Cyclopedia
of
Telephony and Telegraphy

A General Reference Work on

TELEPHONY, SUBSTATIONS, PARTY-LINE SYSTEMS, PROTECTION, MANUAL SWITCHBOARDS, AUTOMATIC SYSTEMS, POWER PLANTS, SPECIAL SERVICE FEATURES, CONSTRUCTION, ENGINEERING, OPERATION, MAINTENANCE, TELEGRAPHY, WIRELESS TELEGRAPHY AND TELEPHONY, ETC.

Prepared by a Corps of

TELEPHONE AND TELEGRAPH EXPERTS, AND ELECTRICAL ENGINEERS OF THE HIGHEST PROFESSIONAL STANDING

Illustrated with over Two Thousand Engravings

FOUR VOLUMES

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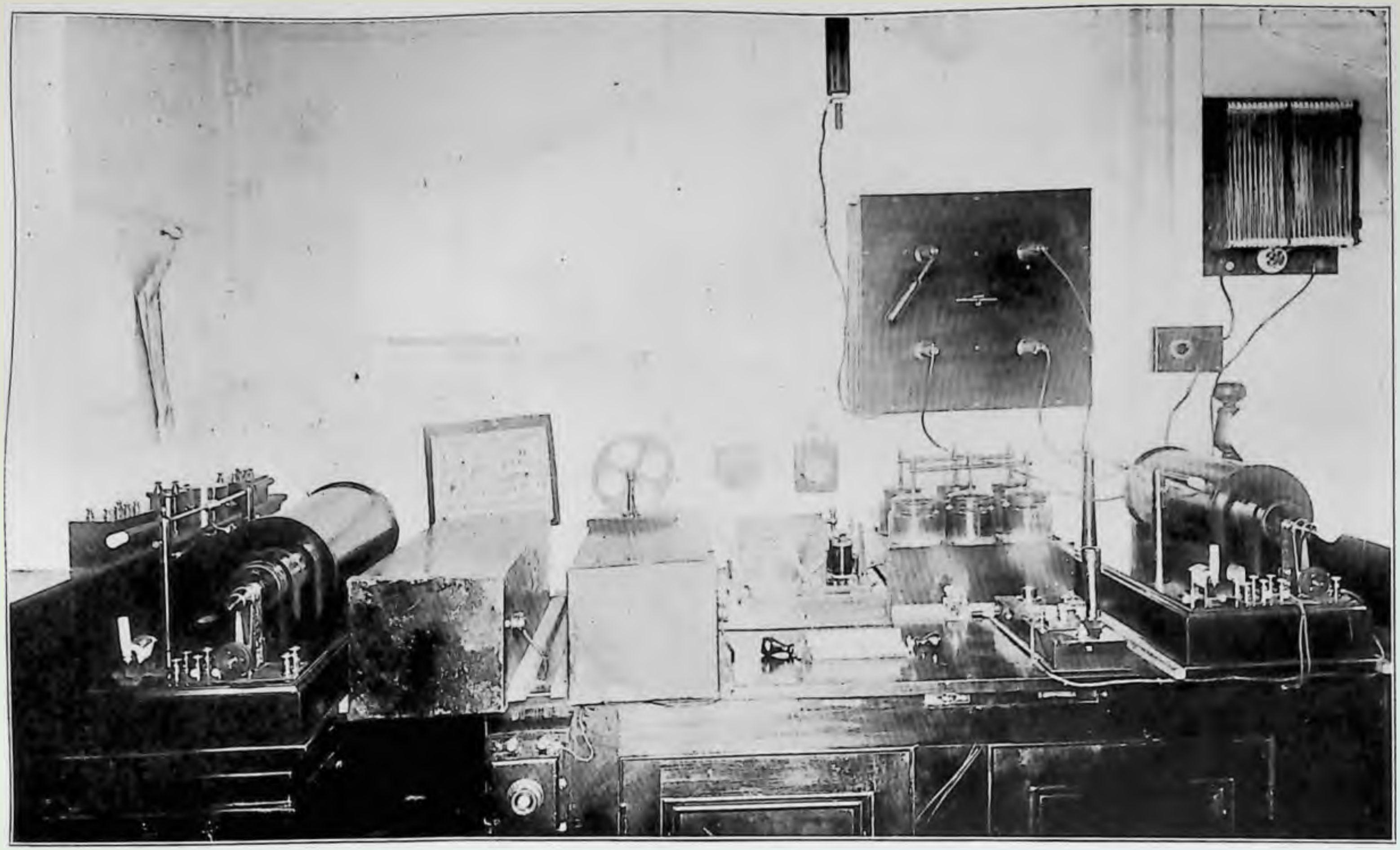

INTERIOR VIEW OF A MARCONI WIRELESS TELEGRAPH STATION

Foreword

THE present day development of the "talking wire" has annihilated both time and space, and has enabled men thousands of miles apart to get into almost instant communication. The user of the telephone and the telegraph forgets the tremendousness of the feat in the simplicity of its accomplishment; but the man who has made the feat possible knows that its very simplicity is due to the complexity of the principles and appliances involved; and he realizes his need of a practical, working understanding of each principle and its application. The Cyclopedia of Telephony and Telegraphy presents a comprehensive and authoritative treatment of the whole art of the electrical transmission of intelligence.

¶ The communication engineer—if so he may be called—requires a knowledge both of the mechanism of his instruments and of the vagaries of the current that makes them talk. He requires as well a knowledge of plants and buildings, of office equipment, of poles and wires and conduits, of office system and time-saving methods, for the transmission of intelligence is a business as well as an art. And to each of these subjects, and to all others pertinent, the Cyclopedia gives proper space and treatment.

¶ The sections on Telephony cover the installation, maintenance, and operation of all standard types of telephone systems; they present without prejudice the respective merits of manual and automatic exchanges; and they give special attention to the prevention and handling of operating "troubles." The sections on Telegraphy cover both commercial service and train dispatching. Practical methods of wireless communication—both by telephone and by telegraph—are thoroughly treated.

¶ The drawings, diagrams, and photographs incorporated into the Cyclopedia have been prepared especially for this work; and their instructive value is as great as that of the text itself. They have been used to illustrate and illuminate the text, and not as a medium around which to build the text. Both drawings and diagrams have been simplified so far as is compatible with their correctness, with the result that they tell their own story and always in the same language.

¶ The Cyclopedia is a compilation of many of the most valuable Instruction Papers of the American School of Correspondence, and the method adopted in its preparation is that which this School has developed and employed so successfully for many years. This method is not an experiment, but has stood the severest of all tests—that of practical use—which has demonstrated it to be the best yet devised for the education of the busy, practical man.

¶ In conclusion, grateful acknowledgment is due to the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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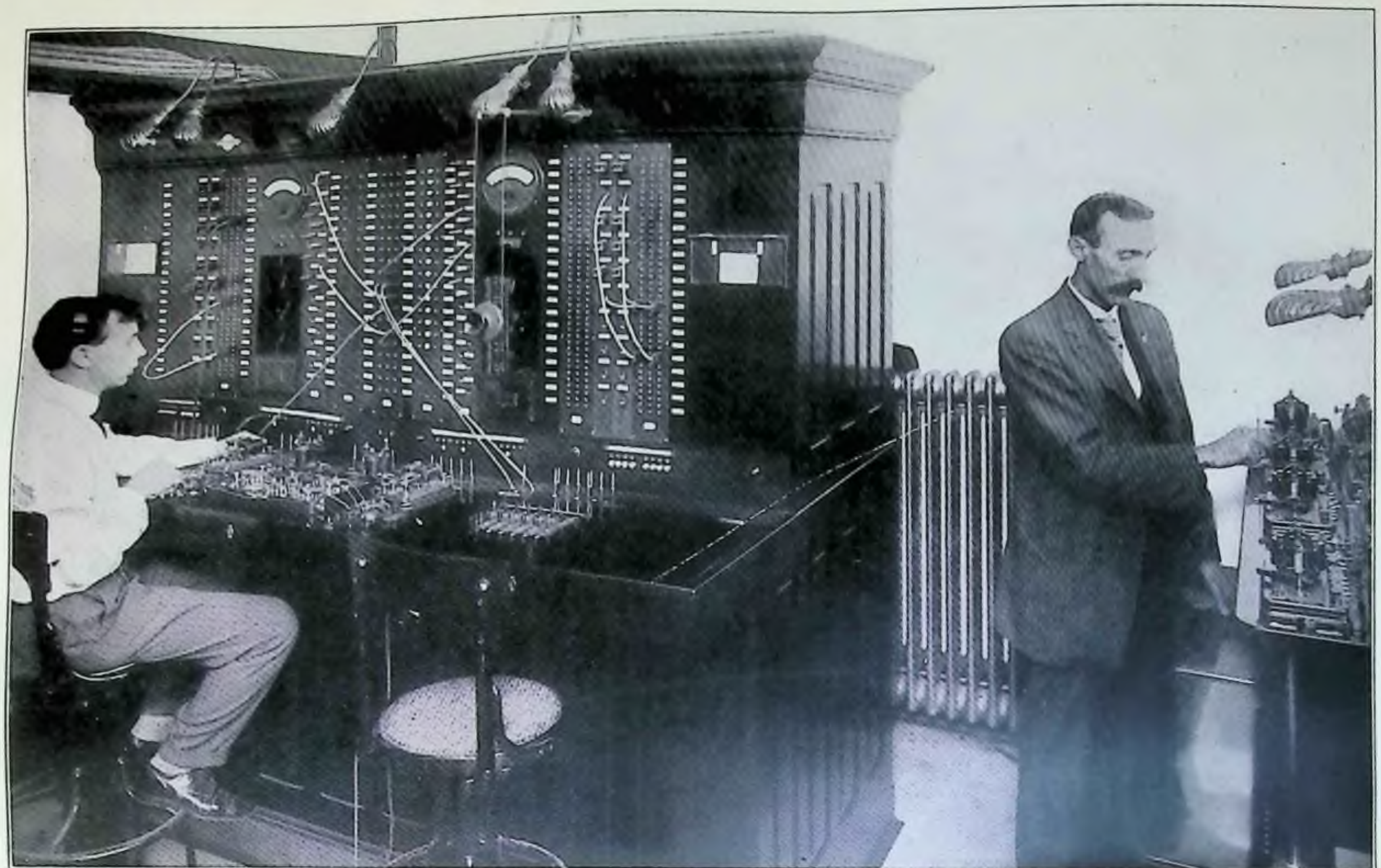

