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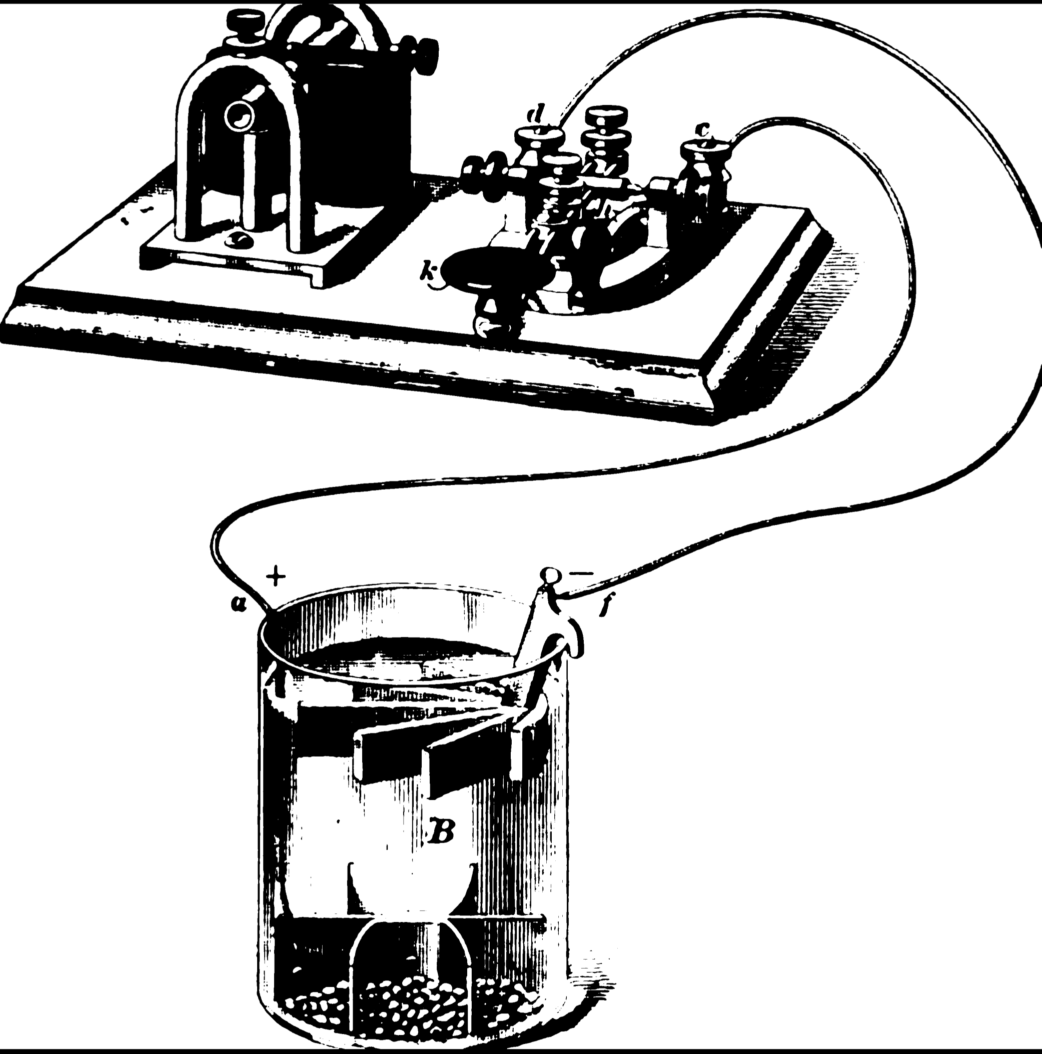

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EXAMPLES AND THEIR SOLUTIONS

TELEGRAPHY

(VOL. I)

SCRANTON:
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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice—together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

This and the following volume are devoted to the subject of telegraph engineering. On account of the complete treatment of this subject, it has been necessary to divide the subject matter into two volumes. The entire field of telegraphy has been covered, and the utmost pains have been taken to treat the subjects in a manner most useful to telegraph operators as well as to those engaged in the construction, installation, and maintenance of telegraph systems. In these two volumes will be found descriptions of new systems—including high-speed and wireless-telegraph systems—that promise to be of importance and which cannot be found in any other treatise. The use and connections of dynamos and storage batteries, which are rapidly replacing primary batteries, especially in large telegraph offices, have been fully described and illustrated. The systems in use by the large telegraph companies, the care and adjustment of telegraph repeaters, duplex and quadruplex systems, the causes and remedies for the troubles that continually occur on these systems, and the testing of telegraph circuits and lines have been carefully and fully explained. In this respect as well as in others, these two volumes constitute the best treatise on the subject that can be obtained.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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TELEGRAPH CABLES—*Continued.* *Section.* *Page.*

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* · · ·
£	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 $\overset{o}{-\;\;-}$ $\overset{c}{--\;\;-}$ $\overset{r}{-\;\;--}$ $\overset{y}{--\;\;--}$ $\overset{z}{---\;\;-}$ $\overset{\&}{-\;\;---}$ 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 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

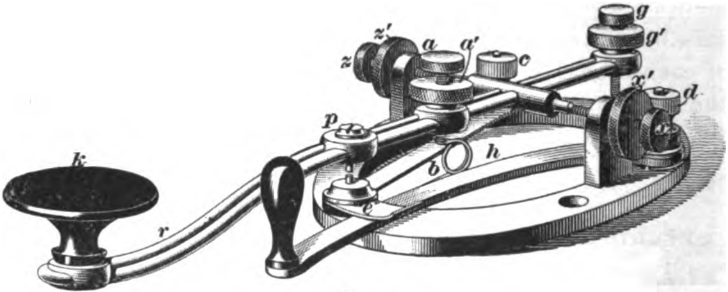


FIG. 1.

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 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

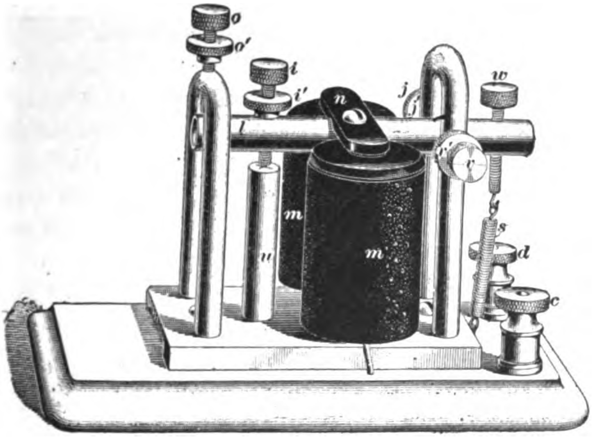


FIG. 2.

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

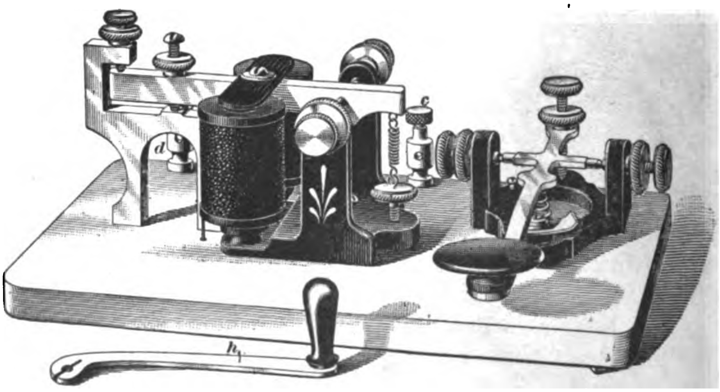


FIG. 3

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

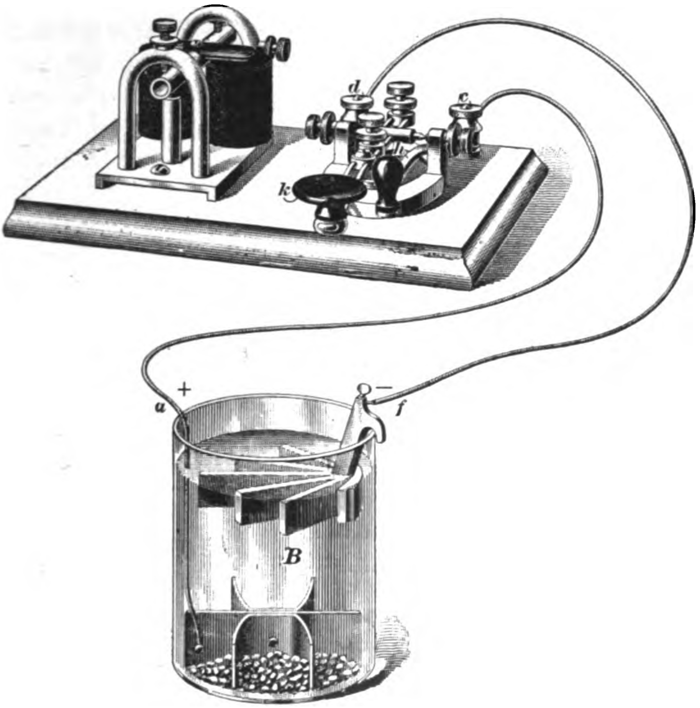


FIG. 4.

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 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.

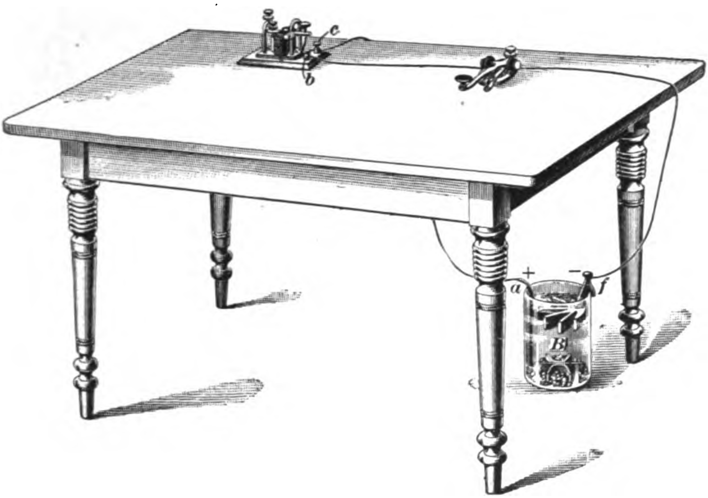


FIG. 5.

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

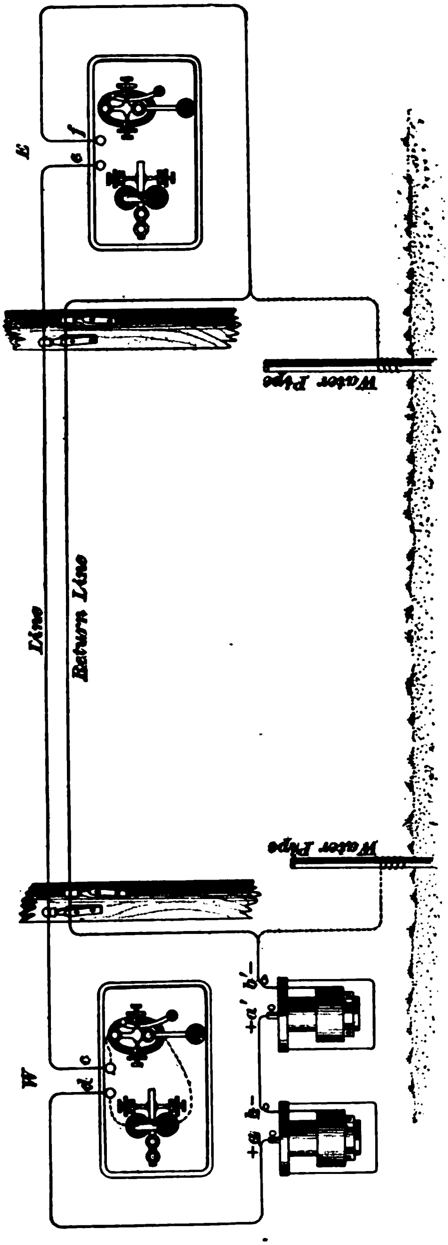


FIG. 6.

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

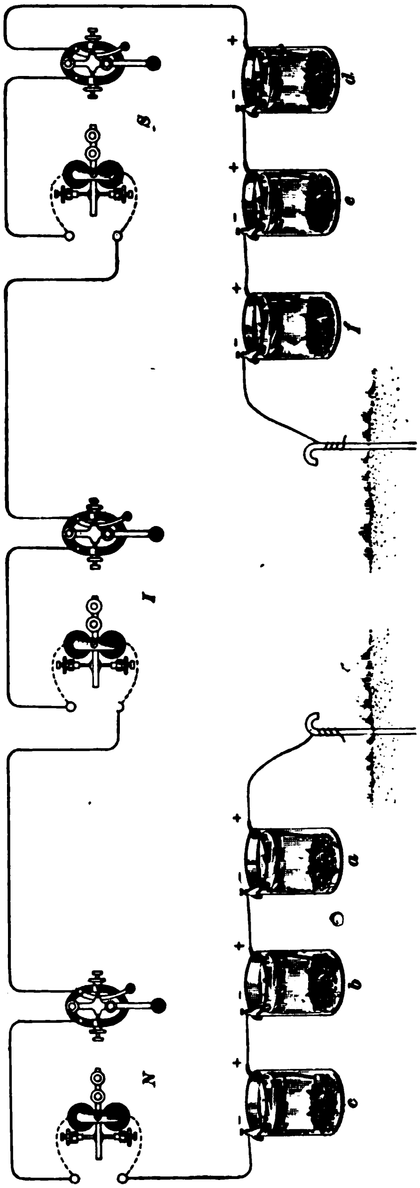


FIG. 7.

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.

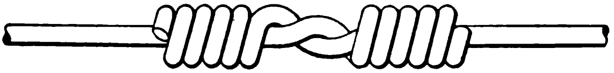


FIG. 8.

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 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."

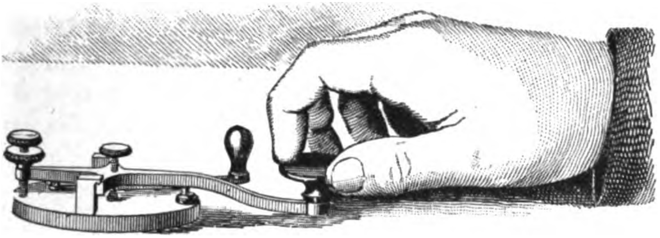


FIG. 9.

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.

a *t* *w*   *e* *d* *x*
▪▬ ▬ ▪▬▬   ▪ ▬▪▪ ▪▬▪▪

u *e* *q*   *v* *e* *3*
▪▪▬ ▪ ▪▪▬▪   ▪▪▪▬ ▪ ▪▪▪▬▪

u *i* *2*   *u* *d* . (Period)
▪▪▬ ▪▪ ▪▪▬▪▪   ▪▪▬ ▬▪▪ ▪▪▬▬▪▪

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:

And
▪▬ ▬▪ ▬▪▪

Humane
▪▪▪▪ ▪▪▬ ▬▬ ▪▬ ▬▪ ▪

Inmate
▪▪ ▬▪ ▬▬ ▪▬ ▬ ▪

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 *rept* (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:

p	*p*	*p*	*s*	*f*
.....	.....	.....	...	.–.
p	*p*	*p*	*s*	*f*
.....	.....	.....	...	.–.

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

i	*i*	*i*	*p*
..	..	..	.....

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*

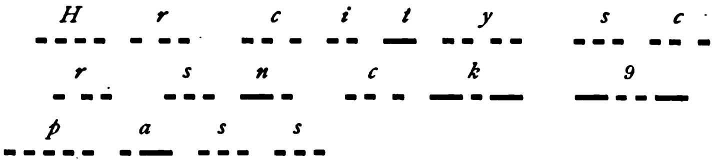
If the message is for some place other than that to which it is sent, and hence has to be relayed, and if collect instead of paid, it would be as follows:

(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.

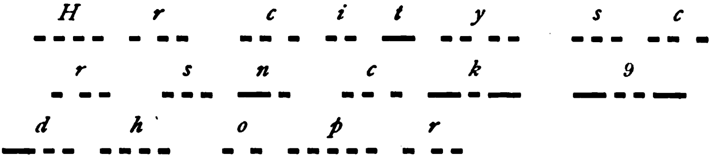
When a message is sent free on account of a pass, the number of the pass is not sent; but, if free on an operator's account, *opr* is sent, preceded by the abbreviation *dh* for deadhead. The first line for such a message containing 9 words would be as follows:

(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.

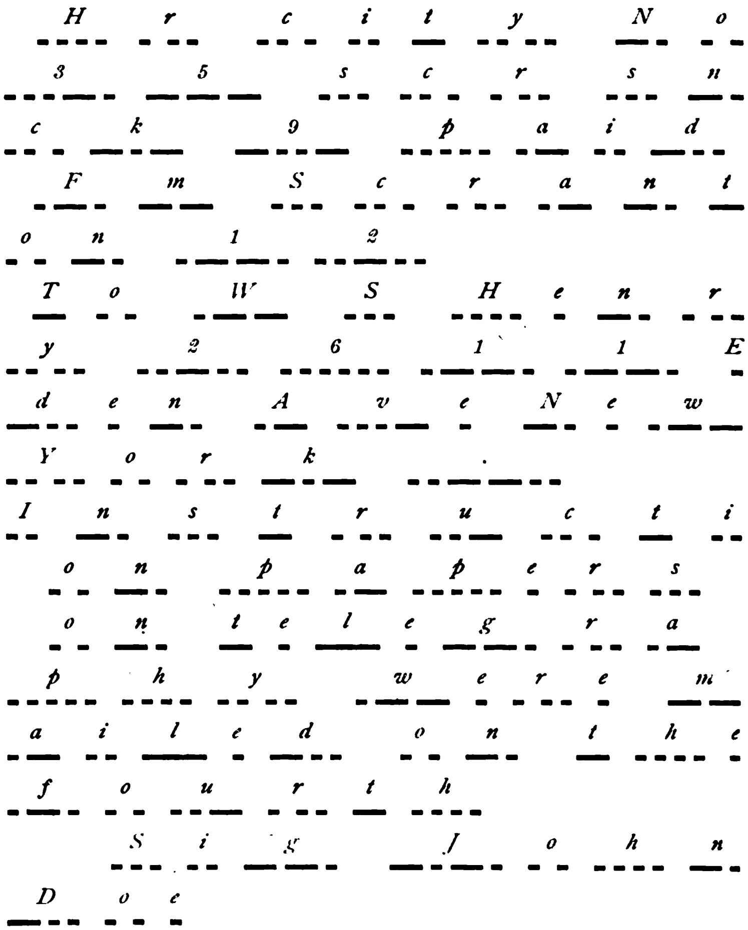
69. The Address.—The address should consist of the full name and address of the person to whom the message is sent. The number of the street, as Third street, should be written in words. When the office at which a message terminates is on the same line, the name of the place is not sent, but only the 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 *g a*, 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

—and all titles and directions after the signature; except that such titles as *president*, *manager*, *chief police*, *general superintendent*, etc., not exceeding 2 words, immediately preceding or following the signature, go free. Names of cities and places made up of two parts are counted as 1 word. Each initial or abbreviation, even if consisting of a single letter, must be counted as 1 word. There are exceptions to this latter statement. The examples and exceptions given below will illustrate the above remarks.

A compound word, made up of several distinct words connected by hyphens, is to be counted as so many different words, although such words may be found in dictionaries. *Mother-in-law* and *man-of-war* are each counted as 3 words. However, such words as *anywhere*, *everywhere*, *railroad*, *railway*, and *tonight* are recognized as simple English words, and are counted as 1 word, unless the customer in writing the message inserts a hyphen in them. Even the words *can't*, *don't*, and *won't*, although not correctly written without the apostrophe, are in common use, and may be accepted as 1 word when the apostrophe is not inserted.

De Witt	1 word
West Virginia	1 word
District of Columbia (or D. C.)	1 word
New York	1 word
United States	1 word
Lbs.	1 word
Cwt.	1 word
A. M.	1 word
P. M.	1 word
O. K.	1 word
C. O. D. (or cod)	1 word
F. O. B. (or fob)	1 word
Per cent.	1 word
Brown, Jr.	2 words
New York State	2 words
32d (or 32nd)	3 words
Ten thousand	2 words
10 000	5 words
No. 154 W. 98th St.	9 words
196⅓	6 words
287.55	6 words

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.

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 penal offense to divulge the contents of messages." This does not prevent the production of a certain message in court when a legal summons is issued for it.

86. Courteous Clerks.—In small offices where the operator also acts as a receiving clerk at the window, he should aim to be courteous and helpful to those sending telegrams. For instance, if an individual, evidently not accustomed to sending telegrams, seems to be having trouble in writing the message, the clerk may render an appreciated service, and help make telegraphing more popular by saying, "Shall I help you to write your telegram ?" Often the customer finds it difficult to reduce the message to a 10- or 15-word telegram, and is on the point of tearing up the message when he learns the cost, with the intention of sending it by mail, instead. In such cases, the clerk should suggest to the customer, as he generally can, a way to cut or re-write the message, thus reducing the number of words without destroying its sense. Many messages can thus be saved to the telegraph company, and, moreover, the customer will generally thank such a polite and obliging operator, and will send telegrams oftener. In this manner, and in every other way possible, the clerk or operator should strive to increase the business of the company. It should be needless to say that everything you do for the good of your company will make you more valuable to them.

87. Railroad Business.—Much less formality is necessary in conducting railroad business than in transmitting commercial messages. The names in addresses and signatures are sometimes abbreviated to the initials only. No checks are sent, and the entire date is also omitted, and many words in the body of the message are abbreviated. Instead of spelling out the name of the place, usually only the office call is given. When, however, the business over one railroad line passes to the line of another company, it is transmitted the same as any other free or paid message.

In despatching trains, many prescribed forms are in use, in order to economize time. But, owing to the lack of 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*
Cq a s 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

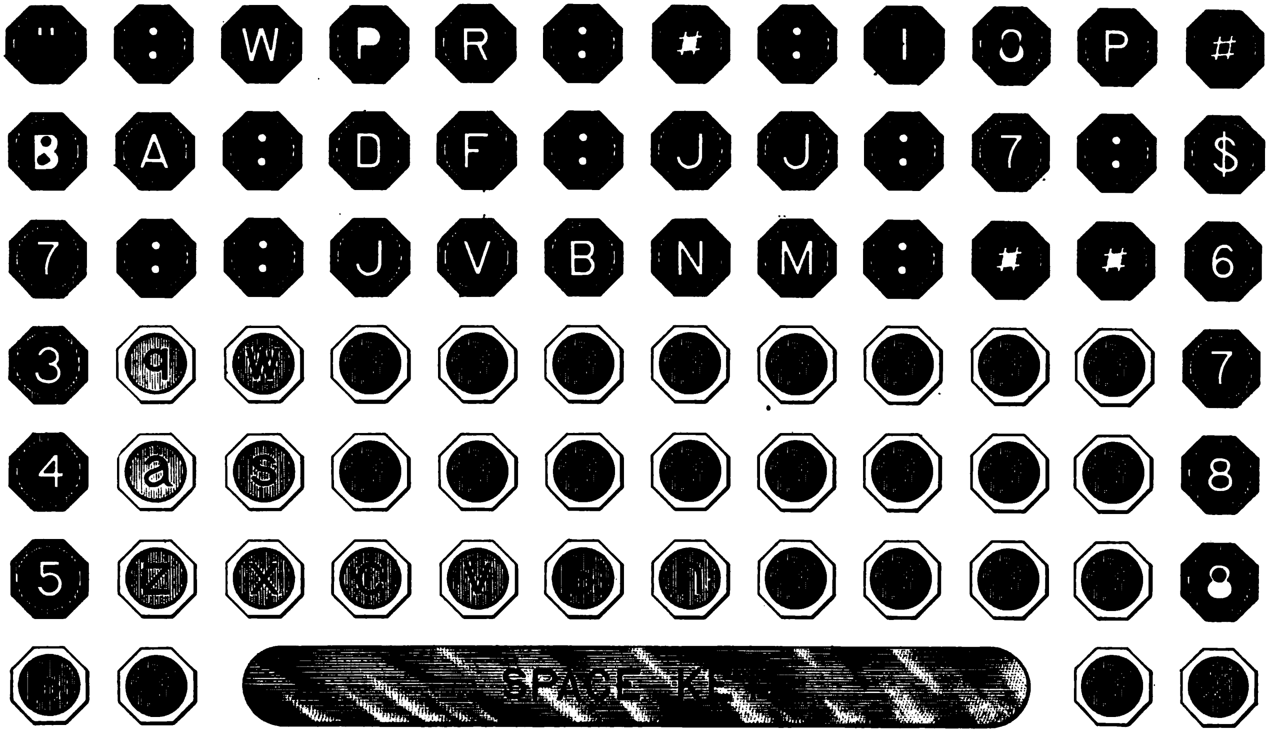


FIG. 10.

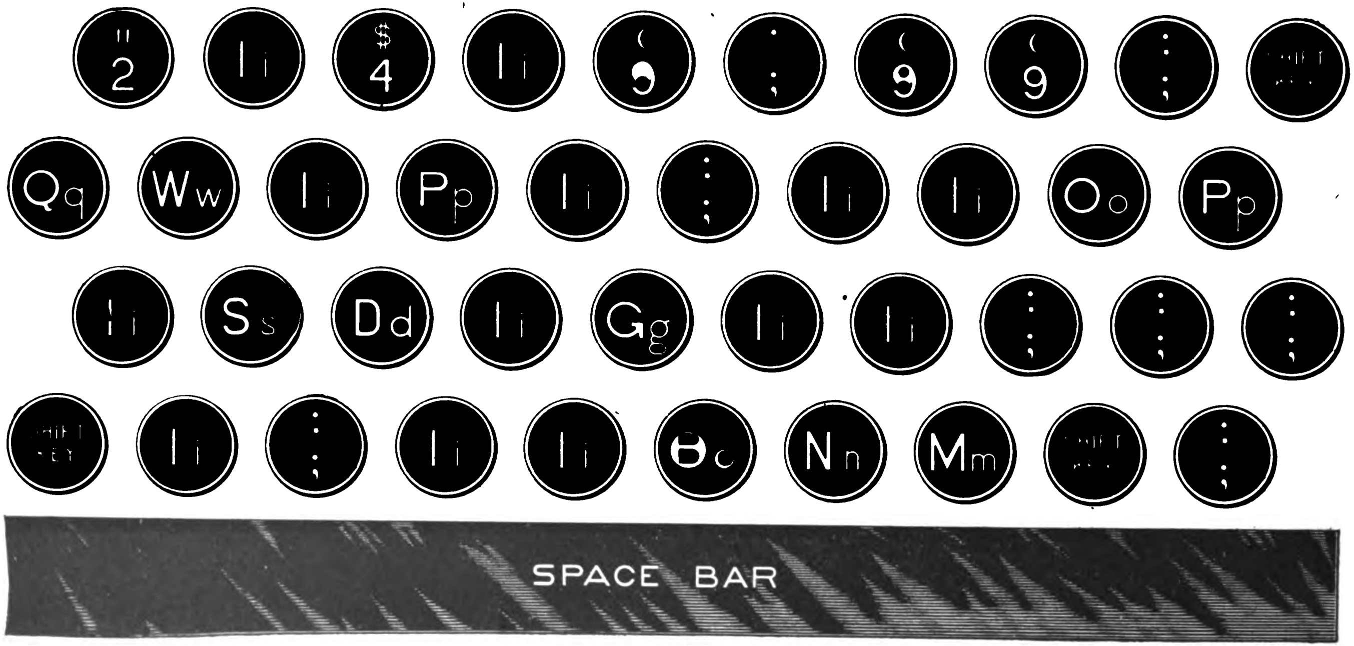

" 2
I i
$ 4
I i
(9
: ;
(9
(9
: ;
SHIFT KEY
Q q
W w
I i
P p
I i
: ;
I i
I i
O o
P p
I i
S s
D d
I i
G g
I i
I i
: ;
: ;
: ;
SHIFT KEY
I i
: ;
I i
I i
B c
N n
M m
SHIFT KEY
: ;
SPACE BAR

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

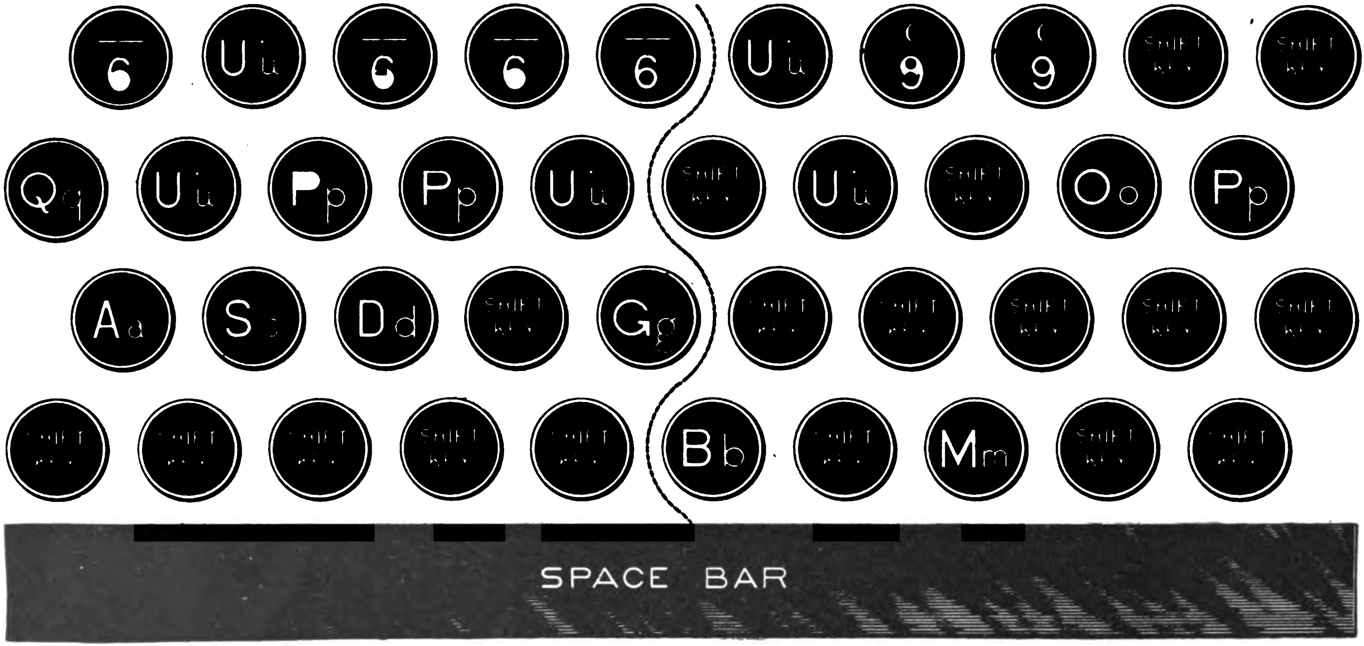

6
U u
6
6
6
U u
9
9
SHIFT KEY
SHIFT KEY
Q q
U u
P p
P p
U u
SHIFT KEY
U u
SHIFT KEY
O o
P p
A a
S s
D d
SHIFT KEY
G g
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
SHIFT KEY
B b
SHIFT KEY
M m
SHIFT KEY
SHIFT KEY
SPACE BAR

FIG. 13.

