about 50 cells is used, but if the resistance of an insulation is to be measured in megohms, the methods to be described under the heading of "Accurate Tests" should be followed.

269. In testing for continuity, the distant end of the line should be grounded or connected with another wire known to be good, and the galvanometer and battery applied, either between the wire under test and ground or between the wire under test and the good wire. In this case, a permanent deflection of the galvanometer needle will denote that the wire is continuous, while if the needle returns to zero, it is an indication of a broken wire.

TESTS WITH TELEPHONE RECEIVER.

270. The importance of the telephone receiver as a testing instrument is greatly underrated and, consequently, is not very extensively used. However, a good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than the magneto testing set or the detector galvanometer.

271. Convenient Testing Set.—The ordinary watch-case receiver, with a head-band for attaching it to the ear

of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed, and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat pocket of the user, and if two cells are used, may be bound together side by side by a wrapping of ordinary adhesive tape. One terminal of the battery is connected to one terminal of the head-receiver, while to the remaining terminals may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both hands of the user.

272. Method of Using Receiver.—In using the receiver for making rough tests for grounds or crosses in a cable, one terminal of the testing circuit, including the receiver and batteries, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at each end. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must all be carefully separated from each other and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire, but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, the terminal of the testing set should be tapped against the wire several times in succession; a continuance of the clicks will then

indicate that the wire is grounded, while the cessation of the clicks after a few taps will indicate that the insulation is good.

273. In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires at the near end of the cable, the wires at this end all being carefully separated from one another. A continuation of the clicks upon tapping will in this case indicate that the wire being tested is continuous, while the cessation after a few taps will indicate that it is broken. It is probably better, in making this test, to use an ordinary vibrating bell instead of a receiver, for then, if the wire is only partially ruptured so as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it might allow enough to pass to produce a decided click in the receiver.

IDENTIFYING WIRES IN CABLES.

274. It is frequently necessary when a certain wire has been picked out at one end of a cable to identify that same wire at the other end in order that connection may be made with it. In order to do this, the wire desired should be grounded at one end, being carefully insulated from all the other wires. At the other end the wires should all be separated from each other and be free from the ground. A circuit containing a battery and a receiver or galvanometer detector or ordinary vibrating bell should then have one of its terminals grounded, while the other terminal should be applied successively to the various wires in the end of the cable. A continuation of the clicks in the receiver, a permanent deflection of the galvanometer

detector, or a ringing of the vibrating bell will indicate when the wire desired has been touched.

275. Identifying Without Cutting.—It is frequently desirable to identify a wire at some intermediate portion of a cable without cutting the wire. This may be done by removing the sheath, or the outer coating, if the cable has no sheath, and loosening up the wires so that each one may be touched. The same test as that in the preceding article may then be made by using a needle-pointed terminal to the testing circuit that may readily pierce the insulation and make contact with the conductor within.

ACCURATE TESTS.

MEASUREMENTS OF RESISTANCE.

276. The Wheatstone Bridge.—Measurements of resistance are usually made by means of the Wheatstone bridge, this instrument being very accurate for all resistances except those very large or very small, and possessing the additional desirable features of great simplicity and portability. The methods of using the Wheatstone bridge have been sufficiently treated in *Electrical Measurements*, and need not be further dealt with here. It may be said, however, that the form of bridge best adapted for general testing purposes has a rheostat capable of being adjusted to any resistance from 1 ohm to about 11,000 ohms. The arms by which the ratio is obtained should be capable of having the values of 10, 100, and 1,000 ohms, thus being able to obtain multipliers from $\frac{1}{100}$ to 100.

277. The galvanometer for ordinary resistance measurements is preferably mounted in the same case as the resistance coils of the bridge and with the keys for opening and closing the galvanometer and battery circuits. The galvanometer most suited for this work consists of a special

form of D'Arsonval, in which the coil forming the needle is suspended in the field of a powerful permanent magnet. These galvanometers have the advantage of not being affected by the proximity of other magnetic fields, and are, moreover, quite sensitive. Of course, for the most accurate tests, some form of reflecting galvanometer should be used. In some portable bridges, a battery is mounted in the same case with the other parts of the apparatus, this forming a very desirable feature and adding greatly to the ease with which rapid tests may be made, inasmuch as it is not necessary to carry extra batteries and to connect them up every time a test is to be made.

278. High Resistance by Wheatstone Bridge.—It is sometimes desirable to determine by means of a Wheatstone bridge a resistance that is too high to be measured by it in the ordinary direct manner. Provided another resistance is at hand that can be accurately measured by the bridge, the unknown resistance, if not too high, may be determined in the following manner: First measure the lower resistance and let it be y ohms. Then connect this resistance y in parallel with the high unknown resistance and measure the combined resistance of the two joined in parallel and let this be z ohms. Then, if x is the unknown high resistance whose value is desired, we have

$$z = \frac{xy}{x + y},$$

from which we get

$$x = \frac{yz}{y - z}. \qquad \textbf{(3.)}$$

Where x alone is higher than can be directly measured on the bridge, y should be as high as can be *accurately* measured on the bridge, or as high as can be obtained, say at least several thousand ohms. When y is accurately known or measured and x is not too high, this is a very good method. This method may be used to check up resistances that have been measured separately.

279. Measurement of Line Resistance.—In measuring the resistance of a line by means of the Wheatstone bridge, the terminals of the line circuit should be connected in the unknown arm of the bridge. Sometimes it occurs in the case of a grounded circuit that earth currents will interfere to such an extent as to render accuracy impossible. In this case, if a parallel wire is available, the resistance of which is known, they may be connected together at the distant end and the resistance of the two in series measured. The resistance of the first will then be the difference between the total measured resistance and that of the known wire.

280. Line Resistance.—A method for measuring the resistance of a line wire was given in *Electrical Measurements*. A better method, where there are three or more line wires, or two line wires and a ground circuit, between the same two offices is as follows: Let the resistance of three line wires be x, y, and z, respectively. At the distant station have the ends of x and y joined together. Then, by means of a Wheatstone bridge at the home station, measure the resistance of the loop so formed and let it be a ohms. Then have the distant ends of x and z joined and measure the resistance of this loop, calling it b ohms. Similarly, have the distant ends of y and z joined, measure the resistance of this loop, and call it c ohms.

Then,

$$x + y = a.$$
$$x + z = b.$$
$$y + z = c.$$

Solving these equations for x, y, and z, we get

$$x = \frac{a + b - c}{2}. \qquad (4.)$$

$$y = \frac{a + c - b}{2}. \qquad (5.)$$

$$z = \frac{b + c - a}{2}. \qquad (6.)$$

Hence, the resistance of any one or of each one of the the three line wires may be calculated from these three measurements.

281. Resistance of Ground-Return Circuits.—The resistance of the ground-return circuit may be measured by the preceding method when there are two line wires between the same two offices. Let the resistance of the two wires be x and y ohms, respectively, and that of the ground circuit be z ohms. Measure the resistance of the loop formed by having the two distant ends of the two line wires joined together and call it a ohms. Then have the x wire grounded at the distant office and measure the resistance between the home ground plate and the home end of the x wire, and call it b ohms. Similarly, have the distant end of the y wire grounded, and measure the resistance between the home ground plate and the home end of the y wire, and call it c ohms. Then the resistance of the ground return z may be calculated by formula **6.** Usually most of this resistance z is located at the contact surfaces between the plates and the ground, as already explained in *Telegraphy*, Part 2. The resistance of a good ground return should not exceed 10 ohms. It is evident that we may also obtain the resistance of the two line wires by substituting the quantities a, b, and c in formulas **4** and **5.**

EXAMPLE.—It was desired to measure the resistance of two wires x and y, and also the resistance of the ground path z between two stations A and B. The party making the test at A instructed station B to join the wires x and y together. A measurement of the resistance of the loop so formed was made at A with a Wheatstone bridge, giving 2,490 ohms. The operator at B was then instructed to ground the wire x, and the operator at A measured the resistance between his end of the wire x and his ground; this gave 1,270 ohms. The operator at B was then instructed to ground the wire y, and the operator at A found the resistance between his end of y and his ground to be 1,300 ohms. What was the resistance of each wire and of the ground path?

SOLUTION.—By formulas **4, 5,** and **6,** in which $a = 2{,}490$, $b = 1{,}270$, and $c = 1{,}300$, we get the desired resistances:

$$x = \frac{2,490 + 1,270 - 1,300}{2} = 1,230 \text{ ohms};$$

$$y = \frac{2,490 + 1,300 - 1,270}{2} = 1,260 \text{ ohms}.$$

The ground path

$$z = \frac{1,270 + 1,300 - 2,490}{2} = 40 \text{ ohms}. \quad \text{Ans.}$$

282. Elimination of Earth Currents.—Earth currents will often render measurements of line resistances, where the ground is used as a part of the circuit, as in the last method, very unreliable. These currents may oppose or aid the testing current. When the earth currents are fairly steady, their effect may be eliminated by making a measurement, then reversing the battery and making another measurement. The average of the two measurements should be taken as the resistance of the circuit. For good results, the earth current should not only be steady but it should also be small compared with the testing current.

INSULATION TESTS.

283. In making insulation tests, the general methods outlined in *Electrical Measurements*, under the heading, "Insulation," may be followed in some cases. The method generally used, together with the proper apparatus, will, however, be described here in some detail.

284. Galvanometer.—For tests of extreme accuracy, the Thomson or sensitive reflecting galvanometer is best suited, but the use of this instrument is attended with many difficulties that render it unfit for many forms of practical work. As a laboratory instrument, however, where it can be properly shielded from the magnetic fields set up by neighboring electrical machinery or by trolley or lighting circuits, this instrument is unexcelled. The D'Arsonval galvanometer, however, is sensitive enough for nearly all practical work, and possesses the advantage of being

entirely free from the effects of external fields. It is now made in portable form, so that it can be unpacked and set up in a few moments.

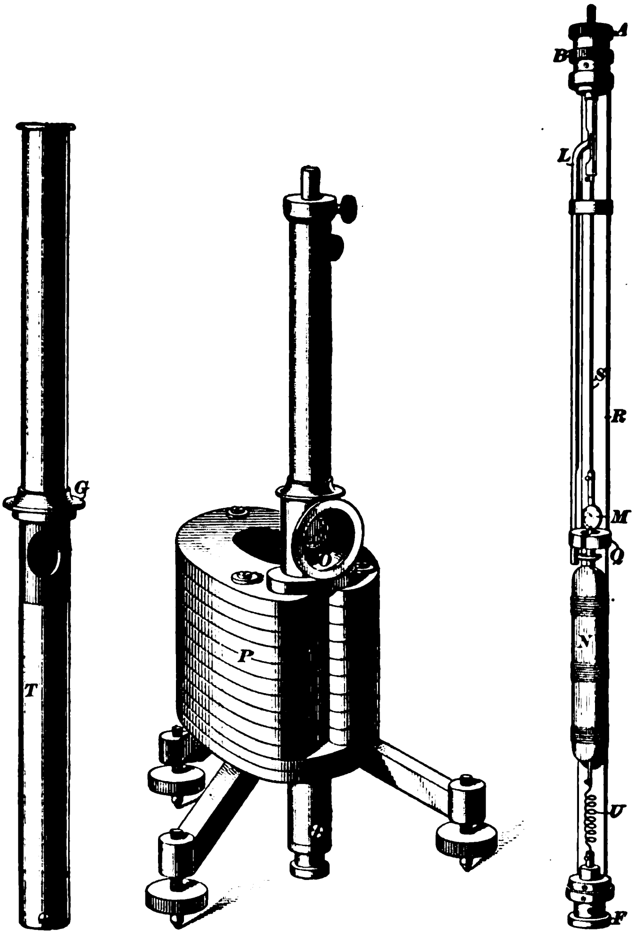


FIG. 85.

285. D'Arsonval Galvanometer.—One form of D'Arsonval galvanometer used in this country is shown in Fig. 85, in which *P* are the permanent magnets by which the field of force in which the coil is suspended is maintained.

The needle and suspension are mounted within the tube *T*, shown at the left-hand portion of this figure, this tube being removable from the frame of the instrument when it is desired to make any changes or repairs of the working parts within. The system, as the coil *N* and its supporting parts are termed, is shown in detail at the right of the figure. *R* is a rib supporting at the top and the bottom the torsion heads *B* and *F*. The rectangular coil *N* consists of many turns of fine wire, and secured to it above is a mirror *M* for reflecting a ray of light through the window *O*

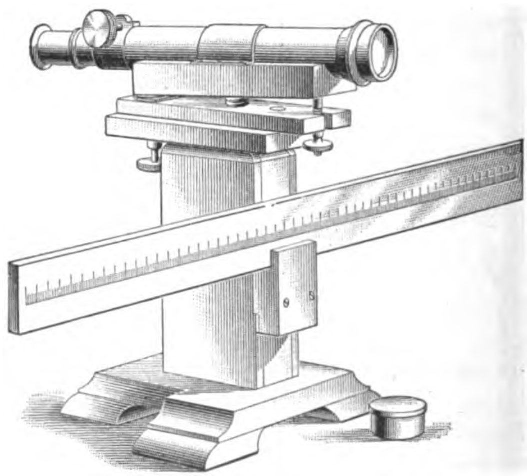


FIG. 86.

of the frame. The coil is suspended by a straight, elastic fiber *S* of some conducting material, such as phosphor-bronze, while the lower part of the coil is connected by a coiled spring *U*, usually of the same material, with the lower torsion head *F*. Current is led through the coil *N* by means of the suspension fiber *S* and the coil spring *U*. The torsion of the suspending fibers tends to hold the coil in a certain normal position, which position may be regulated by turning the torsion heads *B* and *F*, usually by turning *B* alone. When it is desired to move the instrument, the thumbscrew *A* at the top of the system may be tightened,

thus drawing up the rod L and causing the fork carried by its lower end to engage a disk Q, which raises the coil just enough to remove its weight from the suspension fiber S.

This galvanometer is used in the same manner as the reflecting galvanometers described in *Electrical Measurements.* The lamp and scale may be used as shown in Fig. 988 of that section, but a better way is to mount a telescope carrying a horizontal scale directly in front of the galvanometer, in such manner that portions of the horizontal scale will be reflected by the mirror of the galvanometer into the tube of the telescope. Such a telescope and scale combined is shown in Fig. 86. Special scales are provided for this purpose, the numbers on which are reversed, so that when a reflection in the mirror is viewed through the telescope, they will appear normal. This method of reading the galvanometer is more desirable than that using the lamp, because the readings may be made with greater accuracy by means of a cross-hair in the telescope, and, further, because the presence of a lighted lamp is not always necessary. However, a lamp placed to illuminate the scale (not the galvanometer mirror) will often render the reading of the scale much easier.

286. Galvanometer Shunts.—The shunt accompanying the galvanometer should, of course, be adjusted to the particular resistance of the galvanometer coil, and should preferably have multiplying values of 10, 100, and 1,000.

287. Method of Measuring Insulation Resistance.—The method usually followed of measuring insulation resistance with a galvanometer is to first obtain the deflection through a known resistance, using a suitable known shunt around the galvanometer, with the given battery, and from it to calculate the deflection in scale divisions that would be produced were the entire current of the same battery to pass through the galvanometer and a resistance of 1 megohm. This latter quantity is called the *working constant* of the galvanometer. After the working

constant is obtained, the deflection is taken with the insulation resistance of the line or cable substituted for the known resistance. In taking the galvanometer constant, it is usually necessary to use the shunt having a multiplying power of 1,000 (called the $\frac{1}{999}$ shunt), for otherwise the deflection would be too large to be readable.

288. Taking the Constant.—The circuits for taking the galvanometer constant are shown in Fig. 87, where G is the galvanometer, S the shunt, B a battery of 50 or 100 cells, and R a standard resistance, usually of 100,000 ohms, i. e., $\frac{1}{10}$ of a megohm. Upon closing the key K, a certain deflection d will be noted upon the galvanometer. If the shunt used has a multiplying power of 1,000, it is evident that without the shunt the deflection would have been 1,000 times as large, could it have been measured. Further, if a resistance of 1 megohm had been used instead of $\frac{1}{10}$ megohm, the deflection would have been only $\frac{1}{10}$ of d. Therefore, we may say that the deflection K produced by the current from the battery, passing through 1 megohm and through the galvanometer, without the shunt, would have been

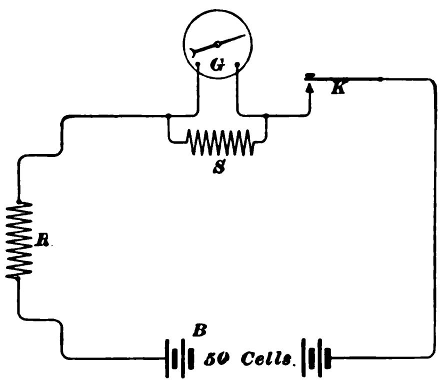


FIG. 87.

$$K = \frac{1,000 \times d}{10}.$$

If m represents the multiplying power of the shunt, d the deflection, and R the resistance *expressed in megohms*, then the constant K may be expressed by the formula

$$K = R \times m \times d. \qquad \textbf{(7.)}$$

The following general rule, therefore, may be given for calculating the constant:

Multiply the deflection by the multiplying power of the shunt and by the resistance in the standard resistance box expressed in megohms or a fraction thereof.

In the case just cited, if the deflection d was 197 scale divisions, then the constant K would be equal to

$$197 \times 1{,}000 \times \tfrac{1}{10} = 19{,}700.$$

EXAMPLE 1.—In taking the constant, a $\frac{1}{10}$-megohm box was used and a deflection obtained of 247 scale divisions, the multiplying power of the shunt being 1,000. What was the constant ?

SOLUTION.— $247 \times 1{,}000 \times \frac{1}{10} = 24{,}700$. Ans.

EXAMPLE 2.—In taking the galvanometer constant, a deflection of 143 scale divisions was obtained through a standard resistance of 2 megohms, the multiplying power of the shunt being 100. What was the constant ?

SOLUTION.— $143 \times 100 \times 2 = 28{,}600$. Ans.

289. Deflection Through Insulation.—After taking the constant, the insulation resistance of the cable or line is substituted for the standard resistance, the connections being then substantially those shown in Fig. 88. All the wires of the cable, except the one being measured, should be bunched together and connected with the sheath, the sheath itself being grounded. At the start use, as a precaution, a small shunt, the $\frac{1}{999}$ or the $\frac{1}{99}$, whose multiplying powers are 1,000 and 100, respectively, and increase the resistance of this shunt until a suitable deflection is obtained. If the insulation resistance is rather high, usually no shunt (that is, a shunt of infinite resistance) will be required, and the shunt box can be cut out entirely, which is done by removing all the movable plugs. Upon

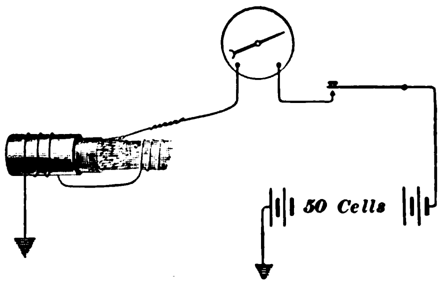


FIG. 88.

the closure of the key, a certain deflection of the galvanometer will be obtained at once, but this deflection, instead of remaining constant as it did with the circuits shown in Fig. 87, will be seen to slowly diminish, this being due to the electrification of the cable. The diminishing deflection would seem to indicate that the insulation resistance of the cable was increasing by the passage of the current; but this effect is due to electrification, which phenomena, as was pointed out in *Electrical Measurements*, is not thoroughly understood, but may be stated as being in the nature of a soaking in of the charge of electricity into the insulation. After about half a minute, on a short length of ordinary telephone cable, the electrification will practically have ceased; but the rule is, in taking insulation resistance, to allow one minute for electrification, after which the reading is taken.