PHANTOM AND MORSE TEST BOARD
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THE ELECTRIC TELEGRAPH.

PART I.

APPARATUS AND THE MORSE CODE.

In order to get the beginner's point of view, it is taken for granted that the reader knows nothing of electricity or the practice of telegraphy. If there is a slight knowledge of either of these, so much the better; but as a starting-point, we will consider that altogether familiar use of the electric current in the ringing of a door-bell by pressing on a button. In so doing the new arrival "telegraphs" the fact to the household, and asks for admission, and those within respond to his message, although neither the one nor the other may know a dot from a dash. The simple combination of battery, wire and apparatus by which this action is carried on is as truly a telegraph circuit as is the longest in the land, and a glance at its elements will serve as a stepping stone to the more complex apparatus of the electric telegraph.

The different parts of the electric-bell device may be seen in their relation one to the other by reference to Fig. 1. In the center is the push-button P, pressing upon which brings the point of spring S into contact with the metal strip R. On one side is the cell A, with its two poles C and Z; on the other is the bell, with its electromagnet M, its armature hinged upon a spring K, carrying a hammer H, to strike the bell. Attached to the back of the armature is a spring, making contact at D with a back-stop T. These parts are so adjusted that when the armature is attracted by the magnet the contact at D is broken. Looking now at the diagram, if the wiring is traced from the point C back to the point Z, but one break will be found in the continuous contact of the wire with the different parts, and that is between the spring S and the strip R.

If, by means of the push-button, S is forced against R, the break is closed; the current speeds from the point C of the cell through the wire back to the point Z, charging the electromagnet M, which attracts armature-carrying hammer H. But by this movement the contact, and therefore the electric circuit, is broken at D, the current ceases, electromagnet M releases the hammer H; contact of the armature and back-stop at D is thus restored; magnet M is again charged, attracting the armature; the result being a vibration of the hammer, continued as long as spring S is kept in contact with R. The energy is derived from the cell, but the control of it lies in the push-button; and the effect of the making and breaking of the circuit at R is such as to appeal to the ear. By means not very different the same organ is addressed in teleg-

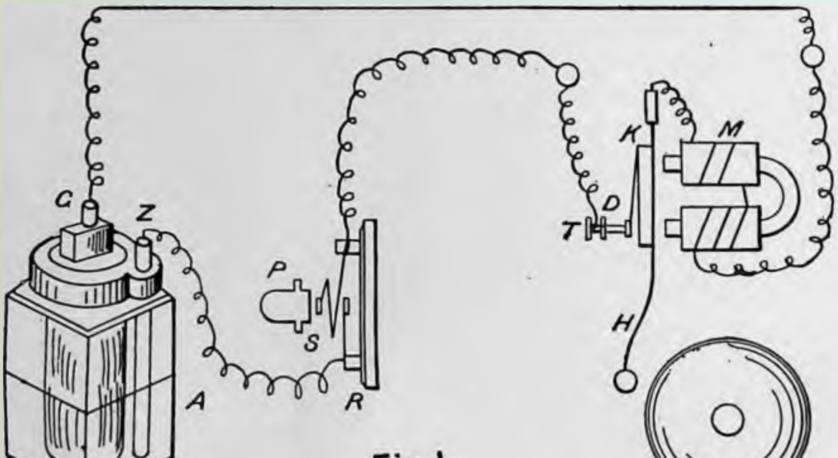


Fig 1.

raphy; but the appeal is of a kind legible only to the expert. The bell device serves the further purpose of bringing the learner face to face, at the outset, with the fact of the inconceivable speed of the energy he is employing,—a feature which allies it to light in the velocity of its movement.

Having now gained a general idea of the action of a current in moving an armature, we will suppose that the reader, if in a city, has stepped into one of the many branch offices of a great telegraph company, or it may be into a town or village office of the same, and for the first time is taking notice of the outfit. In such an office there will be seen (secured to the wall) a small switchboard, but the interest centers on the table, or desk, where there are usually three forms of apparatus, known as the relay, key and sounder, with the wires connecting the various parts. On the window-sill, or under the table, is the battery of one or two cells, for the operation of the sounder, shown in the Instruction Paper "Elements of Electricity." The uninitiated, listening to its clicks for the first time, naïvely expresses surprise that they "can make nothing of them." This set of apparatus, installed in thousands of small offices all over the continent, and duplicated many times in the large offices, is shown in outline in Fig. 2. The relay, described in "Elements of Electricity," is not heard at all; the main battery which operates it may be scores of miles away; the current from it has its path in the main, or air, line

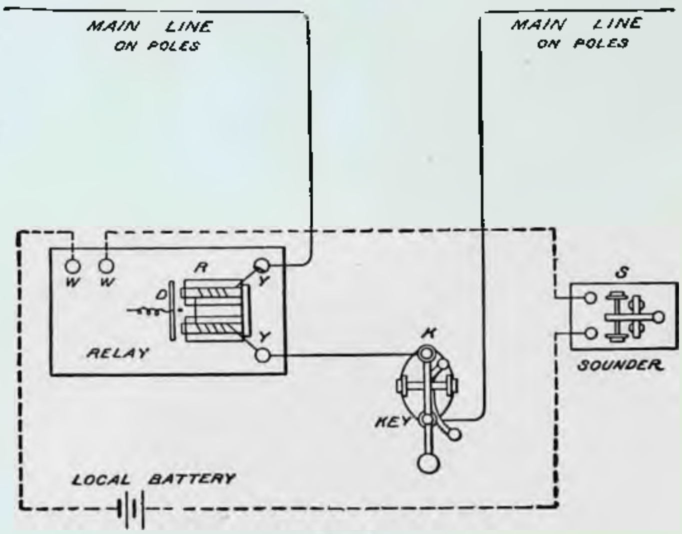


Fig 2.

coming in from the pole in the street. Passing through the coils of the relays and the keys, it makes its exit through the office window, to resume its place on the poles which support it to the terminus of the line.