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.

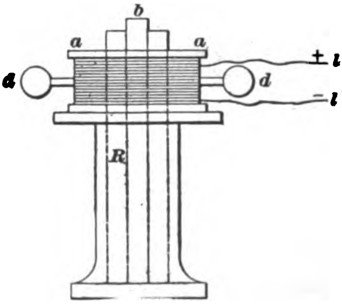


FIG. 1.

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'* 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.

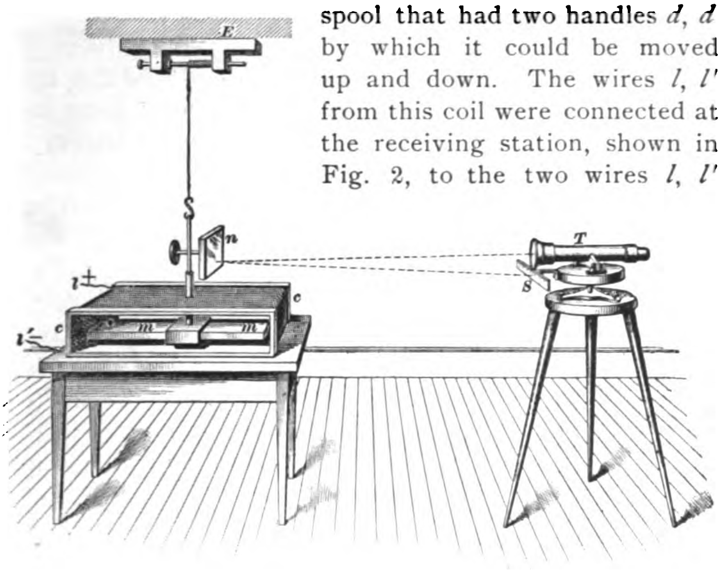


FIG. 2.

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

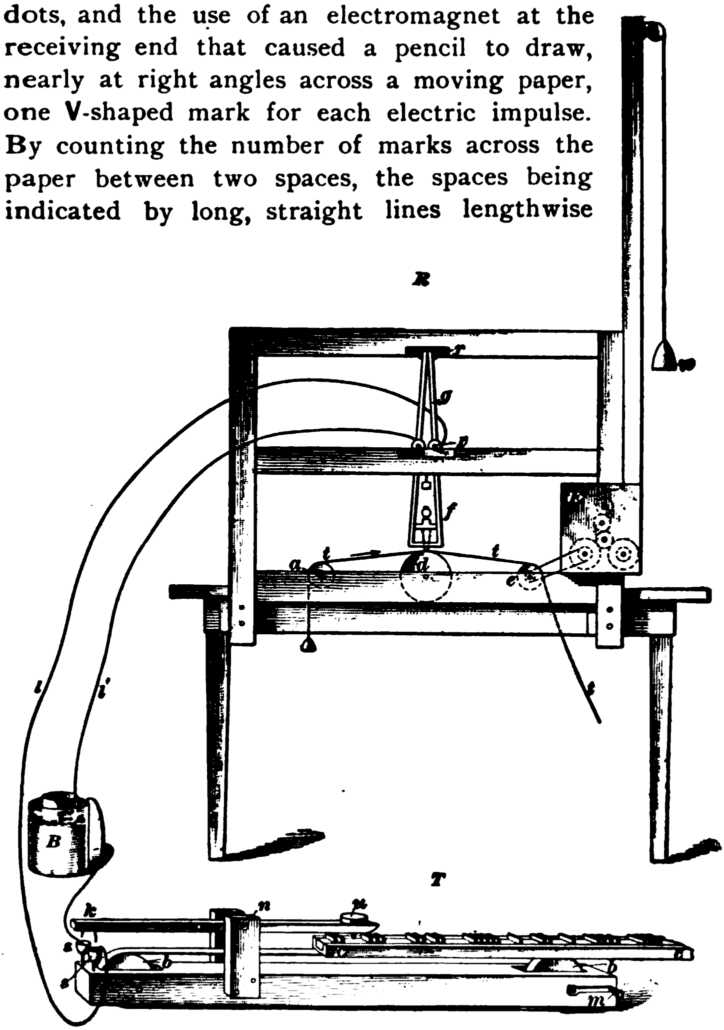


FIG. 3.

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 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

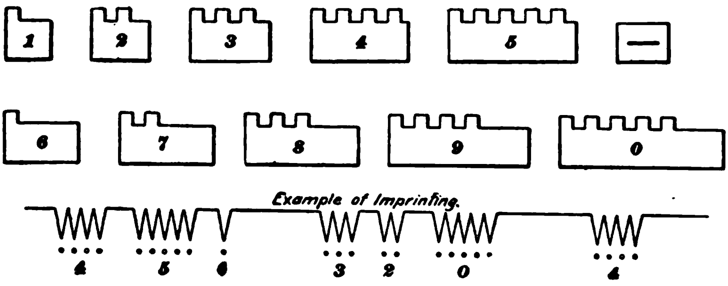


FIG. 4.

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*,

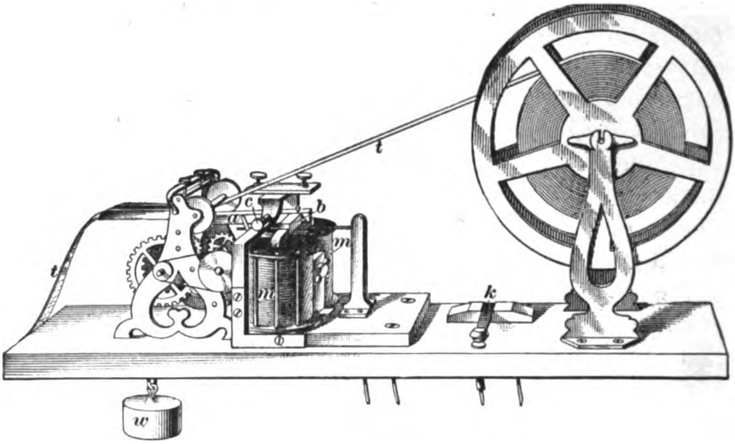


FIG. 5.

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 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.

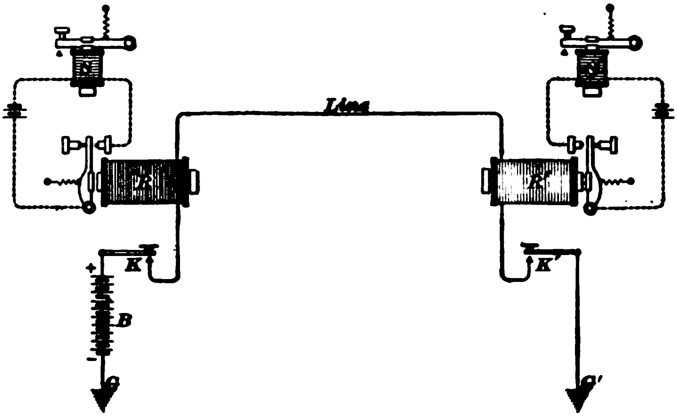


FIG. 6.

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, 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

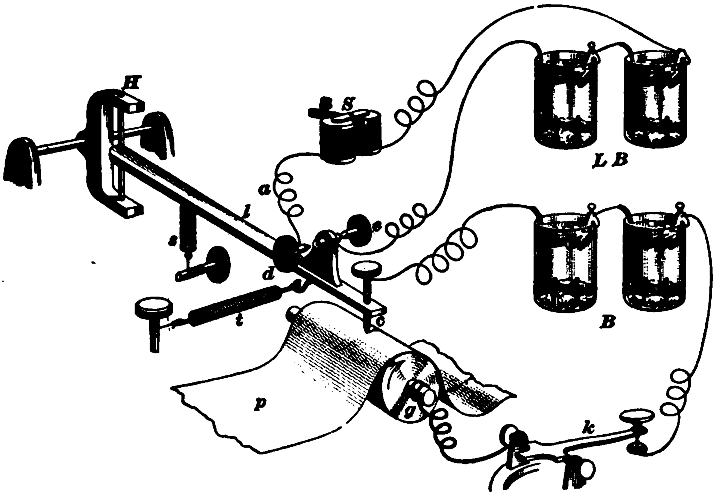


FIG. 7.

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 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.

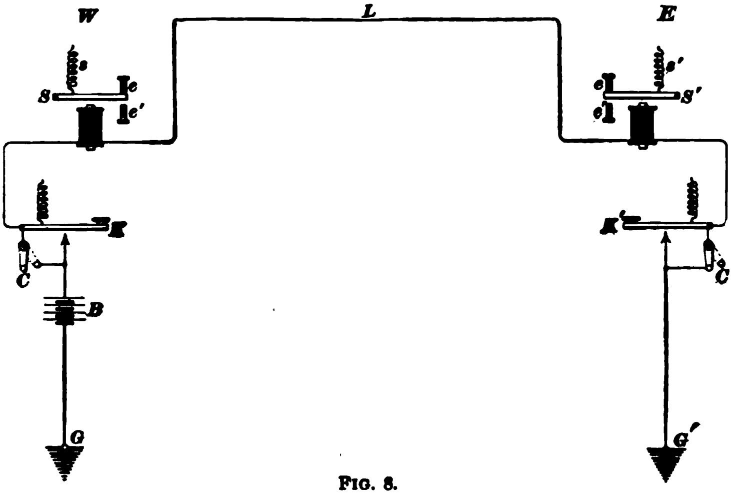


FIG. 8.

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 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

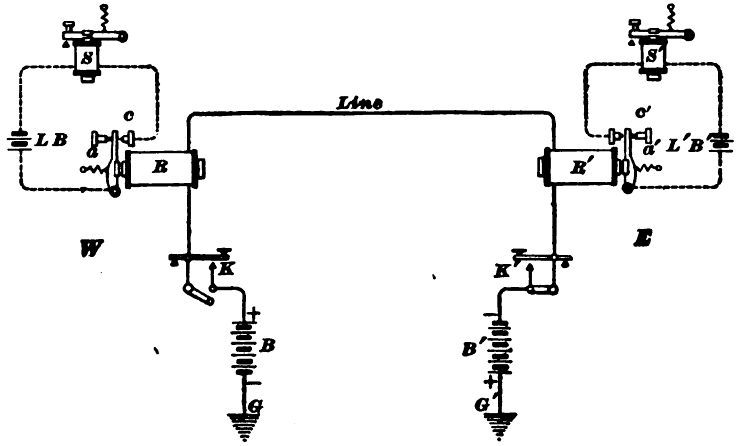


FIG. 9.

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,

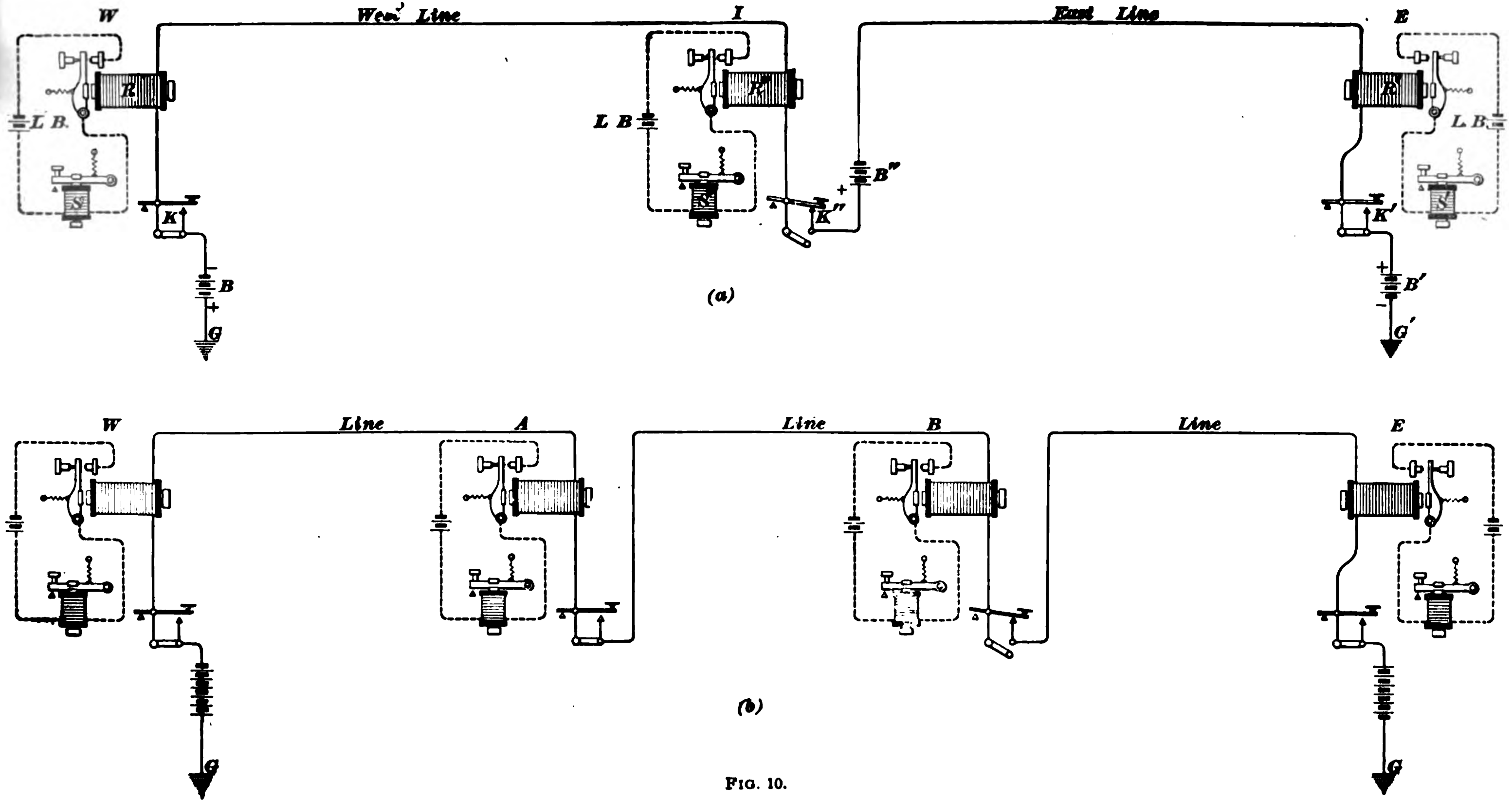

W
West Line
I
East Line
E
R
R″
R′
L B
L B.
S
S″
S′
K
K″
K′
B
B″
B′
G
G′
+
−
(a)
W
Line
A
Line
B
Line
E
G
G
(b)

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

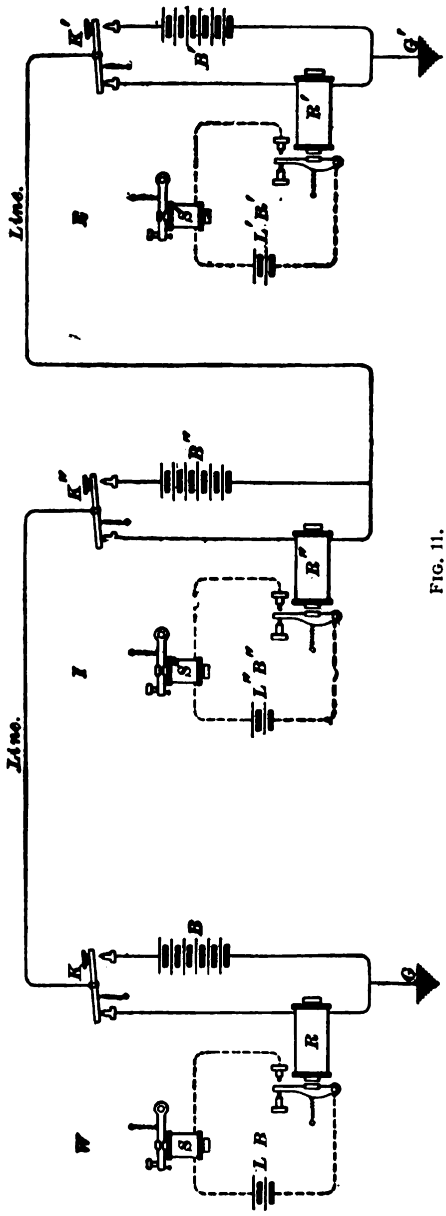


FIG. 11.

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.*
Cqas means *closed quiet and steady.*
Scotus 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 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

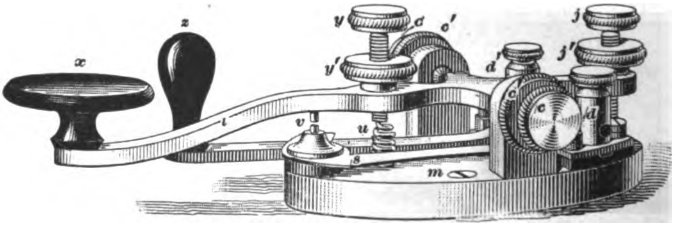


FIG. 12.

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, 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.

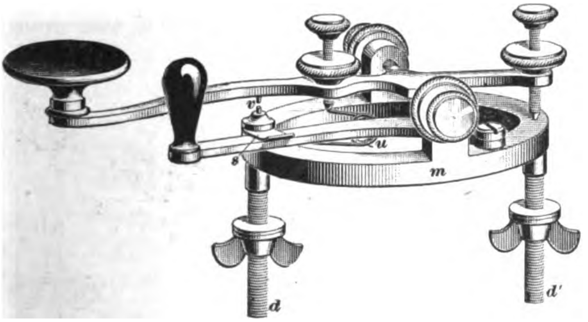


FIG. 13.

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 thumbscrews, 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 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.

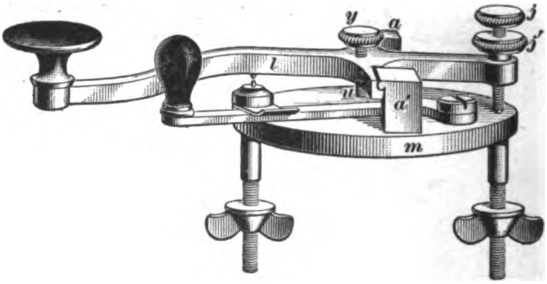


FIG. 14.

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

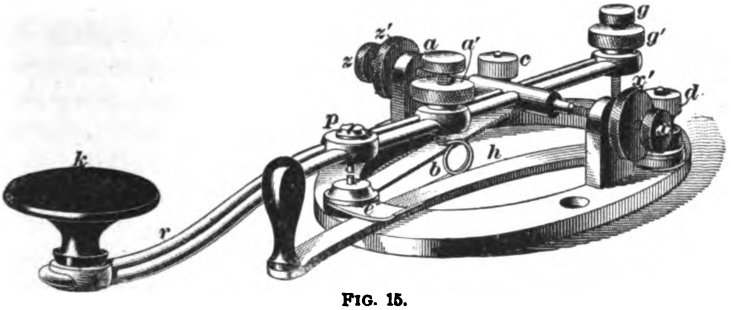


FIG. 15.

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 *c* and *d* and their locking nuts *c'* 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.

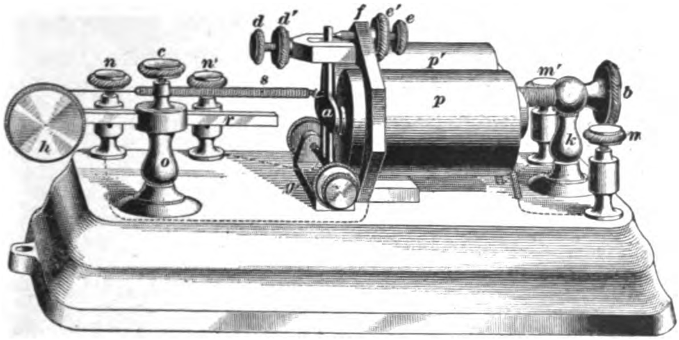


FIG. 16.

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*.

The binding posts *m* and *m'* are the ones to which the main lines are connected, and, for this reason, are called the *main-line* binding posts. One end of the coil *p* is connected underneath the wooden base with the binding post *m*, the other end is connected to one end of the coil *p'*, and the other end of the coil *p'* is connected underneath the base with the binding post *m'*. The coils *p* and *p'* are enclosed and protected by polished hard-rubber casings. The binding posts *n* and *n'* are called the *local* binding posts, because they are connected with the local battery and sounder circuit. The binding post *n* is connected underneath the base through the brass piece *f* to the screw *e*, the other post *n'* is connected with the metal piece *g* and through a fine wire spiral with the armature *a*. Consequently, when the magnet draws the armature against the stop-screw *e*, the local circuit is closed at that point. The screw *e* and the end of the armature, which comes into contact with it, are both tipped with a piece of platinum. The base is made of polished hardwood, with an under rim of metal. The connections made under the wooden base are indicated by the dotted lines.

It hardly seems necessary to say that the coils *p* and *p'* should be connected in series with each other, with the windings in such a direction around the iron cores that the front end of one iron core has north polarity and the front end of the other iron core has south polarity. All telegraph electromagnets are generally connected in this manner, and, unless specially stated to be different, they will be assumed to be so connected.

61. Improved Western Union Relay.—This relay, shown in Fig. 17, is used by the Western Union Telegraph Company and by many railroad companies. About the only difference between it and the Bunnell relay consists in the armature lever. The Western Union relay has a lever *l* made of aluminum or brass, to which is fastened the soft-iron armature *a*.

In the older style relays, called *standard* relays, it was specified that all four binding posts should be placed in a row along one side, so that many relays of this type will be found in use today. However there being no particular advantage in this, it is no longer required nor followed by the manufacturers in their later relays. All main-line relays differ so little in construction that one description practically applies to all.

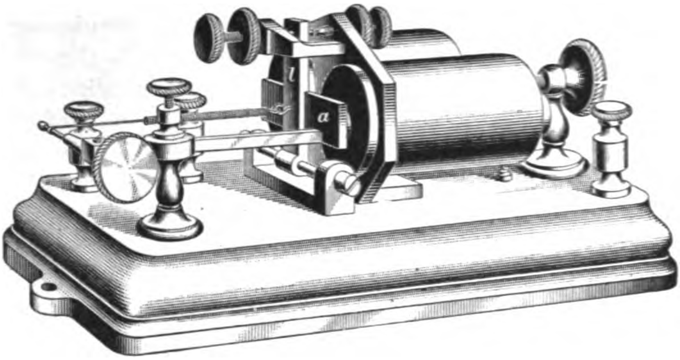


FIG. 17.

62. Pony Relay.—The **pony relay** is somewhat smaller than a main-line relay, and differs from the latter only in size and details of construction. A pony relay, representative of its type, is shown in Fig. 18. This one has

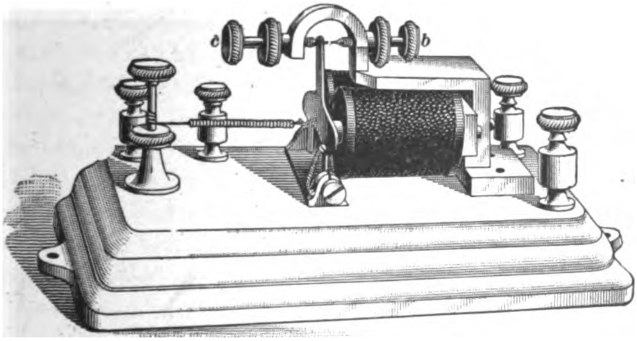


FIG. 18

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.

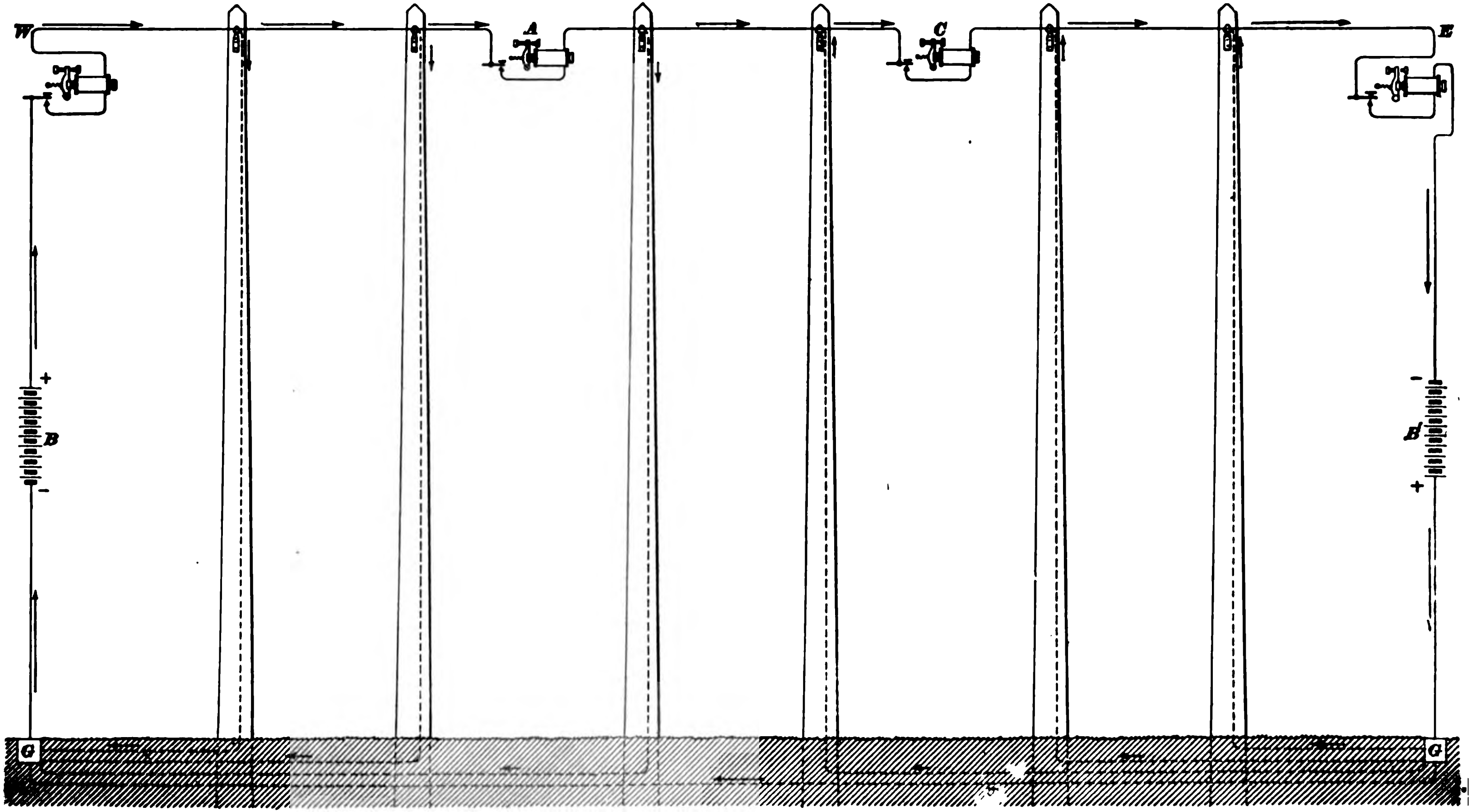


FIG. 19.

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 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

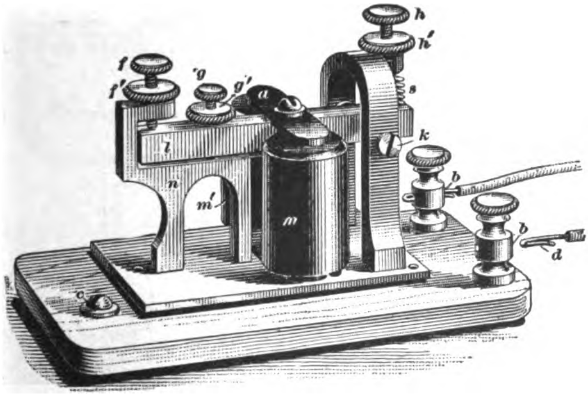


FIG. 20.

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 *e* is supported at three points, only two of which can be seen in the figure, on a second resonator 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

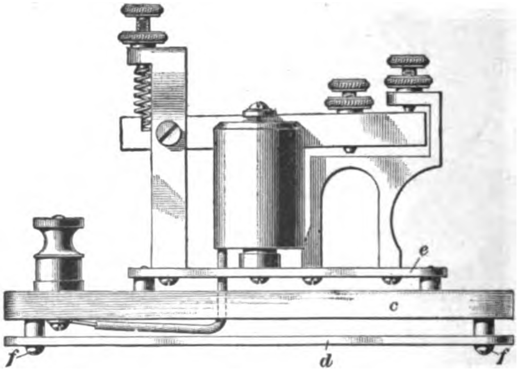


FIG. 21.

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 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.

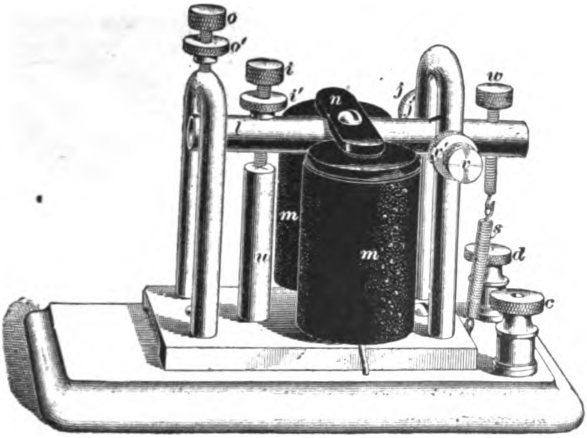


FIG. 22.