290. Calculation of Insulation Resistance.—In making insulation tests at the factory, the whole cable, excepting the two ends, of course, is submerged in a tank of salt water. The manufacturers generally use as high as 200 volts in making this test. This requires a known resistance of 500,000 ohms (half a megohm) and the $\frac{1}{999}$ shunt of the galvanometer in order to obtain the constant K.

The constant K was obtained by calculating the deflection that the given electromotive force would have produced if the total resistance of the circuit were 1 megohm and no shunt had been used around the galvanometer. In taking the deflection through the insulation resistance, a certain deflection at the end of one minute was observed, which will be called d', the galvanometer shunt this time being one whose multiplying power will be called m'. Without this shunt it is evident that the deflection would have been m' as large, i. e., $m' \times a'$, could it have been measured directly. It is also evident that the deflections, if no shunts are used, will vary inversely as the resistance in the circuit with the galvanometer, and, therefore, where X is the required insulation resistance, the following proportion will hold:

$$X : 1 :: K : d' \times m'.$$

Solving for X, we have

$$X = \frac{K}{d' \times m'}. \qquad (8.)$$

That is, *the insulation resistance is equal to the constant of the galvanometer divided by the product of the multiplying power of the second shunt used and the deflection obtained through the insulation.*

When the shunt resistance has an infinite value, that is, when it is cut out of the circuit and no shunt is used, the value of m' is 1. In such a case, X would be simply the constant K divided by the deflection d'.

291. This method is not strictly accurate, because the combined resistance of the galvanometer and shunt should be added to that of the known resistance and to that of the insulation resistance in making the computations. However, the error introduced by neglecting this is usually so small that it is always neglected in making ordinary insulation tests.

In order to determine the insulation resistance per mile, multiply the insulation resistance of the cable as measured by its length expressed in miles or a fraction thereof.

EXAMPLE 1.—In taking the constant of a galvanometer for an insulation test, a deflection of 184 scale divisions was obtained with a $\frac{1}{10}$-megohm box and with a multiplying power of the shunt of 1,000. The deflections, taken through the insulation resistance of 3 wires, one at a time, in a cable 10,123 feet long, with a shunt whose multiplying power was 10, were as follows: 23, 19, and 25 scale divisions, respectively. What was the insulation resistance of each of the wires?

SOLUTION.—The constant of the galvanometer is equal to

$$184 \times 1,000 \times \tfrac{1}{10} = 18,400.$$

Insulation resistance, first wire, $\frac{18,400}{10 \times 23} = 80$ megohms. Ans.

Insulation resistance, second wire, $\frac{18,400}{10 \times 19} = 96.84$ megohms. Ans.

Insulation resistance, third wire, $\frac{18,400}{10 \times 25} = 73.6$ megohms. Ans.

EXAMPLE 2.—What is the insulation resistance per mile of each of the wires in the preceding example?

SOLUTION.—Length of cable $= \frac{10,123}{5,280} = 1.917$ miles.

Insulation resistance per mile, first wire, $80.0 \times 1.917 = 153.36$ megohms. Ans.

Insulation resistance per mile, second wire, $96.84 \times 1.917 = 185.64$ megohms. Ans.

Insulation resistance per mile, third wire, $73.6 \times 1.917 = 141.09$ megohms. Ans.

MEASUREMENT OF LINE CAPACITY.

292. The simplest and probably the most satisfactory method for measuring the capacity of a line or cable is to compare the capacity to be measured with that of a standard condenser. It is first necessary to obtain the deflection of the galvanometer needle when the standard condenser is

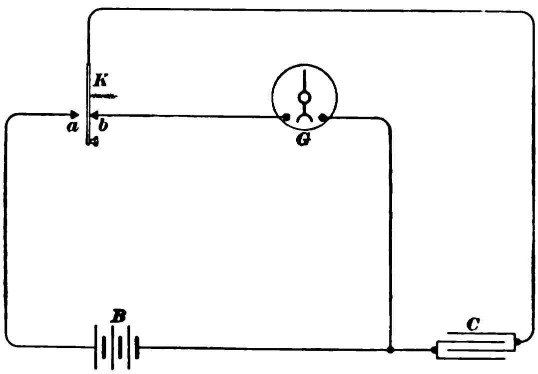


FIG. 89.

discharged through it. For this purpose the apparatus is arranged as shown in Fig. 89, in which *G* is the galvanometer, *C* the standard condenser, *B* a battery of from 1 to 15 cells, and *K* a discharge key resting normally against the contact *b*, but capable of being depressed against the contact *a*. The capacity of the condenser *C* should, if possible,

be adjustable from about $\frac{1}{10}$ to 1 microfarad, but in case an adjustable condenser is not available, one having a capacity of about $\frac{1}{10}$ microfarad will be found most suitable for telephone work.

When the key is depressed, a current from the battery charges the condenser. The charging should be allowed to continue for about 15 seconds, in order to give the charge a chance to soak in. The key should then be suddenly released, which will establish such connections as to allow the condenser to discharge through the galvanometer. A certain throw or kick of the galvanometer needle will take place, and this extreme reading should be noted down.

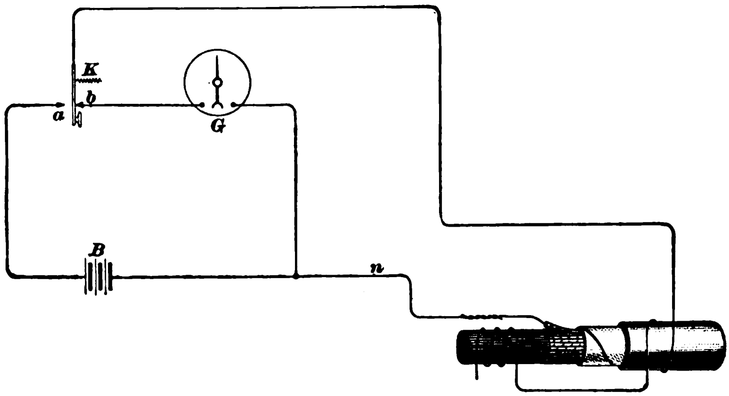


FIG. 90.

Several readings should be taken to avoid error and to obtain an average. The cable or line is then substituted for the condenser, as shown in Fig. 90, where the wire *n* leading from the galvanometer and battery is connected to the wire of the cable to be measured, all the other wires being insulated from it and connected with the sheath of the cable. The key *K* should be connected to the sheath, as shown. If the line whose capacity is being measured is of bare wire, the wire *n* from the battery and galvanometer should be connected to it, while the wire from the key should be grounded. Several readings are then taken on the galvanometer, and the average of them obtained as before.

Between readings, the condenser or line, as the case may be, should be fully discharged by holding the key in the discharging position for at least 5 seconds.

If no shunt is used on the galvanometer, or if the same shunt is used in each case, the two capacities will vary in proportion to the respective readings of the galvanometer; thus, calling d the deflection obtained with the standard condenser, d' that with the cable, Q the capacity in the standard condenser, and Q' the capacity of the cable, we have

$$Q' : Q :: d' : d;$$

or,

$$Q' = \frac{Q \times d'}{d}. \qquad \textbf{(9.)}$$

If it is necessary to use a shunt in taking the readings from the cable or condenser, the corresponding deflections should be multiplied by the multiplying power of the shunt before using them in the formula. The use of a shunt in capacity tests should be avoided if possible.

The capacity per mile is found by dividing the total capacity by the length of the cable in miles. The best results are obtained when the capacity of the standard condenser is very nearly equal to that of the condenser, and the deflections therefore nearly the same.

EXAMPLE.—A test was made to determine the capacity of a cable. The capacity of the standard condenser was 1 microfarad. The deflection or throw from the standard condenser was 37 divisions, and that from the cable was 42. What was the capacity of the cable?

SOLUTION.— $Q' = \frac{42 \times 1}{37} = 1.135$ microfarads. Ans.

LOCATION OF FAULTS.

293. Faults on a line may be of two kinds: The line may be entirely broken or it may be unbroken, but in contact with some other conductor or with the ground. The former fault is termed a *break;* the latter, a *cross* or *ground.*

294. A **break** may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired so as to form a cross or ground. A **cross** may be of such low resistance as to form a short circuit, or it may possess high resistance, thus forming what is termed a *leak*. The location of faults is a matter often involving much ingenuity and mathematical knowledge. Some methods for locating between what two offices a fault occurs were given in *Telegraphy*, Part 2, under the heading "Tests With Relay and Key." For locating the ordinary faults, such as usually occur on lines or cables, the following methods may be relied on.

TESTS FOR LOCATING A BREAK.

295. The location of a break in a wire can be determined by capacity tests, as the capacity of the part of a wire bears the same relation to the capacity of the whole wire as the length of the part does to that of the whole.

When one good wire, having the same capacity per mile, is accessible, a condenser need not be used, but, instead, deflections may be taken on the broken wire and on the good wire. Let D be the throw on the broken wire and D' the throw on the good wire. L is the distance to the break and L' the total length of the good wire. Then,

$$D : D' :: L : L';$$

or,

$$L = \frac{D \times L'}{D'}. \qquad \textbf{(10.)}$$

EXAMPLE 1.—A test was made to find a break in a cable conductor near to which ran another sound wire. The throw on the broken conductor was 35 divisions and that on the good wire was 80 divisions. What was the distance to the break, the total length of the cable being 3,100 feet?

SOLUTION.—Using formula **10**,

$$L = \frac{35 \times 3,100}{80} = 1,356 \text{ ft. Ans.}$$

EXAMPLE 2.—A break occurs in a cable 3 miles long. It is known that the capacity of the entire conductor was .39 microfarad per mile, or 1.17 microfarads in all. Upon testing, it is found that with a standard condenser of $\frac{1}{3}$ microfarad and a suitable battery and shunt to the galvanometer, the deflection is 98, while with the same shunt and battery, the deflection obtained from one end of the cable is 141. How far from the testing end is the break?

SOLUTION.—Using formula **9**, $Q = \frac{1}{3}$, $d = 98$, $d' = 141$.

$$Q' = \frac{\frac{1}{3} \times 141}{98} = .4796 \text{ microfarad.}$$

$$\text{Distance from testing end} = \frac{.4796}{.39} = 1.23 \text{ miles. Ans.}$$

EXAMPLES FOR PRACTICE.

1. In a test for the capacity of a cable, the capacity of the standard condenser was 2 microfarads. The throw produced by the condenser was 53 divisions and that by the cable was 32 divisions. What was the capacity of the cable? Ans. 1.207 microfarads.

2. A test was made to locate a break in a cable conductor. A sound wire was accessible. The throw on the broken wire was 29 divisions and that on the good wire was 75 divisions. The length of the tested cable was 5,760 feet. What was the distance to the break? Ans. 2,227 ft.

TESTS FOR LOCATING GROUNDS.

296. These faults occur much more frequently than breaks and are often difficult to locate, especially if more than one ground or cross occurs on the same line.

297. Tests Without Available Good Wire.—The existence of a wire whose insulation and continuity are known to be perfect (such wires are usually termed good wires) is often a great aid in helping to locate a cross. Where no good wire is available, however, the following method may be used: Carefully insulate both ends of the wire from the ground and from other conductors. A Wheatstone bridge with a sensitive galvanometer is then connected

between one end of the wire and the ground, as shown in Fig. 91, and the resistance of that end of the line wire, through the fault, to the ground is measured. Let this resistance be r. The same test is now repeated at the other end of the line, and a resistance r' is observed. Call z the

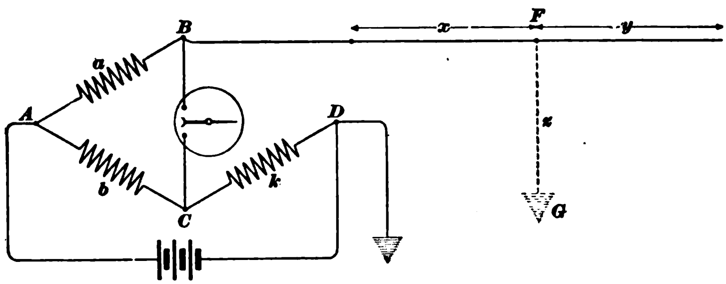


FIG. 91.

resistance of the fault itself, x the resistance of the line wire from the first end to the fault, and y the resistance of the remaining portion of the line wire. The first resistance measured, r, is the combined resistance of the first portion of the line wire and the resistance of the fault. Thus,

$$r = x + z.$$

Similarly, $$r' = y + z.$$

Calling L the resistance of the line, we have the equation

$$L = x + y.$$

Solving these three equations for x, y, and z, we obtain

$$x = \frac{r - r' + L}{2}. \qquad (11.)$$

$$y = \frac{r' - r + L}{2}. \qquad (12.)$$

$$z = \frac{r + r' - L}{2}. \qquad (13.)$$

The value of L, if not already known, may be calculated from the known size and length of the wire.

EXAMPLE.—A test was made for a fault where no good wire was available. The resistance measured at the first station was 600 ohms, and that at the second station 630 ohms, and the resistance of the line was 1,150 ohms. What was the resistance to the fault from the first station? from the second station? What was the resistance of the fault?

SOLUTION.— $r = 600$, $r' = 630$, $L = 1,150$.

$$z = \frac{600 + 630 - 1,150}{2} = 40 \text{ ohms. Ans.}$$

$$x = \frac{600 - 630 + 1,150}{2} = 560 \text{ ohms. Ans.}$$

$$y = \frac{630 - 600 + 1,150}{2} = 590 \text{ ohms. Ans.}$$

EXAMPLES FOR PRACTICE.

1. A test for a fault was made upon an aerial line of 1,112 ohms resistance. The resistance of the line was 12.92 ohms per mile. The resistance measured at the first station, through the fault, was 630 ohms, and that at the second station 542 ohms. What was the resistance of the fault? How far was it from the first station, and how far from the second?

Ans. The resistance of the fault was 30 ohms. The distance from the first station to the fault was 46 mi. 774 yd. The distance from the second station was 39 mi. 1,108 yd.

2. A wire touched the ground so that there was no resistance z in the fault. A test was made at the station, and the unplugged resistance in the rheostat amounted to 326 ohms. What was the distance to the fault, the resistance of the wire being 16.1 ohms per mile?

Ans 20 mi. 438 yd.

298. Test From One End Only and Without an Available Good Wire.—The following method for locating a partial ground or an escape is about the only way where there is no *available good wire* and when the tests must be made *from one end only*. However, it is rather unreliable in practice, because the resistance of the partial ground may change between the two measurements and so give a more or less incorrect result, and, moreover, the normal resistance of the line must be known from some

previous measurement or calculated from the length, size, and conductivity of the line wire. Let this resistance be a. Then measure the resistance of the line $B\,B'$, with the distant end grounded, as shown in Fig. 92, and call this b.

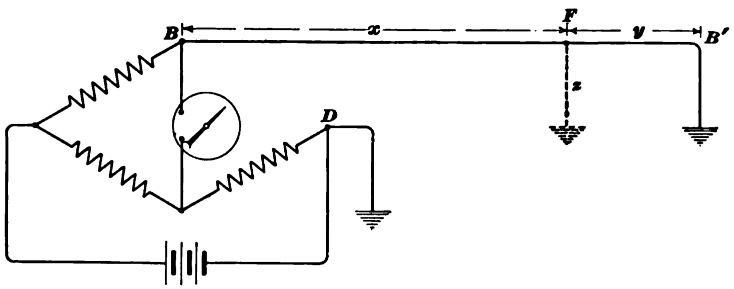


FIG. 92.

Also, measure the resistance with the distant end open, as in Fig. 91, and call this c ohms. Then the resistance x to the partial ground from the testing station is given by the following formula:

$$x = c - \sqrt{(b - c)\,(a - c)}. \qquad \textbf{(14.)}$$

By dividing x by the resistance per unit length of the wire, known from some previous measurements or by its size from a table, the distance to the partial ground is obtained.

NOTE.—Formula **14** is derived as follows: In Fig. 91, let the resistance of the home end of the line to the point F, where the partial ground occurs, be x, from F to the distant end be y, and the resistance of the fault be z ohms. Then, calling a the normal resistance of the whole line,

$$x + y = a.$$

When the partial ground is present but the distant end open,

$$x + z = c$$

Finally, when the partial ground is present and the distant end grounded, y and z are in parallel with each other but in series with x; then,

$$x + \frac{y\,z}{y + z} = b.$$

Solving the above three equations for x, we get the resistance from the testing station to the partial ground or escape

$$x = c \pm \sqrt{(b - c)(a - c)}.$$

Evidently the minus sign (—) must be used, because x cannot be greater than c.

299. Ground on a Line of Known Resistance.—Where there is a dead ground on a line whose length and resistance are known, it is a simple matter to locate the distance to the dead ground from the testing station. Let a be the known resistance of the line and l the length of the line in miles; then, $\frac{a}{l}$ is the normal resistance of the line per mile. To locate the position of a dead ground on this line, measure the resistance between the home end of the line and the ground and let this be e ohms. Then, the number of miles X_m from the testing station to the dead ground is given by the formula

$$X_m = \frac{e\,l}{a}. \qquad \textbf{(15.)}$$

300. Varley Loop Test.—Where there is an available good wire, the Varley loop method is probably the most convenient and best method for locating a ground or cross

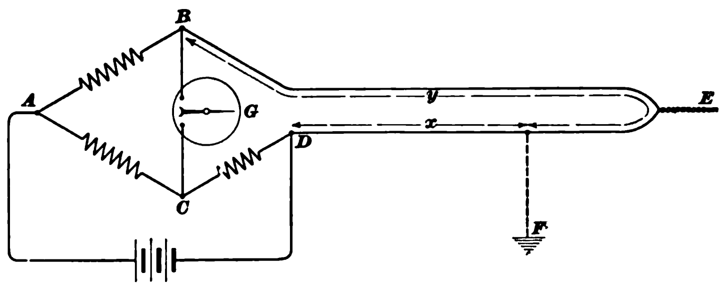


FIG. 93.

on a line. The distant ends of the good and bad wires are joined together and the resistance of the loop so formed is measured with the Wheatstone bridge, if not already known from some previous measurement, by connecting as shown

in Fig. 93. G is a reflecting galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; AB and AC are the ratio arms of the bridge, and CD is the rheostat or variable arm. DE is the faulty line, BE the good line, and F the location of the fault, assumed to be a ground in this figure. The ends of the loop are connected across the terminals of the bridge, so as to form the unknown

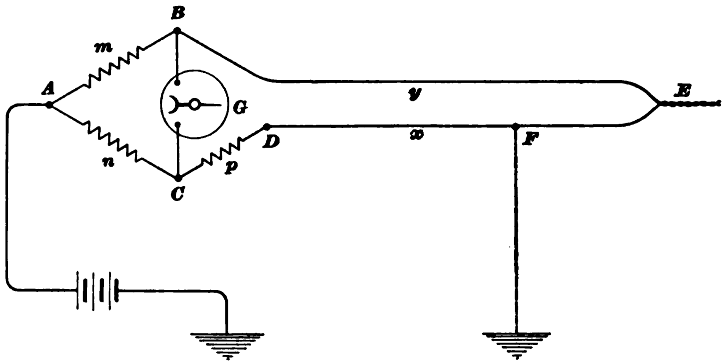


FIG. 94.

resistance or fourth arm of the bridge. The battery is connected between A and D. Balance the bridge and let the resistance of the loop, found by working out the bridge proportion as usual, be R. Then connect one end of the battery to the ground, instead of to D, as shown in Fig. 94. Call y the resistance of the loop from B through E to F, x the resistance from D to F, and R, the total resistance of the loop, is equal to $x + y$. Then, when the bridge is balanced,

$$\frac{m}{n} = \frac{y}{p + x} = \frac{R - x}{p + x};$$

$$mp + mx = nR - nx;$$

$$mx + nx = nR - mp.$$

Hence, $$x = \frac{nR - mp}{m + n}. \qquad \textbf{(16.)}$$

This is entirely independent of the resistance of the fault or of any earth currents that may exist. Having found x, and knowing the resistance of the faulty wire per foot, the distance to the fault is readily calculated. If the faulty line is not grounded but is crossed with another, then the battery should be connected to the wire with which the faulty wire is crossed, and not grounded, as shown in the figure.