Examining Fig. 2 and comparing it with the bell-ringing device shown in Fig. 1, we find the cells of battery and the wiring common to both; the sounder corresponds to the bell proper; the key marked K answers to the push-button. The dotted lines in Fig. 2 represent the "local" circuit, and the cells are the "local" battery, so called because its action is confined to the place (Latin, *locus*) or station with which it is immediately connected. See the "Gravity Cell" in Elements of Electricity; the leads from the two poles being shown. If the *wherefore* of this pair of conductors and their connected parts is understood, the method of Morse telegraphy is within easy distance; and with the little light gained from the comparison of the electric bell with the telegraph circuits, we may take a step further in advance. For closer examination, therefore, this local circuit and its parts are reproduced on a larger scale in Fig. 3 and with more lettering. Each of the two cells of battery is surmounted by two projections called poles,—the terminal connections of two dissimilar substances, as copper and zinc, or zinc and carbon. The cell is explained in

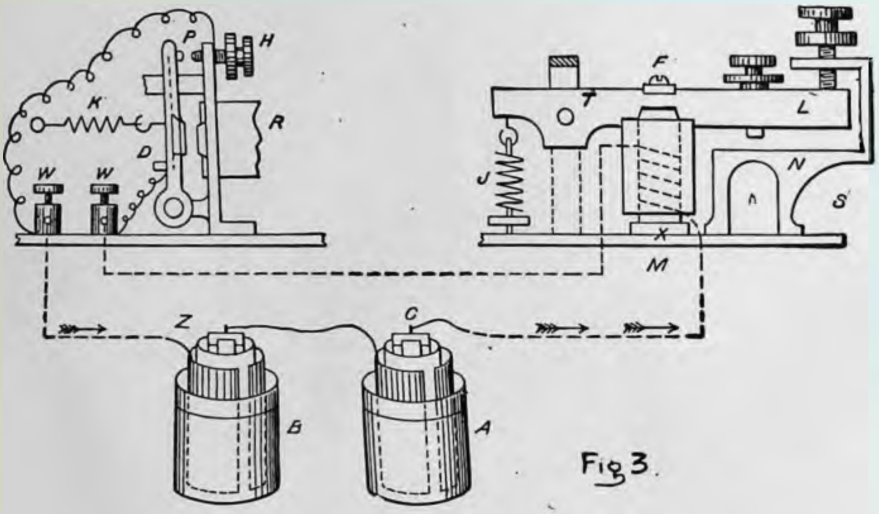


Fig 3.

"Elements of Electricity;" all that need be noted now is that by outwardly joining up the cells so that the unlike substances are in metallic contact, a current is the result. First the carbon terminal or pole of one cell is connected to the zinc pole of the other; then from the carbon pole C of cell A runs a wire (dotted line) which can be traced through the coil of magnet M; thence to the armature D, and local points at P of the relay R back to the zinc pole Z of cell B. Of relay R only the moving parts are shown. The thumbscrews, wherever found, have connected to them wires from the different parts of the instrument, and are merely conveniences for making contact with the outside wiring.

Besides the battery of two cells and the conducting wires (dotted lines), the circuit, as already intimated, includes an electromagnet, consisting of a pair of upright coils (only one is shown), which, with the surmounting armature F and its adjacent parts, constitutes the sounder S. Each of the two upright coils of wire has a core of soft iron with a strip of iron X, joining them underneath. Close to the upper ends of the cores, but not touching, is a strip of soft iron F, called the armature, secured to a lever L, moving on trunnions T, at one end, its free end moving between two stops, the spring J serving for its adjustment. The movement of armature D of relay R is also limited by stops, and, tracing our dotted line circuit, we find a point P, where the circuit may be "broken" by withdrawing armature D from the front-stop H; just as in the case of the push-button, the circuit is "made" by pressure on the button, and "broken" by the withdrawal of it. In other words, in this armature D, with its front and back stop, and spring K, we have a telegraph key in a form the simplest and most easily understood, but not the most easily operated.

In a local circuit arranged as in Fig. 3, when armature D of relay R rests against its front-stop H, the current magnetizes the cores of electromagnet M of the sounder; armature F is strongly attracted thereto, making a sharp click as it strikes the down-stop N; a reverse or upward movement is determined by spring J if armature D of the relay is withdrawn from the front-stop, giving a sound less sharp than in the downward movement. The difference in sound between the front and back-stroke of the lever is something of which the learner must early take note, because the front is the marking stroke, or the one from which he reads, the back-stroke being unintelligible. In the former case (armature D against the front-stop), the circuit is said to be "made" or "closed;" in the latter it is "broken" or "open." Closed and open are the terms in general use among telegraphers. In the case of the electric bell, the push-button puts us in control of the energy which attracts the hammer to the gong. In the local arrangement we have been considering, the control of the sounder S lies in the armature D, whether moved by the finger, or in the usual way by the current.

In this dotted-line arrangement the wires are the carriers or conductors of an energy which has its source in chemical action in the cells. In the poverty of language it is said to "flow" or "run" within the cell from the zinc to the copper plate, or from zinc to carbon; and in the external portion (dotted line) from copper or carbon to zinc. Moving thus along the conducting wire and through the connected instruments it is called a current (Latin, *curro*, to run) and in doing so it is said to make a "circuit," which may vary in length from a few feet to hundreds of miles. Its velocity is such that wherever a fitting pathway is afforded, it seems not so much to flow as to be omnipresent. In a series of tests made in New York by the United States Coast Survey, two separate wires were obtained to San Francisco, where they were joined, or, as telegraphers say, "looped." To each of the New York ends of the wire, instruments were connected, and signals sent on the one wire returned on the other in a space of time just perceptible. The current had traversed the continent and back in a small fraction of a second,—a kind of movement which the words "flow" and "run" hardly describe.

It is the purpose of this description, to explain to the reader how it is that the signals heard on the sounder can have a meaning to the operator; how it is that the down and up movement of the lever of the key K, Fig. 3, can transmit intelligence to a distant station; then, briefly at first, but later on more completely, to instruct him in the method of operation, use and adjustment of each instrument in the set, so that in a reasonable period of time he will himself be able to send and receive the signals which before were unintelligible. At this point a number of questions may suggest themselves to the thoughtful student. Some of them, it may be, cannot be answered; others may belong to the theory of the art; but our present aim is entirely practical, the point being to beget in the student the ability to translate writing and speech into the "Morse" language; the consideration even of the main-line circuit is therefore deferred.

Summing up the examination of the local circuit there are

(1) The cells of battery as the source of energy,

(2) The conducting wires,

(3) The sounder S, consisting of an upright electromagnet having for an armature a movable lever; and

(4) A point P in the circuit at which, by a movement of the armature D of relay R, we can control at will the armature of sounder S.

In speaking of the relay R, Fig. 3, and its armature, the remark was made that in it we have a telegraph key in form the simplest and most easily understood, but not the most easily operated. Remove the dotted line wires from the thumbscrews of relay R and insert them, as in Fig. 4, in the terminals of a key K′, described in "Elements of Electricity." We now have a "learner's outfit"—battery, key, sounder and connecting wires. Even with