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.

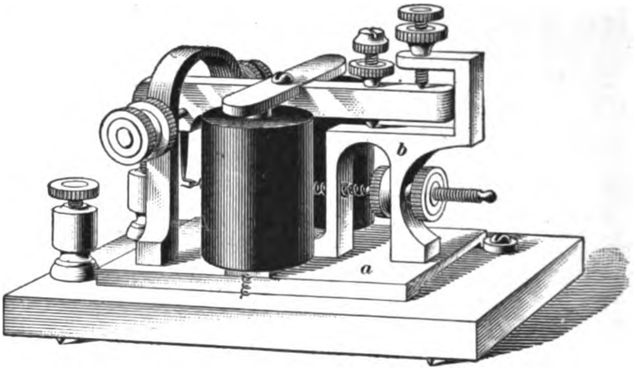


FIG. 23.

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.

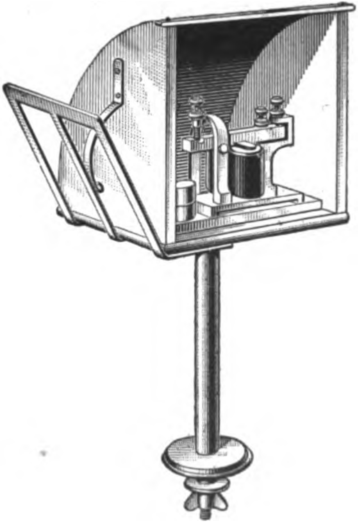


FIG. 24.

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 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.

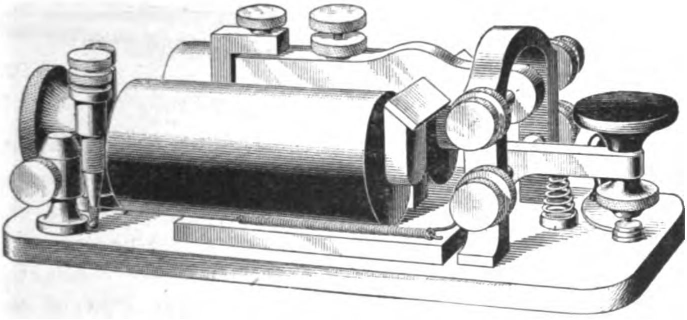


FIG. 25.

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 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.

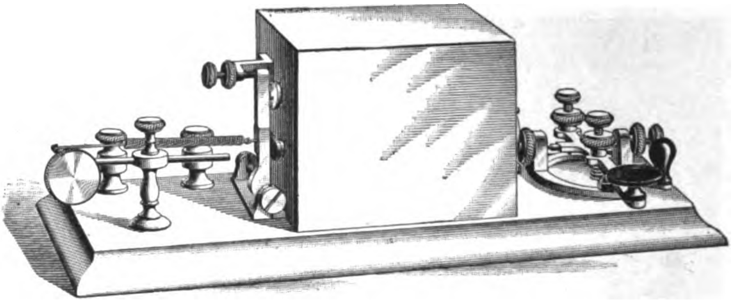


FIG. 26.

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

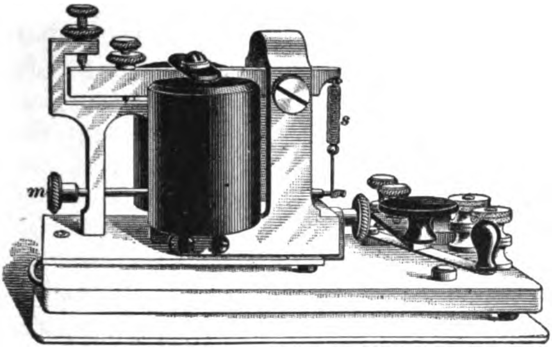


FIG. 27.

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 **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

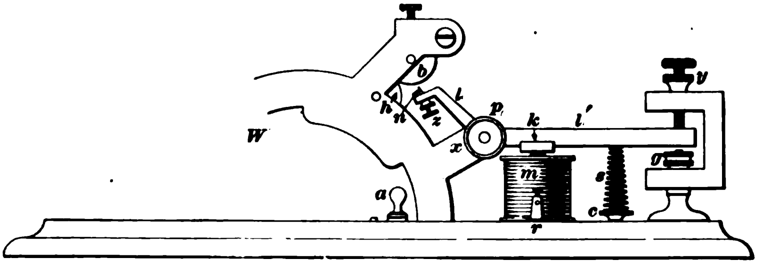


FIG. 28.

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 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.

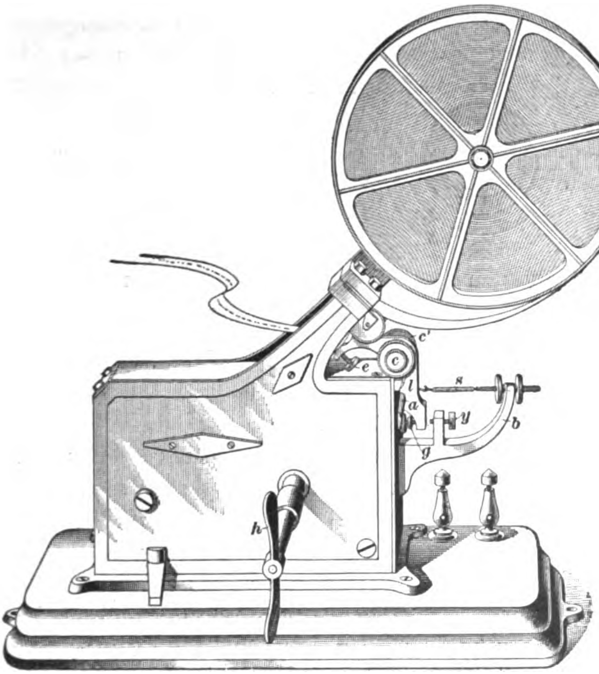


FIG. 29.

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

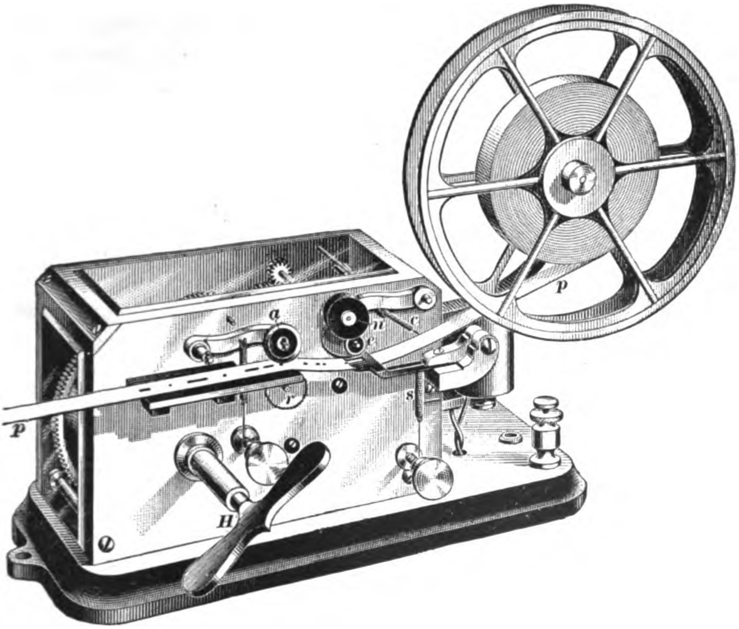


FIG. 30.

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.

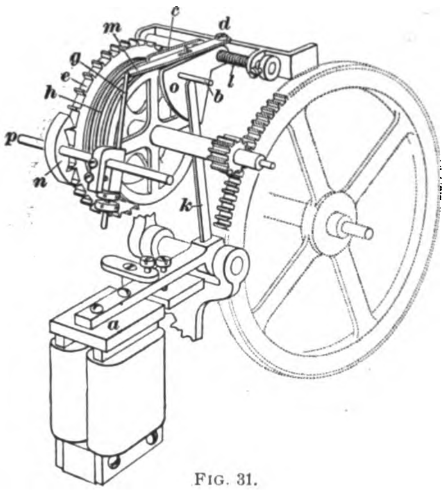


FIG. 31.

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

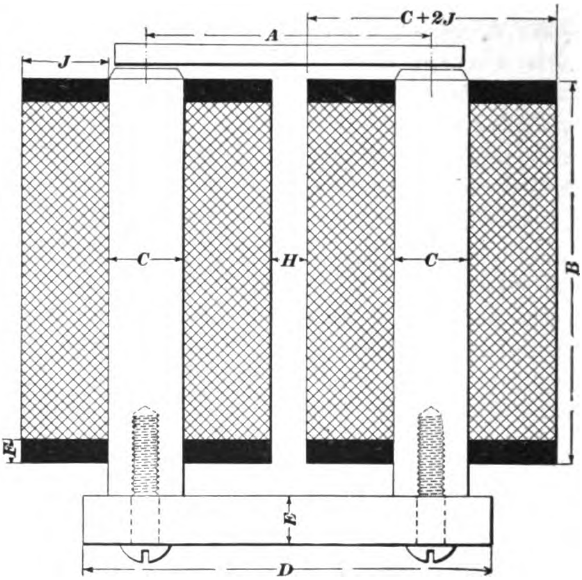


FIG. 32.

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:

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

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

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

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

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

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

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

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,

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

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 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.

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

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 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.

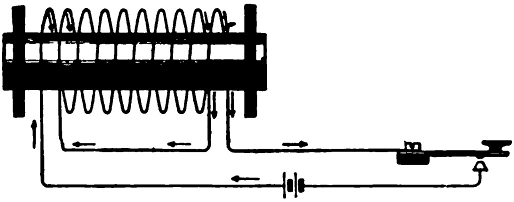


FIG. 33.

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 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 2⅓ 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.

TABLE 3.

	A	B	C	D	E	F	H	J	$C + 2J$
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

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 ¼ 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.*

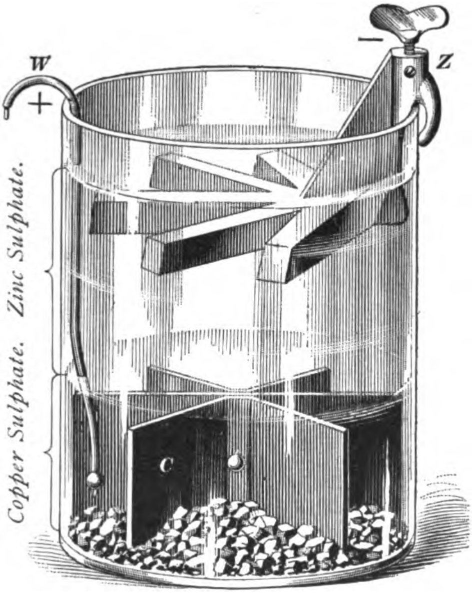


FIG. 34.

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 ½ 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, fitti nearly water-tight. Inside the jar is a perforate der suspended by a rod of iron from the middle of and held in place by insulating washers, in case a is used, and a brass c Within the perforate is deposited chemic cupric oxide (2¾ po the large No. 1 cell). care is taken in the r ture of this material copper is thoroughly c About 1½ inches from tom of the perforated c are attached three lug of porcelain and held perforated cylinder by of iron stove bolts. lugs sustain the wei the zinc element, and, at the same time, keep the thoroughly insulated. The zinc is practically pure, a its surface thoroughly amalgamated. Attached to th by means of a copper rivet is a No. 12 copper wire ru to the top of the jar and forming the negative termi the cell. The zinc element and the copper wire are pr closely together, and the exposed copper is covered w rubber insulation.

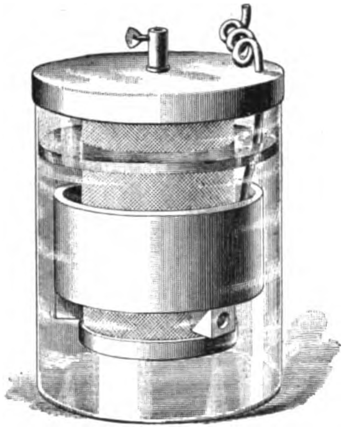


FIG. 85.

The solution consists of 1½ pounds of caustic soda hydrate of soda, dissolved in 6 pints of pure cold wa The water used should be free from lime or carbonace material. A heavy paraffin oil, floating on the surface the caustic-soda solution, seals the cell and prevents atmosphere, with the carbonic-acid gas that it contai from reaching the solution. The carbonic-acid gas w change the hydrate of soda to carbonate of soda, and t latter is useless in the cell, if not injurious. Such usele consumption of the hydrate of soda would shorten the life 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 ½ 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, 2½ pints, or within 1½ 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 ¾ 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.

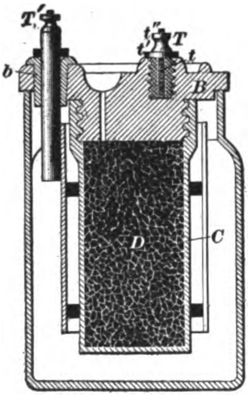


FIG. 36.

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

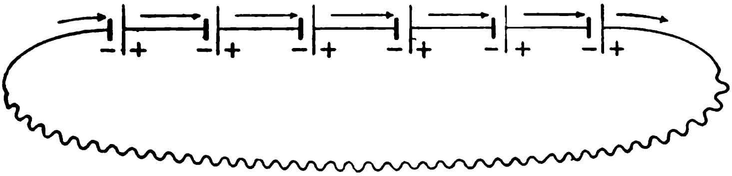


FIG. 37.

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

$$B = s\,b.$$

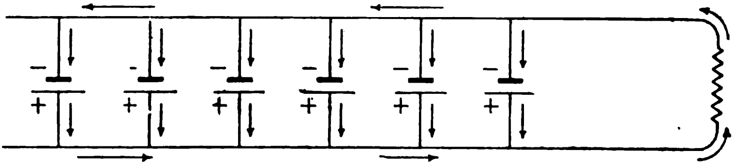


FIG. 38.

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 $= \frac{2\,b}{3}$.

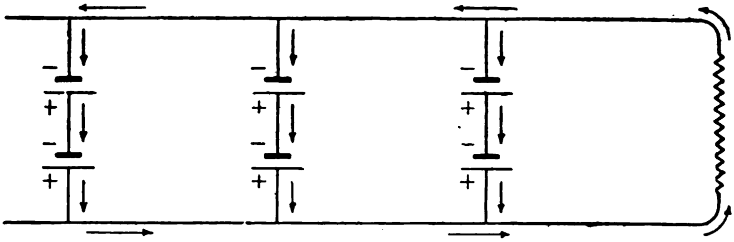


FIG. 39.

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?

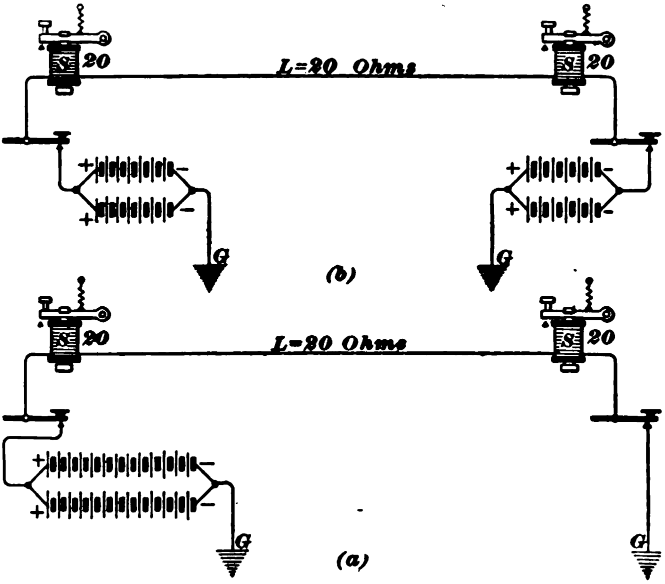


Fig. 40.

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

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, $W = C^2 R,$

and $w = C^2 \frac{s\,b}{p}.$

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

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 $\frac{s\,e}{\frac{s\,b}{p} + R}$ (see formula **12**) has a maximum value, for a given number of cells N, when $\frac{s\,b}{p} = R$.

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

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

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

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

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:

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

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

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

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

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

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

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

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

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

Example.—It is required to send ¼ 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

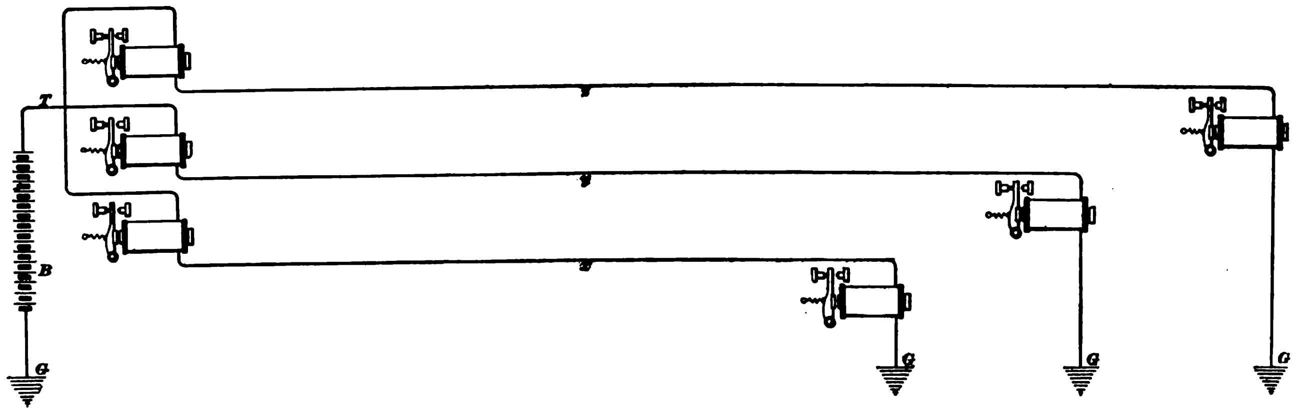


FIG. 41.

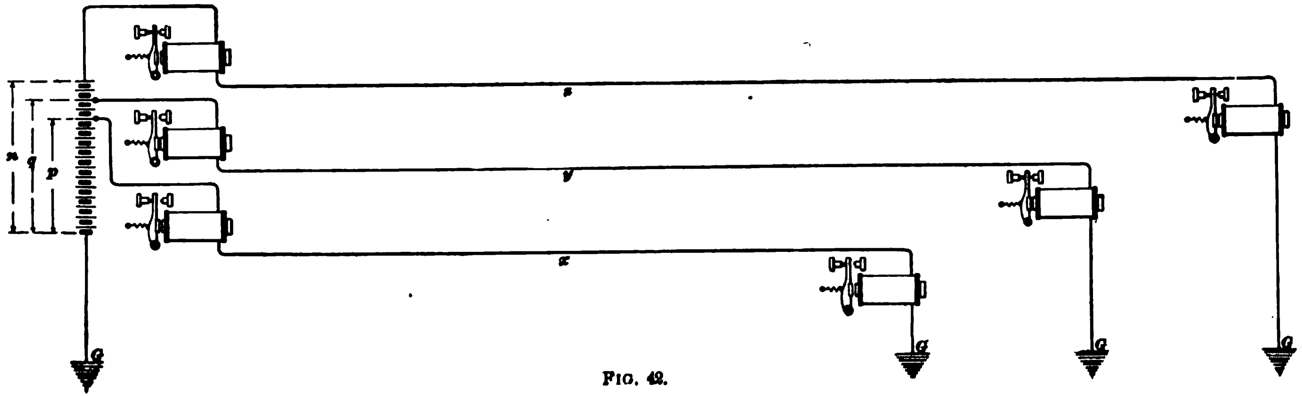


FIG. 42.

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

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

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

$$\frac{\frac{28{,}000}{3} \times 4{,}000}{\frac{28{,}000}{3} + 4{,}000} + 444 = 3{,}244 \text{ ohms.}$$

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.

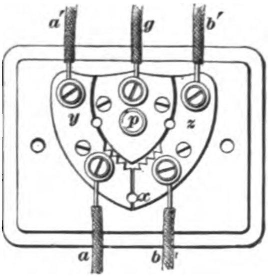


FIG. 43.

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;
$\pi = 3.1416$;
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.

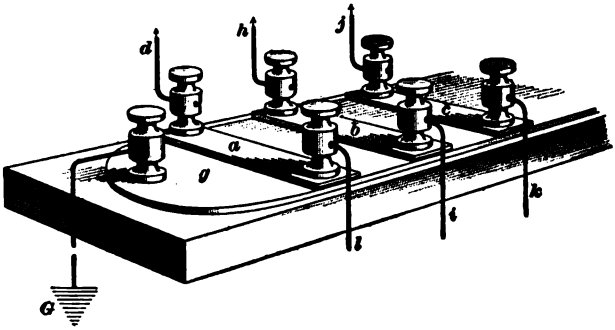


FIG. 44.

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.

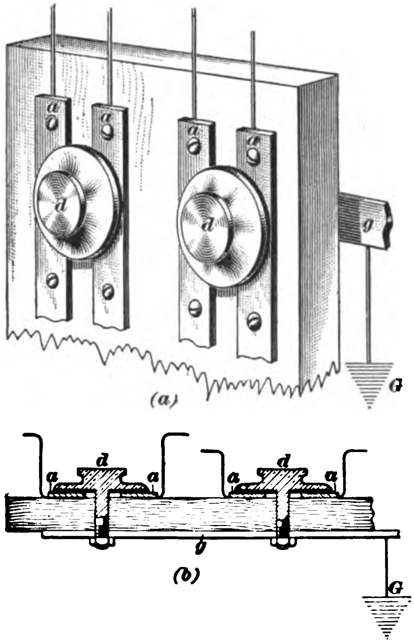


FIG. 45.

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

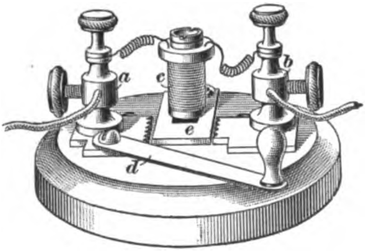


FIG. 46.

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* 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.

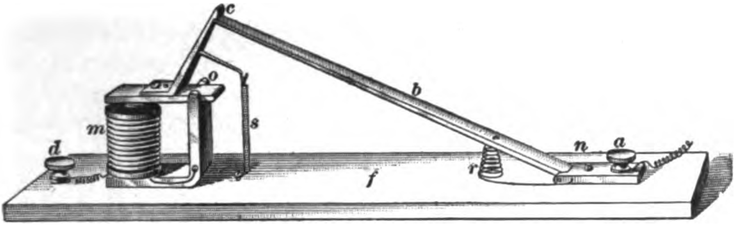


FIG. 47.

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 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 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.

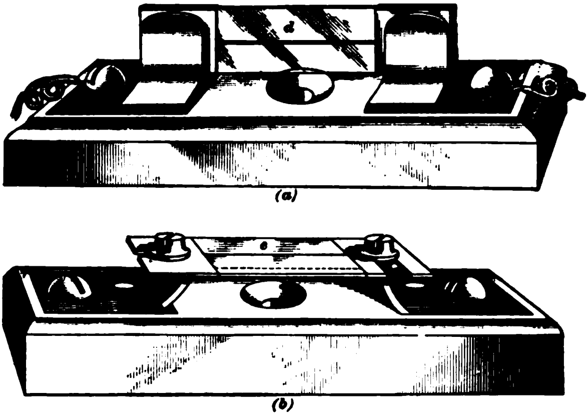


FIG. 48.

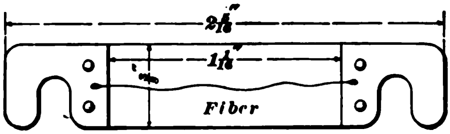


FIG. 49.

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 ¾ 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 takes a fuse 1¼ 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.

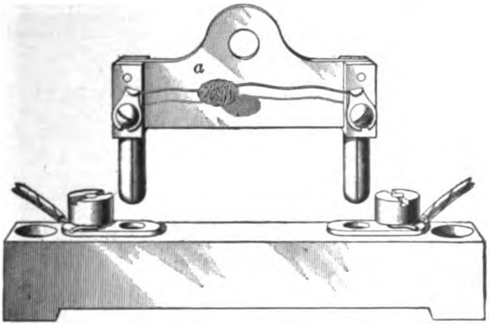


FIG. 50.

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 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.

FIG. 51.

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 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.

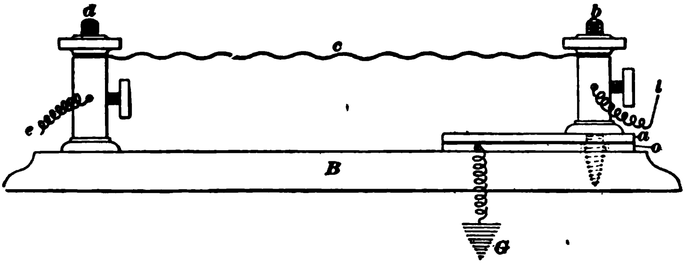


FIG. 52.

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

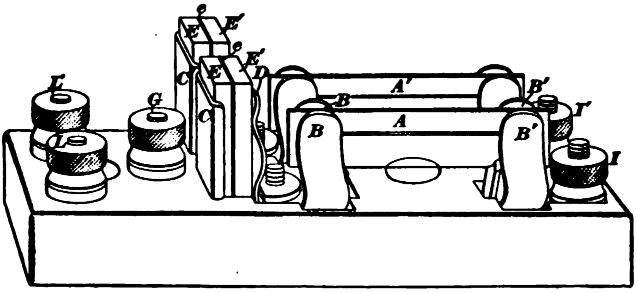


FIG. 53.

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 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.

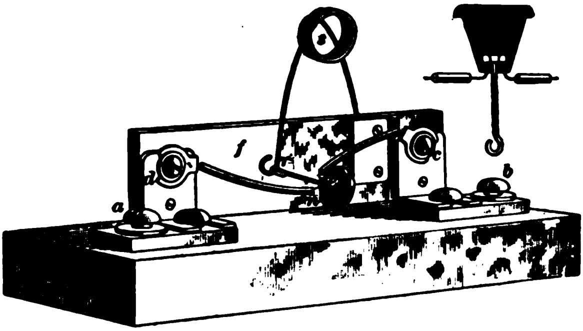


FIG. 54.

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 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

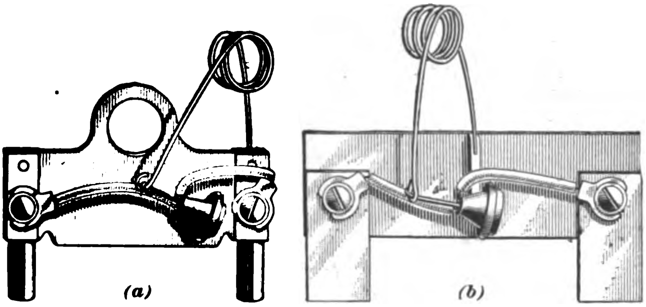

(a) (b)

FIG. 55.

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.

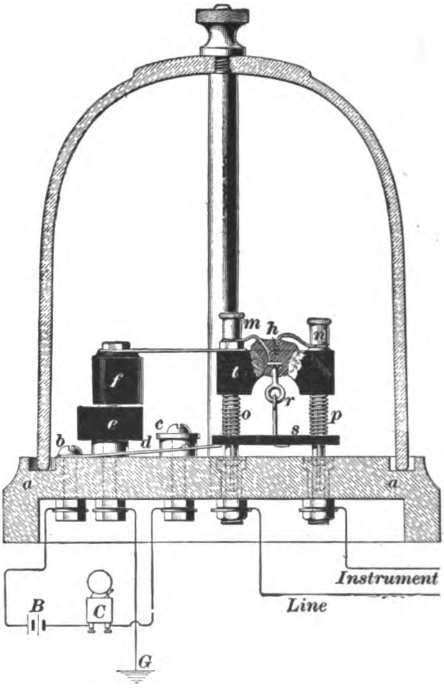


FIG. 56.

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 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 ¼ 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_3 and P, and at the

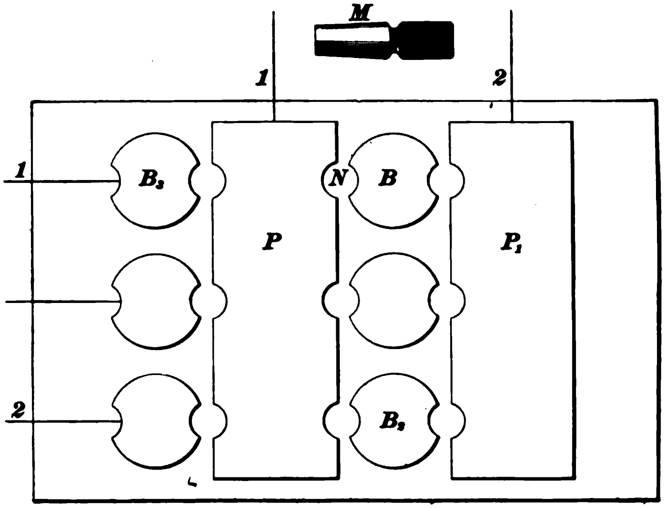


FIG. 57.

junction of B_2 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.

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.