EXAMPLE.—A ground occurs on one conductor of a cable 10,000 feet long, composed of three No. 14 B. & S. gauge insulated copper conductors. At the distant end, the grounded conductor was joined to one good conductor. On testing, the bridge was balanced with the following resistances: $m = 10$ ohms, $n = 1{,}000$ ohms, and $p = 4{,}642$ ohms. One good wire was used to complete the loop. Where is the ground, the resistance per thousand feet of the conductor being 2.521 ohms at the temperature of the test?

SOLUTION.— $R = 2 \times 10 \times 2.521 = 50.42$ ohms.

$$x = \frac{1{,}000 \times 50.42 - 10 \times 4{,}642}{10 + 1{,}000} = 3.9604 \text{ ohms.}$$

Distance from testing station $= \frac{3.9604}{2.521} \times 1{,}000 = 1{,}570.9$ ft. Ans.

301. Murray Loop Method.—This method is quite similar to the preceding and there is little choice between them. Sometimes one may be more convenient than the

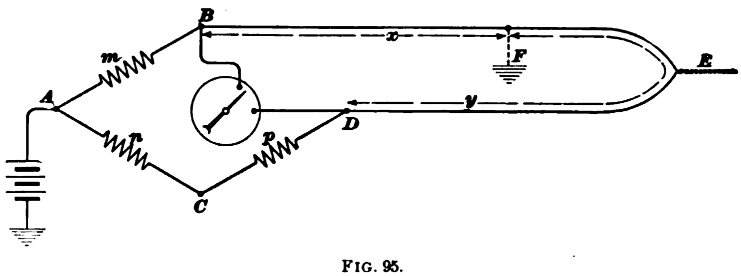


FIG. 95.

other. First have the distant ends of the available good and bad wires joined together. Then connect the loop so formed as in Fig. 93, for the Varley loop test, and measure the resistance of the loop. Let this resistance be R. Then

connect the loop and battery as in Fig. 95, thus having really only two adjustable arms, because $A\ C$ and $C\ D$ form only one arm now. F is now the junction between the arms x and y. When the bridge is balanced, we have

$$\frac{m}{n+p} = \frac{x}{y}.$$

But, $$x + y = R.$$

Solving these two equations for x, the resistance of the line wire to the fault, we get

$$x = \frac{m\,R}{m+n+p}. \qquad \textbf{(17.)}$$

A test made by this method gives a result that is independent of the resistance at the fault.

EXAMPLE.—In order to locate a ground on one conductor in a cable, the Murray loop method was used. At the distant end of the cable, the bad wire was joined to a good wire and the resistance of the loop so formed was measured by the Wheatstone bridge and found to be 63.44 ohms. One end of the galvanometer was then disconnected from the junction C between the arms n and p (see Fig. 95), and was joined instead to the point D between the arm p and the good wire. The bridge was then balanced and it was found that there was 1,000 ohms in the arm m, 1,000 in n, and 282 in p. Each conductor in the cable consisted of one No. 12 B. & S. gauge insulated copper wire, having a resistance of 1.586 ohms per 1,000 feet at the temperature of the test. What was the distance in feet from the testing station to the fault?

SOLUTION.—By substituting in formula **17**, in which $R = 63.44$ ohms, $m = 1{,}000$, $n = 1{,}000$, and $p = 282$, we get as the resistance along the bad wire to the fault,

$$x = \frac{1{,}000 \times 63.44}{1{,}000 + 1{,}000 + 282} = 27.80.$$

Then, the distance to the fault in feet from the testing station is

$$\frac{27.80 \times 1{,}000}{1.586} = 17{,}528 \text{ ft., or } 3.32 \text{ mi.} \quad \text{Ans.}$$

302. Allen Loop Test.—Allen's modification of Murray's loop test gives a very simple and quick method of testing where the resistance of the loop is not already known.

The loop $B\ E\ D$ is connected to the bridge, as shown in Fig. 96, and a balance obtained. Then,

$$\frac{m+y}{n}=\frac{x}{p}.$$

Now, reverse the connections of the loop with the bridge,

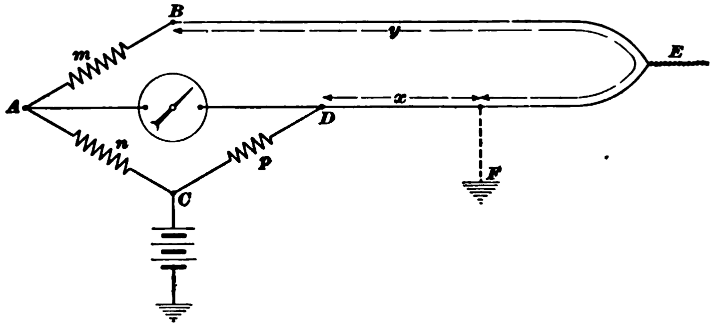


FIG. 96.

joining the bad wire to B and the good wire to D. Obtain a new balance on the bridge, then

$$\frac{m'+x}{n'}=\frac{y}{p'}.$$

Solving these two equations for x, we get

$$x=\frac{p\,(m\,n'+p'\,m')}{n\,n'-p\,p'}. \qquad \textbf{(18.)}$$

This formula simplifies when m, m', n, and n' are multiples of 10, as they usually are, in practice. A measurement made by the Allen loop test is independent of the resistance at the fault.

LOCATING CROSSES.

303. Where the two crossed wires run along parallel and have the same resistance per mile, it is rather a simple matter to locate a cross. Where such is not the case, the resistance of each wire per mile must often be considered.

304. Resistance at the Cross Negligible.—It is first necessary to determine if the resistance at the cross is negligible. This may be done as follows: Connect the lines

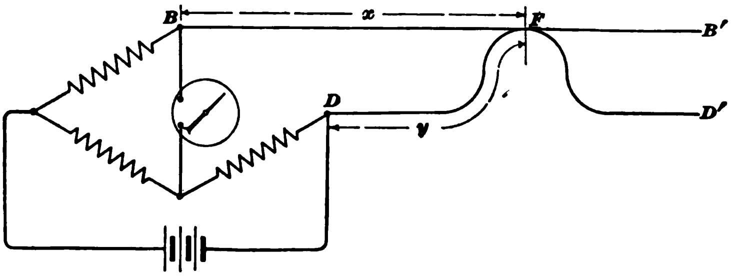


FIG. 97.

with a Wheatstone bridge as shown in Fig. 97, so as to measure the resistance from B to D through the cross F. Call this a.

Then, $$x + y = a.$$

Now have the wires connected together at the nearest station beyond the cross and again measure the resistance. Call this b. If b is only a little less than a, then the resistance of the cross is probably negligible, but not necessarily perfectly negligible. For if the cross is near the testing station and the resistance of the line wires to the next station where the lines are intentionally connected together is very high, then the second measurement b may be but little less than the first measurement a, in spite of the fact that the resistance of the cross is not perfectly negligible. If the resistance of the cross is negligible, then, if the two wires are of the same size and material and run along parallel the whole distance from the testing station to the cross, the distance w to the fault in miles is given by the following formula:

$$w = \frac{a}{2s}, \qquad \textbf{(19.)}$$

in which s is the resistance per mile along one of the wires.

305. Resistance of the Two Line Wires per Unit Length Not Equal.—If the wires are still parallel with each other, but the resistance of one is m ohms per mile and the other n ohms per mile, then the formula becomes

$$w = \frac{a}{m + n}. \qquad \textbf{(20.)}$$

RESISTANCE OF THE CROSS NOT NEGLIGIBLE BUT CONSTANT.

306. Varley Loop Method.—First insulate the distant ends of the two crossed wires. Then connect as shown in Fig. 98, and measure the resistance from D to B through

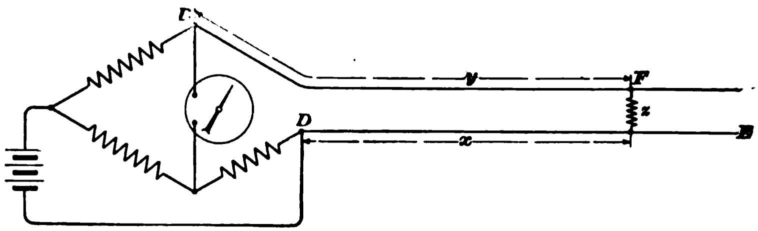


FIG. 98.

the cross at F. Let the resistance of the cross be z ohms, and the resistance found by balancing the bridge be R ohms Then,

$$R = x + y + z. \qquad (1.)$$

Now ground either wire, say DE, anywhere beyond the cross, as at G, and connect as shown in Fig. 99. When the bridge is again balanced, we have

$$\frac{m}{n} = \frac{y + z}{p + x}. \qquad (2.)$$

From equations (1) and (2), we get the formula

$$x = \frac{nR - mp}{m + n},$$

which is exactly the same as formula **16.**

Then, by dividing x by the resistance of the wire $D\ E$ per unit length, we have the distance from D to the fault along the wire $D\ E$. The resistance of the cross z eliminates and the method is accurate, provided the resistance z has remained the same during both measurements.

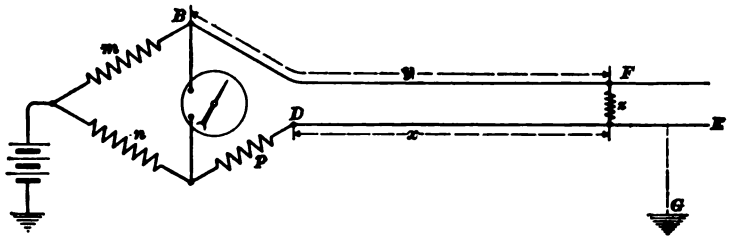


FIG. 99.

307. Method Requiring Three Measurements.—Measure, as in the preceding method, the resistance from B to D through the cross whose resistance we will call z ohms, connecting the bridge as shown in Fig. 98. Let the resistance so measured be a; then,

$$x + z + y = a.$$

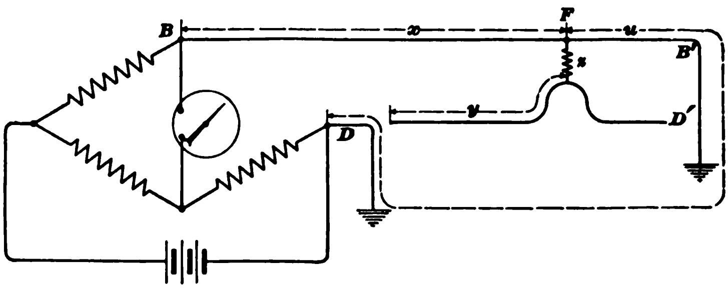


FIG. 100.

Now measure the resistance of the line $B\ B'$ by having the distant end B' grounded, and the ends of $D\ D'$ open as shown in Fig. 100. Let this resistance be b; then,

$$x + u = b.$$

Finally, measure the resistance through y, z, and u, by

connecting the bridge as shown in Fig. 101. Let this resistance be c; then,

$$y + z + u = c.$$

Subtracting the last equation from the sum of the first two equations, we get

$$a + b - c = 2x.$$

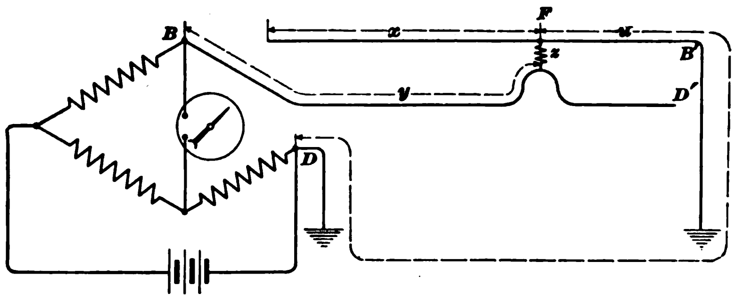


FIG. 101.

Hence the resistance x from the testing station to the fault is given by the following formula:

$$x = \frac{a + b - c}{2}. \qquad \textbf{(21.)}$$

Dividing x by the resistance of the wire x per mile gives the distance in miles to the cross F. It will be noticed that the resistance of the cross z eliminates, so that if z remained constant during the second and third measurements, the formula is accurate and independent of the value of z.

308. Resistance of Cross Neither Negligible Nor Constant.—A method will now be given in which the resistance of the cross is eliminated, whether constant or variable, and the test requires, moreover, only two resistance measurements. However, the ordinary bridge connections have to be slightly modified, which is an objection.

First, connect up as shown in Fig. 100, and measure the resistance of the line *B B'*, including the ground-return path. Let this be *a*; then,

$$x + u = a. \qquad (1.)$$

Then connect the bridge as shown in Fig. 102, using only two arms *p* and *n* of the bridge; the third arm *m*, being on open circuit, is not used. The galvanometer, instead of being connected to the end of the arm *m*, is connected to the end of the wire *D*. Thus, *B F* forms the third arm and *F B' C* the fourth arm of the bridge. The resistance of the cross *z* and that portion *y* of the line *D D'* is included in the bridge or galvanometer circuit, and, therefore, this resistance *z* and *y* will not enter into the result for the

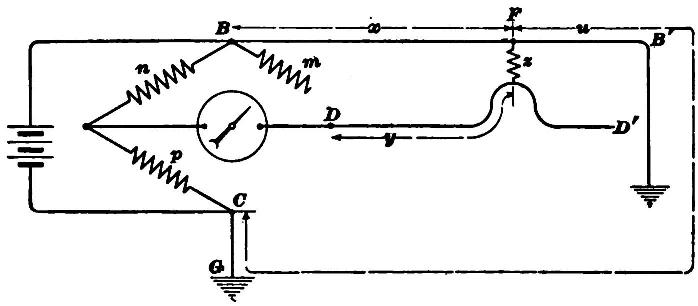


FIG. 102.

same reason that the resistance of the galvanometer never does in measurements made with the Wheatstone bridge method. Hence, the resistance of the cross does not enter into the measurement, and, furthermore, the final formula is entirely independent of this resistance whether it is constant or not. The resistance *u*, from *F* through *B'* and back through the ground to *G*, forms the fourth arm of the bridge. From the well-known principle of the bridge, after adjusting it until there is no deflection, we have

$$\frac{n}{p} = \frac{x}{u}. \qquad (2.)$$

Solving equations (1) and (2) for x, we obtain the following formula for the resistance along the wire $B\ B'$ to the cross:

$$x = \frac{n\,a}{p + n}. \qquad \textbf{(22.)}$$

Finally, by dividing x by the resistance of the line $B\ B'$ per mile, we get the distance in miles from B to the cross F.

If more convenient to do so, the end B of the wire may be joined to the end of the arm m. In this case x in equation (2) must be changed to $m + x$ and we get the following formula for x:

$$x = \frac{n\,a - p\,m}{p + n}. \qquad \textbf{(23.)}$$

TANGENT GALVANOMETER.

309. The principle and the method of using the **tangent galvanometer** have been given in *Electrical Measurements*, and it is only necessary to give here a short description of the particular form of the instrument that is most commonly used for telegraph testing. Tangent galvanometers are very rapidly going out of use. Ammeters and voltmeters of the Weston type are very much more satisfactory and can be obtained sufficiently sensitive and accurate for all practical work.

310. The tangent galvanometer known as the *Western Union Standard* is shown in Fig. 103 (*a*). On the base at the right are the terminals of three resistances, arranged so any one, or all three, can be short-circuited by brass plugs. A diagram of the arrangement of the coils and resistances is shown in Fig. 103 (*b*). These resistance coils of 5,000, 500, and 10 ohms, respectively, are often very convenient when making a measurement. For instance, if the deflection is too small and it is not convenient or possible to increase the electromotive force, the deflection may be increased by inserting the plugs so as to short-circuit one or more of the

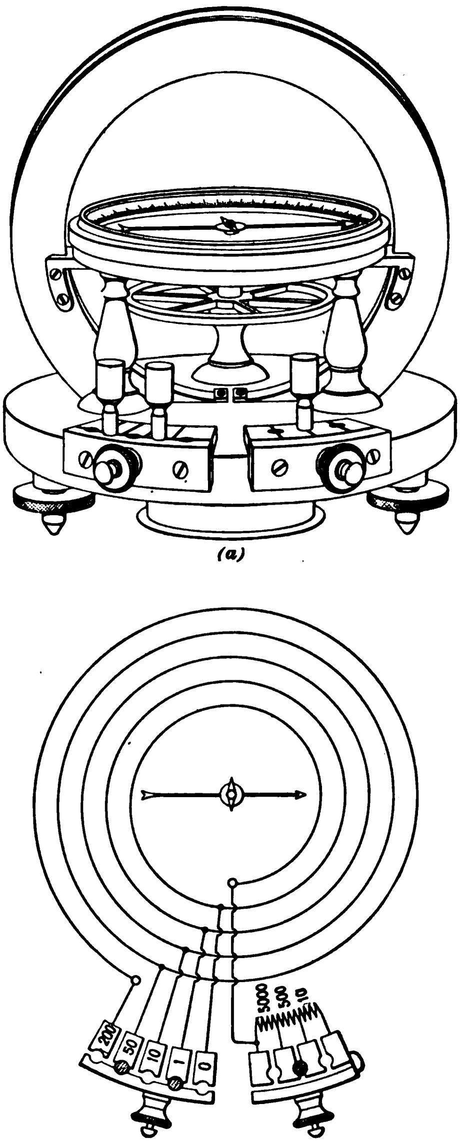


FIG. 103.

resistance coils on the right. Conversely, if the deflection is too large, it may be reduced by removing one or more of the short-circuiting plugs.

311. Dial Graduated in Tangents.—In some tangent galvanometers in use, the dial is divided on one side in degrees, but on the other side the figures correspond to the tangent of the angle of deflection. This is more convenient, as it avoids the necessity of looking up the tangent in a table corresponding to the deflection of the pointer in degrees, but the scale is not apt to be so accurate. The student has been furnished with a table of tangents, suitable for use with the tangent galvanometer, in the volume of *Tables and Formulas*.

312. These tangent galvanometers may be obtained with a needle suspended by a silk fiber. This makes the instrument more sensitive, but also more delicate and liable to injury. The tangent galvanometer is ordinarily used for measuring the strength of currents, internal resistance, electromotive force, and condition of cells.

ELECTROMOTIVE FORCE AND INTERNAL RESISTANCE OF BATTERIES.

313. There are a number of methods for accurately determining the internal resistance and electromotive force of cells. Probably the most accurate methods for determining electromotive forces are those requiring Standard Clark cells, accurate resistances, or condensers. These are suitable only for laboratories, however. For practical measurements the half-tangent or half-deflection and Mance's bridge methods for internal resistance, and the volt and ammeter method for both internal resistance and electromotive force, are the most suitable.