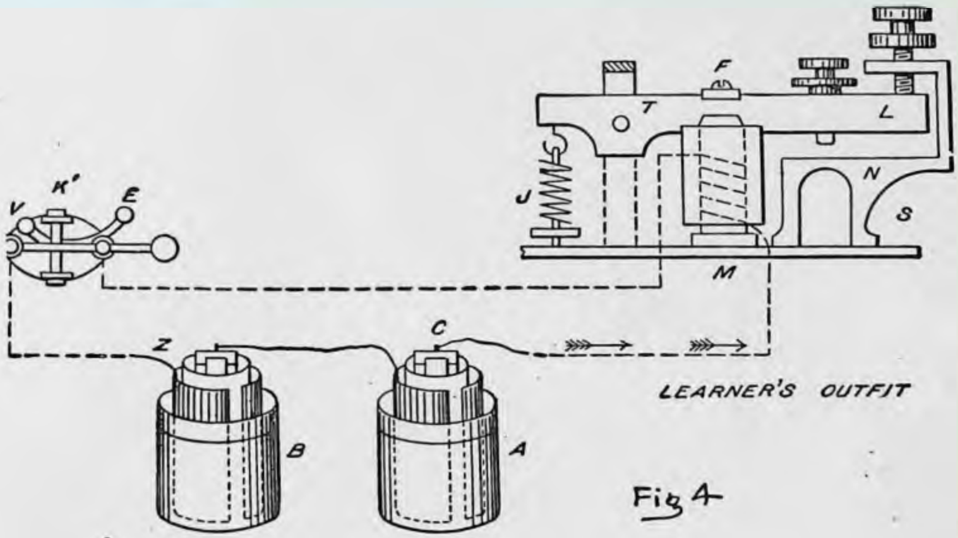


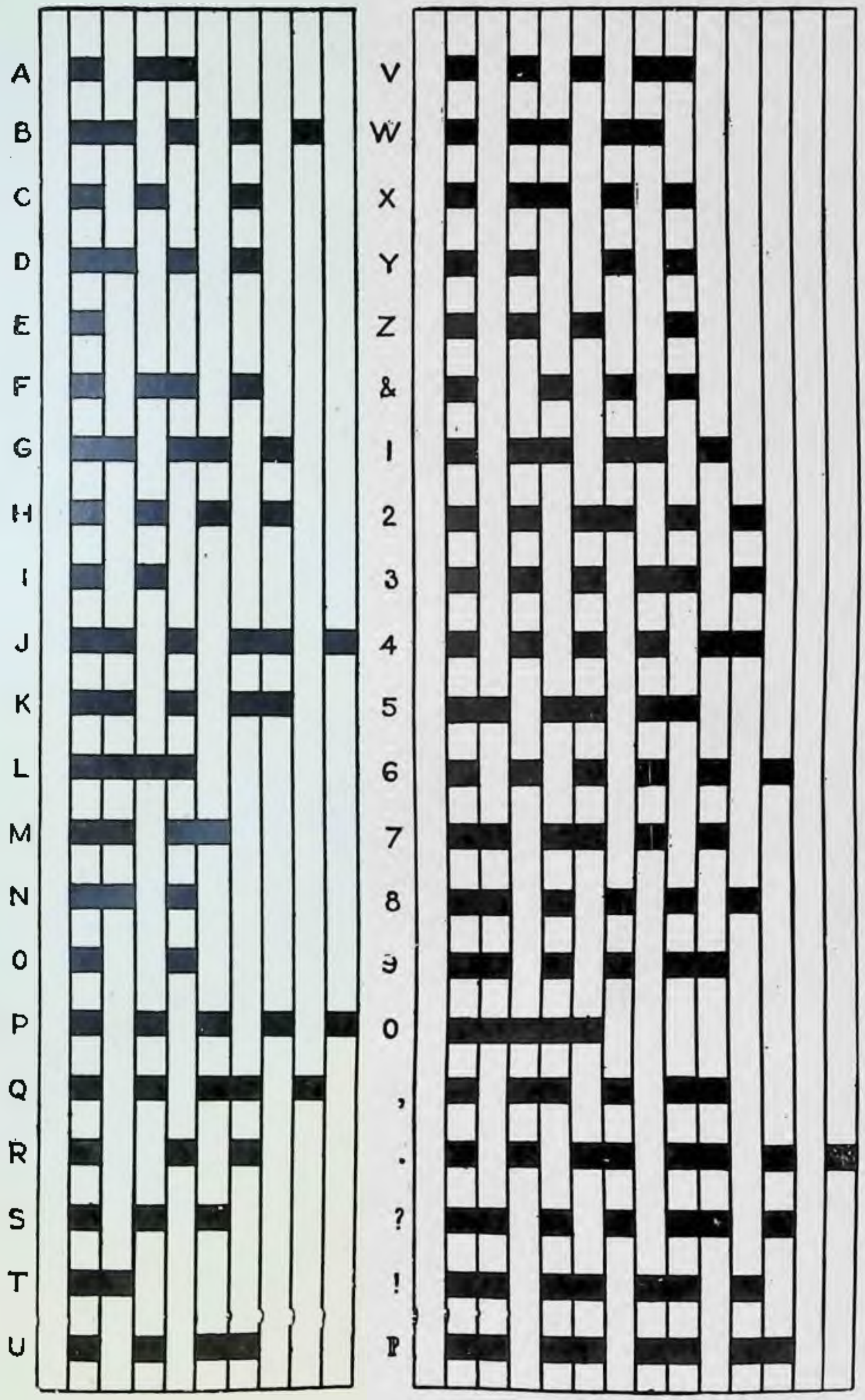
Fig 4

these, signalling to considerable distances can be carried on, and the medium for it is the Morse Telegraph Code, whose elements and their combinations to form letters are now to be taken up.

THE MORSE CODE.

It is taken for granted now that the student is provided with "a learner's outfit," comprising the apparatus shown in Fig. 4. The key K is provided with a curved arm E, hinged at V. By moving this to the right the key is opened. If, by tapping on the rubber knob of the lever, dots are made on the open key, it will be found that the armature of the sounder follows its movements. Having attained thus the control of an electromagnet, only a time element is needed in connection with the movements of the key to produce intelligible signals. In other words, if the open key is closed, by depressing the lever, now for a short, now for a longer time, or if the time between the moments of depression is varied, it is possible, by assigning the letters of the alphabet to different combinations of these movements, to make the instrument spell out the words of a language. To this end there was devised a system of dots, spaces and dashes, so arranged and combined that, singly or in groups, they are made to represent the different letters, figures and characters of the English language. If the learner (the key being open) hits the rubber knob a short, sharp blow with the finger, the sounder will give two clicks, one with the downward motion of the armature and one with the upward. The former has a sharp click, the latter a dull sound called the "back-stroke." The signal thus formed is called a dot, and its prolongation by a longer depression of the key is a dash; the down-stroke of the armature marks the beginning of a dot or dash, and the up or back stroke its end. In the movements for the production of the signals the time unit is the dot; by its duration all the dashes and spaces are measured. The single dot, produced as described, is the signal for the letter E, the letter in most frequent use having assigned to it an element the simplest and most easily formed. Prolong the dot to twice the time and we have the dash — the signal for the letter T; to four times the time, a longer dash, forming the letter L; to five times the time, and we have the signal for a cipher (0). To the hand the only difference between a dot and a dash is a longer depression of the key; to the ear the difference is in the interval between the down and up, or back-stroke of the armature. If the back-stroke were absent it would be impossible to distinguish E, T and L one from the other. It is not an uncommon thing for even the experienced operator to "get the back-stroke," in which case he dampens the up-stroke of the sounder with his finger until the ear catches the down-stroke again.

In the selection of the combinations which make up the code of signals, the principle, "the easy signal for the frequent letter," is observed throughout. The time value of the dot is constant, but the dash and space have each three different lengths. Two dots separated by a space of time approximately equal to a dot



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represent the letter I, but two dots separated by a space equal in time to two dots represent O. The former is a mere interval, the latter is called the letter space; the word and sentence space are multiples of it — usually twice for the former and thrice for the latter. In naming the elements of the signal for the letter O, for example, they are read "dot, space and dot."

The entire scheme of the Morse Code, with its dots, spaces and dashes, their combinations and their relative time values computed according to the unit of time — the dot — and the letters, figures and characters they represent, is shown graphically in the accompanying chart, which the student must now, for a time at least, make his constant guide and reference.

FIG. 5.

That we are able to present the alphabet in this preferred form is due to the courtesy of the D. Van Nostrand Company of New York, publishers of "Modern Practice of the Electric Telegraph" by F. L. Pope, to which manual, for details of nearly every topic in connection with telegraphy, the student is referred.

In this connection it may be of interest to state that the Morse Code, in the form in which it is now used, is the work of Alfred Vail of Morristown, N. J., and that in the selection of the signals for the different letters he was aided, so the story goes, by a chance visit to a printing-office, where he noticed that in the type cases the size of the different compartments was determined by the frequency of the use of the letter.

The attention of the learner having been called to the relative time values of the elements which go to make up the signals, he is now in a position to attempt for himself the making of them, and to take his first step as a sender. His instrument for this purpose is the key, with regard to which it has already been explained that it is merely a convenient device for the admission and non-admission of the current to the electromagnet of the sounder, according to a prearranged code. A suggestion as to the manner of holding the key can be gained from the cut (Fig. 5) given herewith. In it will be noticed the thumb pressing lightly upward against the rubber knob, the fore and second fingers curved, their tips slightly embedded in the knob, the wrist kept well above the line of the lever. This illustration, long familiar to telegraphers from its use in advertisements, and known among them as the "Catlin grip," is not intended for exact imitation. As in the case of handwriting, individual proclivities will assert themselves; but if the learner infers from it how to gain a firm command of the key, without cramping the fingers and forearm, he will have learned all that the text-book or a teacher can tell him.

At this stage some learners simply place the code chart before them and beginning at A, with its dot and dash, plod through the entire alphabet; then back and forth over the same ground, until they have obtained a certain mastery of the signals; and many good operators have learned in just this way. The writer has heard Mr. James D. Reid, "the father of telegraphers," relate that even on his way to assume his first position he re-enforced his limited practice by tapping out the alphabet with a pencil or a knife on the window of the railway coach or on the arm of a seat. But it seems more in keeping with up-to-date methods of instruction pursued in other branches to give to the exercises now to be entered upon a growing and developing character. With this end in view the different combinations of dot, space and dash are classified and arranged in six different modes—the signals for letters, figures, and common punctuation points only being considered at present. A mere glance at the chart will indicate to the eye the differences already noted in the lengths of the dashes; the letter L is represented by a dash twice as long as T; and the signal for a cipher is a dash two and a half times as long as T. It is as well for the beginner to observe these relative lengths; but in actual work the dashes undergo some shortening without danger of error.

1. Dot only, . E .. I ... S .... H ..... P
2. Dash only, — T—— L——— cipher — — M — — — 5
— — — — paragraph
3. Dot preceding the dash, . — A .. — U ... — V .... — 4
. — — W
4. Dot following the dash, — . N — .. D — ... B — — .. 7
— .... 8 — — . G — — — . exclamation
5. A combination of (3) and (4) . — . F — . — . J — . - K
.. — . Q . — .. X . — — . 1 .. — .. 2 ... — . 3
— .. — 9 . — . — comma .. — — .. period
— .. — . interrogation
6. Dot and space, .. . C . . O . .. R .. .. Y ... . Z . ... &

The method to be followed by the student looks to the repetition of the signals for these letters and characters, first in direct order as given, and then in reverse. In this way his work is graduated, and his ear will soon become accustomed to the difference as the elements increase or decrease. Especially is this true in regard to the first mode; and in connection with the second it is to be noticed that while the dot always has the same time value, the dash, as already stated, has three different values, as indicated by the length of the lines for T, L, and cipher in the chart. The T dash repeated gives us the letter M; used thrice, the Fig. 5, and four times, the signal for a paragraph.