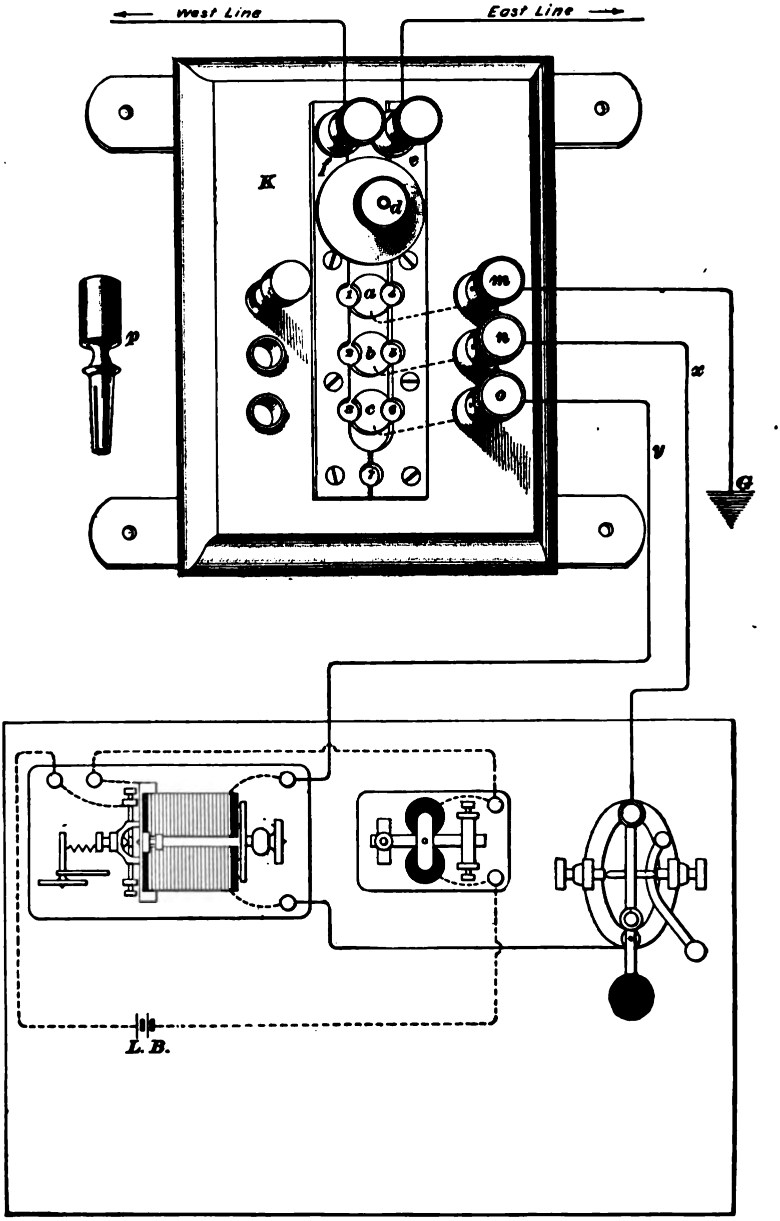


FIG. 58.

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 × .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 baseboard; similarly, *v* is connected to *c* and *d*, *w* to *l* and *i*, 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.

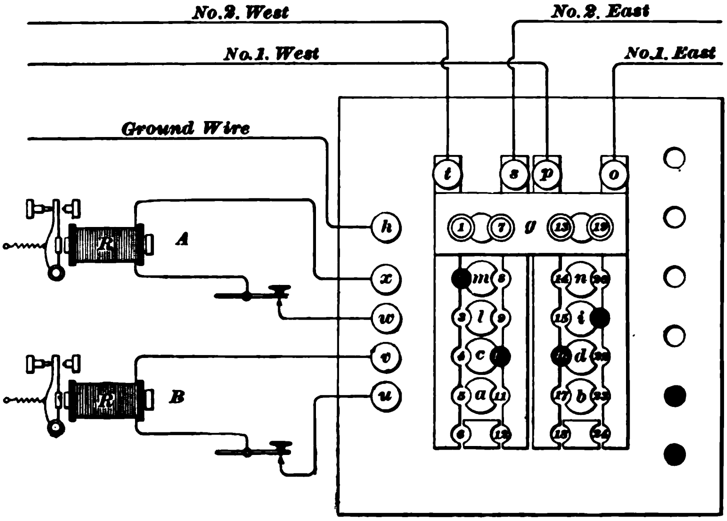


FIG. 59.

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

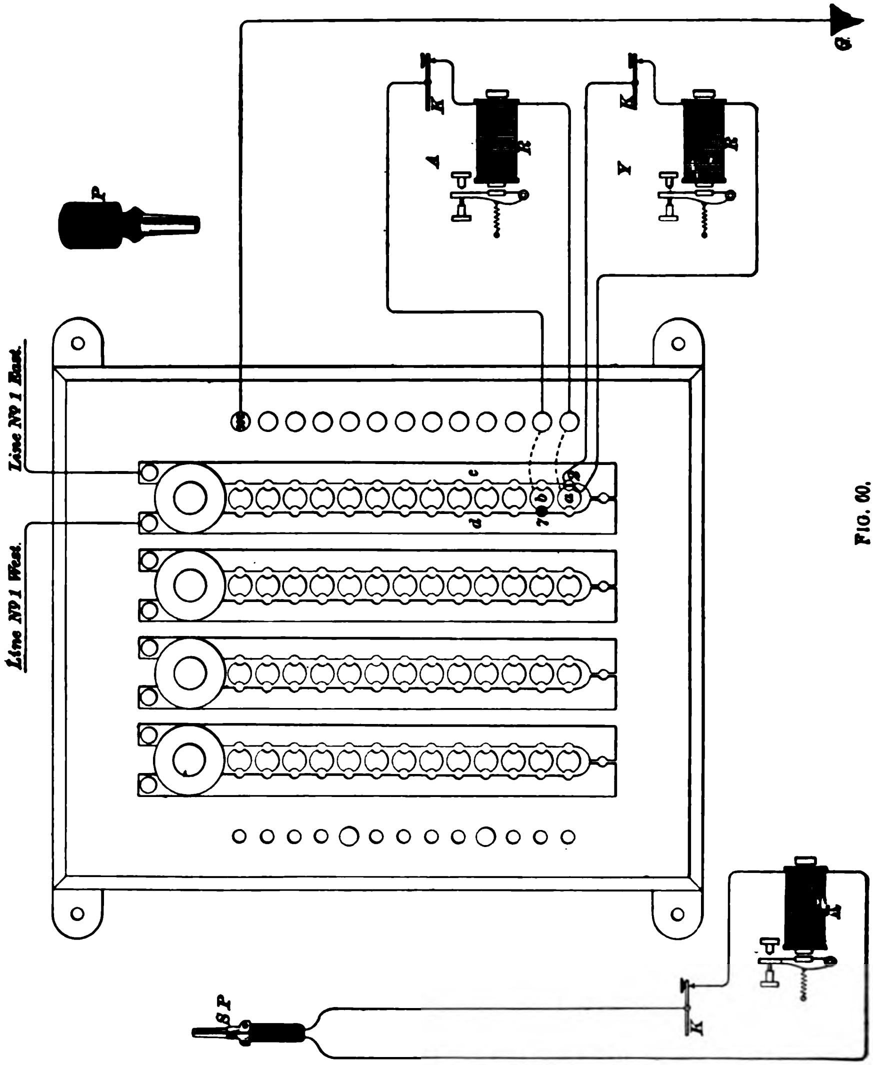


FIG. 60.

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 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

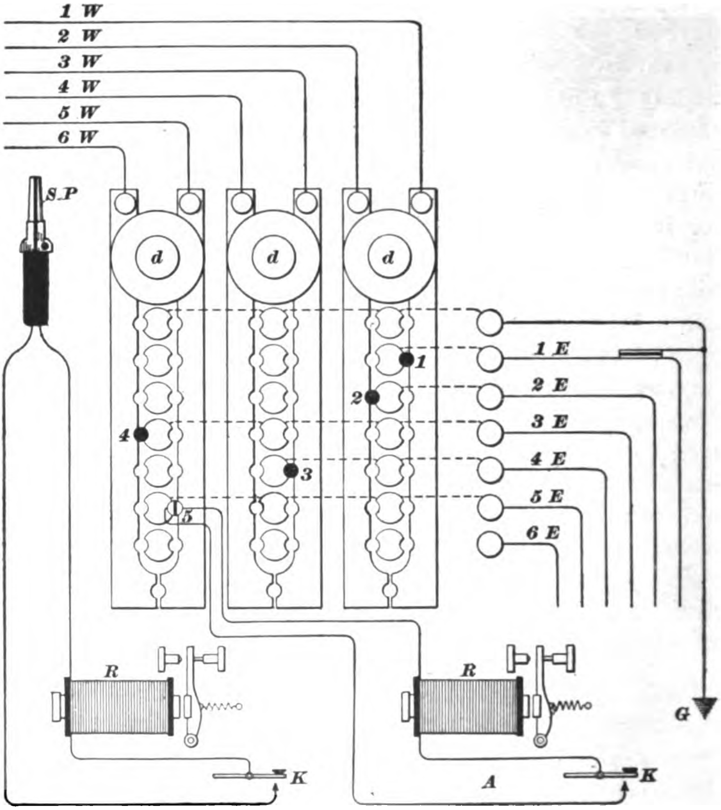


FIG. 61.

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

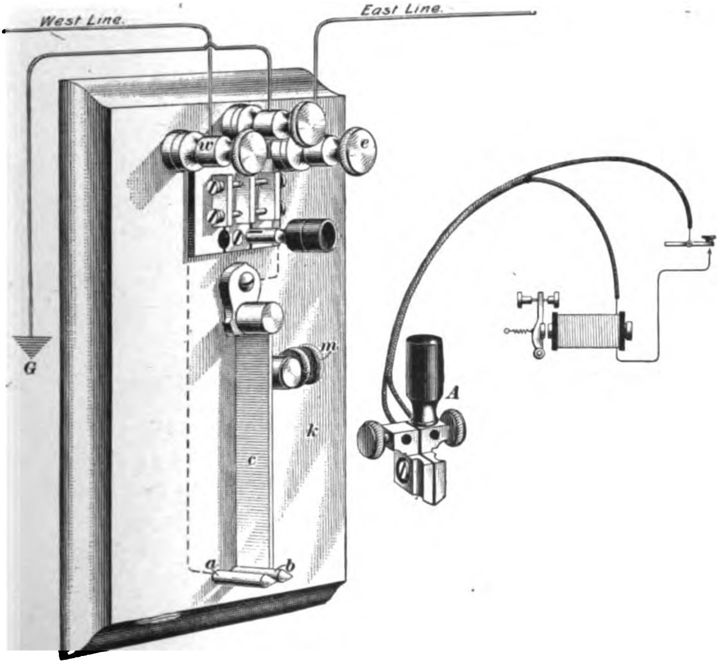


FIG. 62.

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 *e* 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

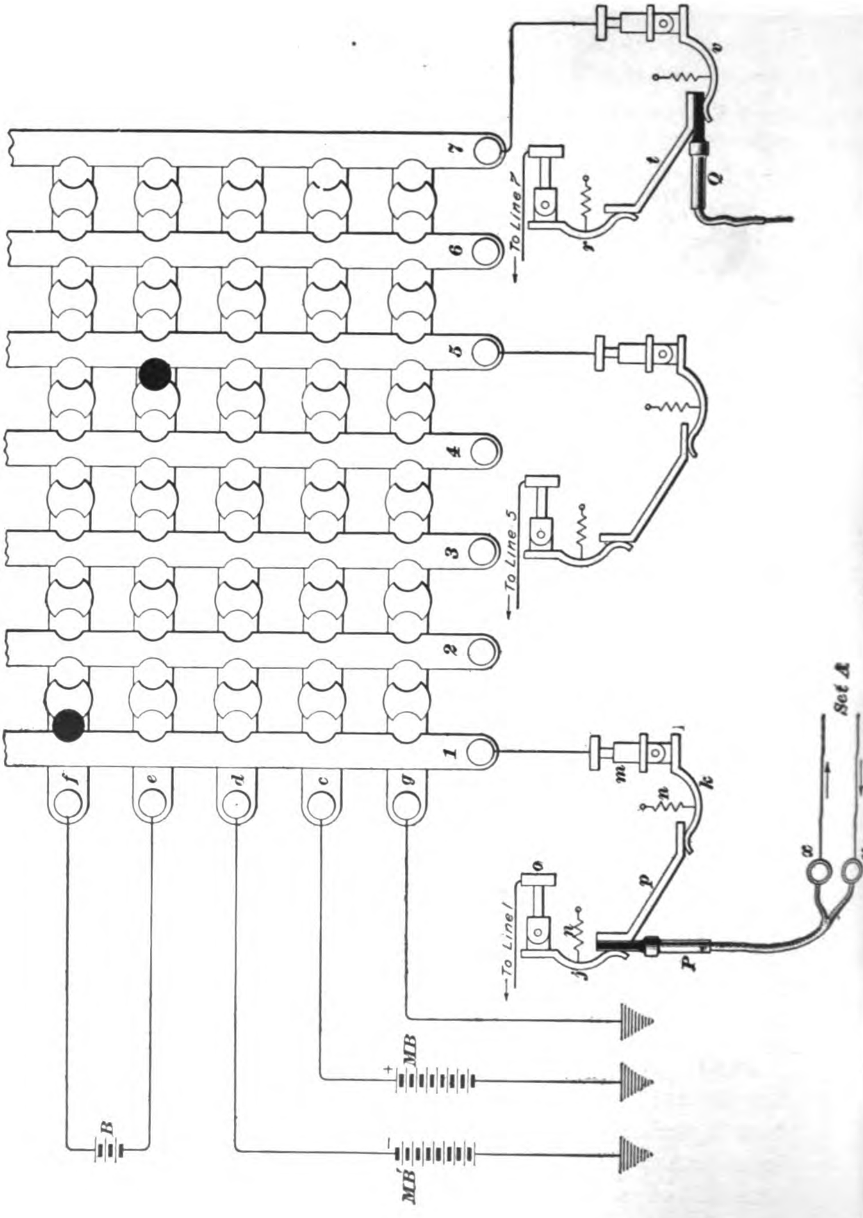

1
2
3
4
5
6
7
f
e
d
c
g
B
+
MB
−
MB'
To Line 1
To Line 5
To Line 7
m
n
k
p
P
j
h
o
x
y
Set A
r
t
Q
v

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, ½ inch wide, and ⅜ 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.

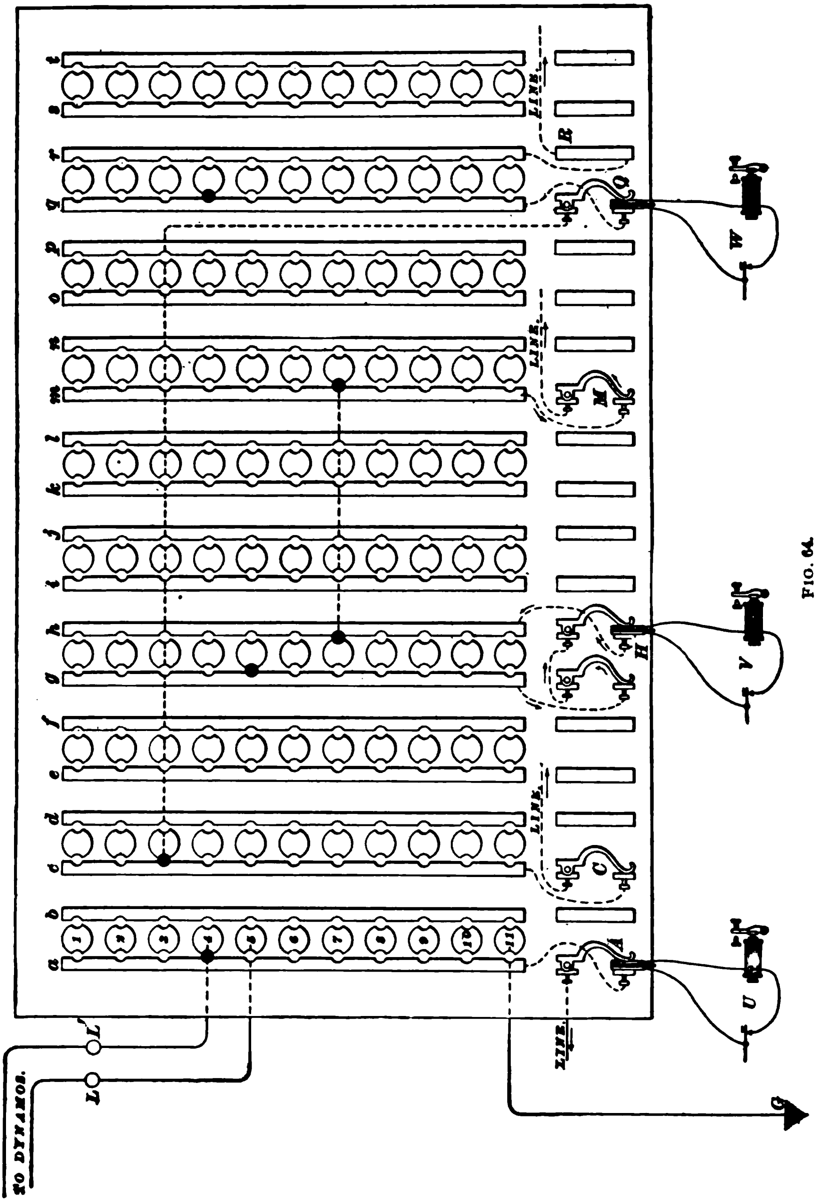
Where dynamos are used in the place of gravity cells for the main batteries, the disks in the rows to which the dynamos supply current are not joined together directly by a horizontal strip back of the board. Instead, each disk is connected through a separate incandescent lamp or other non-inductive 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


a
b
c
d
e
f
g
h
i
j
k
l
m
n
o
p
q
r
s
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1
2
3
4
5
6
7
8
9
10
11
LINE
LINE
LINE
LINE
R
Q
W
M
H
V
C
A
U
L'
L
G
TO DYNAMOS.

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 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

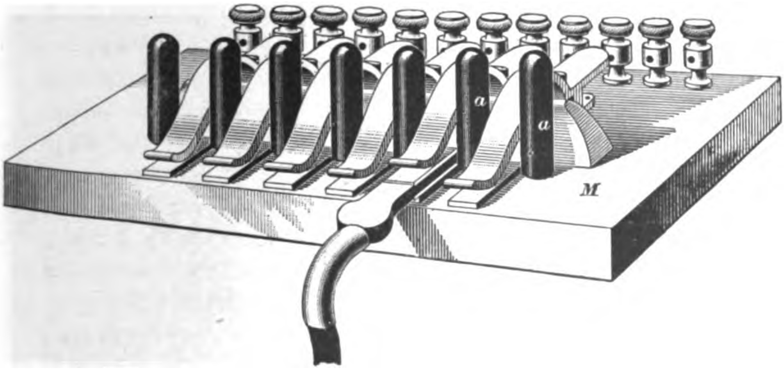


FIG. 65.

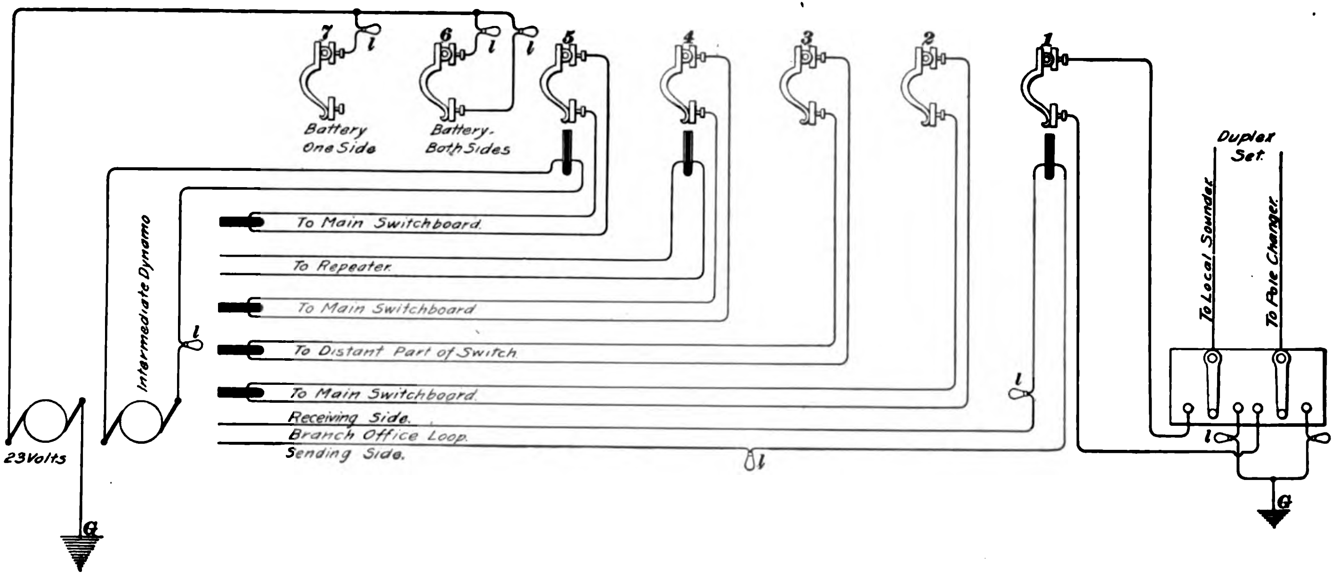

7
6
5
4
3
2
1
l
l
l
Battery One Side
Battery. Both Sides
Duplex Set.
To Local Sounder.
To Pole Changer.
To Main Switchboard.
To Repeater.
To Main Switchboard
To Distant Part of Switch.
To Main Switchboard.
Receiving Side.
Branch Office Loop.
Sending Side.
Intermediate Dynamo
l
l
l
l
l
23 Volts
G
G

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.

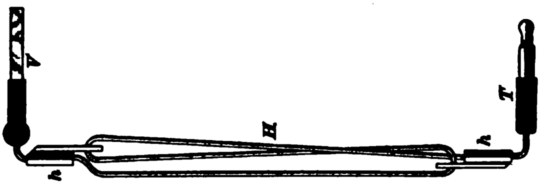
218. The Postal Telegraph Company's loop switches are arranged in a somewhat different manner, there being only one wire in a branch-office loop, as will be seen in connection with the descriptions that will be given later of this company's duplex and quadruplex systems.

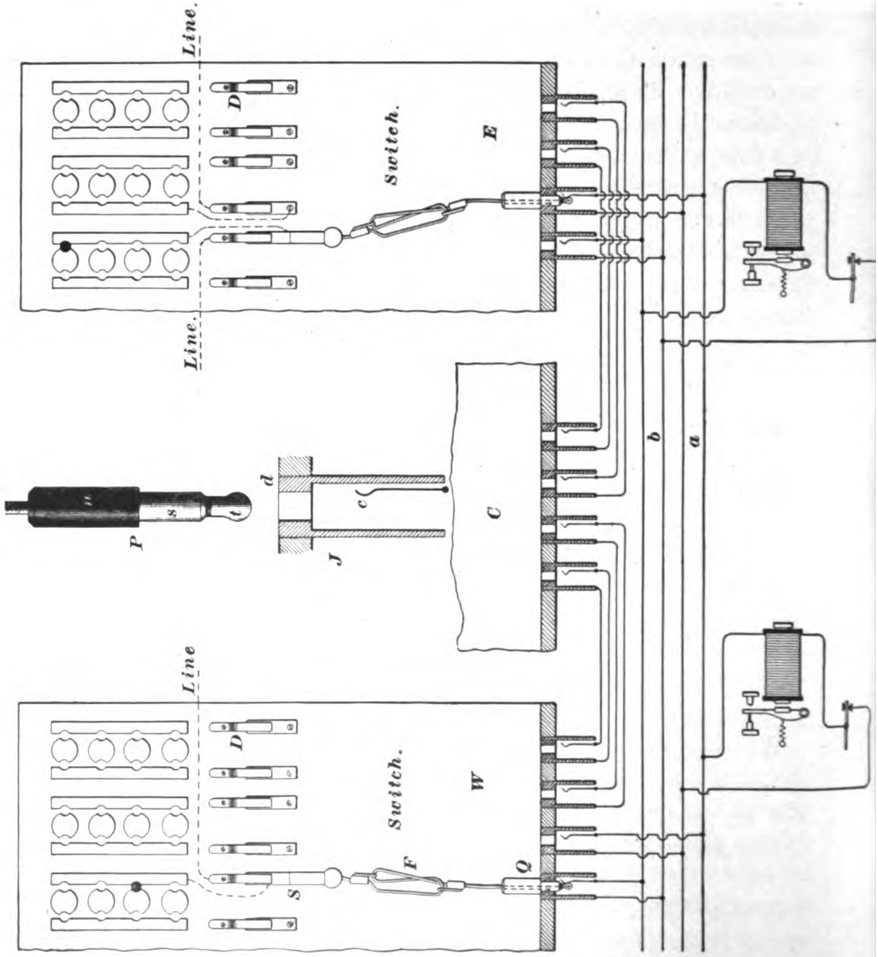
219. Loop switches make an extremely convenient and flexible system whereby many changes and combinations may be made between the lines and the various telegraphic apparatus. It allows the concentration of the various multiplex and repeater sets in one room, under the supervision of a few experts, and 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 SWITCHBOARD.

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


V
h
H
h
T


Line.
D
Switch.
E
Line.
P
u
s
t
d
c
J
C
b
a
Line
D
Switch.
W
F
Q
S

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.*

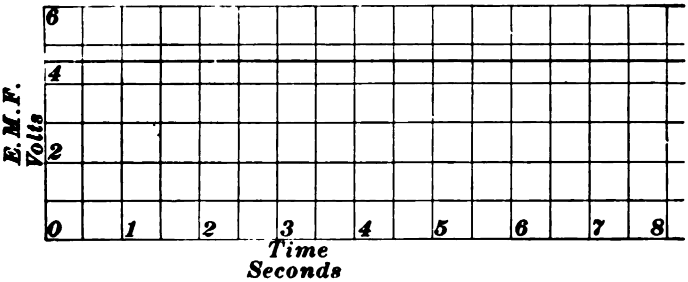


FIG. 1.

Strictly speaking, a **continuous current** is one in which the electromotive force has an absolutely 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.

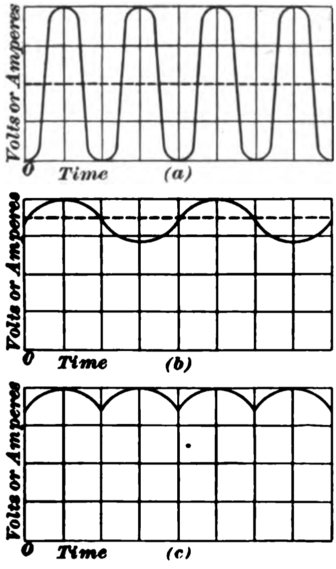


FIG. 2.

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.

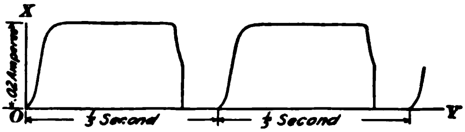


FIG. 3.

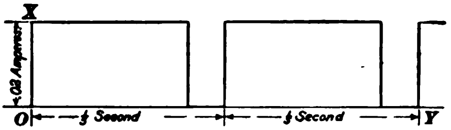


FIG. 4.

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 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.

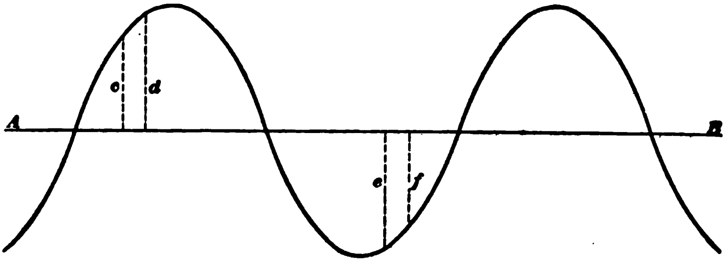


FIG. 5.

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

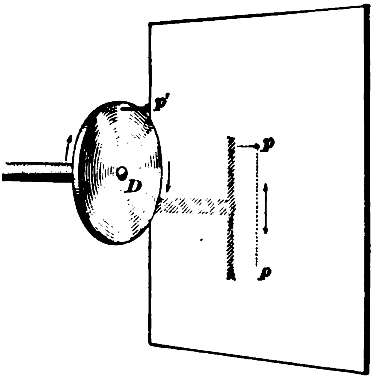


FIG. 6.

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

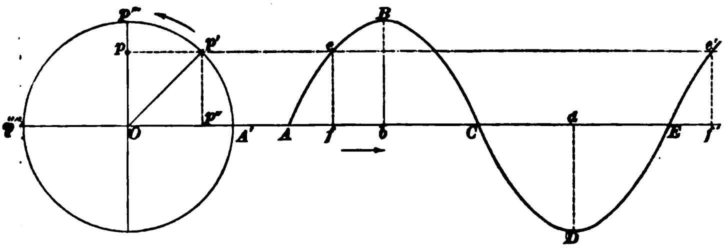


FIG. 7.

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 e'* 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 *e'* 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 $A\,e\,B\,C$ 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 $T n$, since each line cuts through each of the T turns. Evidently, therefore, for 1 ampere of current, $L = T n$, and for a current of C amperes, the total number of lines will be C times larger, or $C n$, 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

$$C L = T C n, \text{ or } L = \frac{T C n}{C}.$$

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.

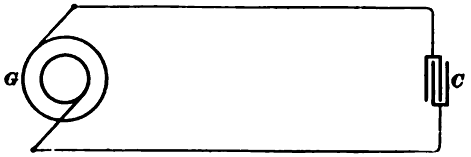


FIG. 8.

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.

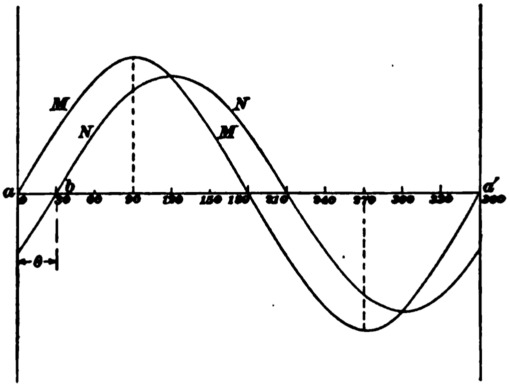


FIG. 9.

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:

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

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

$$C = \frac{E}{\sqrt{R^2 + (2\,\pi\,n\,L)^2}}. \qquad \textbf{(3.)}$$

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**

$$C = \frac{1}{\sqrt{(.4)^2 + (2 \times 3.1416 \times 60 \times .001)^2}} = 1.818 \text{ amperes.} \quad \text{Ans.}$$

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

$$\text{Impedance} = \sqrt{R^2 + \left(\frac{1}{2\pi n Q}\right)^2}, \qquad (4.)$$

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

$$C = \frac{E}{\sqrt{R^2 + \left(\frac{1}{2\pi n Q}\right)^2}}. \qquad (5.)$$

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:

$$\text{Impedance} = \sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n Q}\right)^2}, \qquad (6.)$$

$$C = \frac{E}{\sqrt{R^2 + \left(2\pi n L - \frac{1}{2\pi n Q}\right)^2}}. \qquad (7.)$$

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 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.