314. Half-Tangent Method.—For the half-tangent method, an adjustable resistance box and a tangent galvanometer are generally used. However, it may be made with an ordinary Wheatstone bridge set, and a much more convenient way is to use a milliammeter in place of the tangent galvanometer. These two modifications will be explained presently.

315. In series with the cell or battery whose internal resistance is desired, connect an adjustable known resistance and the tangent galvanometer. Use such a coil of the galvanometer or arrange the adjustable resistance so that a deflection between 60° and 80° is obtained. It is best in this case to use as little of the adjustable resistance as possible. With cells like the gravity having an appreciable

internal resistance, no resistance is necessary at all external to the cell. If the deflection is too large, it is preferable to use a galvanometer coil having fewer turns. Suppose there is a small resistance a external to the cell. This must include the galvanometer resistance unless the latter is small enough to be neglected. Note the galvanometer deflection in degrees and from a table of natural tangents obtain the tangent corresponding to this angular deflection. Divide this tangent in half and from the same table obtain the degrees corresponding to this half-tangent. Then increase the known adjustable resistance until the deflection is reduced to the degree obtained from the table. Let the known total external resistance now be c ohms. Since the tangent of the second deflection is half the tangent of the first deflection, it is evident that the current has been reduced one-half and the total resistance must, therefore, have been increased to double its first value. Hence, if B is the internal resistance of the cell or battery, then

$$2(B + a) = B + c.$$

From which we get

$$B = c - 2a. \qquad \textbf{(24.)}$$

Evidently, if no external resistance a was used when the first deflection was obtained, B would be equal to c.

316. Half-Deflection Method Using an Ammeter.—An ammeter or milliammeter of suitable range can be used in place of the tangent galvanometer, and it is much more convenient. All that is necessary is to adjust the resistances, so that one reading on the scale is just one-half the other. The reading gives the current directly. The internal resistance is worked out in the same manner, using formula **24.**

317. Half-Deflection Method Using a Bridge Set.—The bridge in this case is used as a simple adjustable resistance. The proper connections are shown in Fig. 104.

The bridge galvanometer G must be shunted by a low resistance S, consisting of a few ohms, so that the joint resistance of the galvanometer and shunt may be negligible in comparison with that of the battery, and, furthermore, it is usually desirable to thus reduce the sensitiveness of the

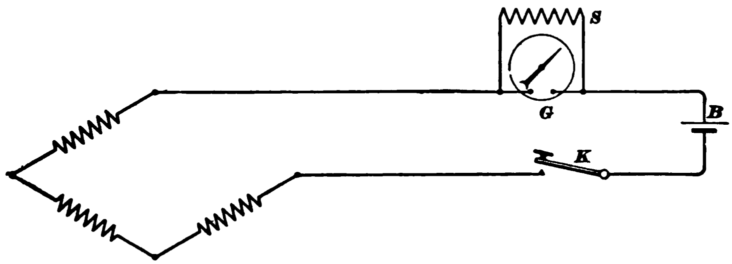


FIG. 104.

galvanometer. Obtain a convenient deflection with any resistance unplugged in the box and note down this resistance a and the deflection of the galvanometer. Then increase the resistance in the box until the deflection is reduced one-half. Note this resistance c. The internal resistance of the cell or battery is given by formula **24.**

EXAMPLE.—A gravity cell, connected in series with a tangent galvanometer and a resistance of .3 ohm, gave a deflection of 65°. The resistance of the galvanometer and all connecting wires was .1 ohm. The tangent of 65° was found in a table of natural tangents to be 2.14451. The angle, having a tangent of $\frac{1}{2}$ (2.1451) = 1.07225, was found in the same table to be very nearly 45°. It was found necessary to add an extra resistance of 3 ohms in series with the cell and galvanometer in order to reduce the deflection from 65° to 46°. What was the internal resistance of the cell?

SOLUTION.—By formula **24,** the internal resistance $B = c - 2a$, in which $c = 3 + .3 + .1 = 3.4$ and $a = .3 + .1 = .4$. Hence, $B = 3.4 - .8 = 2.6$ ohms. Ans.

318. Mance's Bridge Method.—The connections for this method of measuring the internal resistance of the battery B is shown in Fig. 105. The battery B is connected

in the arm of the bridge where the unknown resistance is usually connected, and the junction points A and D, between which the battery is usually connected, are joined together through the key K, which is normally open. It is usually necessary to shunt the galvanometer by a resistance S in order to reduce its sensitiveness so that the deflection will remain on the scale. The key K_1 remains closed normally in order to protect the galvanometer. When the connections are made, cautiously depress the key K_1 and adjust the shunt and various resistances until a convenient deflection is obtained. Then depress the key K, which will probably

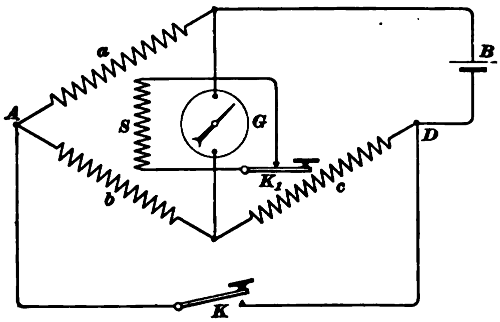


FIG. 105.

alter the deflection. A balance is obtained when the resistance arms have been so adjusted that *no change* in the galvanometer deflection occurs on opening or closing the key K, the other key K_1 being held open all the time. The resistance of the battery is then found by the ordinary bridge proportion; that is, the internal resistance of $B = \frac{c\,a}{b}$.

If the internal resistance of the battery is small, it is convenient to insert a resistance in series with the battery. This resistance must afterwards be subtracted from the resistance obtained from the bridge. The advantage of Mance's bridge method is that the deflection does not enter into the result.

319. Volt-and-Ammeter Method.—By this method both the internal resistance and the electromotive force of the cell are obtained simultaneously from the same measurements, and, moreover, the measurements may be made when the cell or battery is generating the same current that it would when actually working on a telegraph line or local circuit. It, therefore, may be made to give the internal resistance under normal working conditions. The connections for this method are shown in Fig. 106, in which A is an ammeter and V a voltmeter of suitable range, R a resistance of such a value that the battery B to be tested will furnish its normal amount of current, and K a switch or key. Let B be the internal resistance of the battery, C the current measured by the ammeter A, E the electromotive force of the cell when the key K is open, and V the difference of potential at the terminals of the cell when C amperes are flowing through R on account of the key K being closed. E and V are measured by the voltmeter. The resistance of the voltmeter should be at least a thousand times that of the battery, or, better, several thousand times. The ammeter and resistance R must be low enough to allow the battery to work at its normal rate of output, and it is better that the ammeter resistance should be very low.

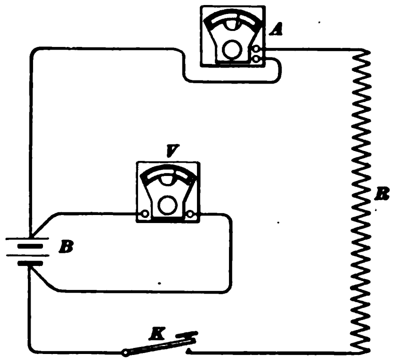


FIG. 106.

With the key K open, read the voltmeter. This will be E, the electromotive force of the battery when practically no current is flowing, that is, when the battery is practically on open circuit. Then close the key K and immediately read simultaneously, or as nearly so as possible, both the ammeter and the voltmeter. These two readings give the current C and the difference of potential V at the battery

terminals when C amperes are flowing through the circuit. Then, $E - V$ is the drop or fall of potential necessary to drive the current C through the battery against the internal resistance B. But this fall of potential by Ohm's law $= B \times C$; hence,

$$B = \frac{E - V}{C}. \qquad \textbf{(25.)}$$

This is the internal resistance at an output of C amperes. At another rate it may be different.

If the total resistance R external to the battery is known, the ammeter will not be necessary, for the current C is equal to $\frac{V}{R}$ and can, therefore, be calculated.

320. To Determine Condition of Cells.—To determine merely if a cell or battery having an appreciable internal resistance, such as a gravity cell, is above a minimum standard condition, the following method is often used. As already stated, the copper band on the tangent galvanometer has no appreciable resistance; hence, if this coil is connected directly in series with a battery, the current is limited practically by the internal resistance of the battery.

Determine, once for all, the minimum deflection that a cell in good working condition will give. Then, if the deflection falls below this with another cell or a whole battery, something is wrong with the cell or with one or more of the cells in the battery. No more current will be obtained from a whole set of cells connected in series than from one cell where the external resistance is negligible, because the total resistance of the circuit varies directly as the number of cells connected in series, and, hence, the total resistance varies directly as the total electromotive force. This was fully explained in *Telegraphy*, Part 1, under the heading "Small External Resistance."

321. When the deflection from a whole battery falls below the standard, a careful inspection may show one or

more defective cells. If not, a defective cell may be located by testing each cell separately. If there is no especially bad cell in the set, then the condition of the battery as a whole is poor.

This method cannot, of course, be used with batteries or cells that have little or no internal resistance. A storage battery, if tested in this way, would probably ruin not only itself but also the galvanometer, on account of the large current that would flow, since the total resistance of the circuit is so small.

322. Bunnell Battery Gauge.—This gauge, shown in Fig. 107, consists of a coil of wire and an armature to which the pointer is attached. It is very convenient for determining the condition of from one to five ordinary cells. A good Leclanché cell will indicate about 9°; standard dry battery 14°; Lockwood American District (blue vitriol) 6°; crowfoot, Western Union form, 8°.

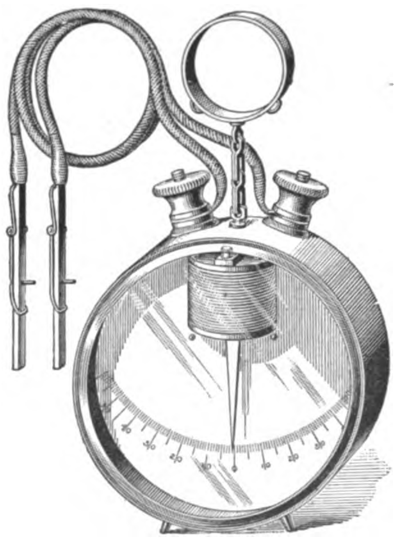


FIG. 107.

This gauge can be used standing upright on the table or desk, or suspended by the chain and ring, which brings the needle to zero when no current is passing through the instrument. On account of their normal position being upright, these gauges may be used as permanent circuit indicators for fire-alarm, burglar-alarm, and district-telegraph lines. The action of the needle is "dead beat." It moves to and remains, without oscillation, at whatever indication the current calls for. There are two silk-covered conducting cords provided with tips,

made so as to enter any ordinary binding post, and, being square, can be also firmly held by the English form of binding post. These tips have a spring clamp by which they can firmly grip naked wire (up to No. 16) at any exposed point.

WIRELESS TELEGRAPH.

EARLY INVESTIGATORS AND METHODS.

323. The idea of telegraphing between two stations that are not directly connected by at least one wire is quite old. Morse, Lindsay, Willoughby Smith, and others proposed and some of them actually did telegraph across a body of water by running a wire for some distance parallel to the shore on either side and then connecting each end of each wire to a plate submerged in the water; one plate on either side was directly opposite a corresponding plate on the other side of the stream. If the wires parallel to the shore are long enough and the stream not too broad, the electric current will flow across the stream at one point from plate to plate, through the wire on the opposite side, and finally across the stream at the other point and into the wire on the first side. Enough of the current will follow this path, in preference to flowing along the stream, to operate a relay. The ability to telegraph in this manner is due to the fact that the resistance of the body of water across the stream from plate to plate is less than the resistance along the stream between the two plates on the same side. To be sure, more or less current will flow from one plate to another on the same side of the stream. It is invariably better, where it can be done, to connect the two telegraph stations by an overhead wire or submerged cable. This is sometimes called the *conduction method*. Willoughby Smith put such a system in operation in 1885, between the shore and a lighthouse, a distance of 60 yards, and it was successfully used for a number of years.

324. Another very different method has been proposed and was put in operation by Mr. W. H. Pierce, who has worked more or less on the subject since 1882. The success of this method is due to electrostatic and electromagnetic effects and to conduction through the earth. The best results were obtained by using two long parallel wires grounded at both ends. One wire, with the earth return, forms a long rectangular coil and acts as a primary coil; and the other with an earth return, as the secondary coil of an induction coil, the two coils being separated by the distance across which it is expected to telegraph. There may, in addition to electromagnetic induction, be electrostatic induction between the two long parallel wires and conduction through the earth between the opposite ground plates at the two ends. An alternating or rapidly interrupted current is used in the primary or sending side, and an ordinary key may be used to make Morse signals by interrupting the rapidly pulsating or alternating current. A telephone receiver is used in the secondary circuit to read the signals. A sound, due to the alternating current that causes the diaphragm of the receiver to vibrate, corresponds to dots and dashes, and silence corresponds to spaces. The length of the two parallel wires should be at least equal to the distance separating the two wires. Telegraphic and telephonic communications have been successfully carried on by this method between stations from 3 to 5 miles apart.

325. The most successful method for telegraphing through space without a connecting wire has been perfected by Guglielmo Marconi, an Italian. His method depends on the coherer invented by Branly (about 1890) and also on discoveries made by Lodge and Righi. To Maxwell and Hertz is due the credit of predicting and demonstrating, respectively, the fact that electromagnetic waves are propagated through space with the velocity of light. Such waves are frequently called **Hertzian waves.** These waves are identical in some respects to light waves, but have different frequencies and wave lengths and other different properties.

For instance, while wood and many other substances are not transparent to light waves, they are transparent to electromagnetic waves. Most metals, however, are opaque to almost all waves. Our optical nerves are capable of detecting light waves but cannot detect electromagnetic waves. Electromagnetic waves range from 2½ inches in length to about 18 miles and have a frequency from 480,000,000 to 10,000 periods per second, respectively; whereas the length of light waves range from 165 millionths of an inch to 272 millionths of an inch and have a frequency from 740 trillion to 434 trillion periods per second, respectively. A coherer, which will be described presently, is insensible to light waves, but will readily detect some electromagnetic waves.

326. Calzecchi Onesti, an Italian, was about the first (in 1884) to discover the sensibility of filings to Hertzian waves. He found that metallic filings in a loose state offered an appreciable resistance, but when exposed to Hertzian waves the resistance decreased enormously, but that on shaking them up the resistance was increased to its original value.

Professor E. Branly, of Paris, developed the discovery of Calzecchi Onesti, and made about the first instrument, now called a coherer, publishing the results of his investigation in 1891.

Professor O. J. Lodge, of England, was probably the first to call Branly's instrument a coherer and to use it in 1893 for detecting electromagnetic waves at a distance (about 125 feet) from the generator and to tap the tube by means of a clock movement in order to restore the resistance of the filings to their normal condition.

Professor Popoff, of Russia, was the first to automatically cause the hammer of a sounder or bell to restore the coherer to its natural state, or to *decohere* it, as it is usually called. He had also used vertical wires in lightning-discharge investigations.

Marconi was the first to use in connection with a wireless-telegraph system the long vertical wire, previously employed by Popoff. Besides this, Marconi has probably done more good work in perfecting details and the system as a whole than any other one man.

PRINCIPLES OF TRANSMITTING AND RECEIVING APPARATUS.

327. In Fig. 108, *p* and *s* represent the primary and secondary winding of an induction coil, having an ordinary interrupting device *c d*, like that used on a common vibrating bell. It consists of a stop *d* and a small piece of iron *c* fastened to a flat spring. With the key *K* open,

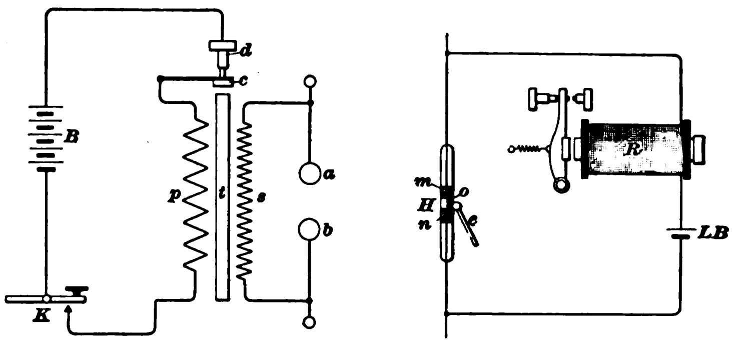


FIG. 108.

c rests against *d* and so tends to keep the circuit closed between them. The ends of the secondary coil are connected to two brass balls or spheres *a* and *b*. There is a small air gap of about an inch between *a* and *b*.

328. When the key *K* is closed, the iron core *t* is magnetized and attracts *c*, thereby opening the circuit between *c* and *d*, which allows the core to immediately demagnetize and release *c*, allowing the latter to spring back against *d* and again close the circuit, when the core will again

attract *c*. The constant repetition of this action causes the circuit to be broken many times a second and a torrent of sparks will pass across the gap between *a* and *b* as long as the key *K* remains closed. Although the primary circuit is broken only an appreciable number of times per second, nevertheless it has been shown by mathematical and experimental demonstrations that the current between the balls *a* and *b* surges back and forth many millions of times per second and that electromagnetic or Hertzian waves are sent out in all directions into space from the disturbance or spark that is produced between *a* and *b*. The waves ordinarily produced have a frequency of many millions of vibrations per second.

329. Coherer.—*H* is a small glass tube, called a coherer, having in it two small metal plugs *m* and *n*, the small space *o* between them being partially filled with loose, coarse metal filings. The resistance of the metal filings in the space *o* between the metal plugs *m* and *n* is ordinarily very high, thousands of ohms, and, consequently, enough current cannot flow from the single cell *L B* to energize the relay *R*. However, if Hertzian waves of sufficient intensity, or amplitude, are emitted from *a b* and strike the coherer *H*, the resistance of the filings may be reduced to 100 ohms and often much less.

Therefore enough current can now flow from the local battery *L B* through the coherer *H* and the relay *R* to energize the latter, and thus close a local circuit, not shown, however, in this figure. The current through the coherer will continue to flow even if the waves from the transmitter *a b* cease. However, the least mechanical jarring of the coherer after the waves from *a b* have ceased will restore the filings in the coherer to their normal high resistance and hence cause the relay armature to open the local circuit. A convenient way of jarring the coherer is to arrange an ordinary vibrating bell, the hammer of which is here represented by *c*, so that it will continually tap the tube lightly as long as the relay holds the local circuit closed. This

tapping of the tube does not restore it to its normal high resistance as long as sufficiently intense waves from *a b* strike it, but the first tap after the waves cease restores it to its normal high resistance and hence the relay opens and the tapping ceases. *R* is rather a high resistance and sensitive relay, and *L B* a local battery of one cell.

330. Explanation of the Action of a Coherer.—The following explanation of the action between the filings in a coherer, which is given by Professor Lodge in his book "Signaling Through Space Without Wires," is the one generally accepted.