The third mode includes those letters and characters in which a dash or dashes is preceded by a dot or dots. They represent the letters A, U, V, W, Fig. 4. And for mode four we have a reversal of the elements in the preceding one; dot follows dash, and signals are thus composed for letters N, D, B, G, Figs. 7 and 8, and the exclamation point.

In the fifth mode the order is miscellaneous; and the more complex and difficult signals thus obtained, have assigned to them the letters least often used. They are F, J, K, Q, X, figures 1, 2, 3, 9, the comma, the period and interrogation. Last come the so-called spaced letters — of all the signals, requiring in their formation and grouping the most care. They are C, O, R, Y, Z, &; and their persistent repetition, both singly and in combinations of short words, is enjoined upon the student.

The telegraphic equivalents of all the letters, figures and more common punctuation marks having been given, attention is next called to groups of letters having signals somewhat similar.

For the letters and characters in these groups the student can find for himself the signals in the code card. He can, by inspection, determine for himself the exact difference in each case, as, for instance, in the first of the following groups A differs from I by the change of a dot into a dash.

1. I, A, S, U, H, V.
2. A, F, X, comma, W, 1.
3. U, Q, 2, period, 3.
4. K, J, 9, ?, G, 7, !

The signals for these letters and characters having by repetition become familiar to the ear, the combination of letters into words, may next be taken up. In the course of the plodding thus far pursued, the learner may begin to think that the slow analysis by the brain and the mental noting of every signal must be an irksome task. But he will find as he advances that by degrees the analysis becomes mechanical; certain sounds come to mean letters, groups of sounds, words. The real alphabet of the expert telegrapher is largely one of words; to him the clicking of the sounder is a language, and its interpretation as easy as that of speech. It is therefore with the combination of letters into words that we have now to do. And in pursuance of the progressive plan the exercises revert at this point to the order in which the signals were classified; that is, words are made up first of dot letters, then of dash letters, and so on.

1. Of the dot letters can be formed the words is, she, ship, hips, his, pies, sip, pipe, sheep.

As it is not possible to furnish many words made up exclusively of the letters in each group, single letters from other groups are here and there borrowed to make up some exercise words; as for instance, in the old-time favorites with learners, pippin and Mississippi, in which N and M belong to another group.

Exercises in words containing dot letters:

Dishes, dispel, high, dipped, Spanish, spite, shipshape, diminish, dishevel, phase, dapple, hiss, hissing.

2. Dash letters: Met, tell, till, time, mill, pellmell, metal, limit, telltale, mamma, mammal, minimum, little, time, tittle, tattle, emit, timid, multiple, multitude, dimmed, mallet, skillet, skimmed.

3. Dot before dash letters: Awe, awful, awl, law, mauve, value, valve, wave, Eva, vault, view, lava, vamp, haul, pawl, squaw.

4. Dash before dot letters: Bend, bidden, gilded, laden, dined, begemmed, dunned, dabble, nab, ban, Denbigh, Big Indian, quagga.

5. Combination of (3) and (4): Julep, jungle, junk, Fiji king, fast bind, fast find, quit, equal, quaff, quake, exit, exist, ex-queen, exquisite, exhaust, skiff, piquant. Affix a k to kin and it is kink, bequeath, quaint, mujik, Ajax, Xanthine, jejune, jujube, keg, fix.

Thus far no words containing a spaced letter have been admitted. The hand and ear are thus first accustomed to the signals whose elements are separated by a uniform interval of time. By reference to the code card the learner will notice the difference in the spacing between s and c, i and o, s and r, h and y, h and z. The addition of the spaced letters makes the alphabet complete, and a number of excellent practice words omitted heretofore are now available.

6. Spaced letters: Or, err, to err is human, errant, corner, Corcyra, correct the error, eczema, corollary, co-operate, Corcoran & Co., coon, raccoon, circus, circle, cycle, bicycle, current, currant, cracker, firecracker, chronicle, coccyx, buzzard, zyrcou, correlate, physics, phantasmagoria, rhododendron, corrupt, cohesion, corduroy, road, dory, hippopotamus. There is no royal road to learning. The voice said Cry. What shall I cry? According to Sinbad the sailor, the roc's egg was enormous in size. Llewellyn, sassafras, crown, point, parallelogram, oyster, eyelet, icicle. ice-cream, puzzle, bamboozle, binocular, verdict, door, category, oracle, rollicking, moored, marooned, pirate, gyratory, circumstance, circumgyratory, paraphernalia, jiffy, effigy, equinox, quiz, Quixotic. Peter Piper's peacock picked a peck of pepper out of a pewter platter.

A few easy messages of ordinary commercial form are here introduced, attention being called to the fact that the destination occupies a line by itself. This is done so that the distributors in the larger offices can catch the "place to" at a glance.

116 B.	R N	M B	11 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Bar Harbor, Me., 12.

To Theo. Faulkner,

Jenkintown, Pa.,

Can give same room as last year—twenty-eight dollars. Answer.

(Sig.) J. S. LYMAN.

17 Ki.	M O	N D	7 Paid.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Kingston Depot, N. Y., 12.

To Mexican Gulf Agricultural Co.,

Dallas, Tex.

Arrive there Monday morning, 8.55.

(Sig.) ALLEN.

184	U D	B	20 D. H.

RECEIVED at the . . . BUILDING, . . Broadway, N. Y. July 12, 1902.

Dated Mamaroneck, N. Y., 12.

To G. F. Harriman,

Pullman Co.,

Detroit, Mich.,

Empire Coupler Co. shipped car load of couplers to-day in D. L. & W. car 58,031.

(Sig.) H. M. WYATT.

In the top line the first space contains the number, and generally the call of the sending station; the second and third spaces, the signals of the sending and receiving operators; the fourth, the check. In practice the signature is also on a line by itself.

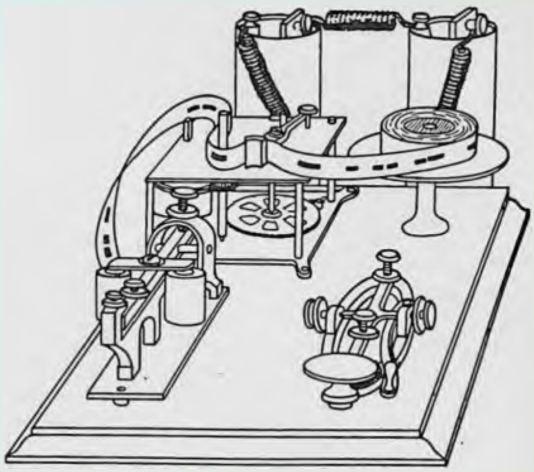
By attention to the response of the sounder as he forms the letters on the key, the learner has now to some extent familiarized himself with the *sound* of the signals as he translates their form, as printed in the code card, into the key movements necessary to produce the dot, space, and dash. Reading the signals as they are embossed on paper by a "register," except for some special uses, has become obsolete in telegraphy, so that it is with the *sound* that the learner has entirely to deal; and the signals from which he must copy are those of a hand not his own on a distant key. In this, as in handwriting, there are individual differences; and the query whether operators can recognize one another over the wire by their "Morse" can be answered affirmatively. Since much depends on the initial practice in the formation of his style, the learner should, if possible, at the outset take a few lessons from an operator. That these remarks are practical and not perfunctory, the writer has personal knowledge at the present time of the contemplated removal of operators from some important circuits because of their defective sending. To aid in the formation of a correct style the signals have been presented in a graded form, beginning with the dot, which is the unit of time, passing on to the dash, then to the various combinations of dots and dashes, and lastly of dots and spaces; all with a view to their reproduction in words, phrases and sentences.

The Automatic Sounder Method. It was intimated that, for beginners, it was advisable to observe closely the relative length of the signals as indicated by the chart, especially the dashes, and that, on this account, it would be well for them to take a few lessons from an operator at the outset. In order, however, to do away with the necessity for this, there is brought to their notice a device of Mr. R. W. Elam of Valparaiso, Indiana, for the reproduction of signals the same in effect as if sent by hand, thus supplying in a great measure the guidance of an experienced teacher.