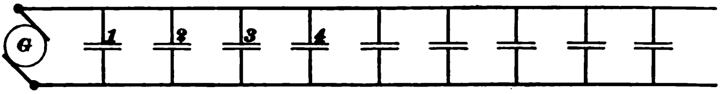


FIG. 10.

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 ⅕ second after contact is made at Newfoundland, no effect can be detected in Ireland, even by the most delicate instrument; after ⅖ 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 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.

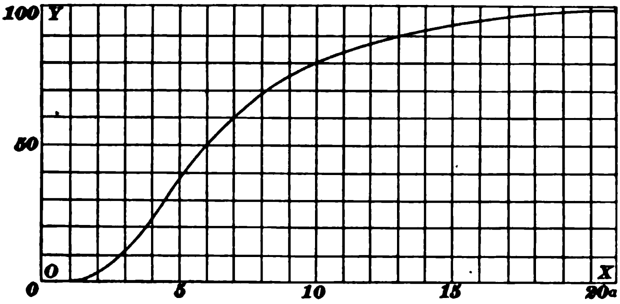


FIG. 11.

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:

$$a = \frac{.02332\, q\, r\, l^2}{1{,}000{,}000}. \qquad (8.)$$

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 KR 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	77.5918
.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 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.

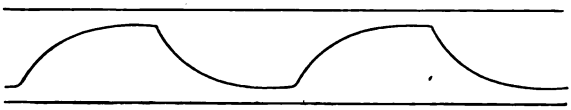


FIG. 12.

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 KR 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 $\doteq \frac{.66}{1.09} = .6$. 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*.

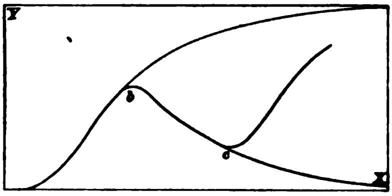


FIG. 13.

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 KR 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 $20a$ 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 ABC 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 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

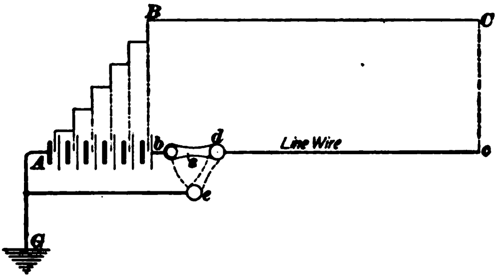


FIG. 14.

unit length is proportional to, and may be represented by, this line bB. Furthermore, the total charge is proportional to bB multiplied by the length bc. But this is the area of the rectangle $bBCc$, hence the total charge may be represented by the area enclosed between BC and the line wire bc.

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 $bBCc$. 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 ABC in Fig. 15. There is now a continuous flow of current through the circuit. Assuming that the resistance from C to A through

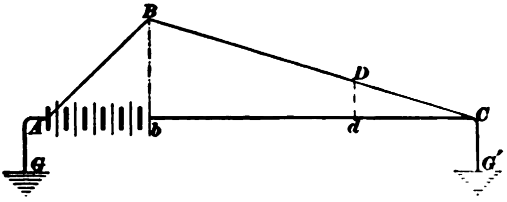


FIG. 15.

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. Bb represents the difference of potential between the point b and the earth, and, similarly, Dd 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 $\frac{1}{2}$ *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

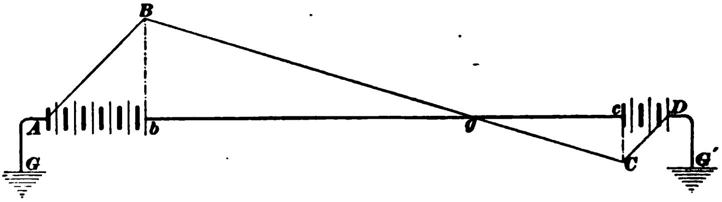


FIG. 16.

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 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

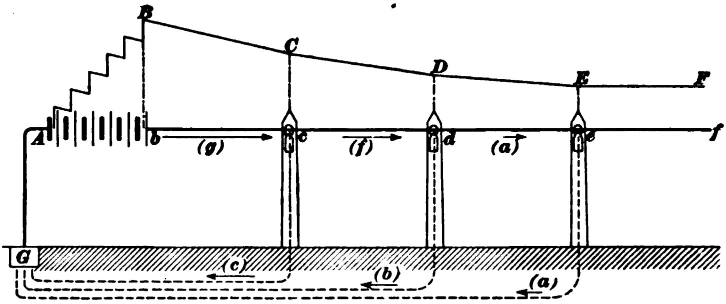


FIG. 17.

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.

$$P = \frac{C_1}{C} = \frac{2}{w + \frac{1}{w}}, \qquad (9.)$$

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 $\sqrt{\dfrac{r\,n}{\frac{s}{n}}}$ 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

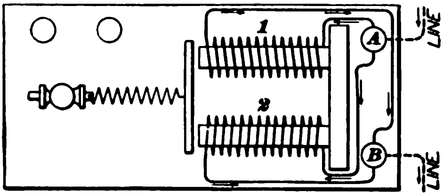


FIG. 18.

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 profitably 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 ± the difference of potential between the points A and B that would be caused by the trolley current alone. The sign ± 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 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.

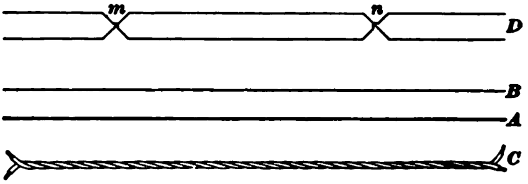


FIG. 19.

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 on a pole is shown in Fig. 20. Insulators having two grooves, and called *transposition insulators*, are used for this purpose.

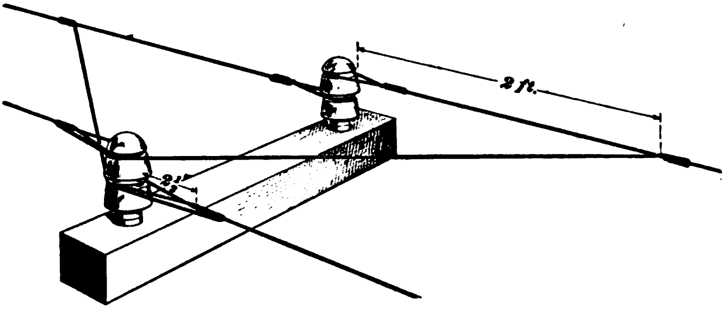


FIG. 20.

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

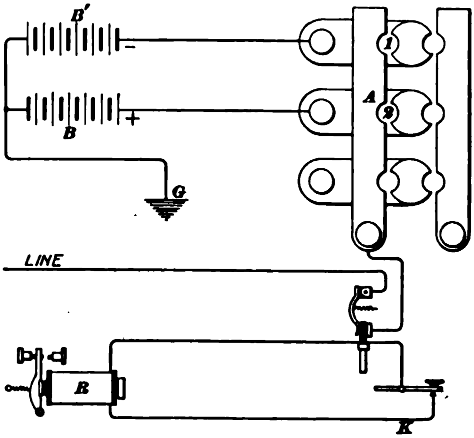


FIG. 21.

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 *e* 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

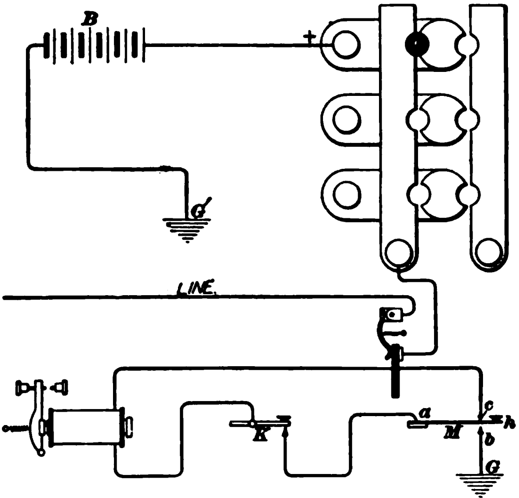


FIG. 22.

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

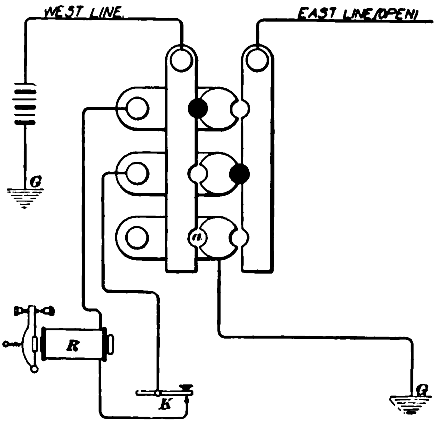


FIG. 23.

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 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*.

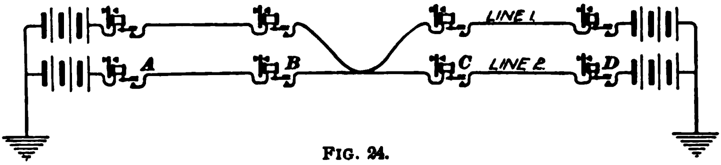


FIG. 24.

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, 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*.

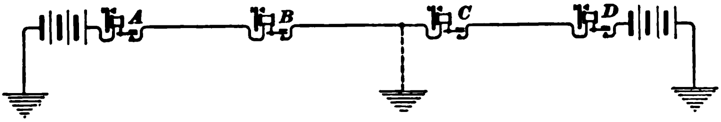


FIG. 25.

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. This iron circuit is shown in Fig. 26. *C*, *C* are the iron

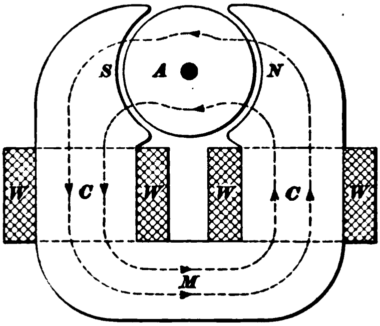


FIG. 26.

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.

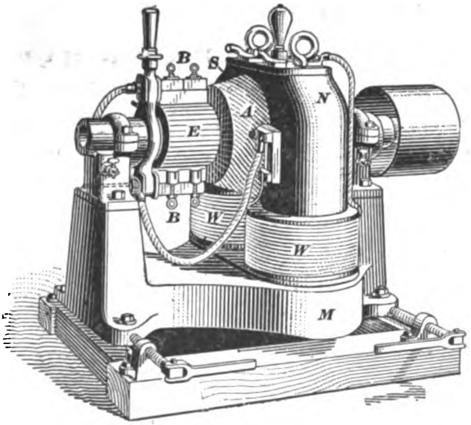


FIG. 27.

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.

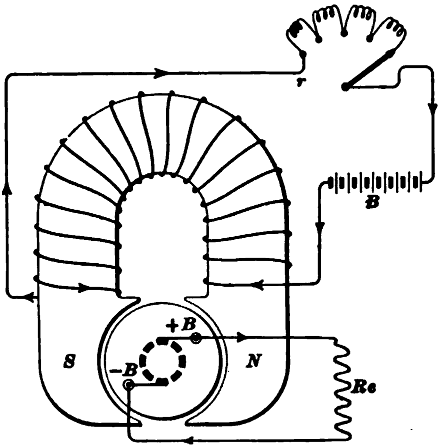


FIG. 28.

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 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

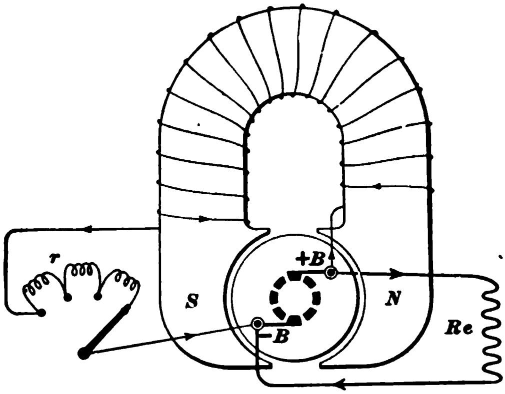


FIG. 29.

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 $+B$,

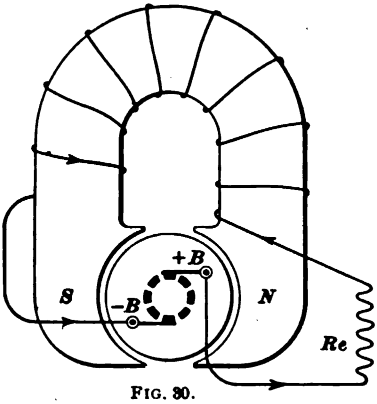


FIG. 30.

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.

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

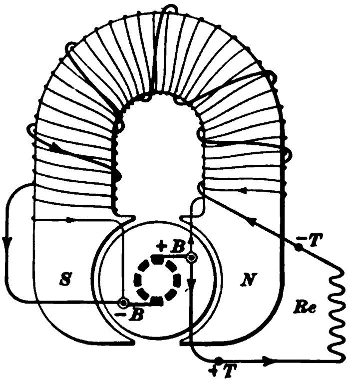


FIG. 31.

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

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* 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 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

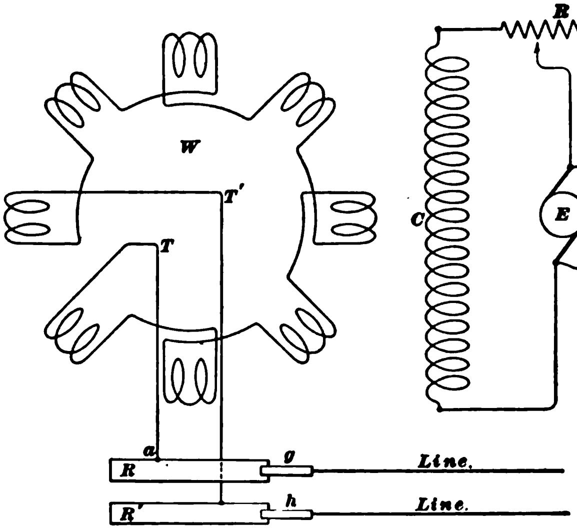


FIG. 32.

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

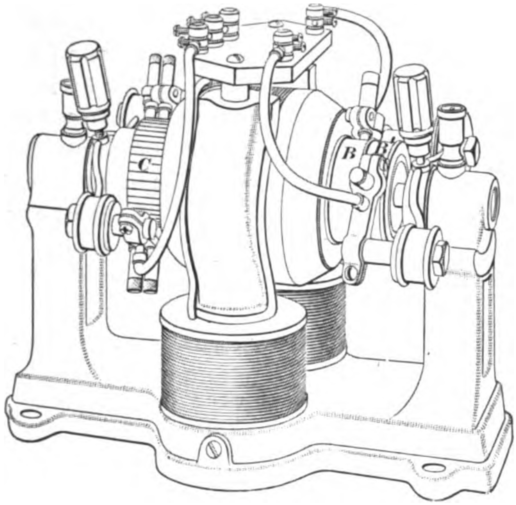


FIG. 33.

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.

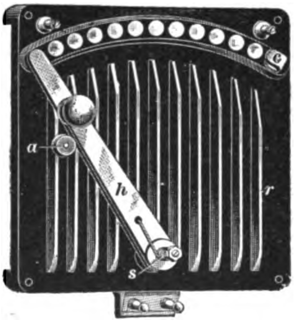


FIG. 34.

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).

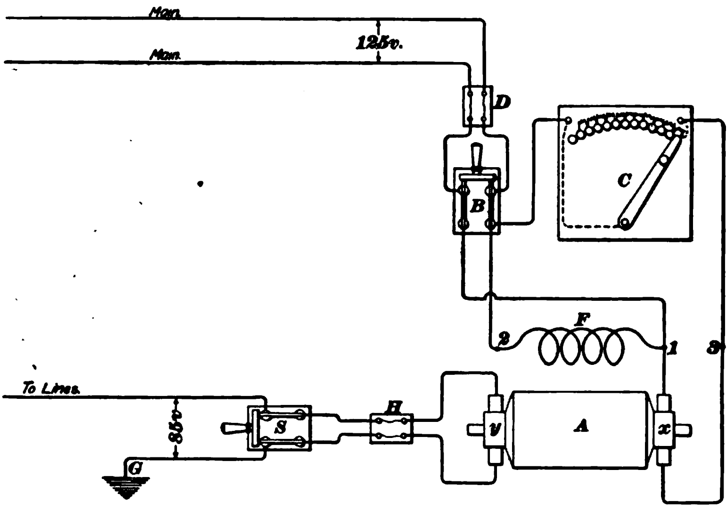


FIG. 35.

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.

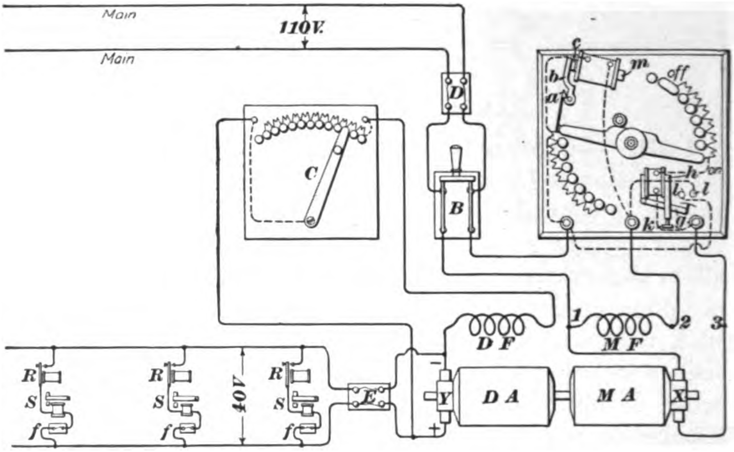


FIG. 36.

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 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

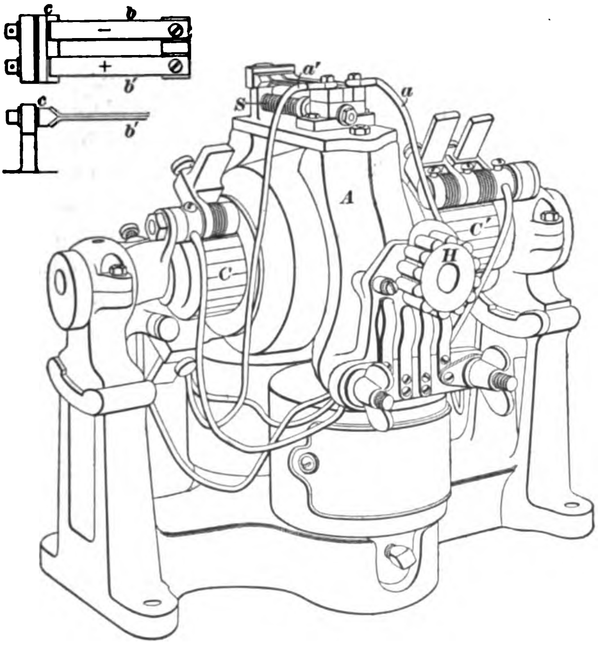


FIG. 87.

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.

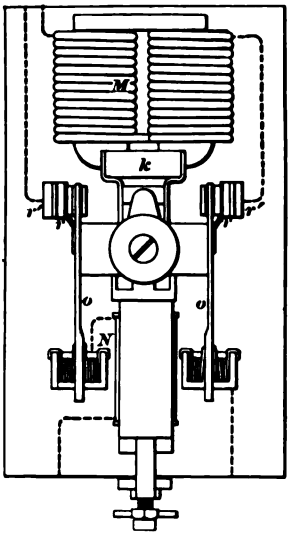


FIG. 38.

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.

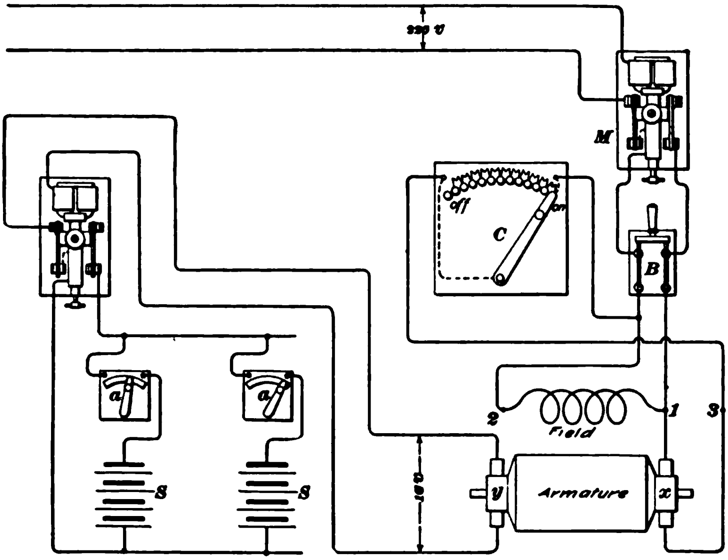


FIG. 39.

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.

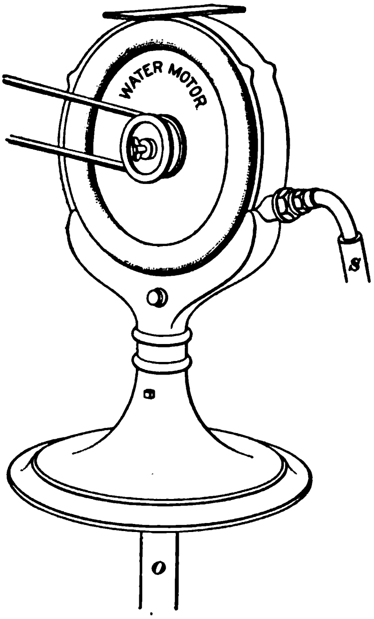


FIG. 40.

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, 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-horsepower 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

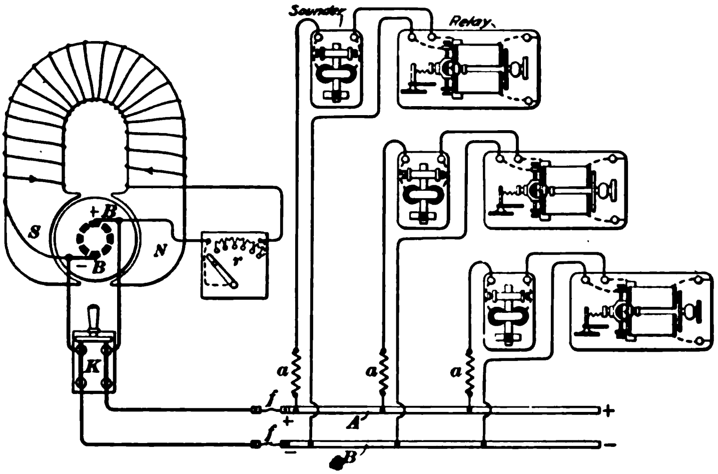


FIG. 41.

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.

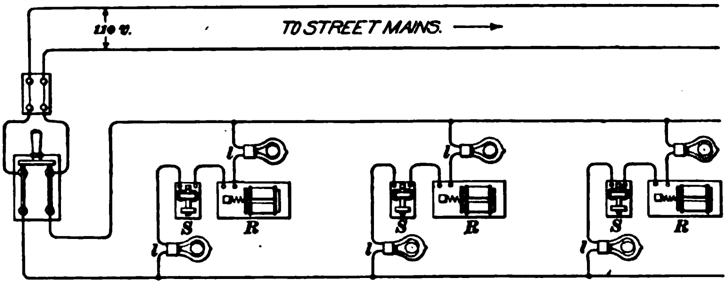


FIG. 42.

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 1½ cents per ampere per hour. This was the cost of current for lamps (¾ 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 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 ¼ cent for the 10 hours. This is less than one-third what it cost for current under the preceding arrangement.

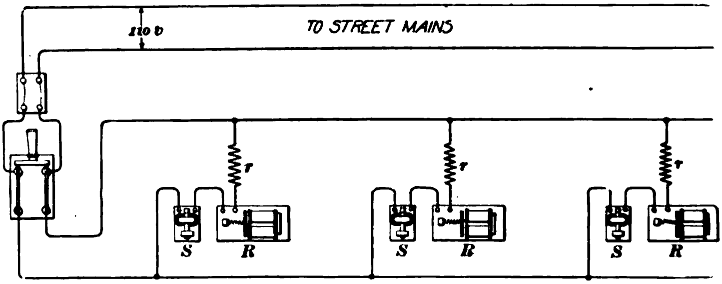


FIG. 43.

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

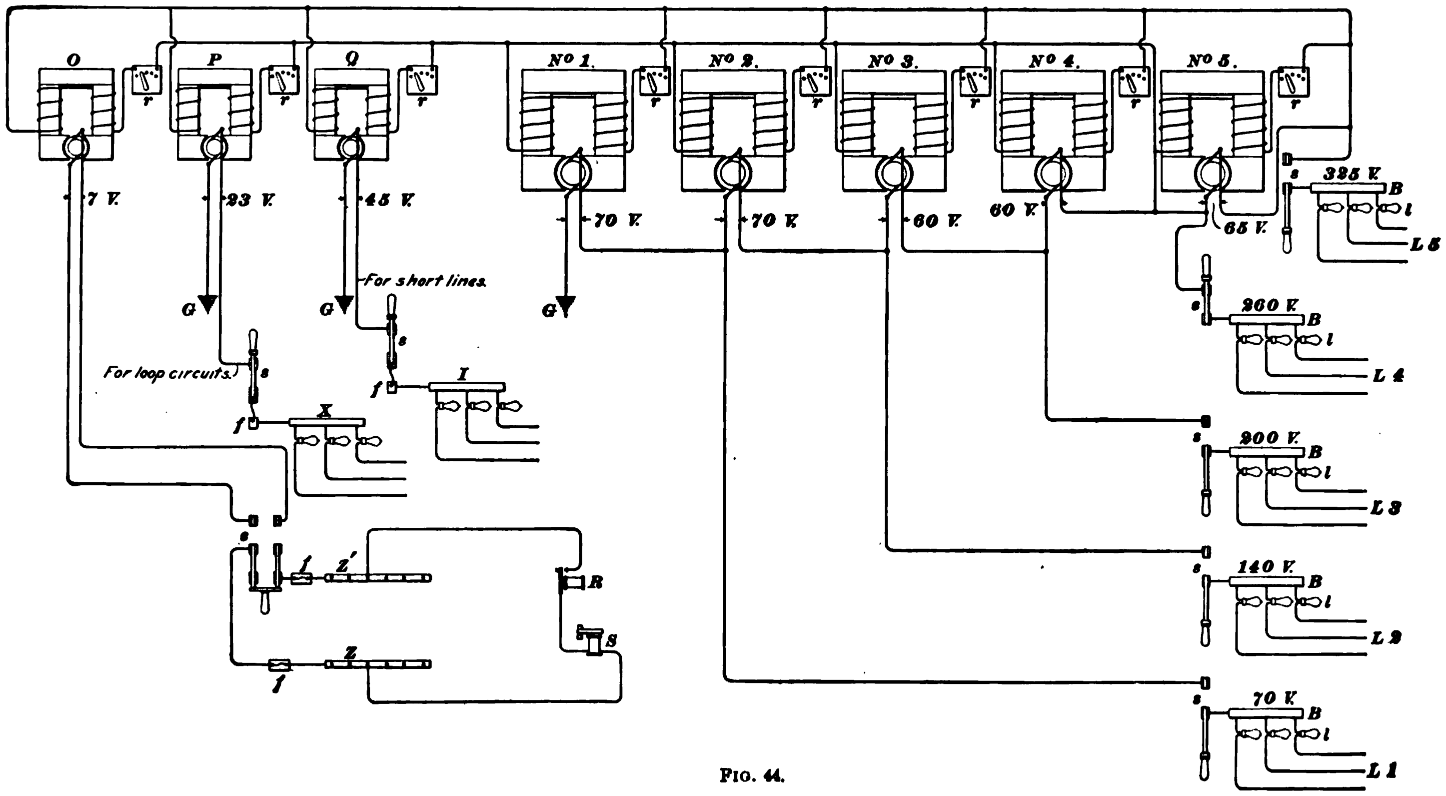

O
P
Q
No 1.
No 2.
No 3.
No 4.
No 5.
r
7 V.
23 V.
45 V.
70 V.
70 V.
60 V.
60 V.
65 V.
G
G
G
For short lines.
For loop circuits.
s
f
X
I
Z'
Z
R
S
325 V.
260 V.
200 V.
140 V.
70 V.
B
l
L 5
L 4
L 3
L 2
L 1

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 *L5* 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

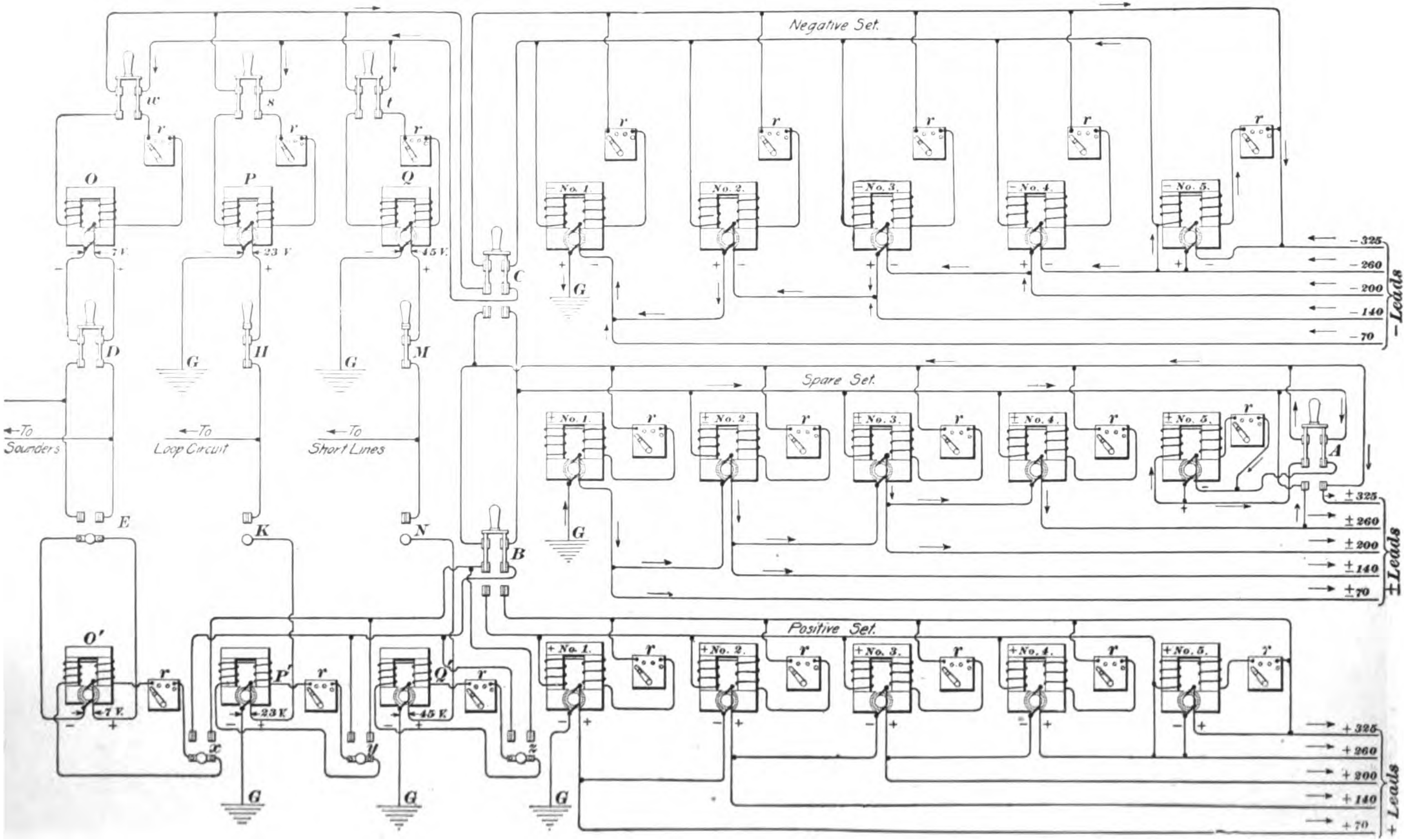

Negative Set.
Spare Set.
Positive Set.
No. 1.
No. 2.
No. 3.
No. 4.
No. 5.
r
O
P
Q
w
s
t
C
D
H
M
E
K
N
B
A
G
O′
P′
Q′
x
y
z
7 V.
23 V.
45 V.
To Sounders
To Loop Circuit
To Short Lines
−325
−260
−200
−140
−70
− Leads
±325
±260
±200
±140
±70
± Leads
+325
+260
+200
+140
+70
+ Leads

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 dynamos in the other set are cut off, thus avoiding even a momentary interruption of the current when changing over from dynamos in one set to those in the other set.