"Suppose there are two fairly clean pieces of metal in light contact connected in series with a single voltaic cell; a film of what may be called oxide intervenes between the surfaces so that only an insignificant current is allowed to pass, because a volt or two is insufficient to break down the insulating film. If the film is not permitted to conduct at all, it is not very sensitive; the most sensitive condition is attained when an infinitesimal current passes, strong enough to just show on a moderately sensitive galvanometer. Now let the slightest surging occur, say by reason of a sphere being charged and discharged at a distance of 40 yards; the film at once breaks down, perhaps not completely—that is a question of intensity—but permanently. Apparently more molecules get within range of each other and a momentary wave seems to weld them together. It is a singular variety of electrical welding. A stronger wave enables more molecules to hold on and the change in resistance seems to be proportional to the energy of the electric radiation from a source of given frequency. It is to be especially noted that the battery current is not intended to effect the cohesion, only to show that it has taken place. The battery can be applied after the spark has taken place and the resistance will be found to have changed as much as if the battery had been on all the time. The cohesion electrically caused can be mechanically destroyed. Ground vibrations or any other feeble mechanical disturbances such as scratches or

taps are well adapted to restore the contact to its original high resistance and sensitive condition. The more feeble the electrical disturbance, the slighter is the corresponding mechanical jar needed for restoration."

331. Metals Opaque to Hertzian Waves.—Waves cannot get at a coherer that is completely shut up in a metallic box, but if wires are led to it from outside, the waves seem to run along the wires into the box and the coherer is nearly but not quite as sensitive to the external waves as if no enclosing box had been used. To screen it perfectly, according to Professor Lodge, it is necessary to have no opening of any kind in the box. Even the joints should be soldered. A lid, if securely clamped, using pads of tin-foil to secure perfect joints, may suffice. The inside of the box is then said to be electrically dark. Even a single wire protruding from the box, although not connected to anything at either end, is sufficient, provided it is insulated from the box itself and does not, therefore, completely fill the hole with metal, to allow the waves to run along it into the box. A small round hole, however, seems to let in but few waves provided no insulated wire protrudes, but a long narrow chink or crack will let in a large number of waves.

MARCONI SYSTEM.

332. The arrangement of transmitting and receiving apparatus patented by Marconi and said to be used by him is shown in Fig. 109. A long vertical wire ends in a plug *P* that may be inserted in the receptacle *m* for transmitting and in the receptacle *n* for receiving.

333. Transmitting Apparatus.—The essential part of the transmitting apparatus is an induction, or *Ruhmkorff*, coil, as it is commonly called. The primary winding *p* and the secondary winding *s* of the Ruhmkorff coil are both wound upon the same iron core, which is here represented, merely for the sake of clearness, as lying between the two

coils *p* and *s*. The current may be rapidly interrupted by almost any ordinary form of interrupter and a condenser C_1 must be connected across the break *c d*. The condenser reduces the sparking between *c* and *d* and also improves the

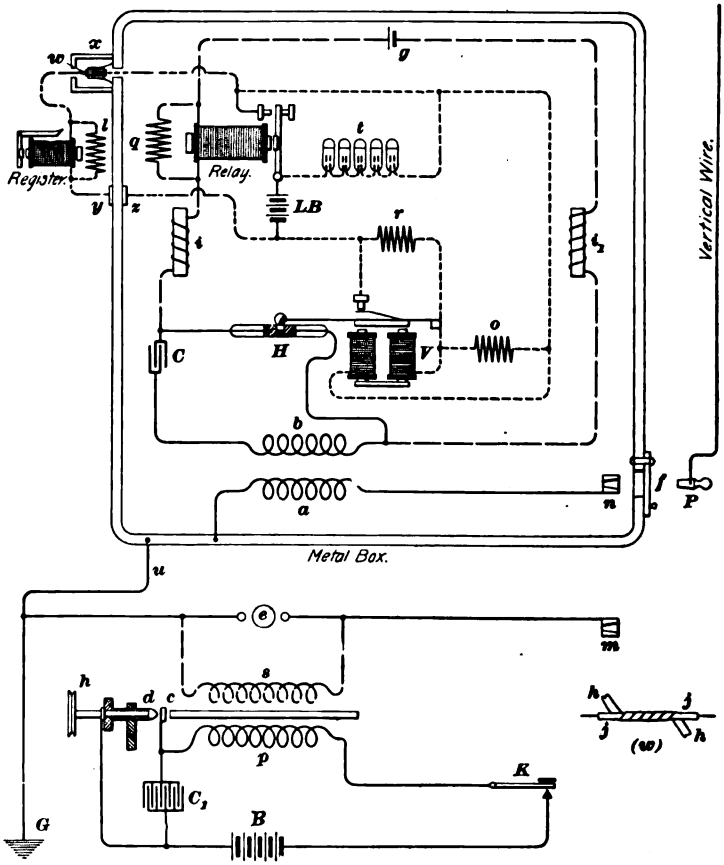


FIG. 109.

action of the coil by causing a more sudden interruption of the current that flows from the battery *B* through the primary *p*. Both *d* and *c*, where they come in contact with each other, are tipped with platinum to better resist corrosion and fusion. Marconi says he found it advantageous

to rapidly revolve the contact *d* by means of an electric motor of some kind geared to the wheel *h*. By this means the platinum contact surfaces on *d* and *c* are kept smooth and any tendency to stick is removed and they also last longer.

When the key *K* is closed, a constant stream of sparks will pass between the large center sphere *e* and the two smaller spheres, one on each side. The total air gap usually varies from 1 to 2 inches, but the coil must be powerful enough to give an 8- or 10-inch spark. One of these small spheres is grounded and the other connected to a long vertical wire.

The current in the oscillator (to be defined presently) surges back and forth between 100,000,000 and 200,000,000 times per second; each time it does so it charges or discharges the long vertical wire. The charging and discharging currents flow up and down the vertical wire and consequently produce electromagnetic waves that are projected out into space, as horizontal circular waves, from every part of the vertical wire. Furthermore, on account of the static disturbances that are produced in the surrounding space between the vertical wire and the surface of the earth due to the electrostatic capacity of the vertical wire, it is probable that so-called electric waves, which vibrate up and down in vertical planes, are also projected out into space.

Since these waves spread out through space in all directions, it is evident that another vertical wire, if not too far distant, will be cut by some of them. The waves that cut the second vertical wire seem to set up oscillating currents that follow it down to the earth.

334. By means of the key *K*, the current flowing in the primary coil may be broken up into ordinary Morse signals. This will cause waves to be projected into space corresponding to the Morse code. To be sure, each dot consists of millions of waves, but all waves cease when the key is opened. The key *K* used by Marconi when in this country was not an ordinary telegraphic key in the strictest sense, although it was somewhat similar. It had a longer lever (about 14 to 18 inches) pivoted at about its middle, but

instead of a finger button there was a handle extending upwards about 3 inches. The key was moved up and down over a wide gap in order to break the spark in the primary circuit when it was opened. This accounts for the fact that a speed of 12 or 15 words a minute seems to be about the best so far attained, while 10 words is a good average speed.

335. Other things being equal, the larger the ball *e*, the greater is the distance through which it is possible to communicate. A solid brass ball *e* 4 inches in diameter, giving waves 10 inches in length, has been used by Marconi. He is said to now use simply two 1-inch solid brass balls, one connected to each terminal of the secondary coil, in place of the three shown at *e* in this figure, and a spark gap, varying from 1 to 2 inches, for all distances up to 110 miles. The length of the wave generated depends on the relation between the resistance, self-induction, and capacity of the oscillator. By the oscillator is usually meant merely the circuit from the top of the vertical wire through *m e* to the ground *G*. The capacity of the oscillator is varied by varying the size of the balls and the length of the vertical wire.

336. Sometimes metallic wings of sheet metal are attached to the balls on each side of the spark gap. This will alter the wave length, and if the receiver can be made, by the use of similar metallic wings, to respond only to waves of a certain length (within limits), this affords a method for synchronizing or tuning the receiver and transmitter. In other words, although waves of all lengths may reach the receiving apparatus, it will not respond unless certain particular wave lengths are present.

337. Receiving Apparatus.—To prevent the oscillations generated at a station from acting on its own coherer and rapidly destroying the same, Marconi encloses all the receiving apparatus, with the exception of the Morse register, in a metal box, and leads the wire connecting to the register through a coil encased in bands of tin-foil, the

tin-foil being connected to earth. The box is usually made of iron merely because it is the cheapest metal. The metal need be only $\frac{1}{20}$ or $\frac{1}{16}$ inch thick. The hole at *f* should be securely closed by a metal door when transmitting. To receive, the door is opened and the plug *P* inserted in the receptacle *n*. The current waves that slide or follow down the vertical wire pass through the primary winding *a* of a step-up *induction coil*, or *transformer*, as it may be called, when they pass through the metal of the box and the wire *u* to the ground *G*. The secondary *b* of this coil is connected in series with a condenser *C* and a coherer *H*.

338. The **induction coil** or **transformer** *a b* should be in tune, or *syntony*, as it is called, with the electrical oscillations transmitted, the most appropriate number of turns and the most appropriate size of wire varying with the length of wave. Marconi says in one of his patents that he

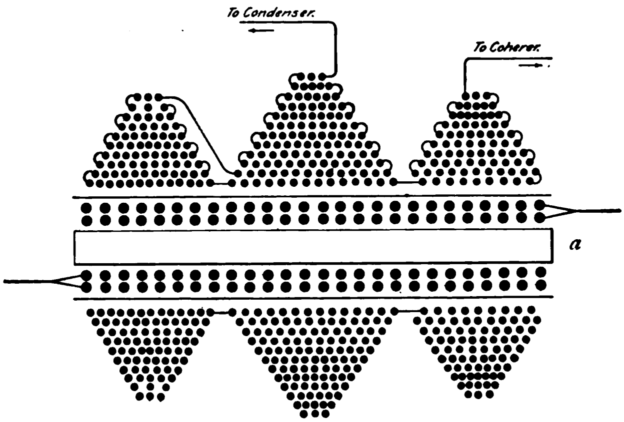


FIG. 110.

obtained the best results (presumably for 10-inch waves) by using a transformer constructed as shown in Fig. 110. The primary *a* is wound on a glass tube about .37 inch in diameter. The primary winding *a* consists of two layers in parallel of 160 turns each of No. 38 B. & S., single-silk

covered copper wire. No iron core is used. The secondary is wound in a very peculiar manner, as shown. There is first wound on one layer of 150 turns. The secondary is then divided into three sections *b*, *c*, *d*. The section *b* has nine more layers with 45, 40, 35, 30, 25, 20, 15, 12, and 5 turns in the respective layers; the section *c* has eleven more layers with 40, 39, 37, 35, 33, 29, 25, 21, 15, 10, and 5 turns in the respective layers; section *d* has nine more layers with 45, 40, 35, 30, 25, 20, 15, 17, and 14 turns in the respective layers. The same sized wire is used as in the primary. These sections must be wound and connected exactly as shown. The coil is .98 inch long.

339. Marconi's Latest Transformer and Connections.—In February, 1901, Marconi received a patent for the following method of connecting his receiving apparatus. The secondary of the transformer is opened in the middle and the inner ends connected to the local circuit, which includes the battery and relay, while the two outer ends are connected to the coherer. It is stated to be advantageous to also connect a condenser across the inner ends of the secondary where the local battery and relay circuit is connected. Details of one form of transformer are given as follows: The primary, which is in circuit with the vertical wire, is wound on a non-magnetic core ¼ inch in diameter and consists of 100 turns of No. 27 copper wire, insulated with single silk and coated with paraffin wax. The secondary consists of No. 32 single-silk covered copper wire wound over the primary, commencing at the middle and winding it in the same manner as the primary. Each half of the secondary is wound with a decreasing number of turns, beginning with 77 in the first layer and ending with 3 in the seventeenth, making 500 turns in all. Other forms are also given. These coils are stated to give the best results when the length of the vertical wire at each station is 150 feet.

340. Transformer. — It was natural to attempt to increase the induced electromotive force acting on the

coherer by an induction coil, analogous to those used in telephony. The above manner of constructing a transformer seems to reduce to a minimum the impedance and to realize the maximum induction between the primary and the secondary for these high-frequency currents.

The only explanation offered for winding and connecting the coils in the particular manner stated above is that given by Marconi, who says that it is done to prevent the effects due to electromagnetic induction from being in opposition to those due to electrostatic induction at the ends of the primary coil. The favorable action of the transformer is most marked. According to Marconi, this device increases the range from 30 to 60 per cent.

341. The **condenser** *C*, Fig. 109, is made, by Marconi, of six plates of tin or copper foil 1.48 inches by .98 inch, separated by paraffined paper .006 inch thick. Three alternate plates form one side and the remaining three plates the other side of the condenser. This condenser has a capacity of about $\frac{1}{4}$ microfarad. With this apparatus he used a vertical wire 140 feet long, composed of seven strands of about No. 18 or No. 20 B. & S. copper, the top being about 120 feet above the ground.

342. The **coherer** *H*, which is shown in Fig. 111, is made of a glass tube *a* about 1.5 to 2 inches long and having an internal diameter of $\frac{1}{10}$ or $\frac{1}{12}$ inch. Two silver plugs *p*, *p* about $\frac{1}{8}$ inch long fit quite tightly in the tube and have connected to them the platinum leading-in wires *w*, *w*, which are sealed in the ends of the glass tube. The plugs are separated from each other by about $\frac{1}{30}$ inch, the space *c* between them being only partially filled with a mixture of nickel and silver filings of uniform size and very clean and dry. Researches that have been made for a practical coherer have shown that the filings on electrodes should be made of a metal slightly oxidizable.

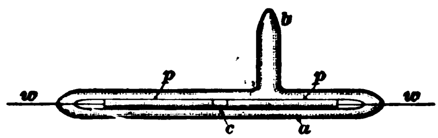


FIG. 111.

The filings should be rather loose and in such a condition that when the tube is tapped, the filings may be seen to move. The filings should be rather coarse, such as produced by a large rough file, which should be frequently washed in hot water, dried, and used warm when making the filings. The mixture should preferably consist of from 90 to 96 per cent. of hard nickel and from 10 to 4 per cent. of hard silver filings. By increasing the proportion of silver, the sensitiveness of the coherer increases, but it is better for ordinary work not to have a tube of too great sensitiveness. The addition of a small quantity of mercury to the filings improves the sensitiveness. There must not be so much mercury as to form a clot or cake in the filings. Sufficient mercury may be obtained by slightly amalgamating the inner surfaces of the silver plugs that are to be in contact with the filings. There should not be more than sufficient mercury to just brighten the surface of the plugs without showing any free globules.

The tube should be sealed and a vacuum, while not essential, is desirable. Care should be taken not to oxidize the filings by too much heat when sealing the tube, and it is better to use a non-oxidizing hydrogen and air flame. A vacuum of about $\frac{1}{1000}$ of an atmosphere is desirable. The tube, if well made, should be sensitive to the waves from the spark produced at the break of an ordinary vibrating bell when working at a distance of not less than 1 or 2 yards from the tube. In order to keep the coherer in good condition, not more than 1 milliampere should ever be allowed to flow through it, even when active. For this reason never more than 1 Leclanché cell, nor over 1.5 volts, should be applied to the terminals of a coherer.

343. Choking Coils.—The coils i and i_1, in Fig. 109, known as **choking coils**, are formed by wrapping a few inches of very thin insulated copper wire around an iron wire about 1.5 inches long.

344. Magnetic Instruments.—An ordinary vibrating bell is used to tap the coherer in order to restore it to its

normal condition when the waves which have been acting upon it cease. The relay connected in the circuit with the coherer should have quite a large resistance, preferably about 1,200 ohms, and the vibrating bell about 1,000 ohms.

Mr. Marconi suppresses, as completely as possible, all parasitic waves originating from contacts made and broken in the receiving apparatus itself and capable of actuating the coherer. To this end he has placed non-inductive shunts around each point where the circuit is broken and around all coils subject to the electromotive force of self-induction; the spools of the relay in particular have been thus shunted. Each one of these non-inductive resistances *l*, *q*, and *o* should have a resistance about four or five times that of the instrument which they shunt.

345. All Contact Points Shunted.—There should also be a smaller non-inductive resistance across all contact points at which a circuit is broken in order to prevent a spark. Such resistances are shown at *r* and *t*. The resistance *t* is preferably made of a series of tubes containing two electrodes and water acidulated with sulphuric acid. The number of these tubes in series should be about 10 where a circuit containing 15 volts is broken, in order to prevent the passage of much current from the local battery. Such cells possess quite an electromotive force, called a *counter electromotive force*, which prevents the flow of a steady current, but allows the high-tension and nearly instantaneous current produced by self-induction upon the opening of the circuit by the relay armature to pass easily through them and so do away with the disturbing sparks that would otherwise be produced at the relay contacts. The vibrator should preferably be arranged to tap the coherer tube underneath in order to prevent the packing or caking of the filings.

346. It is necessary to have the Morse register, which is generally used, on the outside of the box, so that the message may be seen as it is received. One of the wires

from the inside is fastened to the metal box at *z* and the one on the outside at *y*; the metal of the box completes the circuit. The other wire *w* passes through an opening in the box in the following manner: A coil of wire is made containing about 120 turns of about No. 28 B. & S. copper wire. This wire, as shown in the small detached view (*w*), is insulated by the gutta percha *j*, which is then covered with the tin-foil *h*. The tin-foil is electrically connected to the metal box. This method seems to protect the coherer from the oscillations set up by the home transmitter. This coil is usually protected by a metal or wooden casing *x*.

347. Batteries.—The battery *g*, the current from which flows through the coherer *H* and operates the relay, consists of only one cell. The battery *L B* furnishes the current for operating the vibrating bell *V* and the Morse register, and it may consist of any desirable number of cells, usually about 12 cells being required. The battery *B* for operating the Ruhmkorff coil should preferably consist of storage cells or a dynamo, because a steady current of about 6 amperes is required for a coil capable of producing a 10-inch spark.

REMARKS CONCERNING APPARATUS.

348. Ruhmkorff Coils.—It seems, as a result of experiments, that it is well to use a Ruhmkorff coil capable of giving a discharge spark as long as possible. Consequently, very powerful induction coils should be used. Those most used will give a discharge spark of 10 to 16 inches between points, but in operation these sparks are reduced so as to have a length of between 1 and 2 inches. These short sparks are thicker than the long ones.

All types of interrupters have been tried, those with turning contacts, mercury, hammer, etc., but no particular one shows any marked superiority. For long operation the best one of those mentioned is the hammer interrupter. It is certain that the frequency should be small. Marconi

has returned to the simple hammer interrupter after trying others. The Wehnelt electrolytic interrupter, which has failed with some, has given others excellent results.

349. Oscillators. — The majority of experimenters, including Marconi, use the spark gap of Hertz, with two small balls in air. The platinizing of these balls is unnecessary, but some experimenters advise that they be polished from time to time.

350. Antennæ.—Wires and other apparatus that may be connected to the balls on each side of the spark gap are called **antennæ.** This term does not include, however, the secondary of the induction coil. The spark gap and the two antennæ constitute the oscillator. An insulation of rubber along the vertical wire appears useful in diminishing its partial discharge by convection into surrounding moist air.

351. Critical Potential for Coherers.—In order to utilize the properties of the coherer, it is necessary that the critical potential at which the coherer breaks down shall not exceed the electromotive force of the cell plus the electromotive force of self-induction produced by the decrease or the breaking of the current in the local circuit containing the coherer and relay. It is then necessary that the inductance be as small as possible, and that the current flowing have but slight intensity. The first condition being difficult to meet, notwithstanding the use of non-inductive shunts around all inductive parts, it is necessary to reduce the current by the use of a low-voltage cell. The Lalande cell, which gives, with a negative electrode of tin, a potential of .25 volt, has given good results.

Very good results may be obtained with coherers using filings of gold, silver, or with silver alloyed with a hundredth part of copper, placed between German silver electrodes. The use of a slightly oxidizable metal allows one to raise the critical potential sufficiently to use a cell that will work the relay.