STORAGE BATTERIES AND SECTION OF TELEGRAPH TABLE
U. S Telephone Company, Cleveland, Ohio.
The Dean Electric Co

The apparatus is constructed by the National Automatic Transmitter Company and is furnished to students by the American School of Correspondence. In addition to the apparatus itself, the student is supplied with a set of records representing the letters and characters in the Morse code; the apparatus reproduces them in such a manner that, in the formative period, the learner may accustom his ear to the signals as made by an expert. These records are exact reproductions of the characters as made by hand; having been transmitted to the recording perforator by an expert operator through the use of an ordinary telegraph key. So natural are the messages thus reproduced that the individuality of the sender's "wire-writing" can be detected.

The Apparatus. In the form furnished to students it is mounted on a base, 11½ by 12 inches, made of quarter-sawed oak, finely finished; and comprises a learner's outfit consisting of a key, sounder and battery such as have been previously described; with clock-work and circuit-breaking mechanism through which moves a strip of perforated tape. To the axle of the clock-work, where it projects through the frame, is affixed a friction wheel which imparts its motion to the tape. Between the wheel and the tape holder is a curved pad against which the tape is pressed by an arm pivoted nearer to the end next the pad which we will call A; the other end we will call B. A slight deflection, therefore, of end A is quite marked at end B; the movement of the latter is limited by a stop similar to the armature of a relay. Like the relay also, at its end B the pivoted arm and the stop make connection with the poles of a local battery, so that when contact is made between the arm and the stop, the circuit through the sounder is closed; when the contact is broken the sounder is open.



AUTO-ALPHABET INSTRUMENT.

The slight movement of the arm needed to operate the sounder is effected by running the perforated tape between the end A of the arm, and the curved pad; when the end A is against the paper the sounder is open; it is closed whenever end A drops into an opening.

In the tape the student will readily see that the smallest openings represent the dots of the Morse code; the larger ones the dashes of different lengths.

Releasing the brake with which the mechanism is provided, the paper moves forward, imparting to the pivoted arm a series of movements which the sounder translates to the ear; the perforated tape acts as an automatic circuit breaker, producing the signals on the sounder precisely as the key does, and with greater accuracy as to relative units of time. In effect the signals are being sent by hand; to have them at his command is a great advantage to the beginner, some of whose tendencies to error are set forth in a later paragraph.

The course comprises a series of records capable of reproducing the work of an expert as effectively as if he were listening to the actual working of a wire. Another advantage lies in the fact that the speed with which the messages are sent can be varied over a wide range so that the student can use a slow speed when first taking up the work and, as he becomes more expert, can increase this to keep pace with his advance. The instrument can also be made to repeat any given message as many times as the student desires.

To insure good results the local points, where the arm touches the front stop, should be kept clean; and it may be necessary at times to pass a fine file lightly between them. The clockwork needs no attention beyond the winding up, and an occasional oiling.

The parts of the learner's outfit have been described elsewhere, and in such a manner as should make clear how closely it resembles the local circuit of the regular Morse Line. In placing the tape, see that the signals read in the direction away from the marking arm. The speed should be slow at first; the learner should note the perforations and mentally name the letters and characters as they pass toward the arm, so that when the sounder records them, the ear will associate the sounds with the signals.

A number of these strips are furnished the student; but the one with which he should first familiarize himself is that in which the exercises follow the course indicated below; the words are grouped according to the six modes just indicated; they are made up first of dot letters, then of dash letters, and so on. In pursuance of this plan the particular tape in question is perforated to render the following:

Is she ship his pies sip pipe sheep.

The learner may, if he chooses, stop the movement at this point, and, going back to the word "is," reproduce the series any desired number of times. Following upon the word "sheep" the sounder will reproduce the following words composed for the most part of dots:

Dishes dispel high dipped Spanish spite shipshape diminish pippin Mississippi dishevel phase dapple hiss hissing

Following upon this the sounder will render the exercise words in paragraph 2: Met tell till time mill pellmell metal limit telltale mamma mammal minimum little time tittle tattle emit timid multiple multitude dimmed mallet skillet skimmed; paragraph 3: Awe awful awl law mauve value valve wave Eva vault view lava vamp haul pawl squaw, and so on through paragraphs 4 and 5.

Paragraph 6: Or err to err is human errant corner Corcyra correct the error eczema corollary co-operate Corcoran & Co. coon racoon circus circle cycle bicycle current currant cracker firecracker chronicle coccyx buzzard zyrcon correlate physics phantasmagoria rhododendron corrupt cohesion corduroy road dory hippopotamus. There is no royal road to learning.

Some Faults of the Beginner. The learner may now, with key in hand held in the manner indicated, traverse once more the ground over which he has gone; but this time, he goes along with the notations of certain incorrect tendencies and faults which mark the beginner's work. He can take up those letters whose elements are simple dots, viz., e, i, s, h, p, and practice on the words already furnished, or upon combinations of his own. He will be interested at this point, to know that some experienced operators cannot make the five dots which form the letter P. and that many more cannot make the six dots of the figure 6. If the learner would avoid the "seven," "eight," and "ten-dot" habit, he should start in slowly, giving definite values to his dots, making the intervals uniform, until some approach to precision is reached. Avoid shortening or clipping the final dot, and make sure by actual count at first that the correct number for each character is made.

Following upon the dot mode are the four short dash characters for the letters T and M, the figure 5, the paragraph; and the elongated dash characters for L and cipher. Here, again, a tendency to shorten or lengthen the terminal dash and to space unduly the successive dashes should be guarded against. It is well to observe at first the relative time value of the dashes, but in practice the cipher and L dashes approach one another very closely without inconvenience. Occurring alone or among other letters the long dash is translated as L; among figures it is read as cipher. As between T and L, the usual inclination among learners is to make the T too long and the L too short.

In the next mode, in which the dot or dots occur first, the tendency is to separate too much the dot and dash elements. The interval between them should be appreciable to the ear, but no more. The places of these elements are reversed in the fourth mode to form the letters N, D, B, the figures 7 and 8, and the exclamation point. The first two should offer no difficulty, but B, 7 and 8 are troublesome, the tendency being to add in each case to the prescribed number of dots. There are operators who make the figure 8 for B, and a dash and five dots for 8; but no one careful of his work allows himself to fall into this habit.

Then there is that combination of the dot and dash elements which gives us the letters F, J, K, Q, A, figures 1, 2, 3, 9, the comma and the period. Of these, J and K are usually considered the most difficult, the tendency being to make a double N of the J, and the dashes of unequal length in both. The last mode brings us to the test of a good sender, in the deftness with which he makes the spaced letters unmistakable to the receiver; and he does this by such slight modifications of the space as the exigencies of the different combinations call for. The space in these characters is a prolonging of the necessary interval between the elements, and it should be just enough in excess of it to make the letters O, C, Z, for instance, distinguishable from I, S and H; and the spaces between the successive letters of a group of spaced letters should be slightly greater than the ordinary letter space. Some unfamiliar words, such as coerce, offer such a succession of spaced letters that it is usual for careful operators to repeat the word thus: coerce? coerce — the interrogation point implying "Did you get it correctly?" It should hardly be necessary to warn the learner against the stereotyped mistake of beginners — that of going over a great deal of ground and doing nothing thoroughly. The real progress lies in correct work as one goes along, and accuracy at first in the formation of the signals will lay the foundation for safe and rapid work. The student has already been apprised, by means of three examples, what the ordinary message form is; but something more than "a learner's outfit" is needed for the exchange of messages. The point has now been reached for the consideration of the main-line circuit, to which the electric bell and the local circuit have formed a kind of introduction.

THE MAIN-LINE CIRCUIT.

As compared with the local circuit, or learner's outfit, no new

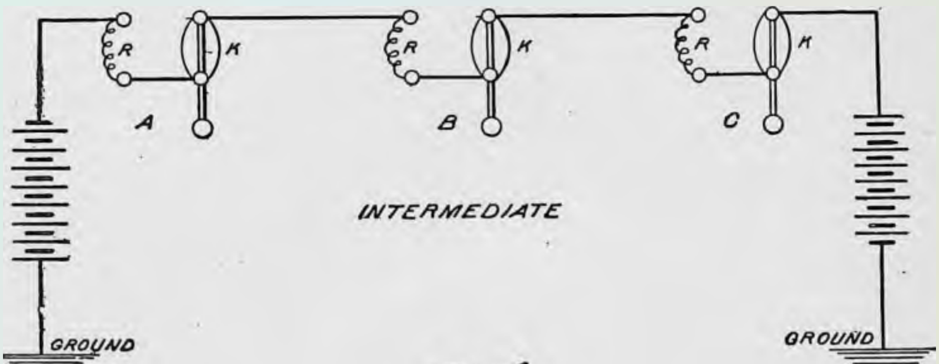


Fig 6.

principle is involved in its operation. The local circuit, with its few yards of connecting wire, has all the essential features of the longest Morse line working single; the differences are merely those of adaptation to new conditions.