166. In Fig. 46 is shown an arrangement of knife-blade switches whereby the same thing may be accomplished for the main-line sets. That is, the whole spare set may be

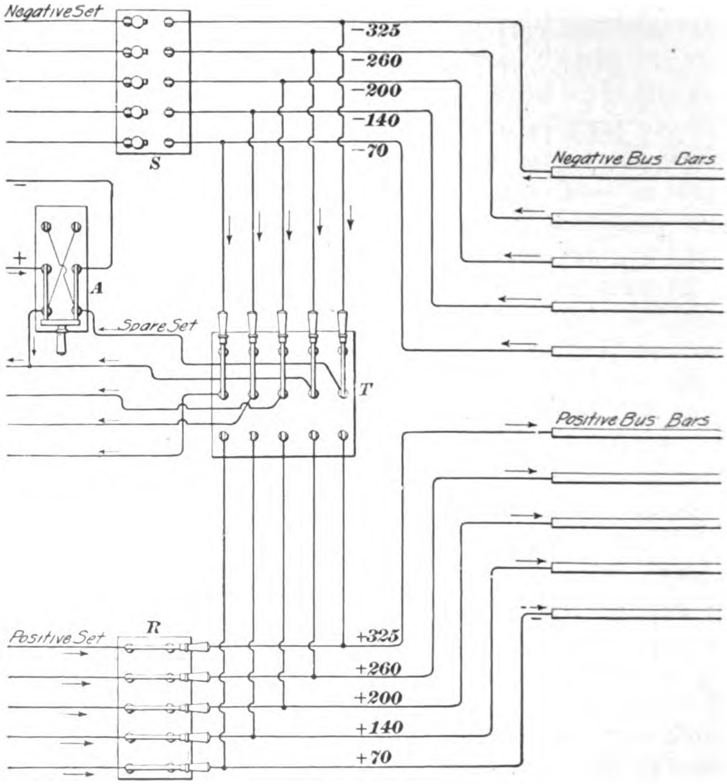


FIG. 46.

thrown in before the regular positive or negative set, which the spare set is to replace, is cut out, thus avoiding even a momentary interruption in the current supplied to the main-line circuits. *R* and *S* are rows of single-throw knife switches and *T* is a row of double-throw knife switches. When both regular sets are in use and the spare set is not in use, all the *R* and *S* switches are closed and the *T* switches open on both sides. If the spare set is to replace the regular negative set, then the switch *A*, which is the same switch as *A* in Fig. 45, is closed on the lower side and the *T* switches are all closed on the upper side before the *S* switches are opened. Thus, before the *S* switches are opened, the spare and negative sets are in multiple with each other, and both sets help to supply negative currents to the lines. In any case, before closing the *T* switches the switch *A* must be closed on the proper side. The direction of the currents when the switch *A* is closed in the lower position is shown by the arrows in this figure; when the switch is closed in the upper position, the currents from the spare set will flow in the opposite direction.

167. Connection of Bus-Bars to Switchboard.—The manner of connecting the bus-bars and disks on the line switchboards is shown in Fig. 47. In this figure, which shows only a portion of a main-line switchboard, it will be seen that each disk in the first or top horizontal row is connected through a lamp *l* to the 200-volt bus-bar, each disk in the second and third rows through a lamp to the 140-volt bus-bar, and each disk in the fourth row through a lamp to the 70-volt bus-bar. Since many more wires are worked on the second potential (140 volts) than on either the first or third, the second has two rows of disks assigned to it, one row being sufficient for each of the other two potentials. Should any circuit containing one of the lamps and a dynamo become short-circuited, the lamp will glow, thus serving the valuable purpose of a visible signal to attract the attention of the chief operator to the fact that the disk or strap on the main-line switchboard directly below it is grounded.

In such a large office only dynamos of the same polarity are connected to any one switchboard. The dynamos of opposite polarity are connected to other boards. The two higher potentials, that is, the 260- and 325-volt bus-bars, 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

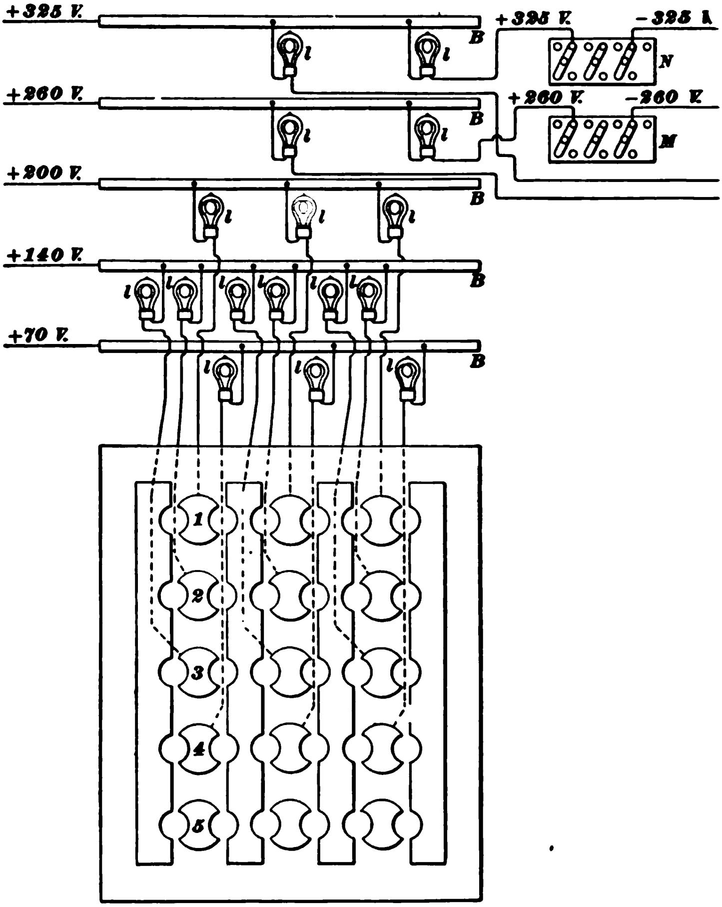


FIG. 47.

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 to 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.

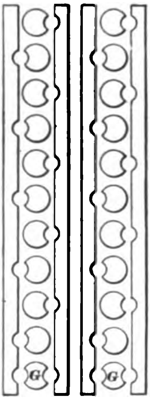


FIG. 48.

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 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.

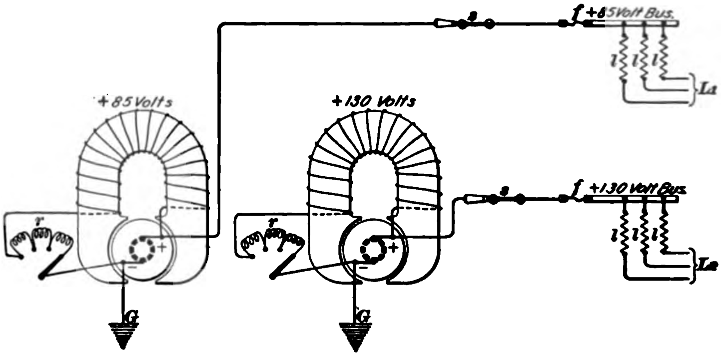


FIG. 49.

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

$$s = \frac{C \times R}{1.9}. \qquad (13.)$$

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

$$W = \frac{C\,T}{4.5} \text{ pounds.} \qquad (14.)$$

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 ⅓ 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 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.

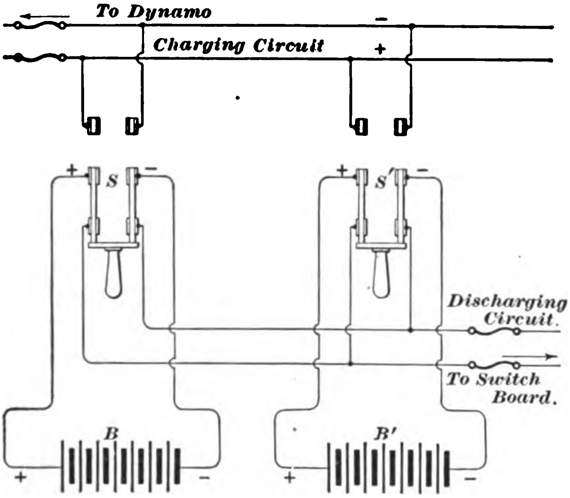


FIG. 50.

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 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.

FIG. 51.

186. Another method of determining the direction of the flow of current is by the use of a pocket compass held 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

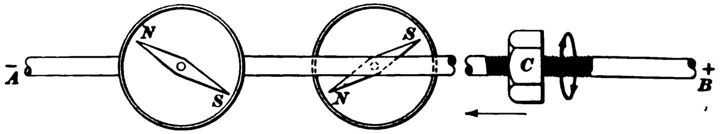


FIG. 52.

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

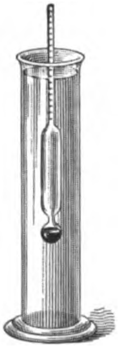


FIG. 53.

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 more of the lamps. This form of rheostat is very convenient, for it enables the amount of current to be gauged with considerable accuracy.

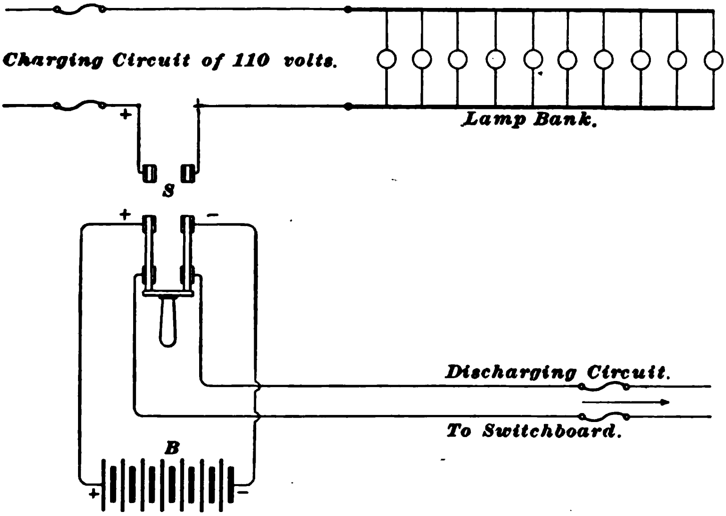


FIG. 54.

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 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*.

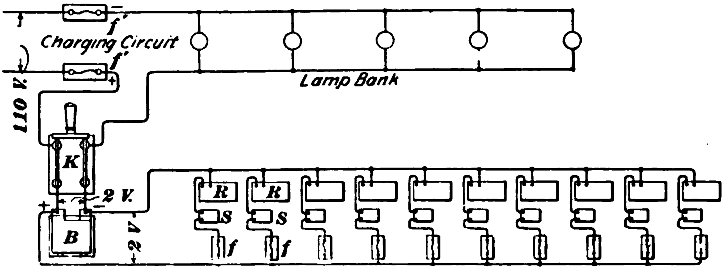


FIG. 55.

In the arrangement shown, there are ten 4-ohm sounders, requiring a maximum current of $10 \times .25 = 2.5$ amperes. A cell whose maximum safe discharge rate is $2\frac{1}{2}$ 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. PR are polarized relays, and PC 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 PC 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 $\frac{1}{4}$ 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

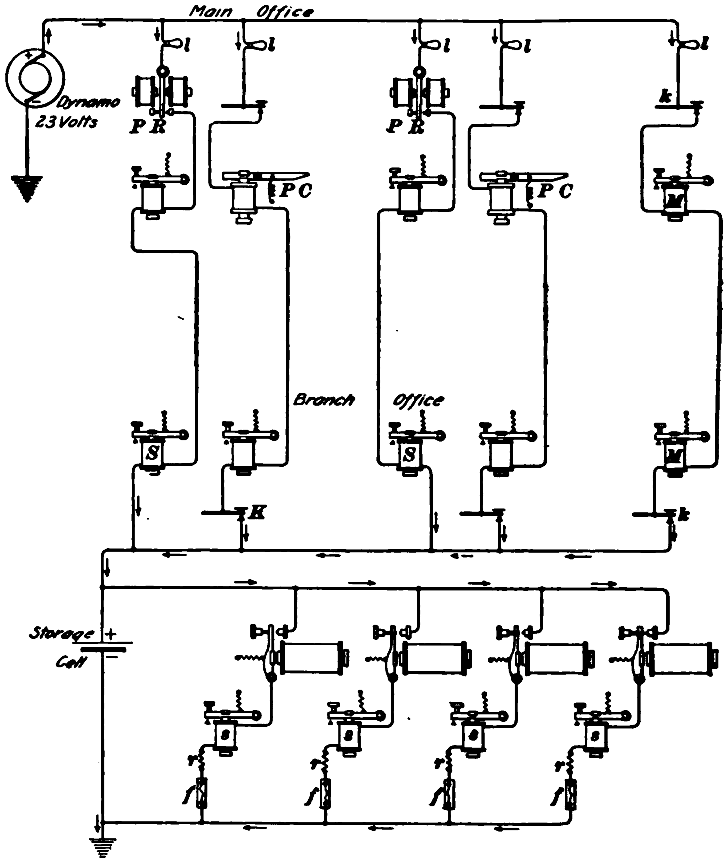


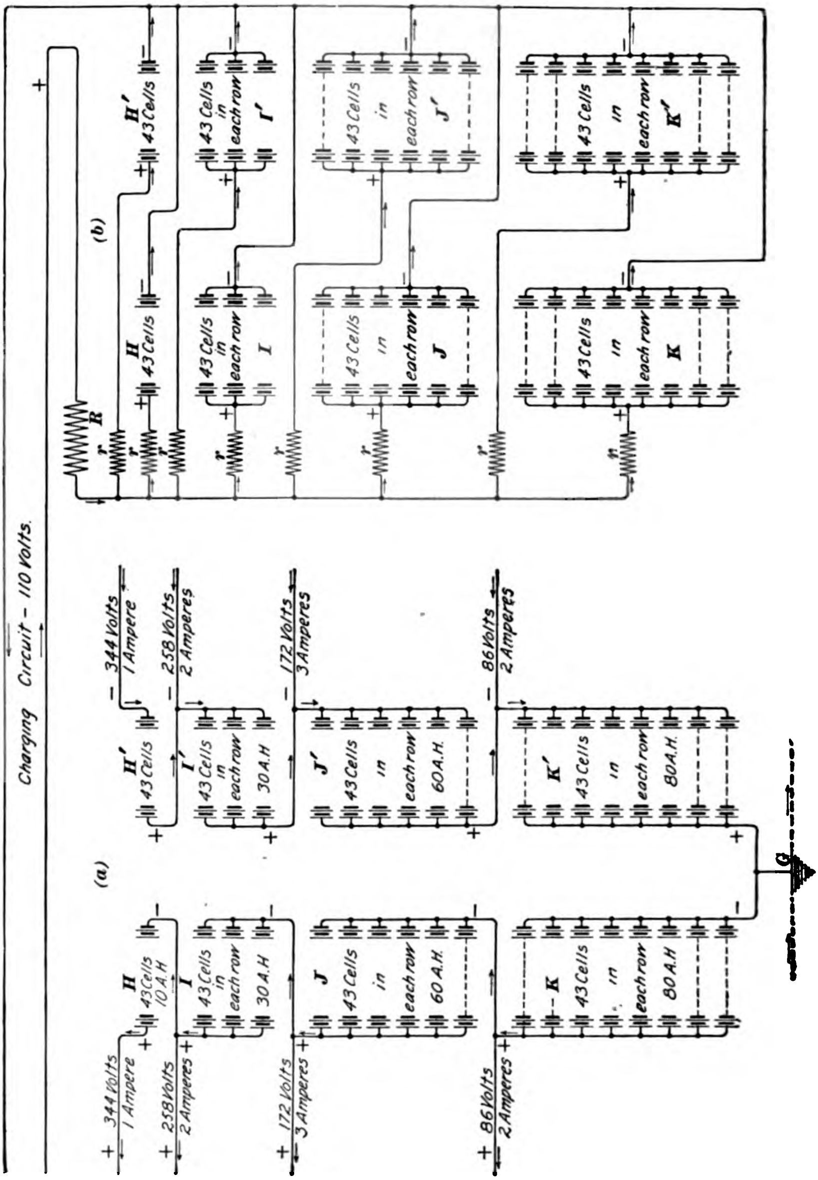
FIG. 56.

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 43 Cells 10 A.H
I 43 Cells in each row 30 A.H
J 43 Cells in each row 60 A.H.
K 43 Cells in each row 80 A.H
H′ 43 Cells
I′ 43 Cells in each row 30 A.H
J′ 43 Cells in each row 60 A.H.
K′ 43 Cells in each row 80 A.H.
− 344 Volts 1 Ampere
− 258 Volts 2 Amperes
− 172 Volts 3 Amperes
− 86 Volts 2 Amperes
G
R
r
H 43 Cells
H′ 43 Cells
43 Cells in each row I
43 Cells in each row I′
43 Cells in each row J
43 Cells in each row J′
43 Cells in each row K
43 Cells in each row K′

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

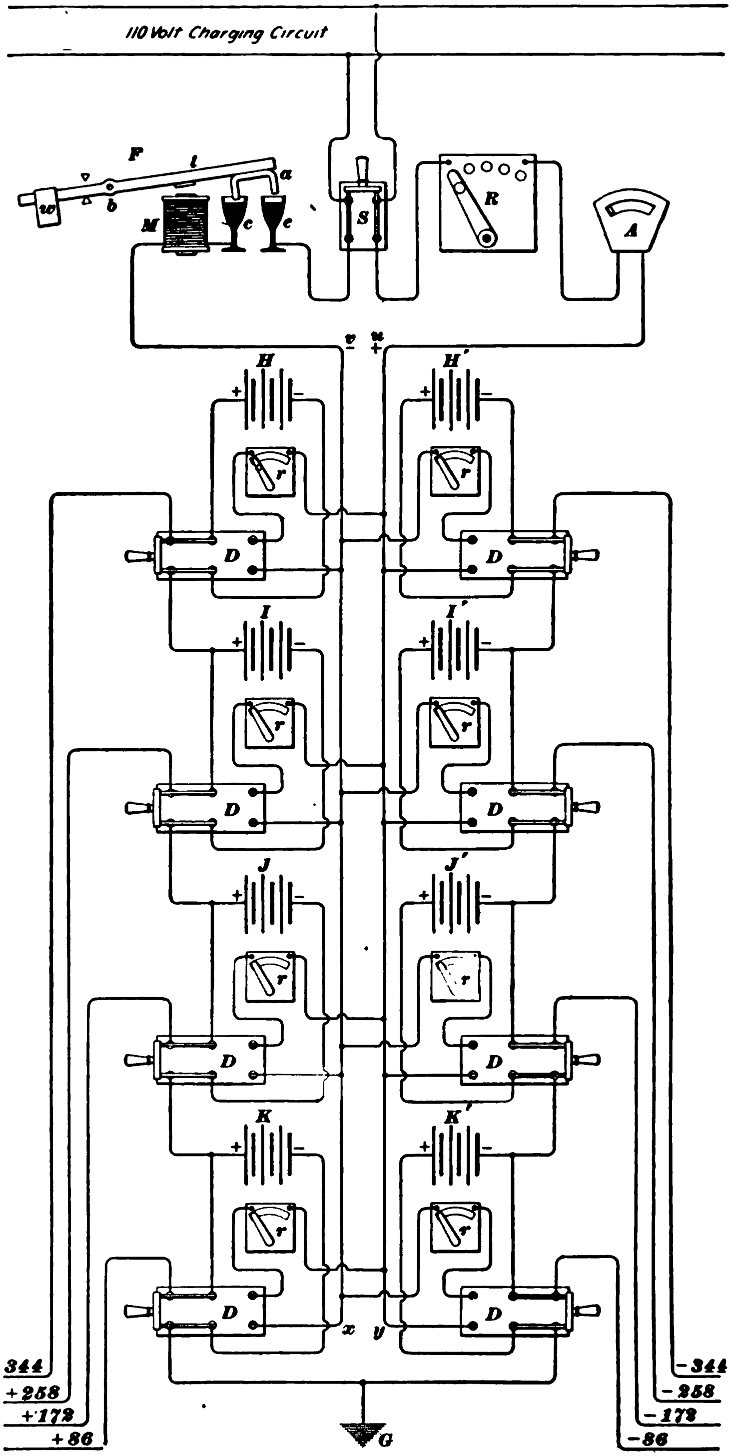

110 Volt Charging Circuit
F
l
a
w
b
M
c
c
S
R
A
v
u
−
+
H
H′
I
I′
J
J′
K
K′
+
−
r
D
x
y
344
+258
+172
+86
G
−344
−258
−172
−86

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 sufficient, for the diameter at the butt will then be approximately correct, no matter what the length of the pole may

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

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
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, ¼ 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.

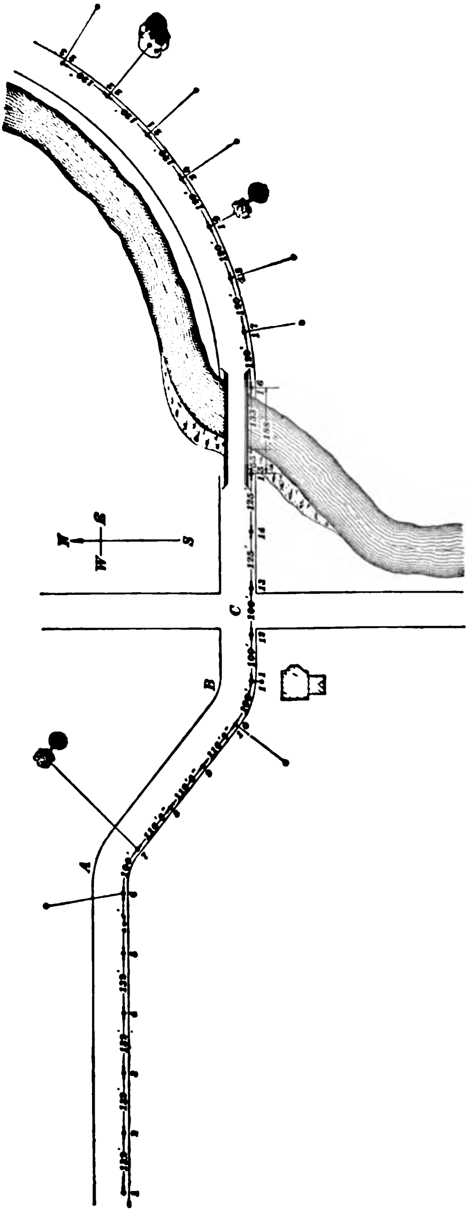


Fig. 1.

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 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

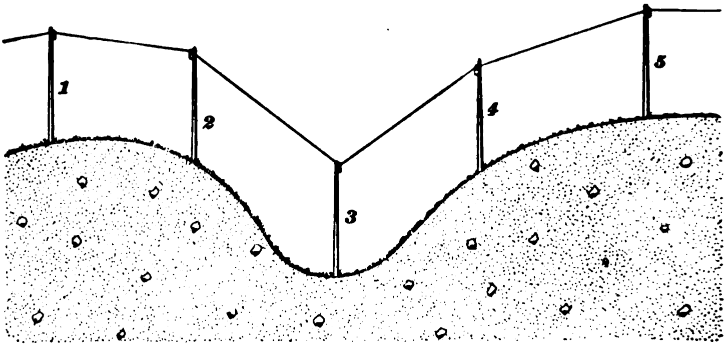


FIG. 2.

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 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.

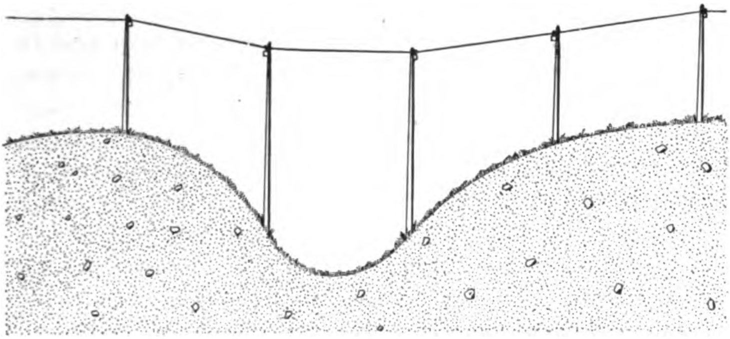


FIG. 3.

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.

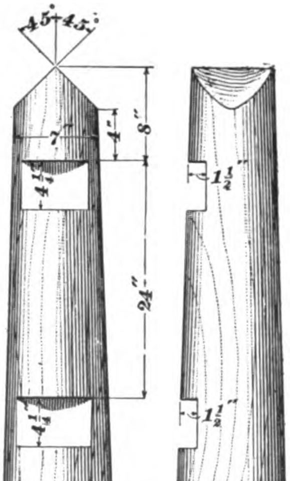


FIG. 4.

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 3¼ × 4¼ inches and vary in length from 3 to 10 feet. They are usually bored for 1½-inch wood pins or for ½-inch steel pins and provided with holes for two ½-inch bolts, as shown in Fig. 5. The number of pins and the distance between them for the various lengths of standard cross-arms are given in Table 5.

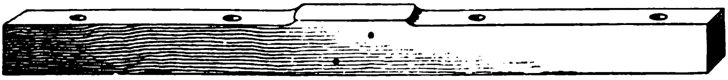


FIG. 5.

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	17½
8	8	4	16	12½
10	8	4	17½	15¾
10	10	4	16½	12¾

The best sizes to use are as follows:

For two wires, 3¼" × 4¼" × 3 feet.
For four wires, 3¼" × 4¼" × 6 feet.
For six wires, 3¼" × 4¼" × 8 feet.
For eight wires, 3¼" × 4½" × 10 feet.

22. The so-called telephone cross-arms are lighter, being made from 2¾″ × 3¾″ stuff, sometimes 3″ × 4¼″, and bored for 1¼-inch pins, and provided with two ½-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 ½-inch lagscrews, such as shown in 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 ⅝ 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 ⅛ inch smaller than the lagscrew, which should always be screwed up for the last 2 inches with a wrench.

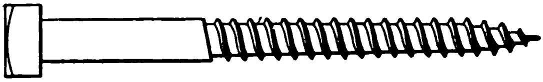


FIG. 6.

24. Carriage Bolts for Fastening Cross-Arms.—It has been found that the entrance of a lagscrew destroys 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 ⅝ inch in diameter and long

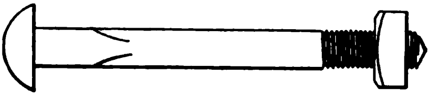


FIG. 7.

enough to extend entirely through the pole and cross-arm. A washer not less than 2¼ 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 1¼ inches wide by ¼ inch 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" × ⅝" lagscrew

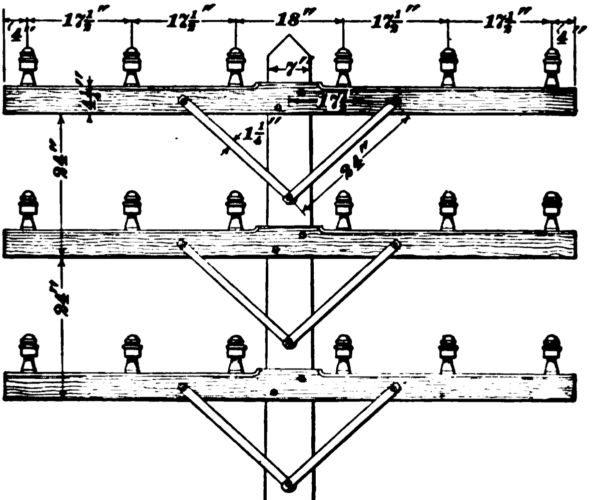


FIG. 9.

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.