352. Self-Decohering Coherers.—The necessity of a tapper with existing coherers is very troublesome, and does not permit the use of a telephone as a receiver. Various experimenters have therefore sought coherers decohering spontaneously without tapping. Tommasina, using a coherer with magnetic filings, has attempted to replace the tapper by an electromagnet, magnetized only when the coherer is affected, thus attracting the filings and decohering them. It has been proved that in this arrangement, the filings become magnetized and then it is no longer possible to easily decohere them. He obtained a good automatic decohering coherer by using two German silver electrodes plunged in carbon powder similar to that used in telephone transmitters. It was apparently not successful for long distances.

SYNTONIC SYSTEMS.

353. A serious inconvenience charged against wireless telegraphy that interferes with its entry into the real domain of practice is the fact that, with the ordinary arrangement of apparatus, as already described, it is impossible to obtain, at the same station, two independent communications, every receiver placed in the radius of action of a transmitter being acted on by the waves sent out by the one transmitter. Various systems, founded upon different principles, have been proposed with a view to avoid this fault.

354. Sending Waves Out in One Direction Only. If it is desirable to direct the waves in a given direction, the vertical wire and earth connections are sometimes omitted and, as shown in Fig. 112, the spheres *g*, *h* of the oscillator are placed in the focal line of a metal cylindrical parabolic reflector *w v*. It is slightly advantageous for the focal length of the reflector to be equal to $\frac{1}{4}$ or $\frac{3}{4}$ of the length of the waves emitted by the oscillator. Moreover, the length and broadest diameter (across the opening of the reflector) should be at least double that of the wave length.

355. Messrs. Lodge and Muirhead have sought to obtain an electric resonance between transmitting and receiving circuits. For this purpose they make the *radiator* and the *collector*, as the oscillator and receiving circuits,

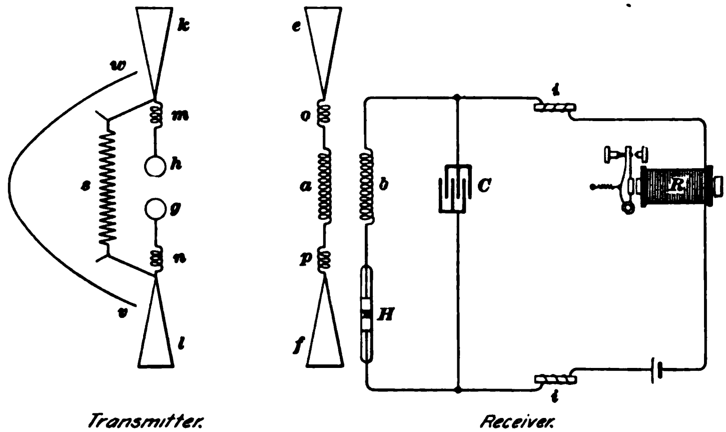


FIG. 112.

respectively, are frequently called, independent of all other apparatus, and tune these to the same period of oscillation by modifying the self-induction of a coil having a variable number of turns, and by adjusting the electrostatic capacity of the apparatus.

356. Tuning Transmitter and Receiver.—The transmitter and receiver may be tuned to emit and receive, respectively, waves of a certain length by attaching metal wings *e*, *f*, *k*, *l* to them, as shown in Fig. 112. Between the wings *k* and *l* and the balls *g* and *h* of the oscillator are connected two coils *m* and *n* having a small inductance. The inductance of these coils and the area, and, therefore, the capacity of the wings *k* and *l*, are adjusted to be in tune with the wave length emitted by the oscillator. Usually but little or no inductance is required at *m* and *n*. The length of the wings should approximate the length of the wave emitted. The entire transmitting apparatus is not

shown here, since it would be the same as that already given. The secondary of the Ruhmkorff coil is shown at *s*. This arrangement was devised by Professor Lodge.

At the receiving station, *a* is the primary and *b* the secondary of an induction coil similar to that already described in connection with Fig. 109. The wings *e* and *f* and the inductance coils *o* and *p* must be adjusted until this receiver is in tune with the transmitter. There would often be sufficient inductance in the coil *a*, so that the coils *p* and *o* would not be required. The capacity of the wings *e* and *f* are readily adjusted by making them of very thin sheet metal and rolling them up upon themselves until they have the proper length and capacity. This may be determined by holding the receiver near the oscillator and in the focal line of the reflector *v w* (if one is used), and making a minute air gap somewhere near the middle of the collector between the two wings *e* and *f*. The wings have the proper length when the distance from the oscillator to the receiver, at which a spark will pass across the minute air gap in the collector, is a maximum. This spark is caused by electric oscillations in the system *e o a p f* when the latter is in tune with *k m h g n l*. When placed at the distant station, the wings may have to be slightly readjusted.

Marconi relies on the proper adjustment of capacity and self-induction to obtain resonance. He connects a long metallic sheet to the antennæ on each side of the spark gap, that is, in the vertical wire, and in *e G* in Fig. 109. He sometimes includes on each side of the spark gap a coil possessing self-induction.

357. These methods have not given good results, probably from the fact that the oscillations produced in the vertical wire at the sending station are very rapidly damped and have not time to establish actual resonance at the receiving station. That is, the current wave produced in the receiving circuit by an arriving electromagnetic wave dies out before another electromagnetic wave arrives. Thus one current wave is not helped or pushed forwards by a

following wave, although the two may be in perfect tune or unison.

358. Results Attained in Selective Signaling.—While it is possible to make a receiver respond to only one transmitter, up to the present time it has not given very good results so far as the distance over which signals may be sent is concerned. A reflector, if used, must, of course, be turned in the proper direction, which is a disadvantage.

In the fall of 1900, Marconi succeeded in simultaneously sending two different messages between two stations in England 30 miles apart, and they were recorded upon Morse registers without delay or mistake. Each receiver in this case was connected to the same aerial wire about 40 feet high. Marconi's arrangement in these trials has not been published at the present time. Other trials showed that messages could be sent from one station to another while between two other stations messages were also being sent, the line between the first two intersecting the line between the second two stations. In March, 1901, Marconi stated that by his system, messages from five different places could be received simultaneously at one point.

THEORY OF WIRELESS TELEGRAPHY.

359. The phenomena of wireless telegraphy are very complex and have given rise to various interpretations. The first idea is to suppose a mutual induction between the two nearly parallel vertical wires. But this will not explain the propagation of waves, and appears certainly to fail, when in consequence of the rotundity of the earth or by an obstacle, the vertical wires are screened from one another. Certain authors have claimed an effect of electrostatic capacity between the uprights, but such an effect would diminish in inverse proportion as the cube of the distance, and very quickly reduce to nothing. Others, impressed by the influence of the ground wire at the sending station, have been led to see in this propagation an effect of conduction

by the earth. This will explain why transmission is better over sea than land. But this will not account for the excellent results obtained by means of a vertical wire hung from a balloon.

360. In reality, the phenomena appear to be a combination of several effects, one or the other of which predominates, according to the conditions. Electric oscillations are produced along the wire and in the space between the vertical wire and the earth. From the seat of this disturbance originate the waves, which are propagated in all the surrounding space. These waves form surfaces of revolution around the vertical wire. The lines of electric force are in meridional planes and are perpendicular to the earth; the magnetic lines of force are in horizontal circles having the vertical wire as a common axis. As a result of the effect of concentration, well known in the propagation of waves along wires or metallic surfaces, the electric density is much greater at the surface of the earth directly connected with the oscillator than in the atmosphere, and in large part the magnetic lines appear to slip along the earth. In the case of a hill intervening, it is supposed that the waves slide up and over it. This concentration, moreover, is the greater the more perfect the conductivity of the surface over which the waves proceed, and the loss of energy in this transmission is thereby lessened over a smooth surface. Yet this concentration does not prevent the diffusion of an important part of the energy into all space, under the form of hemispherical waves, the effects of which are less intense than those near the earth, but, nevertheless, noticeable.

One of Marconi's assistants stated that the amplitude of the vertical waves generally used proved to be about four times the length of the vertical wire. This would make the amplitude of vibration 600 feet for the waves that left the top of a vertical wire 150 feet high.

361. The receiving wire, cut at all points by the lines of magnetic force, is the seat of a resultant electromotive

force proportional to the intensity of the field and to the rapidity of the oscillations. The higher the vertical wire, the more lines of force are cut. With a given length, fewer lines are cut as we ascend farther from the earth. It is not necessary that the receiving vertical wire be connected to the earth, but the range appears to be slightly extended, due to the conduction over the surface of the earth as mentioned elsewhere.

It is theoretically important to increase the electrostatic capacity, the potential used, and the frequency of the oscillations, and to reduce the self-induction as much as possible.

362. If a circuit having certain resistance, inductance, and capacity be placed in a region in which waves are passing in such a position that the successive waves can induce currents in it, then each wave will tend to slightly increase the intensity of the current induced by the preceding wave, provided the waves have a certain particular frequency. The oscillations will increase in intensity, just as small pushes given to a pendulum at the proper times will make it swing violently. Such a system is said to be in tune with the waves or the generator that emits the waves. The generator and receiver are also said to be in resonance or syntony with each other.

If R is less than $\sqrt{\frac{4L}{Q}}$, in which R is the resistance, L the inductance, and Q the capacity of the system, then the discharge due to the electrostatic capacity of the system gradually expends itself in a series of oscillations, the periodic time T of which is given by the expression $T = \frac{2\pi}{\sqrt{\frac{1}{LQ} - \frac{R^2}{4L^2}}}$.

If R is very small in comparison to the other quantities, as is usually the case in apparatus designed to emit electric waves, then $T = 2\pi\sqrt{LQ}$. Now, as T may be varied by changing either one or both L and Q, a very wide range of vibration may be secured. Knowing T and the rate of propagation of the wave (approximately the velocity of light

in air, or 29,857,000,000 centimeters per second), the wave length, which we will designate by l, is the product of this periodic time and the velocity, or it is equal to the velocity divided by the frequency.

363. Wave Length.—In case of an oscillator having simply two spheres of equal size separated by an air gap, as shown in Fig. 108, the wave length l is given approximately by the formula

$$l = 7\,D, \qquad \textbf{(26.)}$$

in which D is the diameter of the spheres.

In the case of one large sphere separated by air gaps from two smaller spheres, one on each side, as shown in Fig. 109, and when the diameters of the small spheres and the length of both conductors or rods connected to these small spheres are very small in proportion to the diameter of the larger central sphere, the wave length is given approximately by the formula

$$l = 1.3\,D, \qquad \textbf{(27.)}$$

in which D is the diameter of the large central sphere. In other cases the formulas become too complicated to be given here.

364. Energy.—The energy represented by the waves that reach the receiving station varies as the square of twice the distance between the oscillator and coherer. Hence, the energy required to transmit signals increases enormously as the distances become greater. There is little or no secrecy except by code; the average speed is not over 12 words per minute; and an ordinary receiver is generally useless, except for short distances, when it is within range of two stations that are transmitting at the same time. These objections will probably be successfully overcome in the future.

365. Effect of Weather and Surface of the Earth. The quality of communication is about the same under

all conditions of fog, rain, wind, etc. However, it is decidedly easier to establish communication over water than over land. The heights of vertical conductors required over land are always considerably greater than those sufficing for sea communication over the same distance.

366. Laws for Height of Vertical Wires.—Marconi has deduced from numerous experiments on sea the following laws, which have been also verified by Mr. Gravey, Engineer of the British Post Office:

First.—To obtain the maximum useful effect, the antennæ of the two stations should be equal and parallel.

Second.—The height H of the vertical wires required for good communication is related to the distance D between the vertical wires by the formula

$$H = a\sqrt{D}, \qquad \textbf{(28.)}$$

a being a coefficient depending on the nature of the apparatus used. This distance for clear space, as given by the formula, is diminished at least one-half when the two stations are separated by high intervening obstacles.

The advantage of having the vertical wires of like height seems to be very slight, and the results appear almost the same if the height of the vertical wires vary simultaneously, keeping their sum constant. For best results they should not differ in height more than 15 to 30 feet.

367. Influence of Curvature of Earth.—It seems as though the curvature of the earth can have but little influence, if any, on the height required for the vertical wire. During the English naval maneuvers in the summer of 1899, Marconi used a vertical wire 150 feet high at each station 75 miles apart at times. In this case there was a hill of water, due to the curvature of the earth, 35 miles long and 700 feet high at the center (550 feet above a straight line joining the top of the wires). Possibly the vertical wire is necessary because its use lengthens the waves and propagates at least some of them in a plane vertical to the surface of the

earth and they are therefore less likely to be absorbed by it. The fact that the waves are lengthened makes them more penetrative and capable of affecting a receiver at a greater distance.

368. Results.—As an instance of distances attained, in 1900 Marconi established communication between two stations 84 miles apart with wires 135 feet high. A straight line joining the upper extremities of the two vertical wires would pass 900 feet below the surface of the sea.

Experiments made inland are less brilliant. In many cases recourse has been made to captive balloons or kites to obtain antennæ sufficiently high. By such means Marconi, in 1899, telegraphed between Salisbury and Bath, 33.5 miles. It was stated in March, 1900, that successful communication had been held in South Africa over a distance of 70 miles by using kites to hold up the vertical wires. This method depends on a steady wind at both stations and often when there is a good wind at one station there is none at the other. It does not appear, in spite of the announcements of the results in the Transvaal, that much use has been made of wireless telegraphy in military operations. At present it seems that messages may be sent about three times as far on the ocean as on land.

In the fall of 1900, Marconi succeeded in transmitting messages from Poole to the Isle of Wight, a distance of 30 miles, by the use of metal (zinc) cylinders 4 feet in height, hung about 25 feet from the ground, thus dispensing with the 177-foot uprights previously used over this range. At the same time he transmitted two simultaneous messages without interference. No explanations concerning the method used have been made public.

In February, 1901, Marconi established perfect communication with vertical wires 100 feet high between St. Catherines, on the Isle of Wight, and Lizard Head, a distance of 200 miles, practically over water the entire distance. This is the longest transmission recorded so far and constitutes a considerable step in advance.

UTILIZING ELECTRIC RAILWAY CURRENT FOR TELEGRAPH CIRCUITS.

369. The following method of supplying local and main-line telegraph circuits with current from the 500-volt circuit of electric railways was described in the "Telegraph Age" by Mr. Wm. H. Deane, who has employed it on the

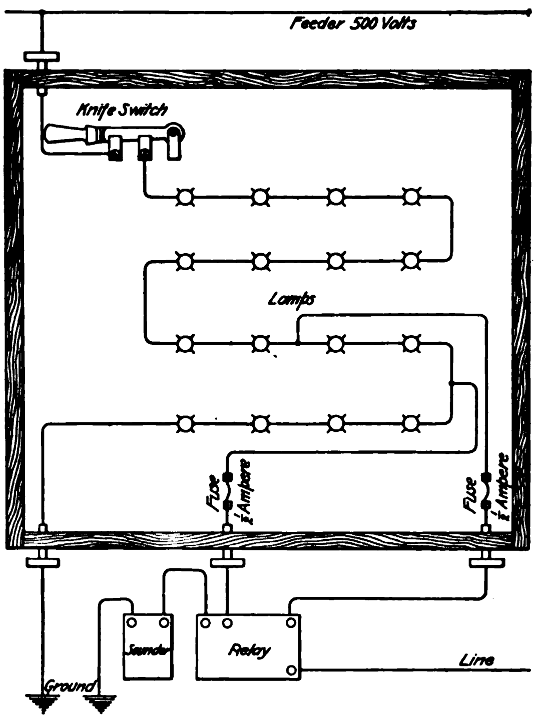


FIG. 113.

telegraph circuits of the Brooklyn Rapid Transit Company since July 1899. The method is illustrated in Fig. 113.

"A wooden box 18 inches square and 8 inches deep is lined with thin sheet asbestos and fitted with sixteen 110-volt lamps of 16 candlepower each and wired in series. The current is led from the feeder through the regulation

porcelain tubes used in electric-light work to a small knife switch located in the box and then through the bank of lamps, and out through another tube and grounded, preferably to the rail.

"One end of the telegraph line or local circuit that is to receive this current is grounded and the other end is brought into the box of lamps and passed through a half-ampere fuse before reaching the lamp connection. In supplying a main line, it is of course understood that this apparatus can only be applied at one end of a grounded telegraph wire. To ascertain quickly the point that will furnish the needed current, the end of this conductor should be touched to the lamp connections and, starting from the grounded end of the bank, moved lamp by lamp upwards until the instrument in the circuit shows that it is supplied with the proper amount of current to do the work required. When this is decided upon, the wire can be permanently fastened to the particular connector selected. The following telegraph lines and quite a number of locals have been equipped in this way and are giving perfect satisfaction: Brooklyn Elevated Division No. 1 telegraph line consists of 25 miles of No. 12 insulated iron wire and looped into 24 relays of 50 ohms resistance each. This circuit works strongly and is tapped between the sixth and seventh lamps from the ground end. Kings County Elevated Railroad Division, consisting of two line wires each 8 miles long, of the same wire as mentioned above, and equipped with 17 relays of 30 ohms resistance, is tapped between the fifth and sixth lamps. Local 4-ohm sounders work strongly when tapped between the fourth and fifth lamps, and when sounders of 20 or 30 ohms are used, excellent results are obtained by tapping between the first and second or second and third lamps."

370. Precautions to be Carefully Observed.—"Care should be taken not to unscrew any of the lamps between the tap point and the ground without first opening the knife switch, as the telegraph circuit is instantly flooded

with a rather heavy current, and although the fuse would protect the circuit, still an unpleasant shock might be given to some one working the wire at the time. The same trouble would be experienced should a filament break in one of the lamps on this end of the bank of lamps; but this rarely happens, as these lamps are not subjected to the hard usage of those used for lighting purposes. Only one case of this kind occurred in a year on the above circuits. This was caused by an old lamp being accidentally used in setting up the apparatus. Great care should be taken that the entire work is done on the strict lines laid down by the underwriters and boards of electrical control."

371. There has not been much trouble from variations of current, and then only at points where there are no feeders and where a tap was made to the trolley wire direct. Over 200 gravity cells have been displaced, and these boxes, enabling the electric railway current to be used, are being installed wherever locals are used, with the most gratifying results.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS

TREATED OF IN THIS VOLUME.

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number as the Question Paper in which the questions and examples occur has been carefully studied.

ELEMENTS OF TELEGRAPH OPERATING.

(1) What is a telegraph key?

(2) What are the essential parts of a key?

(3) How well should the Morse alphabet be known?

(4) What Morse letters and numerals are the reverse of one another?

(5) What are the relative lengths of dots, dashes, long dashes, extra-long dashes, spaces between parts of an ordinary letter, spaces in spaced letters, spaces between letters, and spaces between words?

(6) (*a*) What name is given to the interval between 2 dots or between a dot and a dash in a letter? (*b*) How long should this interval be? (*c*) Compared with a dot, how long is the interval?

(7) Of what does a learner's telegraph outfit consist?

(8) How are large numbers usually spaced?

(9) What is a telegraph sounder?

(10) What are the essential parts of a sounder?

(11) (*a*) Into what two classes may cells be roughly divided? (*b*) Give an example of each.

(12) How would you connect two learners' sets together with two cells at one end only?

(13) (*a*) How much play should the armature lever of a sounder have? (*b*) In its lower position, how close should the iron armature come to the iron core? (*c*) Why should the armature and the core never touch?