First to be made clear is the difference between a metallic and a ground circuit, as exemplified in a local and a main-line; and the location of the latter battery with respect to the the main line. Reverting now to the battery in the local circuit (Figs. 3 and 4), it will be noticed that, where the sides of the cells adjoin, the two unlike poles are connected by a short piece of wire. This, with the longer piece passing through the instruments and connecting the other poles, forms what is called a metallic circuit, because the entire path of the current is of metal. If the short piece of wire between the cells be broken in two and both ends sunk in the damp earth, the circuit will be found intact

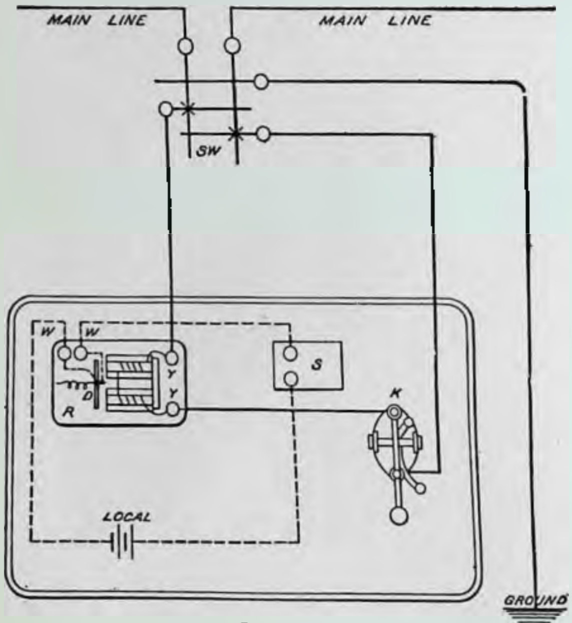


Fig 7.

as before, the current finding a path through the ground; and instead of a metallic we have what is called a "ground," or (in England) "earth" circuit. At this stage we must content ourselves with the fact that the earth acts as a return wire; the reason for it belongs to the theory of electricity. The main line is a ground circuit, not a metallic one; and the location of the main batteries relatively to the rest of the circuit is made plain in Fig. 6. In it are shown two terminal stations, each with main battery, relay R and key K; and between them is an intermediate station. The circuit here shown may be hundreds of miles in length. The cells at each terminal are usually about 150 in number; at terminal A in the drawing the copper pole is grounded, and the zinc goes to the main line; at terminal C these conditions are reversed.

Between the terminals there may be a score or more of intermediate stations, of which only one (B) is represented in the drawing; and as its position in regard to the main line is made clear, the details of an intermediate station, hitherto passed over, are now to be described. For this purpose attention is called to Fig. 7, in which is shown, more in detail than in Fig. 2, an intermediate or way-station, with its main lines appearing at the top, its switchboard, relay, key, sounder and local circuit (dotted line) all complete. As compared with the "learner's out-

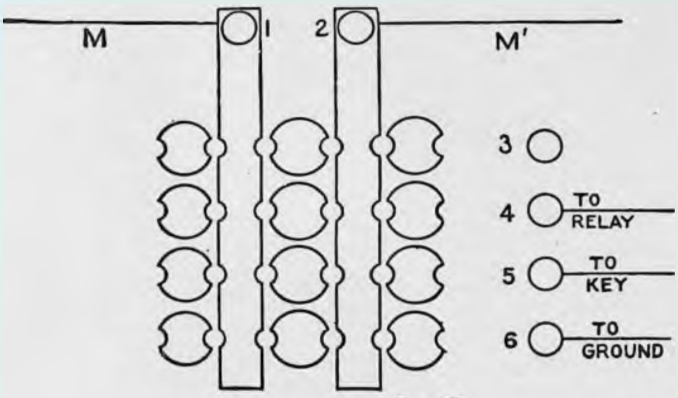


Fig. 8

fit" the additional parts are the relay and switchboard Sw. The wires marked "main line" are identical with those extending in either direction from station B in Fig. 6. In connection with relay R, Fig. 7, the dotted lines which are seen in Fig. 4 inserted in a key are replaced in the thumbscrews of the relay; and the armature and front stop of the relay are again a part of the local circuit. The coils of the relay cores, of which the thumbscrews Y Y are the terminals, form part of the main circuit, just as the coils of the sounder in Figs. 3 and 4 form part of the local circuit; but in the construction of the relay as compared with the sounder, some new features may be noted. The latter instrument is operated by a battery close at hand, for which only a few yards of wire are required; but the relay is only one of a number of similar instruments operated by a battery or batteries through hundreds of miles of wire — a problem in which the matter of economy is also a factor. The cells of battery at each main line terminal was given as 150; but even with this number a meter inserted in the main line of an ordinary telegraph circuit would show a very feeble current. If an ordinary sounder were "cut in" on such a line, there would be no response of the armature to the opening and closing of the circuit, for the reason that the winding of its coils is not suited to the conditions. But in the relay, in order to obtain a sufficient amount of magnetism, the coils are wound with many more turns of much smaller wire. To make room for the additional turns, the soft iron cores are made longer; because of their length they are placed parallel with the base instead of standing up, and the other parts are made to correspond. The winding of the relay coils has its terminals in thumbscrews Y Y, Fig. 7; and if from one of them the main line wire is detached and tapped firmly against the thumbscrew, not only will armature D of relay R respond to the action, but all the relays on the line, be they two or twenty, open and close in unison with the non-contact or contact of the detached wire with the thumbscrew. Then because the movement of the armature of the relay opens and closes the local circuit of each and every relay along the line, the sounder in each local circuit moves in unison with the home relay — a result brought about by merely tapping the thumbscrew of the home relay with the main line wire temporarily detached from it. But the detaching and tapping method has been resorted to only to emphasize for the learner the essential features of a telegraph circuit. In practice the tapping is done much more conveniently with the key, with whose use the learner is presumed to be already somewhat familiar. And as he either has one in his possession, or the use of one, he can examine its construction for himself, so that a description of it here is unnecessary. With the key in the main line circuit to do the work done by detaching the wire from the relay, it is plain that all the instruments in the circuit can be controlled by the movements of the key; when the operator opens the key by moving the curved arm from under the spur (see Fig. 4), all the relays instantly open; when he depresses the lever they all as instantly close. This result is possible because of the velocity of the current — the time consumed in traversing five hundred miles being inappreciable. It should now be plain to the learner how it is that the control of a key at any point in the circuit enables him to exchange signals with a distant station; and, in doing so, he "telegraphs" or, as the word means, writes at a distance; for telegraphy is distance writing, just as telephony is distance speaking.

Mention may be made here of a new form of key which in its construction and operation is a radical departure from the form hitherto in general use. The handling of the ordinary key for any length of time is a serious tax on the muscles of the forearm, resulting in some instances in an ailment known as "telegrapher's cramp." The new form of key was devised with a view to relieve the strain on the forearm by a form of lever which is not only initially different from the ordinary one, but admits of being instantly shifted into various positions, as the sender feels the need.

THE SWITCHBOARD.

One part of the apparatus of a way-station remains to be described; it is called the "switchboard," and is usually secured to the wall over the operating desk. It enables the operator to change the arrangement of the wires leading from the desk with respect to the main line, and to the ground. It is simply a board of well-seasoned wood, fitted in front with metal strips running vertically and terminating in thumbscrews; horizontally across the board are rows of small circles of metal, called discs, whose stems pass through the board, at whose back each row is connected together with a wire terminating in thumbscrews in front and at one side of the board. The strips and discs are so constructed with reference to each other, that connection can be made between them by a metal peg having a short handle of rubber. The switchboard is seen in position in Fig. 7, but is reproduced on a larger scale in Fig. 8. The different rows of discs (each row having a connecting wire at the back) have their terminals in the thumbscrews 3, 4, 5, 6, of which 4 and 5 make direct connection with the relay and key, and 6 makes connection with the ground. Suppose the way-station to be between New York and Albany;

let M represent the main line from New York, making connection with the thumbscrew 1; and M′ the wire to Albany connecting with 2. Look briefly at a few changes in the connections that can be made by means of two metal pegs. Suppose each of the discs in a given row to be numbered as shown on the right of that row. Connect with pegs 1, 3 and 3, 2. In this case the current would simply pass from bar to bar across the middle disc 3 without affecting the instruments at all; and in this position of the pegs they are said to be "cut out." Move the peg in 1, 3 to 1, 4 and the main line circuit is open because there is connection only between discs of the same row. Move the peg in 3, 2 to 5, 2 and the current has to pass through key and relay in going from one upright bar to the other, and the apparatus is said to be "cut in." The drawing represents the switchboard in its simplest form, and the operations indicated are the most ordinary; but if the learner will bear in mind that the discs are connected with each other only in straight lines across the board, he can trace out for himself other peg connections of discs and bars and the changes they bring about in the circuit. For instance, discs 6 all connect with the ground. Remove the peg from 1, 4 to 1, 6 and from 5, 2 to 6, 2; the wire from both directions is now grounded, with the result that there are now two independent circuits—one in each direction from the way-station whose operator could now work with either New York or Albany, but the stations named would be cut off one from the other. Restore the pegs to their original position in 1, 3 and 3, 2, and the terminal stations can work with each other, but the way-station is once more "cut out." This is the position in which the pegs should be placed when the operator leaves the office, or during a thunderstorm. But for the latter incident there is generally arranged a "cut out" outside the office. Many intermediate stations have more than one wire and switchboard to correspond, and it would be possible to fill pages with the combinations that might be effected; but sufficient explanation has been given to indicate the method which, when once understood, can easily be extended and applied to suit larger needs.