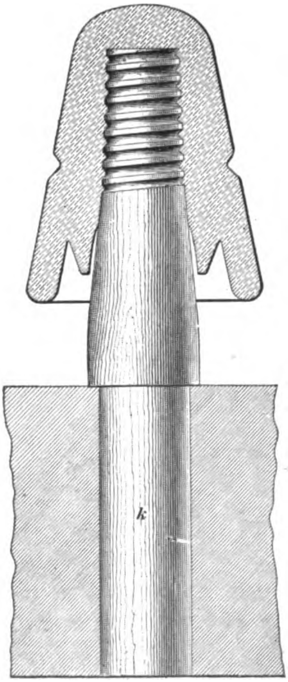


FIG. 10.

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.

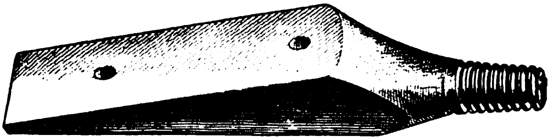


FIG. 11.

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 1⅛-inch 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

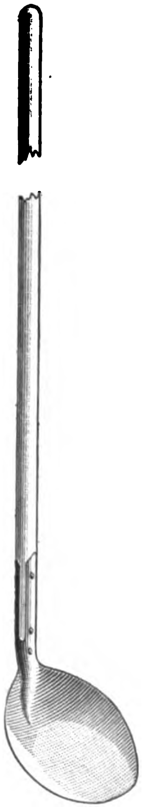


FIG. 12.

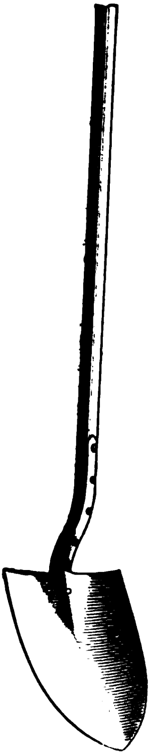


FIG. 13.


FIG. 14.

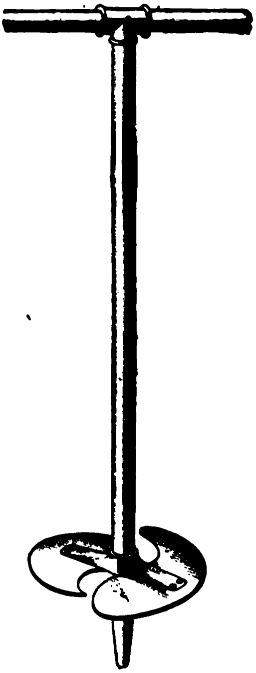


FIG. 15.

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.

FIG. 16.

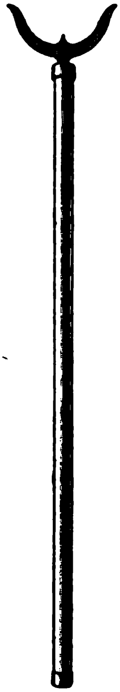


FIG. 17.

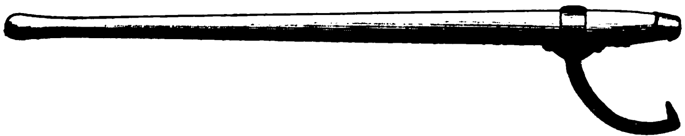


FIG. 18.

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 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 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.

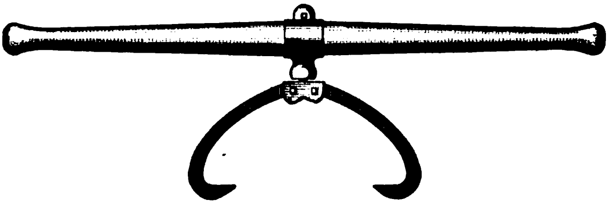


FIG. 19.

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 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.

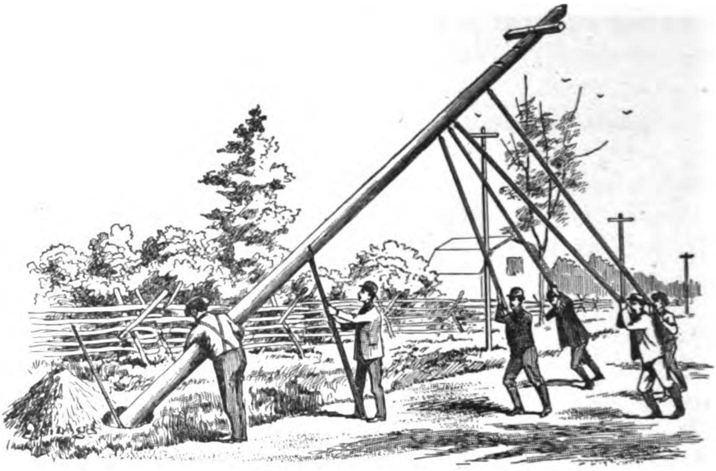


FIG. 20.

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

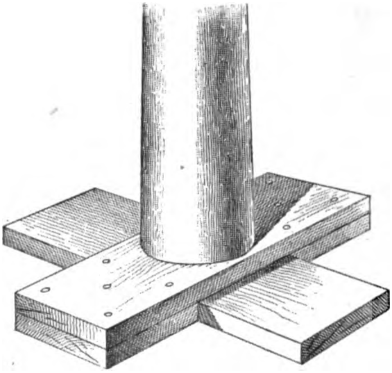


FIG. 21.

after the pole is raised, and it is securely fastened to the pole by long spikes, and braced according to any available method.

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.

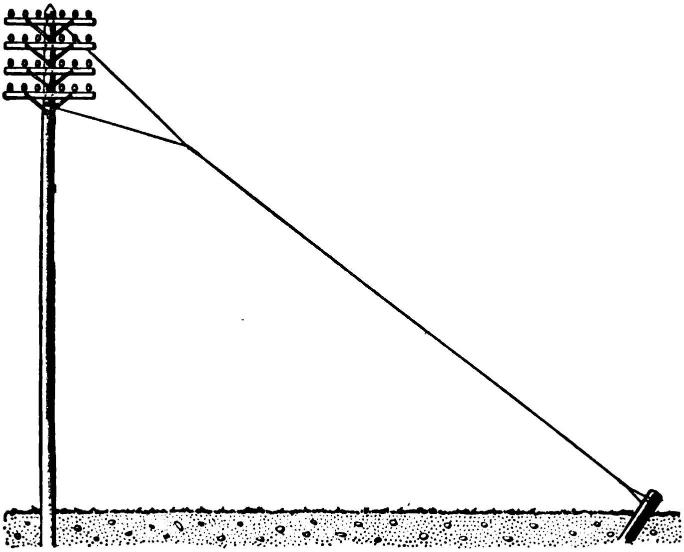


FIG. 22.

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.

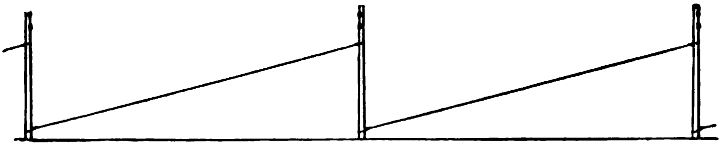


FIG. 23.

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 guying to resist longitudinal strains in either direction is shown in Fig. 24, and is known as **double head guying.**

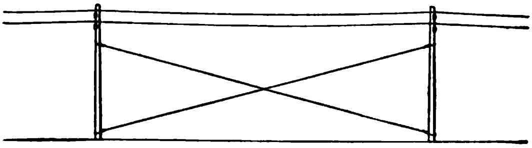


FIG. 24.

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

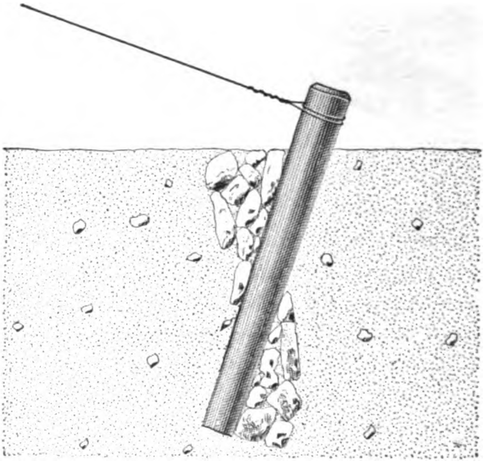


FIG. 25.

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

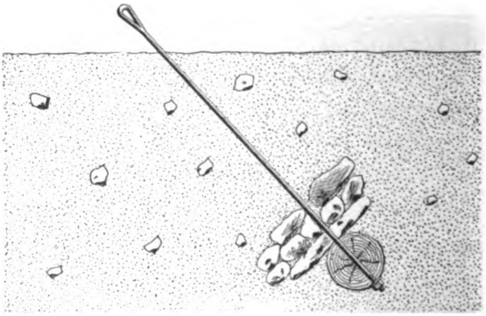


FIG. 26.

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 ⅝ 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 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.

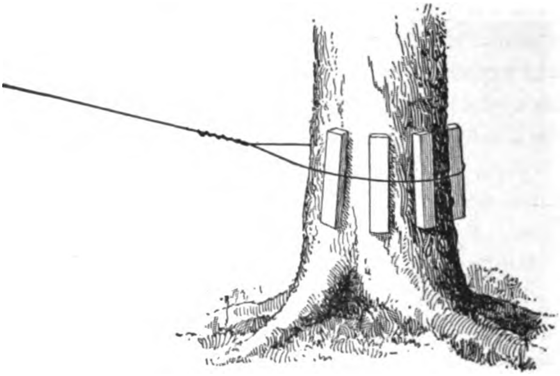


FIG. 27.

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 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.

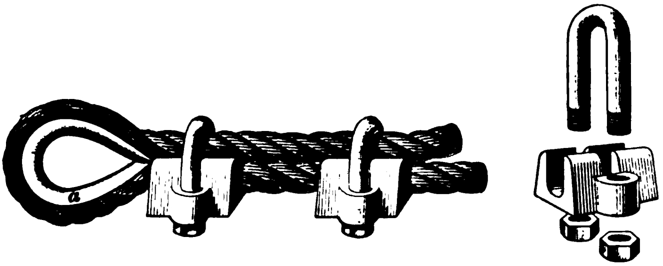


FIG. 28.

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

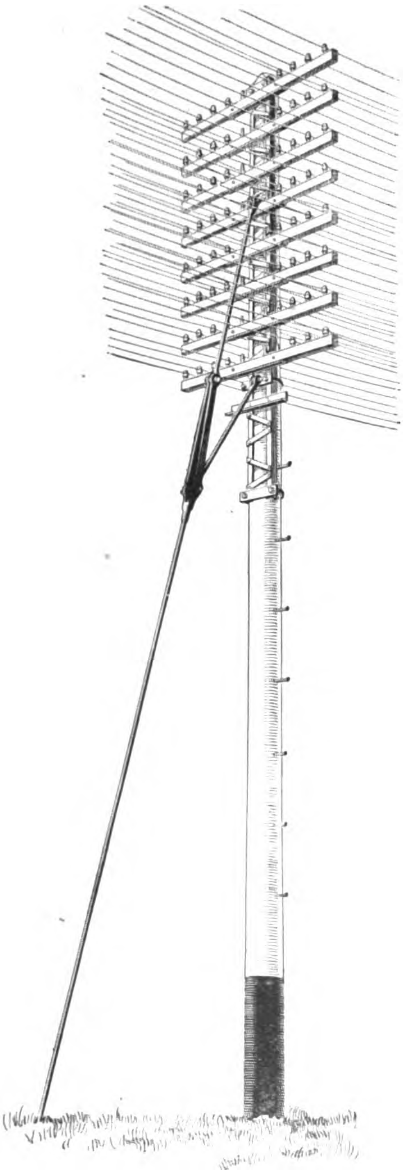


FIG. 30

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

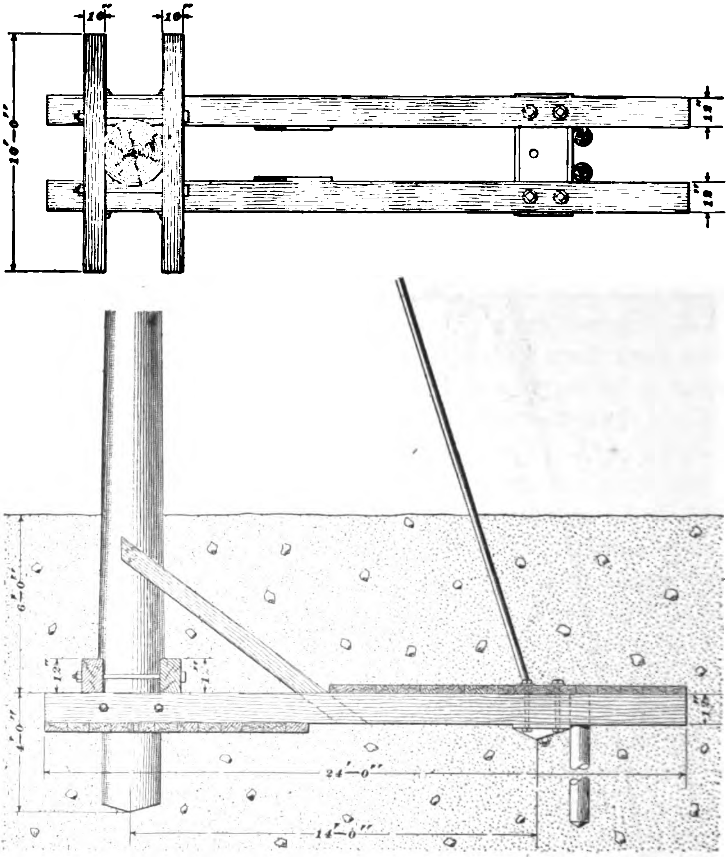


FIG. 31.

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 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.

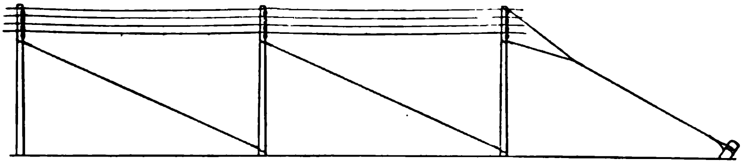


FIG. 32.

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 $\frac{1}{2}$ inch in diameter, with the nut on the end screwed up tight. The cross-arms should be fastened to both poles with $\frac{1}{2}$-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 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

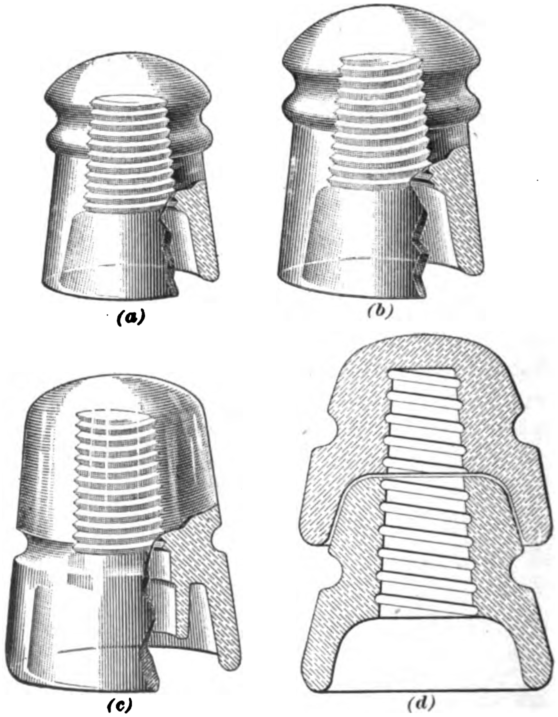

(*a*) (*b*)
(*c*) (*d*)

FIG. 33.

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

$$A \text{ (in C. M.)} = d^2. \qquad \textbf{(1.)}$$

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

$460 \times 460 = 211{,}600$ 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.

$187.5 \times 187.5 = 35{,}156.25$ 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 $\frac{1}{2}$ 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	.0 0025	.012	.0140	.0140	.0156	.01375	.0124	30
31	.008928	.010	.0135	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0120	.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 × .411 = .822 ohm. The resistance of No. 3 is 1.26 times that of No. 2, or .822 × 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 $\text{Area} = \frac{d^2}{1{,}000{,}000} \times .7854$.	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:

$$R \text{ for E. B. B.} = \frac{338,000}{d^2}, \qquad \textbf{(4.)}$$

$$R \text{ for B. B.} = \frac{396,000}{d^2}, \qquad \textbf{(5.)}$$

in which d is the diameter of the wire in mils.

For the resistance of galvanized-steel wire, Roebling gives the following formula:

$$R = \frac{467,000}{d^2}, \qquad \textbf{(6.)}$$

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:

$$W \text{ for galvanized iron} = d^2 \times .0139, \qquad (7.)$$

$$W \text{ for galvanized steel} = d^2 \times .0140, \qquad (8.)$$

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 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

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

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
151 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	13.09000	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

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*Calculated on the basis of Dr. Matthiessen's standard, viz.: 1 mile of pure copper wire of $\frac{1}{16}$ 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 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

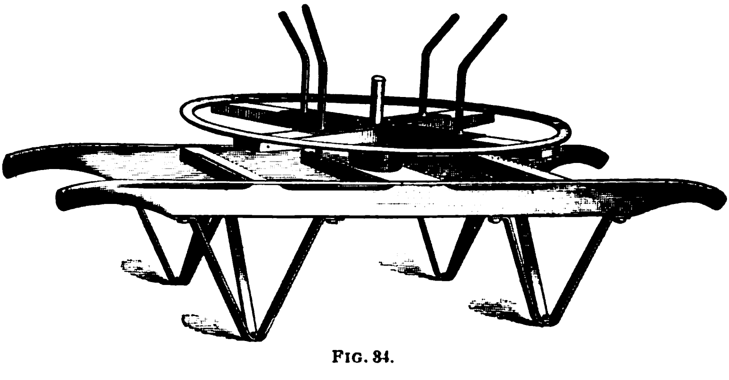


FIG. 34.

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 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.

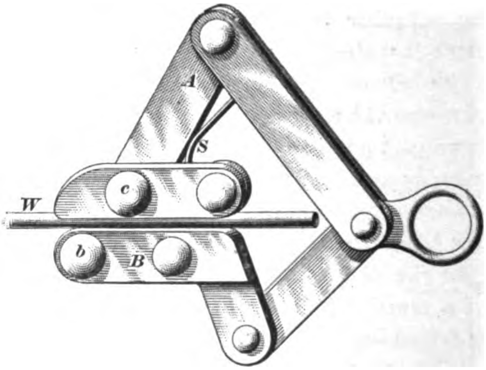


FIG. 85.

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	2½	3⅜	4½	8
– 10	1¼	2½	3	3¾	5	9
10	1½	2⅝	3½	4⅜	5¾	10¼
30	1¾	3	4	5⅛	6¾	12
60	2½	4¼	5½	7	9	15⅜
80	3⅛	5⅜	7	8⅝	11¼	18¾
100	4⅓	7	9	11	14	22¼

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.

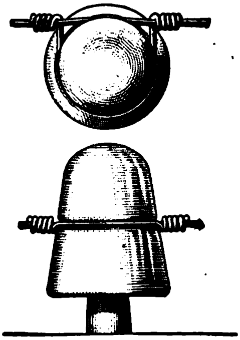


FIG. 36.

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.

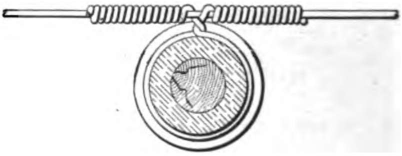
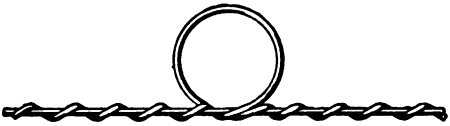


FIG. 37.

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.



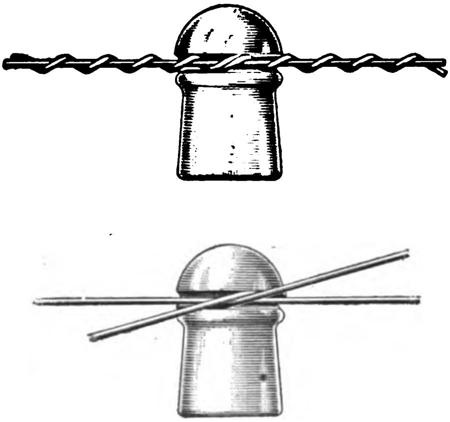


FIG. 38.

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.

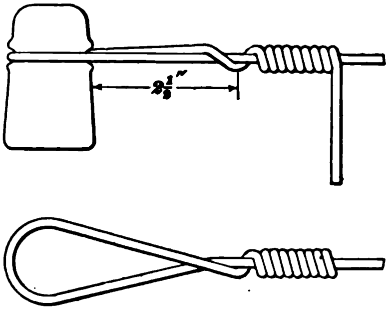


FIG. 39.

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 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.

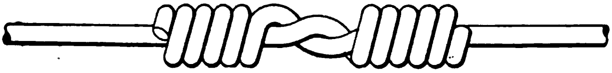


FIG. 40.

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 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 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.

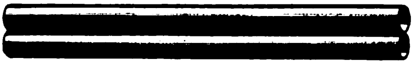


FIG 41.

FIG. 42.

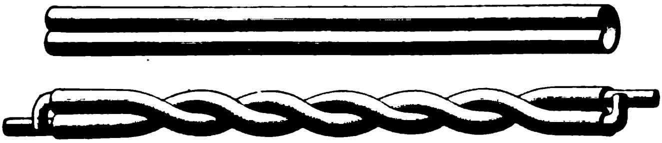


FIG. 43.

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 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;

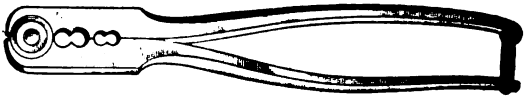


FIG. 44.

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.

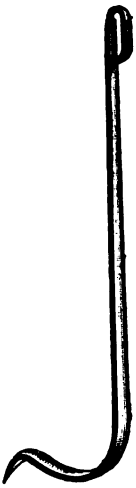


FIG. 45.

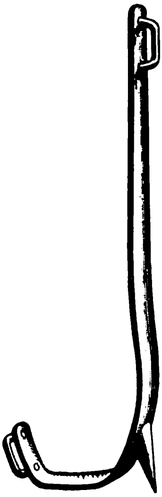


FIG. 46.

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 conductors are bunched, the cable is double-taped and covered with tarred jute, over which is placed a heavy braid of

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

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 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 $1\frac{15}{16}$ inches. Telegraph cables with this number of conductors are usually somewhat larger in diameter.

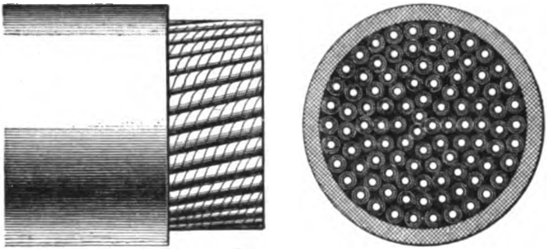


FIG. 47.

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 of 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

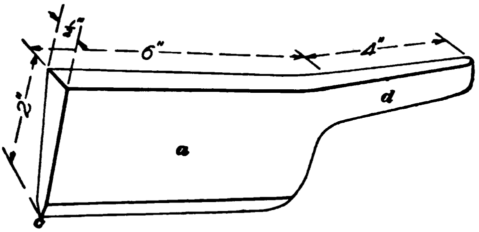


FIG. 48.

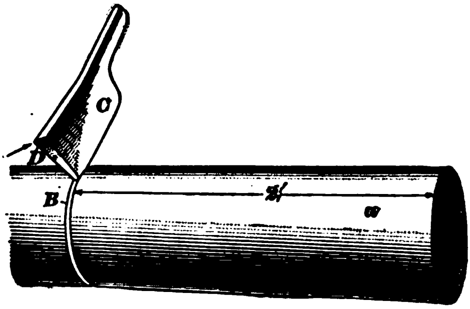


FIG. 49.

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.

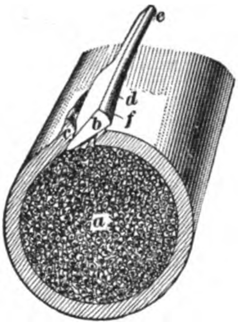


FIG. 50.

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 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

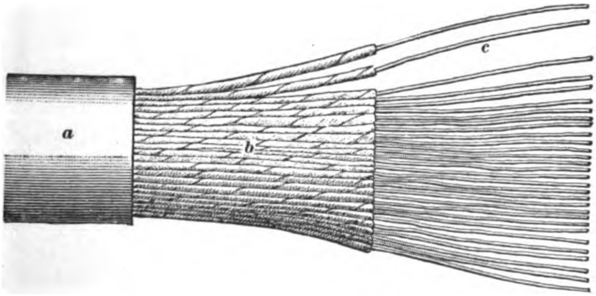
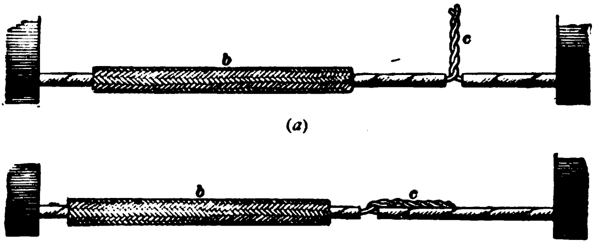


FIG. 51.

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 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



(*a*)

(*b*)

FIG. 52.

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 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.

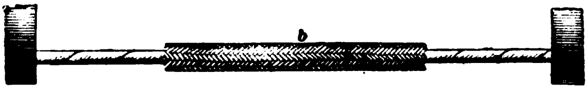


FIG. 53.

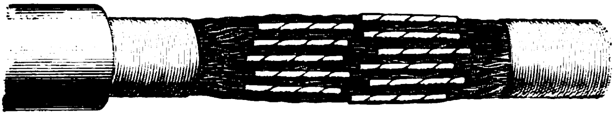


FIG. 54.

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 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.

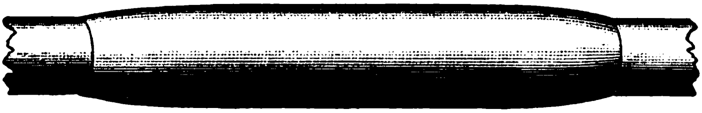


FIG. 55.

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.

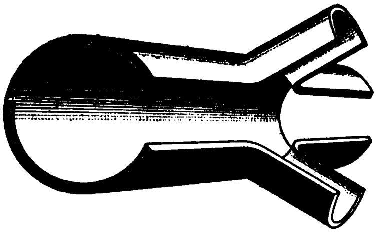


FIG. 56.

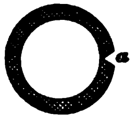


FIG. 57.

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 terminals located out of doors, is it necessary to provide means for excluding all moisture.

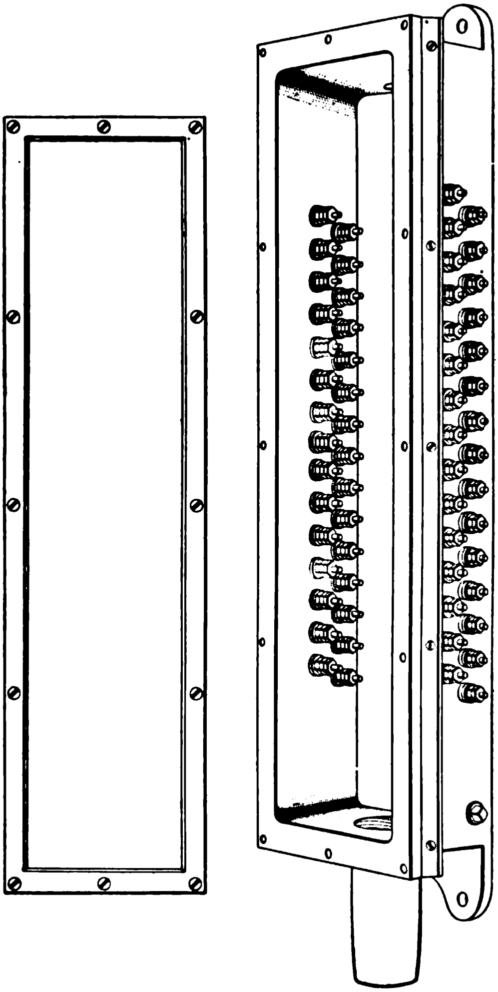


FIG. 58.

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.

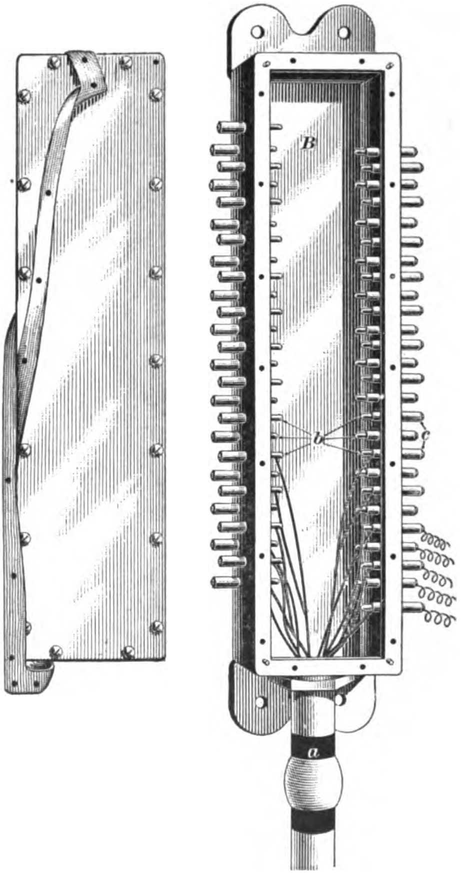


Fig. 59.

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.

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

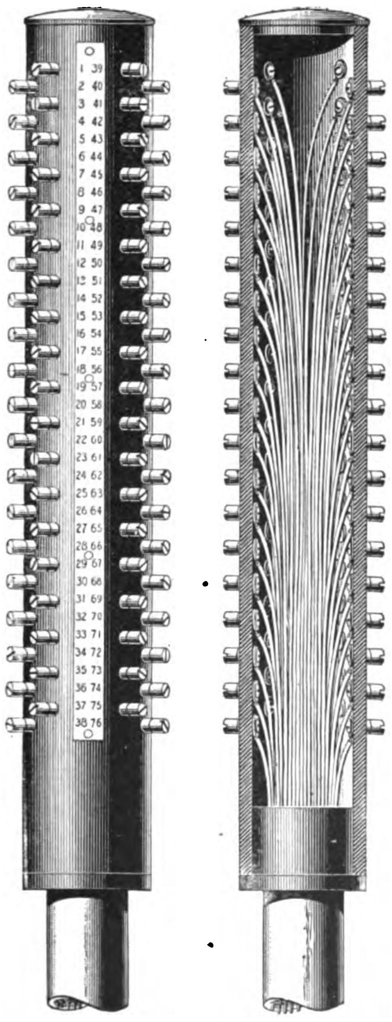


FIG. 60.