(14) (*a*) How should the key contact points be kept? (*b*) How should all binding posts be kept?

(15) How is one telegraph office called up by another?

(16) How does the office called reply?

(17) Into what parts may a commercial message be divided?

(18) Why are two line wires not required for a complete telegraph circuit?

(19) How should the telegraph key be held?

(20) What does the first line including the check of a message state?

(21) (*a*) Of what does the date consist? (*b*) What part of the date does the operator omit in sending? (*c*) What abbreviation does the operator send in connection with the date?

(22) What is a common mistake that beginners need to guard against in making characters that consist of two or more dots or of two or more dashes?

(23) (*a*) How should the street number in the address be transmitted? (*b*) What precedes and what follows the address?

(24) (*a*) What part of the message follows the period that closes the address? (*b*) What abbreviation follows the body of the message? (*c*) What follows this abbreviation?

(25) What difficulty is experienced in making the characters *h*, *p*, and *6*?

(26) How does the receiving operator indicate that a message is correctly received?

(27) Why is *k* a difficult letter to make?

(28) What words or abbreviations in a complete message are transmitted by the sender but not copied by the receiver?

(29) If the last dot in *i*, *s*, *h*, and *p* is prolonged into a dash, what letter or numeral does each one then represent ?

(30) If the receiving operator finds that he is not getting a message correctly, how should he proceed ?

(31) (*a*) How should an omission in the body of a message be located ? (*b*) If the sending operator makes a mistake, what should he do ?

(32) Name the so-called spaced letters.

(33) What is more desirable in an operator than the mere ability to send at a fast rate ?

(34) (*a*) What is the Phillips code of abbreviations ? (*b*) For what class of work is it used very extensively ?

(35) (*a*) Why is it so easy for the word *sold* to be taken for *cold*, and *ship* for *chip ?* (*b*) Also, *seen* for *son*, and *sheep* for *shop ?* (*c*) Also, *sail* for *rail*, and *some* for *Rome ?* (*d*) Also, *hero* for *zero*, and *heal* for *zeal ?* (*e*) Also, *tow* for *low*, and *atone* for *alone ?* (*f*) Also, *hog* for *home ?* (*g*) Also, *poison* for *person ?*

(36) If insufficient space (less than 3 units) is left between the following pairs of letters, what is the result: *a* and *t*, *e* and *d*, *w* and *e*, *v* and *e*, *u* and *i*, and *u* and *d* ?

(37) What other characters may be formed if *j*, *k*, *th*, *an*, *i*, *s*, *h*, and *p* are made incorrectly ?

(38) Why are the following letters likely to be confused: *ta* and *k*, *an* for the figure *1*, *te* and *n*, *ti* and *d*, *ts* and *b*, *st* and *v*, *it* and *u*, *in* and *q*, *at* and *w*, and *ke* and *j* ?

TELEGRAPHY.

(PART 1.)

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(1) (*a*) What is electric telegraphy? (*b*) What two kinds of signals may be used? (*c*) What are the essential parts of an electric telegraph system?

(2) Why is a relay used in a long line circuit instead of a sounder?

(3) (*a*) When did Morse first conceive the idea of the electric telegraph? (*b*) When did he take out his first patent? (*c*) To whom, as an associate of Morse, is much credit due for the development and perfection of the system?

(4) If the internal resistance of a battery is neither very large nor very small compared to the external resistance of the circuit, how should the cells be connected in order to get a maximum current from a given number of cells?

(5) (*a*) How many intermediate offices may be put on one line? (*b*) What is the objection to very many offices on one line?

(6) (*a*) What piece of apparatus is absolutely essential to all present commercial methods of electric telegraphy used in the United States? (*b*) By whom was it invented?

(7) (*a*) What is the purpose of a relay? (*b*) What are its principal parts?

(8) In what holes in Fig. 59 should pegs be placed in order to put the office set *B* in circuit with line wires No. *1* east and No. *2* west and also to ground No. *1* west and No. *2* east ?

(9) How many cells arranged in series will be required and what will be the current in a circuit having ten 150-ohm relays and a line resistance of 1,230 ohms, if the resistance of all the relays is made equal to the sum of the resistance of the line and batteries ? Assume that there is no leakage on the line, and that the electromotive force and internal resistance per cell is 1 volt and 3 ohms, respectively.

(10) (*a*) What two men discovered that the earth could be used as a return conductor of a telegraph circuit ? (*b*) Why is the earth used as a return conductor ?

(11) What instruments were used by Morse on the Baltimore-Washington line in 1844 ?

(12) For what purposes are loop switches used ?

(13) (*a*) What is the needle telegraph system ? (*b*) Where is this system used ?

(14) What precaution must be taken in regard to the switches *C* and *C'* in Fig. 8 ?

(15) Trace the circuit, in Fig. 64, indicated in Art. **212.**

(16) What telegraph codes are in common use and where used ?

(17) On what principle does the Bain chemical recorder depend (*a*) as a recording instrument ? (*b*) as a relay ? (*c*) What one good feature does the chemical recorder possess ?

(18) In what holes in the switchboard, illustrated in Fig. 64, should plugs be inserted, and in what spring jack should the wedge terminal of a desk set be put, in order to connect the desk set and the dynamo supplying the fourth row of disks in circuit with the line coming to spring jack *R* ? (Notice that there is a plug already in *q*–4.)

(19) (*a*) If a 150-ohm relay is to be rewound so as to have a resistance of 300 ohms, what size (B. & S.) wire should be used? (*b*) Theoretically, what current will the 300-ohm relay require if the 150-ohm relay requires 18 milliamperes?

(20) Draw a sketch, using the ground as a return circuit, showing how to connect sounders, relays, and batteries on a line having four offices and twelve cells, the cells being equally divided among the four offices.

(21) (*a*) Why is the Continental or Universal code superior to the Morse, especially for use on submarine cables? (*b*) What advantage has the Morse code?

(22) (*a*) What is the Morse closed-circuit system? (*b*) Why is it called a *closed-circuit* system?

(23) What are the essential parts of an ordinary electromagnet?

(24) (*a*) What is commonly accepted as the proper relation between the resistance of relays, line, and batteries? (*b*) What should be the relative resistance of all relays connected in series in the same line circuit?

(25) (*a*) In the closed-circuit system, can batteries be used at intermediate as well as at terminal stations? (*b*) Must the same number of cells be used at each office? (*c*) If batteries are used at terminal and intermediate offices, how must they be connected in the line circuit so as to assist one another?

(26) With what size wire should the two coils of a small sounder be wound in order to have a total resistance of 40 ohms? The outside diameter of such a coil is .9 inch, the length of the coil 1.1 inches, and the diameter of the iron core .36 inch.

(27) (*a*) What is the Morse open-circuit system, and why so named? (*b*) Is it necessary to use a battery in each circuit at each office in this system?

(28) What causes sticking in a key?

(29) If several exactly similar magnet spools, that is, having the same amount of space for the wire, are wound full of different sized insulated wires, what, theoretically, will be the relation between (*a*) the resistance of the coils and the number of turns of wire? (*b*) the number of turns and the diameter of the insulated wire?

(30) How would you determine in wet weather if the line is in use, even though the relay may not be responding to any signals?

(31) (*a*) If limited to a given number of ampere-turns, how can the strength of an electromagnet, that is, the pull on its armature, be increased? (*b*) Why is it desirable in telegraph electromagnets to make the magnetic circuit short and the cross-section of the iron cores no larger than really necessary?

(32) How may the sound from a sounder be concentrated in one direction?

(33) (*a*) What are two advantages of the Morse closed-circuit system? (*b*) What are two disadvantages of the same system?

(34) How can you tell whether the inaction of a sounder is due to a fault in the main-line or in the local sounder circuit?

(35) In Fig. 59, in what holes should pegs be placed in order to put both office sets *A* and *B* in circuit with line wires No. *1* west and No. *1* east, assuming that no line wire is connected to the vertical strip to which line wire No. *2* east is now connected, or, at least, that line No. *2* east is not in use?

(36) Why will lightning jump across a thin, narrow space filled with air, mica, or paraffined paper, in order to reach the ground, in preference to going along the regular path through the wire coils on the instruments?

(37) What is the time-constant of a circuit possessing only inductance and resistance?

(38) (*a*) What are two advantages of the open-circuit system? (*b*) What are two disadvantages of this system?

(39) (*a*) In order to connect the local relay between line *a'* and the ground, in what holes should plugs be placed in the saw-tooth arrester and switch shown in Fig. 43? (*b*) How would you join both *a'* and *b'* to the ground?

(40) (*a*) What two qualities are most essential in an electromagnet for telegraph instruments? (*b*) What proportions have been found by experiment, practice, and theory to give about the best results for ordinary telegraph electromagnets?

(41) What effect has leakage, especially during wet weather when it is large, on relays along the line?

(42) How would you adjust a relay to overcome the effect of leakage?

(43) (*a*) Why are sounders put in a local circuit, and not in the line circuit? (*b*) Why is the sounder used in preference to the register for most commercial work?

(44) Why are telegraph magnets designated by their resistance, as, for instance, a 20-ohm sounder, when the important feature is really the number of turns of wire?

(45) At a way station, as illustrated in Fig. 58, in what holes would you put plugs (*a*) to cut out the way-office relay and key, and at the same time keep the east and west lines connected together? (*b*) to cut in the key and relay? (*c*) to ground the west line only?

(46) (*a*) What three adjustments has a sounder? (*b*) How would you adjust a sounder?

(47) What will be the current in a circuit containing two 150-ohm relays, a line resistance of 282 ohms, and 24 gravity cells joined up in two parallel rows, each row containing 12 cells in series? Assume the electromotive force and internal resistance per cell to be 1 volt and 3 ohms, respectively.

(48) How would you determine at a way station, as shown in Fig. 58, if the west line wire is open?

(49) What is meant by the internal and external resistance of an electrical circuit?

(50) How would you determine at an intermediate office, as shown in Fig. 58, whether there is an open circuit or a cross in the office connections?

(51) (*a*) If the external resistance is very large compared with the internal resistance of a battery, how should the cells be connected together? (*b*) In the same case, if a larger current is desired, how should additional cells be connected in the circuit?

(52) (*a*) What is a static lightning arrester? (*b*) What is a magnetic arrester?

(53) (*a*) If the external resistance is very small or negligible compared with the internal resistance of a battery, how should the cells be connected? (*b*) In the same case, how should additional cells be joined in the circuit in order to increase the current?

(54) On a telegraph line $12\frac{1}{10}$ miles long, there are four 30-ohm pony relays that require 100 milliamperes to operate them. The line wire is No. 14 B. W. G. copper, which has a resistance of 7.93 ohms per mile. Assuming the electromotive force and internal resistance per cell to be 1 volt and 3 ohms, respectively, how many cells would be necessary and how connected up in order that the combined resistance of all the relays shall be equal to the combined resistance of the line and battery?

(55) (*a*) In what holes should plugs be placed in the switch illustrated in Fig. 59, in order to connect office set *A* in lines No. *2* east and No. *2* west, and to connect lines No. *1* east and No. *1* west, without including an office set? (*b*) In what holes should plugs be placed in order to cross-connect lines No. *1* east and No. *2* west, including office

set *B* in the circuit, and also to connect, between line No. *2* east and the ground, the office set *A*, and to ground line No. *1* west?

(56) What are the special advantages of the switchboard invented by Skirrow and now used by the Postal Telegraph Company?

(57) On what principle does the action of the Rolfe protector depend?

(58) In what hole or holes in the switchboard illustrated in Fig. 63 should plugs be inserted and in what spring jack should the terminal wedge of a desk set be inserted in order to have a complete circuit from the ground through a main-line battery (negative pole to line) and the desk set to line *5*?

TELEGRAPHY.

(PART 2.)

---

(1) What is probably the easiest and most reliable method of determining the polarity of the terminals of a generator used for charging storage batteries ?

(2) (*a*) Of what does the solution for an ordinary form of storage battery consist ? (*b*) Describe the mixing of the solution. (*c*) Why should the acid be poured into the water instead of the water into the acid ?

(3) What is an alternating current ?

(4) What effect does resistance alone have on an alternating current ?

(5) (*a*) What is meant by the maximum speed of signaling ? (*b*) On what does it depend ?

(6) If there is a cross between two line wires, how can you determine from a terminal office between what two way stations it occurs ?

(7) (*a*) What is the principal advantage of dynamos and storage batteries over primary batteries ? (*b*) State one other advantage.

(8) What is a motor-dynamo ?

(9) If there is a bad leak at some one point from a line wire to the ground, how can you determine from the terminal office between what two intermediate stations it is located ?

(10) In the Western Union Company's New York office, how are the dynamos for supplying the current for the line wires arranged ?

(11) What is the advantage of using low-resistance relays on a long circuit containing a large number of relays ?

(12) (*a*) What is the best material for a ground plate ? (*b*) How may a good ground be obtained ?

(13) In using storage batteries, what determines the size of the plates or the number of plates in parallel ?

(14) (*a*) In what way only can the distributed capacity of a submarine cable be neutralized by self-induction ? (*b*) Up to the present time, has this been successfully accomplished and used commercially ?

(15) (*a*) What are earth currents ? (*b*) What sort of earth currents are the most troublesome ?

(16) How can the voltage at the terminals of the dynamo side of a direct-current converter be regulated ?

(17) (*a*) What effect does the presence of self-induction have on an alternating current flowing in a circuit ? (*b*) What effect does capacity have ? (*c*) Can electrostatic capacity neutralize the effects of self-induction ? (*d*) Under what conditions ?

(18) How may earth currents, if troublesome enough to warrant it, be avoided ?

(19) How can the voltage on the dynamo side of a motor-dynamo be regulated ?

(20) What precaution should be taken in connecting storage batteries to a charging circuit ?

(21) If a simple sine-wave alternating current having a frequency of 300 complete periods per second flows in a circuit whose inductance is 8 henrys, what must be the electrostatic capacity of that circuit in order that the effect due to the inductance shall be completely neutralized by that due to the electrostatic capacity ?

(22) (*a*) What is the amplitude of a simple alternating-current curve? (*b*) What is the frequency? (*c*) How is the term frequency often misused?

(23) (*a*) What is the insulation resistance of a line? (*b*) On what does it depend?

(24) How are ordinary direct-current motors, converters, and motor-dynamos started?

(25) How do you determine (*a*) when a storage battery needs recharging and (*b*) when it is fully charged?

(26) (*a*) What is impedance? (*b*) What is the impedance of a circuit possessing resistance and self-induction? (*c*) What is the impedance of a circuit possessing resistance and capacity? (*d*) What is the impedance of a circuit possessing resistance, self-induction, and capacity?

(27) In estimating the current capacity required of a storage battery or dynamo, how much current should be allowed (*a*) for each line equipped with 150-ohm relays? (*b*) for each duplex circuit? (*c*) for each quadruplex circuit? (*d*) for each 4-ohm local instrument?

(28) Distinguish between local capacity and distributed capacity.

(29) (*a*) What is the $K R$ law? (*b*) About what is the limit of the product $K R$ for a line on which the quadruplex system will work successfully?

(30) Why are cut-out devices necessary in the charging circuit of storage batteries?

(31) What is an automatic starting box for motors or converters?

(32) (*a*) What is the advantage of connecting a non-inductive resistance in series with a sounder and therefore requiring a higher electromotive force to get the necessary current? (*b*) What is the disadvantage?

(33) What is an underload and overload circuit-breaker?

(34) (*a*) Is the resistance of the earth circuit zero or a constant quantity? (*b*) When may the resistance of the earth be considered as a negligible quantity?

(35) Where is the resistance in the earth return mostly concentrated?

(36) How may electrostatic and electromagnetic induction on overhead or cable-line circuits be eliminated or avoided if serious enough to cause trouble?

(37) What will be the strength of the current at the receiving end of a cable for which $a = .2$ (formula **8**) 1 second after closing the key at the sending end, if the maximum permanent current is 2 milliamperes?

(38) Why has a line wire apparently a higher electrostatic capacity in dry than in wet weather?

(39) (*a*) What is meant by the working efficiency of the line? (*b*) On what does it depend?

(40) (*a*) What is the ratio between the resistance of the line wire and the insulation resistance per mile for a line of No. 4 iron wire (resistance 6 ohms per mile) having 30 poles per mile and 25-megohm insulators? (*b*) What would it be for 500 miles?

(41) How is the voltage of a given shunt dynamo regulated?

(42) How is the so-called static test for an open line made from a terminal office using two batteries or generators of opposite polarities?

(43) On what does the voltage of a given dynamo depend?

(44) Why is it that, although the speed at which an electric wave travels is over 100,000 miles per second, an electric impulse may flow over a line circuit at a much slower rate than this?

(45) State several ways of charging storage batteries.

(46) What are the most common faults on overhead lines?

(47) Why are extra resistances necessary in line circuits that are supplied by dynamos or storage batteries, and not when supplied by primary batteries?

(48) Why are fuses or circuit-breakers of some kind necessary in the supply mains of dynamos and storage batteries?

(49) (*a*) Why should more than one line never be connected through the same disk on the switchboard and, consequently, through the same lamp or other non-inductive resistance to the bus-bar? (*b*) How are switchboards sometimes made so this cannot be done?

(50) What is a converter?

(51) (*a*) What is a weather cross? (*b*) How may cross-fire be reduced?

(52) What is a shunt dynamo?

(53) What percentage of the total current will reach the distant office in the following line circuit: the line is 400 miles long, the battery is all at one end, the resistance of each insulating support (including insulators and pole) is 20 megohms, the resistance of the line wire is 5 ohms per mile, and there are 25 poles per mile?

TELEGRAPHY.

(PART 3.)

(1) Name some of the conditions that must be considered in selecting the route for a pole line.

(2) How may the lower ends of guy wires be secured?

(3) (*a*) What is a mil? (*b*) What is a circular mil? (*c*) Why is circular measure convenient in expressing the sizes of wire?

(4) (*a*) What kinds of wood are commonly used for telegraph poles? (*b*) What is the approximate life of each kind? (*c*) Which are the best two woods, all things being considered?

(5) What precautions must be taken where it is necessary to span a river by aerial lines?

(6) What is the area in circular mils of a round wire having a diameter of 80.808 mils?

(7) What is the usual requirement in regard to the dimension of poles of various lengths?

(8) (*a*) What is meant by grading a line of pole tops? (*b*) What are the evil effects due to inattention to the proper grading of pole tops?

(9) (*a*) What are cross-arm braces? (*b*) Why are they used? (*c*) How are they secured to the cross-arms and pole?

(10) (*a*) How is a pole held in a vertical position, after being raised, while the tamping is being done? (*b*) What precaution should be taken in filling in around the poles?

(11) Find the area in circular mils of a round wire $\frac{1}{8}$ inch in diameter.

(12) (*a*) In unloading poles along a selected route, should the butts be laid up hill or down? (*b*) Why?

(13) (*a*) What is the best wood for pins? (*b*) How is a wood pin secured in a cross-arm? (*c*) What kind of pins are now coming into use?

(14) When are special pole foundations necessary?

(15) Discuss the relative merits of porcelain and glass for line insulators.

(16) What is the diameter of a wire having a cross-sectional area of 10,816 circular mils?

(17) (*a*) What precautions are sometimes taken to prolong the life of poles? (*b*) What is the wind-and-water line?

(18) How should the gains and roofs of poles be treated after being cut?

(19) (*a*) For average conditions, how deep should pole holes be made? (*b*) What conditions may render other depths of pole holes necessary?

(20) (*a*) What is a **Y** guy? (*b*) Why is it better to use the **Y** guy than to attach the guy wire to the pole at a single point?