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 head, in order to prevent injuries to the cable from lightning or by the passage through it of heavy currents, such as might

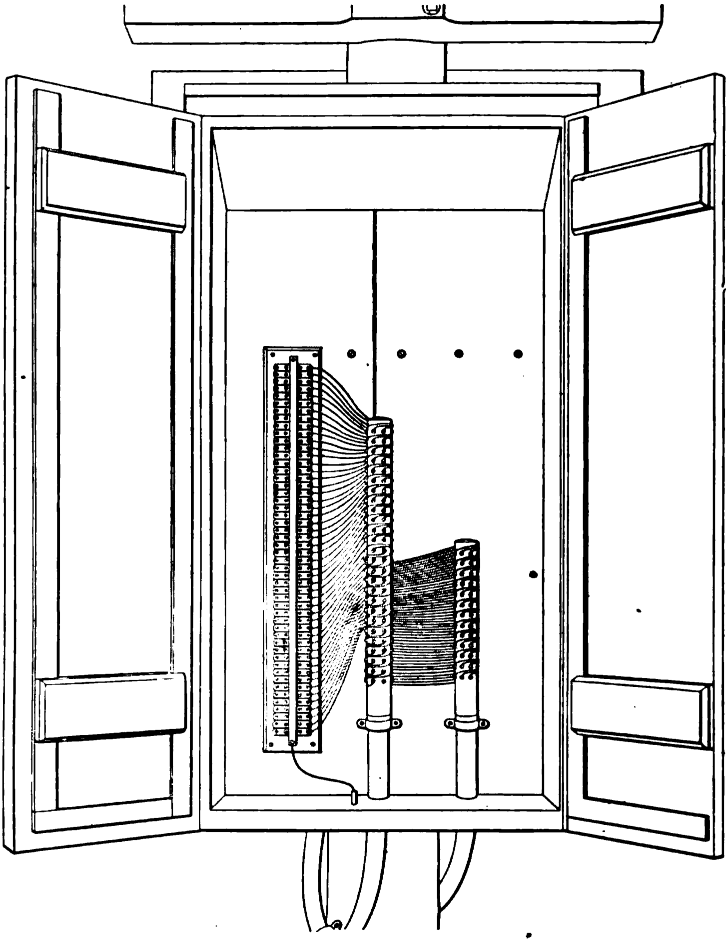


FIG. 61.

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, ⅛ 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 ⅛ 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.

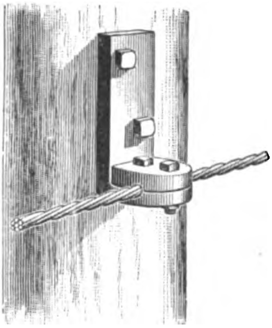


FIG. 62.

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.

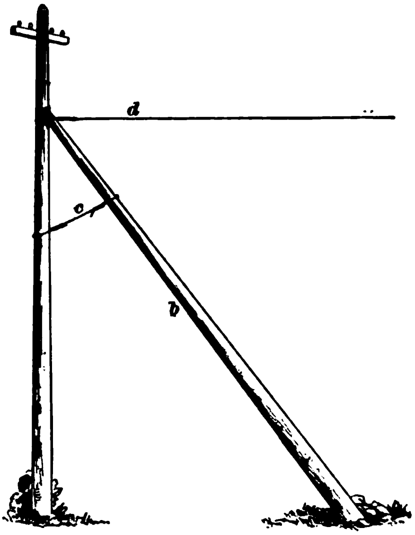


FIG. 63.

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.

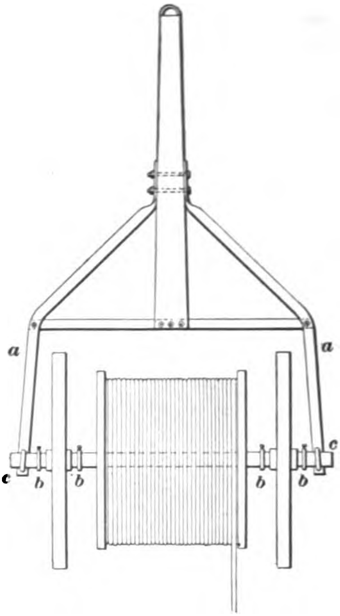


FIG. 64.

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 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.

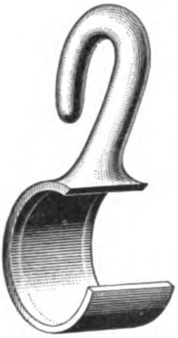


FIG. 65.

FIG. 66.

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.

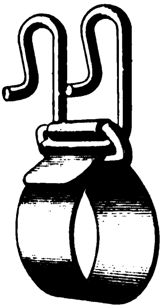


FIG. 67.

187. Cable Stringing.—When the messenger wire is in place and pulled up to the proper tension, a *leading-up*

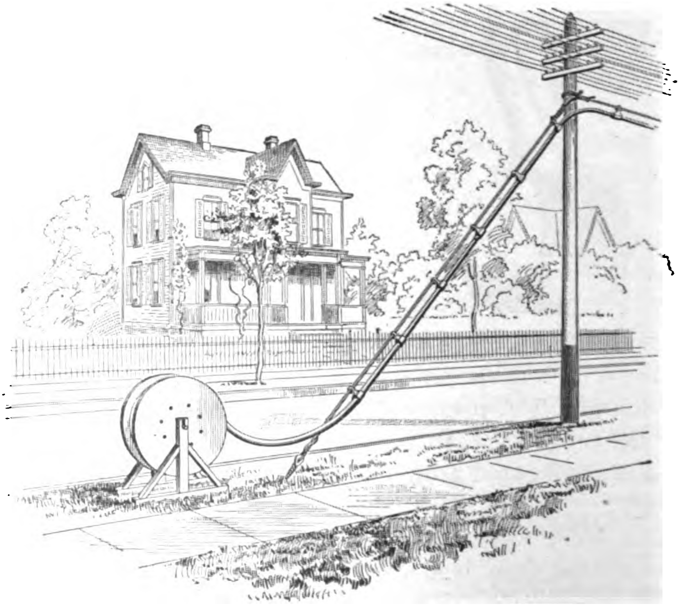


FIG. 68.

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

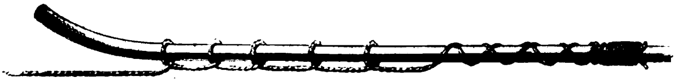


FIG. 69.

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 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.

FIG. 70.

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 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*.

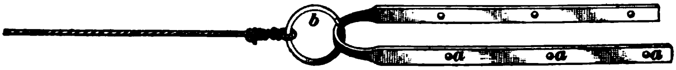


FIG. 71.

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.

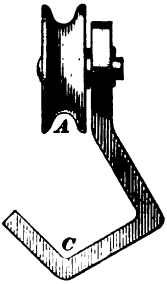


FIG. 72.

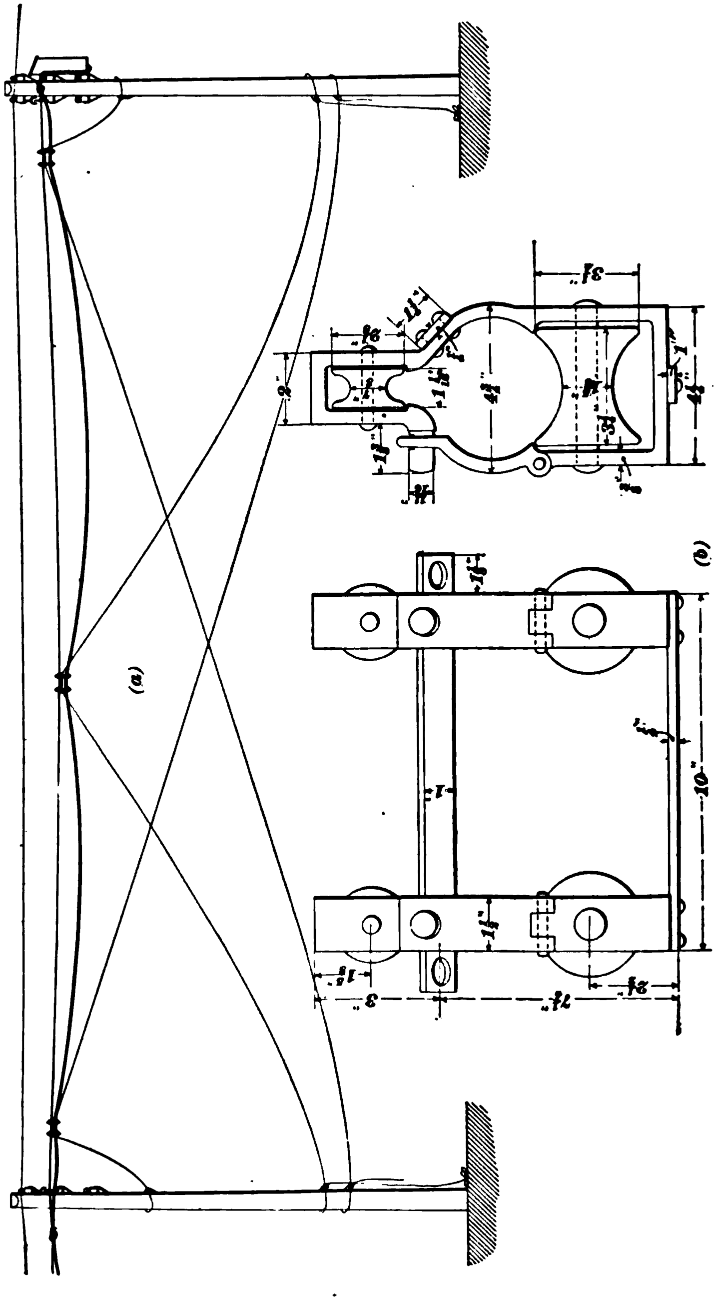


FIG. 73.

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.

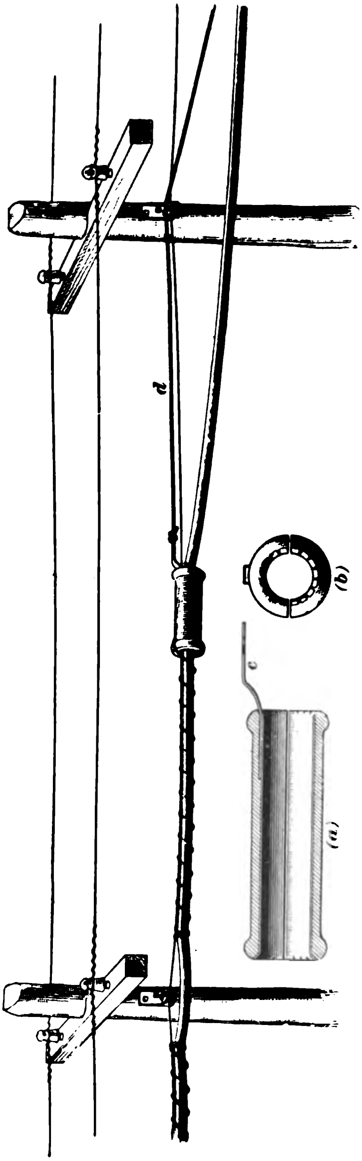


FIG. 74.

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.

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.

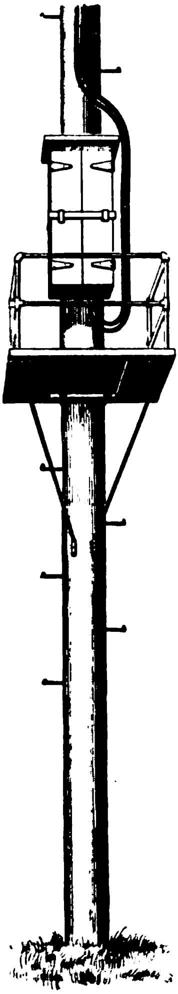


FIG. 75.

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,

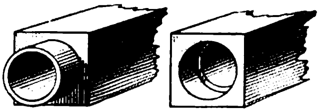


FIG. 76.

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

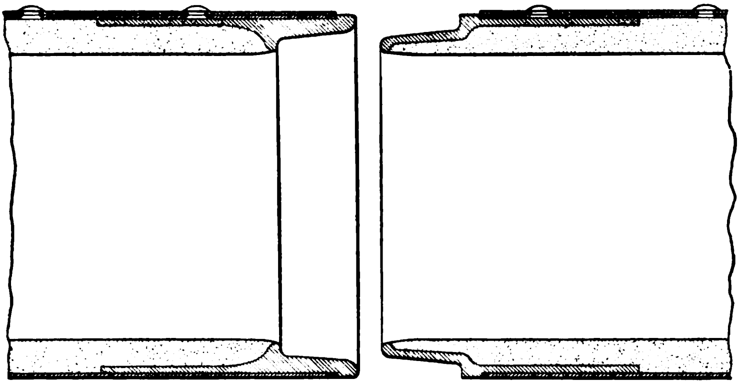


FIG. 77.

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 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.

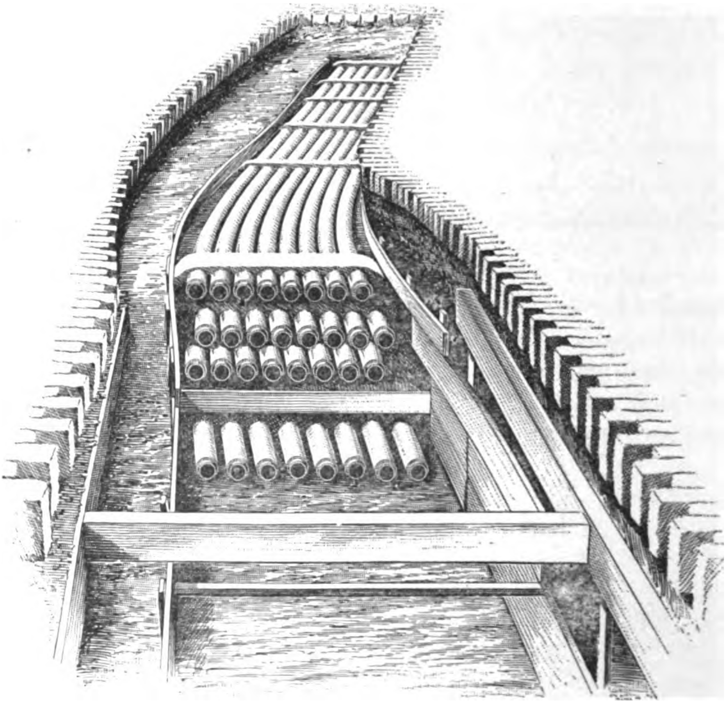


FIG. 78.

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.

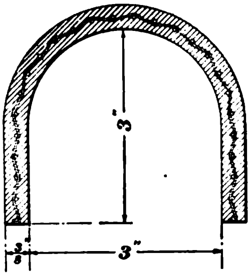


FIG. 79.

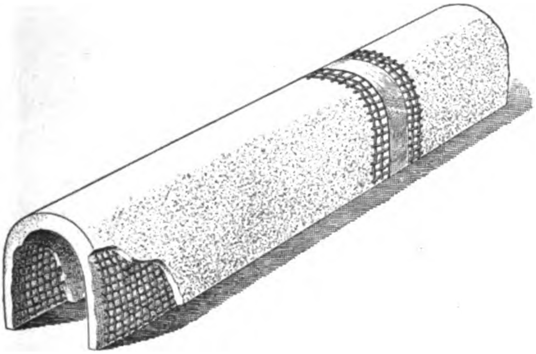


FIG. 80.

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 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.

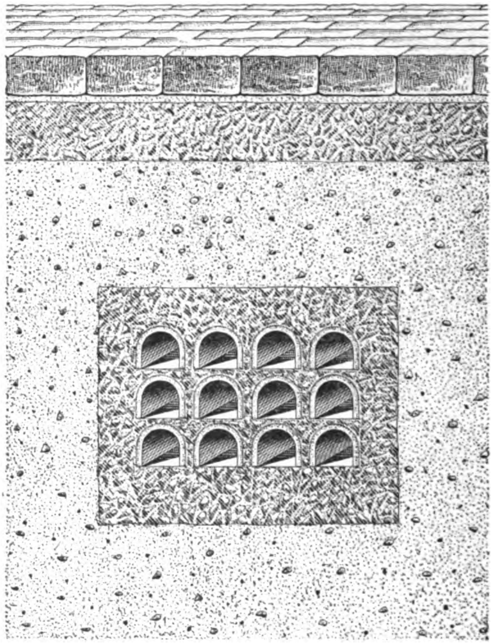


FIG. 81.

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.

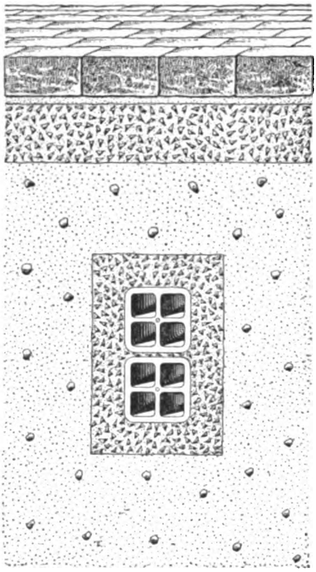


FIG. 82.

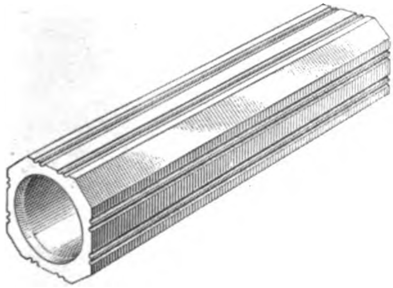


FIG. 83.

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 4⅝ 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 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 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

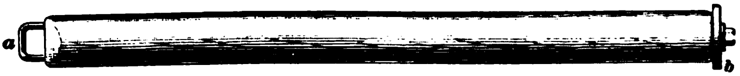


FIG. 84.

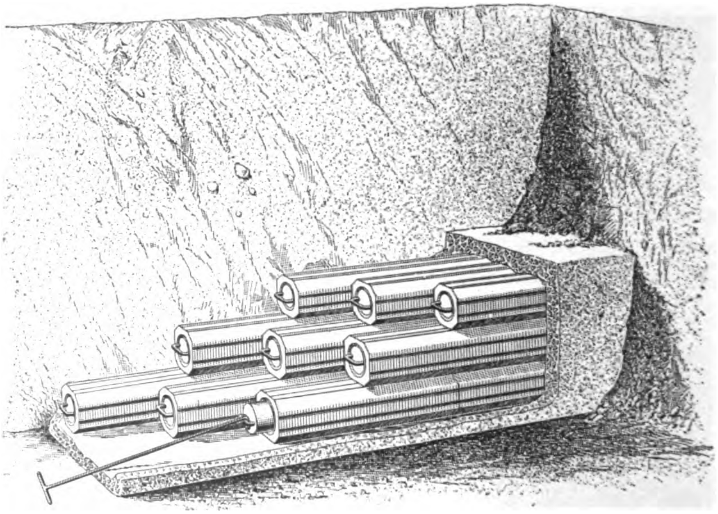


FIG. 85.

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 ¾ 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 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

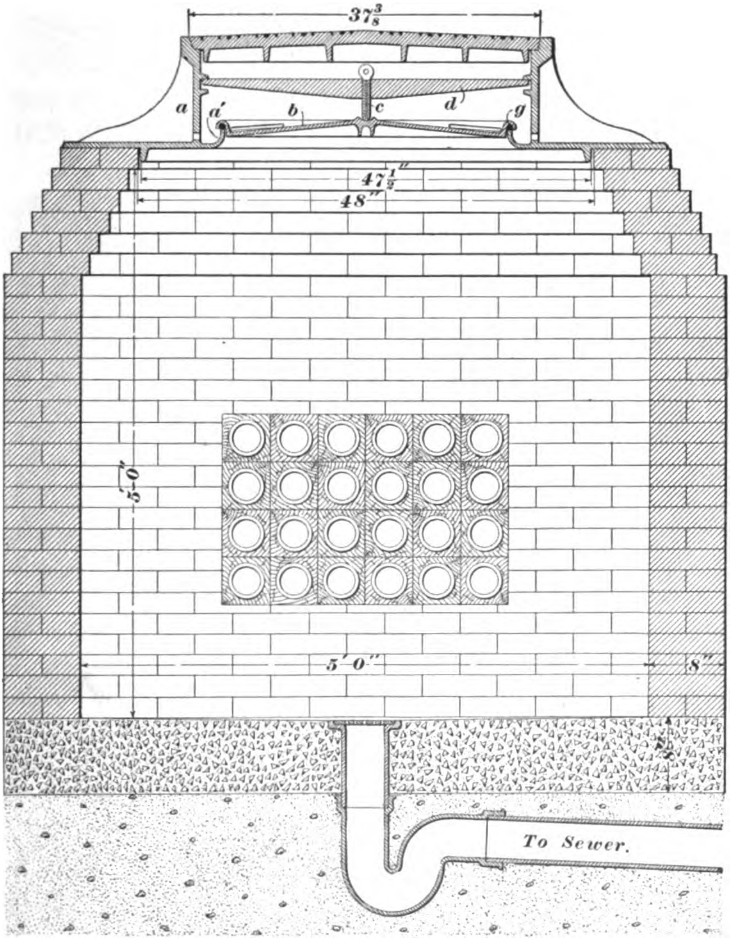


FIG. 86.

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.

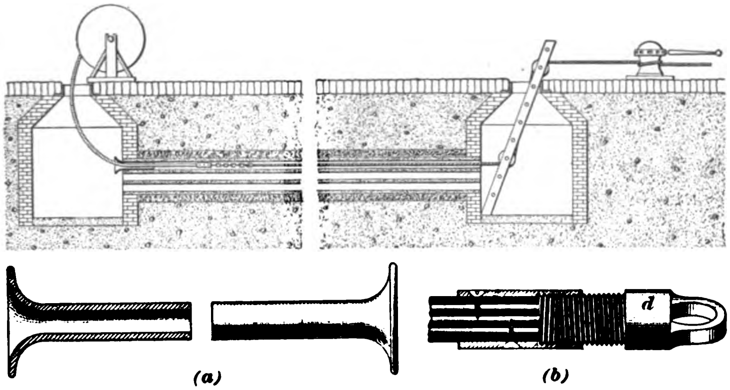
216. Rodding.—The process called **rodding** is used in order to introduce a wire or rope into the duct for the purpose of drawing in the cable. This process consists of pushing a number of jointed rods into a duct from one manhole until the first rod reaches the other manhole. The rods are joined together 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



(a) (b)

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 *handhole* 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 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

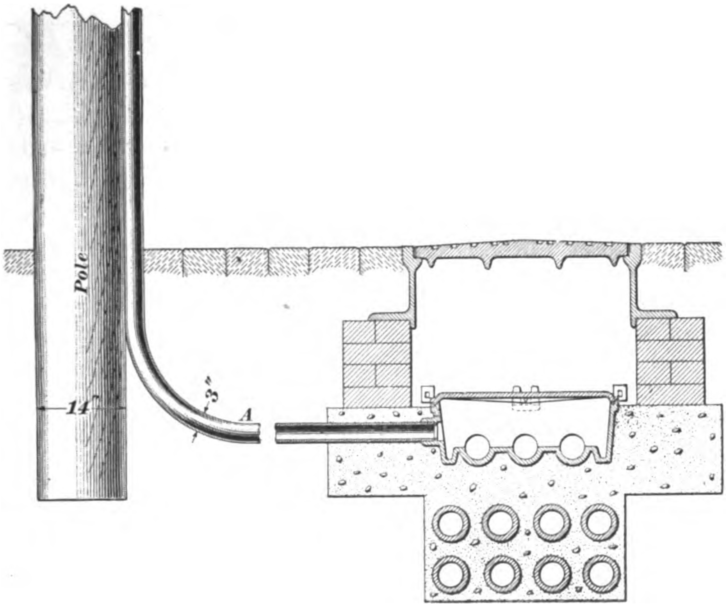


FIG. 88.

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.

ELECTROLYSIS.

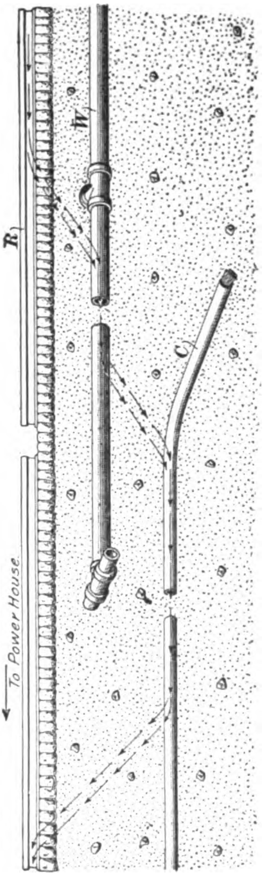


FIG. 89.

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.

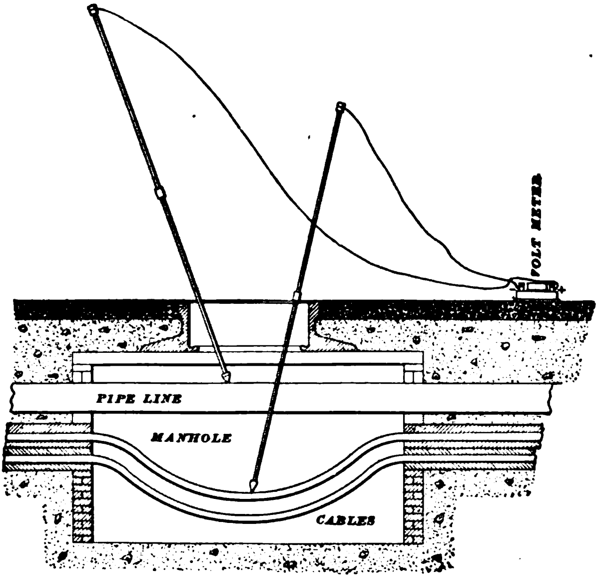


FIG. 90.

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.

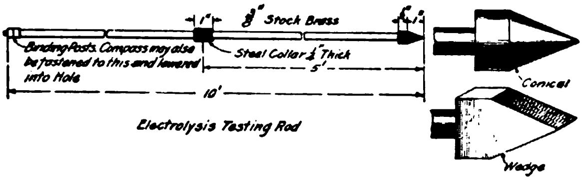


FIG. 91.

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.

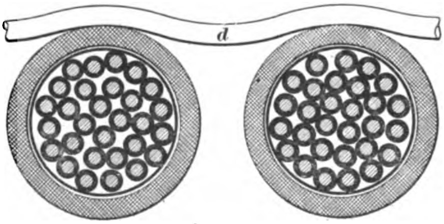


FIG. 92.

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.

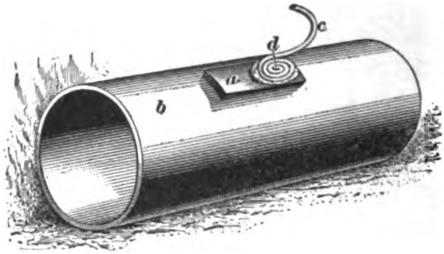


FIG. 93.

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 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

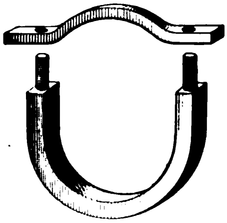


FIG. 94.

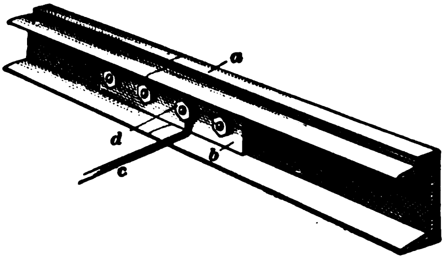


FIG. 95.

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 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.

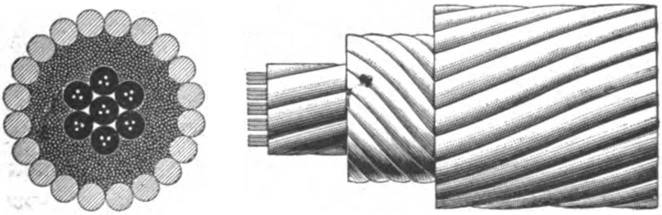


FIG. 96.

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.

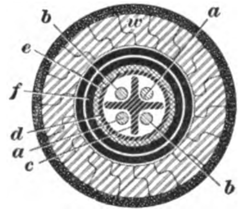


FIG. 97.

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.

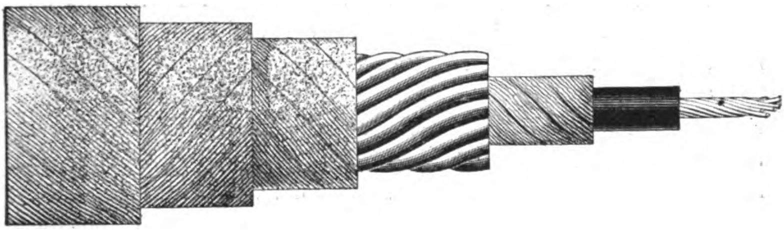


FIG. 98.

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.

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.

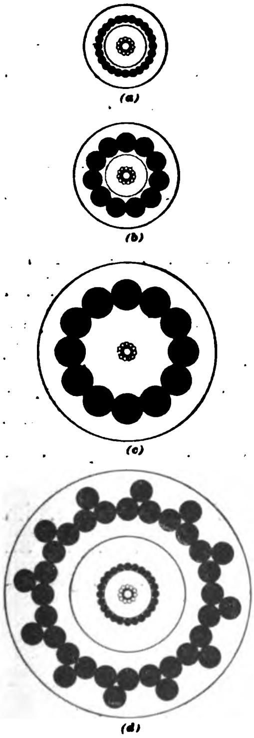


FIG. 99.

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* 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 KR 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 KR 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 KR 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.

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Note.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Amplitude 3- 8" means that amplitude will be found on page 8 of section 3.