(21) (*a*) How are the various sizes of wires usually designated? (*b*) What gauge is most commonly used for copper wire? (*c*) What for iron wire?

(22) What simple rule connects the various sizes of wire in the B. & S. gauge?

(23) Mention a few facts concerning wires in the B. & S. gauge that may be conveniently used in rough calculations.

(24) (*a*) What are the terms by which the various grades of iron wire are distinguished? (*b*) Describe each of these grades.

(25) Why is it that wire should not be drawn as tight in the summer as in the winter?

(26) (*a*) Into what two classes may paper cables be divided? (*b*) What advantages has each?

(27) How are cables supported on poles? Preferably, give the best method used in your own locality.

(28) (*a*) What is the meaning of the term "weight per mile-ohm," or "mile-ohm"? (*b*) How may the weight per mile-ohm be used in measuring the percentage conductivity of a wire?

(29) (*a*) What breaking strength is usually required in specifications for hard-drawn copper wire? (*b*) What mechanical properties should be required in specifications for hard-drawn copper wire?

(30) (*a*) In testing the galvanizing of a sample of iron wire, the sample was immersed three times in a saturated solution of copper sulphate, each immersion lasting 1 minute, and the wire thoroughly wiped off after each immersion. After the third immersion, a deposit of copper appeared on the surface of the wire. What conclusion should be reached concerning this wire? (*b*) Why?

(31) (*a*) Describe two methods of splicing bare wire. (*b*) In soldering an American wire joint, should the solder be applied over the whole joint or not, and why?

(32) (*a*) What advantages has the vitrified-clay conduit? (*b*) Which is considered better, a single-duct section or a multiple-duct section? (*c*) Why?

(33) How are wires led from underground conduits to overhead circuits?

(34) If the weight per mile-ohm of pure copper at a certain temperature is 869, and the weight per mile-ohm of a certain quality of commercial copper at the same temperature is 885, what is the percentage conductivity of the commercial copper?

(35) What are the advantages and disadvantages of aluminum as a line conductor?

(36) (*a*) When it is necessary to run a great number of wires in a limited space, what construction is usually

adopted? (*b*) What kind of cables are mostly used for overhead or underground telegraph work?

(37) Why should some slack be left in each length of a cable?

(38) How is the alinement preserved in laying a vitrified-clay conduit?

(39) (*a*) At what points on underground cables is the sheath liable to injury by electrolysis? (*b*) How may the danger points be located?

(40) What is the weight per mile of a copper wire having a diameter of 71.96 mils?

(41) What advantages has copper over iron wire for telegraph work?

(42) (*a*) Where only a few wires are to be strung on poles, what method is usually employed for paying out the wire? (*b*) Describe the use of a running board.

(43) For what are cable terminals used?

(44) (*a*) What is the cheapest form of conduit for underground cables that allows of the drawing in or out of cables? (*b*) What disadvantages are sometimes urged against this conduit?

(45) Give the formula and describe the method of mixing the concrete and mortar for conduit work.

(46) What methods should be used to prevent the injury of cable sheaths by electrolysis?

(47) What is the resistance per mile of a pure copper wire 101 mils in diameter at a temperature of 75° F.?

(48) (*a*) What is galvanizing? (*b*) Why is it not necessary with copper wire?

(49) What methods are used for determining the proper tension in line wires?

(50) (*a*) What methods are available for reducing the electrostatic capacity of the conductors in cables? (*b*) Which of these methods is most effective, and why?

(51) (*a*) Describe a section of cement-lined pipe conduit. (*b*) How are the joints between the sections made?

(52) (*a*) For what purposes are manholes used in conduit work? (*b*) How far apart are they usually placed? (*c*) Where are they preferably placed?

(53) (*a*) In crossing railroad tracks, what is the least distance allowable between the lowest line wire and the top of the rail? (*b*) How far, at least, should the poles be set from the nearest rail when the pole line follows the railroad?

(54) What poles should have double cross-arms?

(55) (*a*) What size of wire should be used for lightning conductors? (*b*) What poles should be supplied with the lightning conductors?

(56) Why is it preferable to fasten cross-arms to the poles with carriage bolts in place of lagscrews?

(57) Of what are guy wires composed?

(58) (*a*) As a general rule, what should be the least distance between a line wire and the ground? (*b*) Name three kinds of cable terminals or heads.

(59) (*a*) How are splices between two saturated-core cables filled with compound? (*b*) What is a sign of moisture in a cable end or joint?

(60) (*a*) Under average conditions, how many 6-foot pole holes can 1 man dig in a day? (*b*) What tools are generally used in digging pole holes?

TELEGRAPHY.

(PART 4.)

---

(1) What is a telegraph repeater?

(2) (*a*) What must be the position of the switch arm *k* in Fig. 2, in order that the eastern circuit may repeat into the western circuit? (*b*) Explain the operation of repeating from the eastern line into the western line with the button repeater shown in Fig. 2.

(3) What is a button telegraph repeater?

(4) State four ways in which the two line circuits may be used, and also the corresponding positions of the switches *M* and *g* in Fig. 1.

(5) Why should the sending be heavy or firm on circuits containing repeaters?

(6) Name a telegraph circuit mentioned in connection with the subject of "Telegraph Repeaters," or, preferably, one coming under your own observation, that requires one or more repeaters, and state its length.

(7) Why are repeaters needed?

(8) For what purpose are button repeaters used?

(9) (*a*) What is an automatic repeater? (*b*) Why is an operator needed for these repeaters?

(10) (*a*) What is an artificial line? (*b*) Why is it used?

(11) What is the chief function of an automatic repeater?

(12) (*a*) What is duplex telegraphy? (*b*) What is diplex telegraphy?

(13) (*a*) Are all circuits normally closed or open in a Milliken repeater? (*b*) When the key at the western station is opened, why do the eastern relay and the transmitter on the same side remain inactive, that is, closed?

(14) (*a*) On what principle does the bridge duplex system of telegraphy depend? (*b*) What parts in the system are arranged the same as for the differential duplex? (*c*) What instrument in the ordinary Wheatstone bridge has the same position as the relay in this system?

(15) How much movement should the lever of the Milliken transmitter have?

(16) Why was a third coil, condenser, and two resistances, known as the *Smith device*, used in the Western Union quadruplex system?

(17) If the stronger current in a quadruplex system is too small, notwithstanding that the dynamos or batteries are up to full pressure, where would the trouble probably be found?

(18) Describe the use of the induction coil in the Jones quadruplex system.

(19) (*a*) What is a side-line repeater? (*b*) Name two repeaters that may be used as side-line repeaters.

(20) Under what circumstances do no currents actually flow in the line in the Jones quadruplex system?

(21) On what principle does the successful operation of the Toye repeater depend?

(22) (*a*) In the normal condition of the Neilson repeater what instruments are closed and what ones are open? (*b*) What instruments in the Neilson repeater are open and what instruments are closed when the key at the distant western station is open?

(23) State some advantages and disadvantages of the Toye repeater.

(24) Fill in the blank spaces for the ninth combination in Table 3, following the same method of notation as is used in the part of the table that is complete.

(25) (*a*) What is the distinctive feature of the Weiny-Phillips repeater? (*b*) What is the normal condition of all the circuits?

(26) (*a*) What is meant by the single-current system? (*b*) What is meant by the double-current system?

(27) In the Weiny-Phillips repeater shown in Figs. 13 and 15, what instruments are open and what instruments are closed when the key at the distant eastern station is open?

(28) What is the distinguishing feature of the Horton repeater?

(29) What kind of relays are necessary in a double-current system?

(30) (*a*) In the Atkinson repeater, what instruments are closed in the normal condition? (*b*) What circuits are closed and what circuits are open in the normal condition? (*c*) What instruments and circuits are open and what instruments and circuits are closed when the eastern key is open?

(31) Where is the double-current system used?

(32) What is a polarized relay?

(33) In the Horton repeater, through what magnets only is current flowing, and where are circuits open and where are circuits closed at the repeater when the eastern key is open?

(34) In multiplex systems, what is meant by a *static balance?*

(35) How are the sounders arranged at the battery station in the Morris single-battery duplex system?

(36) (*a*) State two ways in which condensers may be connected in an artificial line. (*b*) How are condensers adjusted in each case so as to charge and discharge in the same manner as the line?

(37) (*a*) What is the object to be kept in view in winding differential relays? (*b*) In what three ways is it possible to wind a relay differentially?

(38) How is the Stearns differential duplex balanced ?

(39) (*a*) Why is the polar duplex superior to the Stearns duplex ? (*b*) What is the essential feature of the polar duplex ?

(40) (*a*) Why is a continuity-preserving pole changer preferable to one that opens a circuit in the act of reversing the direction of the current ? (*b*) Why is the continuity-preserving pole changer not used in connection with dynamos ?

(41) When dynamos are used in the polar duplex and quadruplex systems, why are at least two machines used, instead of reversing one machine as would be the case if a battery were used ?

(42) (*a*) What is the so-called ground coil in the polar duplex and quadruplex systems ? (*b*) To what is its resistance equal ? (*c*) Why is it used ?

(43) In duplex and quadruplex systems, (*a*) what is meant by the receiving circuit, and (*b*) what is meant by the sending circuit ?

(44) What are the four important steps taken in balancing the polar duplex ?

(45) (*a*) What is meant by centering the armature of the polar relay ? (*b*) How is it done ?

(46) In multiplex systems, what is meant by a *resistance balance ?*

(47) In balancing a quadruplex system, what instrument should you go by ?

(48) (*a*) In what respect is the bridge duplex inferior to the differential duplex ? (*b*) In what respect is it superior to the differential duplex ?

(49) What is the distinctive and advantageous feature of the Morris single-battery duplex ?

(50) What is a continuity-preserving pole changer ?

(51) If the margin is too small in a quadruplex system, where would the trouble most likely be found ?

(52) How may two messages be sent in the same direction over the same wire at the same time?

(53) (*a*) What is meant by the short-end and long-end batteries? (*b*) What is meant by the No. 1 and No. 2 sides of a quadruplex system?

(54) What is the advantage and disadvantage of a resistance in the circuit between the transmitting apparatus and the relays in the quadruplex system?

(55) (*a*) What is meant by the term margin used in quadruplex telegraphy? (*b*) What are the retarding coils and why are they so called?

(56) Explain briefly how currents of two different strengths are obtained in the line in the Western Union dynamo quadruplex system.

(57) In the Jones quadruplex system, how is the current reversed in direction and how is it changed in strength?

(58) How are the increase and decrease and reversal of the current obtained in the Healy quadruplex system?

(59) What is multiplex telegraphy?

(60) (*a*) Why are signals that pass through repeaters apt to be shortened? (*b*) How may the signals be made more intelligible?

(61) (*a*) What is the quadruplex system of telegraphy? (*b*) On what changes in the line current does it depend for its action? (*c*) How in the ordinary quadruplex system does each key govern its own sounder without affecting the others?

(62) What would indicate an open wire on a quadruplex system?

(63) What would indicate a defect in the ground-coil circuit in a quadruplex system?

(64) On what principles does the Morris single-battery duplex depend for its operation?

(65) In a quadruplex system, what would indicate a foreign current coming in over the line from a cross with another wire?

(66) How is the Frier self-polarizing relay adjusted?

(67) What is the distinctive feature of the Houghtaling transmitter and pole changer?

(68) Name in order the five steps given in the Jones method for balancing the quadruplex.

(69) How may a differential galvanometer be used to tell if the current divides equally between the line and artificial-line circuits?

(70) Calculate the strength of current flowing in the line in the open and closed positions of the transmitter and the ratio of these two currents in the Healy quadruplex shown in Fig. 75, when the line and artificial line each have a resistance of 1,800 ohms and the resistances A, B, and C possess 400, 800, and 267 ohms, respectively, and the dynamo generates an electromotive force of 220 volts.

(71) How are the sounders arranged on the neutral side of the Healy quadruplex?

(72) What would indicate, in the Western Union dynamo quadruplex, a defect in the leak-coil circuit?

(73) To what are most quadruplex troubles due?

(74) In the Western Union dynamo quadruplex, calculate the currents and the ratio of the currents that flow in the line in the open and closed position of the transmitter when the resistance of the line is 1,800 ohms, the resistance of the leak coil 800 ohms, the added resistance 1,800 ohms, the resistance of the lamp in series with each dynamo 600 ohms, and the electromotive force of the dynamos 220 volts.

(75) What would indicate a defective ground wire, that is, a defective connection between the battery or dynamo and the ground in a quadruplex system?

(76) After a careful balance of the quadruplex has been obtained and the incoming signals are still more or less interfered with directly the distant office begins to send on the polar side, where would you suspect the trouble to be?

(77) (*a*) Where would you insert the wedge attached to an ammeter in order to readily measure the strength of the incoming current in the Western Union quadruplex? (*b*) where in the Postal Telegraph quadruplex?

(78) What would indicate a crossed or grounded line wire on a quadruplex system?

(79) (*a*) How would you adjust a dynamo pole changer? (*b*) What precautions must be taken in adjusting it?

(80) (*a*) In a quadruplex system, how would a defective cell in the long end of the distant battery be indicated? (*b*) How would a defective cell in the short end of the distant battery be indicated?

(81) (*a*) What trouble would be caused by a trolley current flowing through the line? (*b*) How would you determine whether the trouble is due to the trolley current? (*c*) How would it be remedied?

(82) In a quadruplex system, how would a defective tap wire at the distant station be indicated?

(83) What trouble would be encountered in attempting to balance a quadruplex if a condenser in the artificial line was punctured by lightning or otherwise?

TELEGRAPHY.

(PART 5.)

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(1) How may two polar duplex sets be arranged to repeat into each other?

(2) What is the difference in principle between the arrangements of duplex or quadruplex repeaters when dynamos are used and when gravity cells are used?

(3) In what two ways may quadruplex sets be arranged to repeat into one another?

(4) What are the distinctive features in the arrangement, when dynamos are used, of the local circuits on the Canadian Pacific Railroad telegraph system?

(5) State one advantage and one disadvantage of the Edison phonoplex system compared with the ordinary Morse system.

(6) What is a multiplex single-wire, or defective-loop, repeater?

(7) Why is the siphon in the Cuttriss submarine-cable recorder made to vibrate?

(8) What arrangement may be used to enable a branch office to call up the central office?

(9) (*a*) In the Van Rysselberghe simultaneous telegraph and telephone system, how many line wires are used and into what circuits including the earth are they arranged? (*b*) How many telephone and telegraph messages may be simultaneously sent by this method by using only one line wire? In this case how is the earth used?

(10) How is the siphon in the Cuttriss submarine-cable recorder made to vibrate ?

(11) What is an artificial cable ?

(12) (*a*) Explain briefly the principle of Cailho's simultaneous telegraph and telephone system. (*b*) How many messages, including both telegraph and telephone, may be sent simultaneously over the same circuit by this method, and what constitutes the complete circuit for each message ?

(13) What kind of a repeater is the Downer ?

(14) What method is used in duplexing submarine cables ?

(15) (*a*) What kind of a repeater is the Moffat ? (*b*) On what well-known repeater principle does it depend ?

(16) What is the principle on which the Edison phonoplex is based ?

(17) (*a*) Are the Moffat and Downer defective-loop repeaters suitable for repeating from one main line into a long branch line ? (*b*) Give a reason for your answer.

(18) State the steps necessary in telegraphing a message by the Wheatstone automatic system.

(19) (*a*) What is the advantage of using automatic cable transmitters in place of transmitting by hand ? (*b*) Name two automatic submarine-cable transmitters.

(20) On what principle does the Downer repeater depend ?

(21) For what purpose is the Half-Milliken repeater used ?

(22) In the normal condition, what circuits in the Half-Milliken repeater are closed and what ones are open ?

(23) How are earth currents eliminated in submarine telegraphy ?

(24) What may be accomplished by the Dillon branch-office quadruplex repeater ?

(25) How is the same result that is accomplished by the Dillon branch-office quadruplex repeater in Western Union

offices obtained in Postal Telegraph offices, on account of the different arrangement of branch-office loops in the latter offices?

(26) What is a double-loop repeater?

(27) Explain the operation of the apparatus shown in Fig. 14, when the distant *B* and *C* stations desire to work double.

(28) In multiplex single-wire repeaters, where is trouble apt to occur, assuming that the duplex or quadruplex apparatus itself is in proper condition?

(29) What is the object of connecting together three multiplex sets as shown in Fig. 14?

TELEGRAPHY.

(PART 6.)

(1) Describe a test for locating a ground on a telegraph line when no good wire is available.

(2) What is meant by the sine-wave system ?

(3) Explain briefly the steps necessary to send and to receive a telegraph message by the Delany chemical method.

(4) (*a*) What two types of galvanometers are used for making accurate tests on lines and cables ? (*b*) Name the advantages and disadvantages of each.

(5) What are two serious objections or defects of wireless telegraph systems ?

(6) What are the advantages and disadvantages of automatic systems, such as the Wheatstone, Delany chemical, etc. ?

(7) What is a coherer ?

(8) State the steps necessary in telegraphing a message by the Pollak-Virag system.

(9) What are the objections to the Pollak-Virag system ?

(10) Describe briefly a method for determining the resistance of a line or of a ground circuit where there are at least two good line wires and a ground circuit between the same two stations.

(11) Explain the principle of the method of measuring insulation resistance with a galvanometer.

(12) Describe the Varley loop test for locating crosses on telegraph lines.

(13) (*a*) How may wires be identified at one end of a cable? (*b*) How may wires be identified at intermediate points in a cable without cutting them?

(14) In taking the galvanometer constant in the direct deflection method of measuring an insulation resistance, a deflection of 342 scale divisions was obtained, using a $\frac{1}{10}$ megohm box and a shunt having a multiplying power of 1,000; what was the constant?

(15) What is the most satisfactory instrument for the measurement of all ordinary resistances?

(16) After the constant of a galvanometer has been determined, and after the deflection produced by passing the battery current through the galvanometer and the insulation resistance to be measured has been noted, describe the calculation of the insulation resistance.

(17) Why may not the magneto-testing set be implicitly relied on in testing out long circuits either for continuity or grounds?

(18) A test was made to locate a ground on a line wire by the Murray loop method. At the distant station the bad wire was joined to a good wire connecting the same two stations, and the resistance of the loop so formed was measured by the Wheatstone bridge in the usual manner and found to be 515.58 ohms. The bridge was then connected with the two line wires as shown in Fig. 95. When balanced it was found that there were 1,000 ohms in the arm m, 1,000 in n, and 2,015 in p. The bad line was a No. 14 B. & S. gauge hard-drawn copper wire, having a resistance of 2.578 ohms per 1,000 feet at the temperature of the test. What was the distance in miles from the testing station to the fault?

(19) A test was made to determine the resistance of each of three line wires between the same two offices. The distant ends of two wires, which we will call x and y, were

joined together and the resistance of the loop so formed was found by means of a Wheatstone bridge to measure 1,077 ohms. Then the wire x was joined to the wire z at the distant end, and the resistance of this loop was found to be 1,130 ohms. Finally the distant ends of the wires y and z were connected and the resistance of this loop was found to measure 1,184 ohms. What is the resistance of each line between the two stations?

(20) If the total insulation resistance of a line wire of known length has been measured, how is the insulation resistance per mile calculated?

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NOTE.—All items in this index refer first to the section (see Preface, Vol. I) and then to the page of the section. Thus, "Amplitude 3 8" means that amplitude will be found on page 8 of section 3.

HARVARD ENGINEERING SCHOOL