In the care and adjustment of his instruments, the operator should see that the local points of his relay and the points of his key are clean; he should be on his guard to see that the armature of his relay or sounder does not hit upon the soft iron of the cores. A good way to assure himself of this is to pass a piece of paper at times between the armature and the core. Instructions in the care of the local battery are now in order; but they differ with the kind of battery used, and are usually furnished in the book of rules of each company.

The purpose up to this point has been to give the reader an idea of the apparatus employed in telegraphy. It has been emphasized thus far that the essential features of the local circuit, viz., battery, electro-magnets, and connecting wires, are all reproduced in the main circuit, the differences being only those of adaptation to new conditions.

With this statement a reversion is now made to the practical —to the matter of the exchange of messages, of which some examples of the ordinary form have already been given. The greater part of the business handled by the commercial companies is of the kind exhibited; but the work of the operator would be easy if it consisted in exchanging only such messages as the samples. In addition to the ordinary form, there are those known among telegraphers by the following terms: Wire, service, forwarded message, repeated back, government, grain, transfer, cipher, number group, circular, C. N. D. (Commercial News Department), marine, and railway D. H. Then there is the press service, making use, in some cases, of fixed forms for a baseball score, golf score, and the like. Of ordinary press matter the volume on certain occasions, such as a presidential convention, is great. At the present time much of the press matter is handled on wires leased from the telegraph companies by the press associations, and their carrying capacity is increased by the use of a code which enables an operator to transmit as fast as an expert typewriter, at his highest speed, can copy. Of code telegraphy, some details will be given later on. In addition to all these the art has been specialized by railway companies in the movement of their trains and traffic, also by brokers and large commercial houses, to such an extent that even an expert operator must serve an apprenticeship in order to fit himself for the rapid work in these specialized forms.

Of the different kinds of messages just enumerated, the first two designations are self-explanatory, the former having to do with the assignment, arrangement, and cross-connection of wires; the latter with the forwarding, re-addressing, and delivery of telegrams. Service messages have to do with the movement of the despatch from the customer to the hands of the party addressed, and, if errors have been made, with their correction.

The following are examples of this form of message:

Marietta Pa ofs.

Give full address Oswald Denberg. We fail to locate your msg date signed National El. Co. S. Y. S. (sig) Munn, New York.

The use of abbreviations will be noted; and for some constantly recurring phrases, such as "see your service," only the initials are used. "Give better address" is similarly represented by G. B. A.

Munn, N. Y.

Pls D. W. C. from original yours today Carnegie Steel Co. signed Union National Bank, A. L. Dignam Cashier. Same reaches us dated Waterbury Conn.; Carnegie say think should be dated Watertown N. Y. Advise my care.

(sig) Phila., Pa.

In this case a "duplicate with care" is requested.

An extra-date message is one that has been received by mail at, say, Albany office; or, having come over another line, has been handed in to be sent forward, and takes this form:

116A Bn Mo 15 Paid

Berlin, N. Y. Oct. 26, via Albany Oct. 26

Adam Brown,

Bridgeport, Conn.

Have been unexpectedly detained. Meet me next Monday at ten. H. Brosnan.

In this case the five words "Berlin N. Y. Oct. 26" are added in and charged for as part of the message. It is customary when the party to whom a message is addressed has left town, to forward it to a given address, in which case the forwarding station, with the word *via*, appears in the date, and the originating station and date are charged for, the same as in the example just given.

Occasionally the sender of a message, to insure its correctness, requests a repetition, in which case the words "repeat back" are inserted in the check and included in the count. For such repetition a charge of a rate and a half is made. A "night message" does not differ in form from the examples of paid messages already given, except that it is always copied on a blank printed in red ink, and in the check is inserted the word "night," which is not counted. In all collect messages, whether day or night, the word "collect" is counted as if part of the body of the message.

Government messages are exchanged between the officials of the United States government and its employees, and differ from the ordinary form in that the address and signature are counted as part of the body of the message, thus:

197W Kn Mg 28 Paid Gov't

Washington, D. C. June 24

Col. H. K. Ames

Memphis, Tenn.

Forward to New Orleans all the tents and rations you can spare in aid of the flooded district.

(sig) E. M. Harrison,

Commissary General.

The text or body of this message contains only seventeen words; but the count of every word in the address and signature makes the check twenty-eight.

A prominent feature of commercial telegraphy at the present day is the facilities provided for the quick interchange of messages between Produce, Stock, and Cotton Exchanges in cities remote from each other, the circuit arrangements being such that the members of these bodies can carry on their trading with a celerity and correctness that leave little to be improved upon. Many of these traders have their own private wires; but the greater part of this class of business is carried on by the New York Produce Exchange with the different grain centres, such as Buffalo, Toledo, Detroit, Chicago, Duluth. In the forms of messages hitherto given each message is preceded by its number, the signals of the sending and receiving operators, and the check. In the exchange of grain orders all this, with the exception of the number, is dispensed with. To show the difference in usage between the ordinary and the exchange form, a message is given in both:

B123 Da Mo 7 Paid

Ex Chicago, May 18

J. C. Ladenberg,

New York.

Sell five July corn at sixty half.

(sig) M. J. ALLEN.

In practice this would be transmitted in abbreviated form, thus:

B186 7 Pd.

Ex. J. C. L. Sell etc. (sig) M. J. A.

Such work, of course, calls for experience on the part of the operator and great familiarity with the names of his patrons; these being granted, the volume of business that can be handled during exchange hours is large.

There has been evolved in connection with the telegraph service a great convenience to the business community in the order by wire to pay to one party money deposited by another — a transaction possible between cities on opposite sides of the continent. The instrument of this exchange is a message called a "transfer," of which the following is the common form:

B171 Dq Rn 17 Free

Hartford, Conn. June 19

J. D. Mallory,

Henderson, Texas.

Pay to N. D. Hilliard, Hotel Baldwin, gilt bald edgeways from E. L. Adams, Jr., Hartford. Vigilant

(sig) H. N. Tallman,

Transfer Agent.

It is a curious fact in connection with the "transfer" that in place of the very commonly used D. H. for "deadhead" in the check, the word "free" has always been retained. It is said that the use of this rather grim phrase with the meaning "no charge" dates as far back as the Roman times, when free admission to the circus and the theatres was gained by the presentation of a carved death's head furnished by the authorities.

THE CIPHER MESSAGE.

In the above message it will be noticed that the amount to be paid is indicated by words without meaning to the outsider; and it concludes with "Vigilant," which is understood to mean "identification is required." The "transfer" is, therefore, in part a cipher — a form of message much in favor among patrons of the telegraph. It involves the representation of a word or phrase by a word arbitrarily chosen, and therefore understood only by those concerned; and this is very nearly the dictionary definition of the word "cipher" used in the sense of a secret writing. Its use in telegraphy serves the double purpose of economy and secrecy; and incidentally some forms of it greatly tax the patience of the operator. As the meaning of the cipher is the concern only of the correspondents, there may be as many systems as there are patrons; but among business men the phrases in common use became so numerous that cipher-making itself became a business. At the present time quite a number of systems are in use; so that, to carry on a secret telegraphy, the patron needs only to buy two copies of any preferred code — one for himself, and one for his correspondent. As the words representing the different phrases are generally chosen arbitrarily, any number of English words chosen at random might be taken to form the text of a "cipher" message. But portions of two or three with fictitious addresses, are here given to bring the learner into touch with the reality.

B67 Ha Ks 10 Paid

New York, June 19

L. M. Hazeltine,

Boulder, Col.

Metemperic entire peasoup velvetleaf bondmaid eighteen birthsongs thalarctos each periwig.

(sig) Alpha.

B68 Pq An 11 Collect

North Adams, Mass. June 21

C. K. Thurber & Co.

New York.

Admixed unaided unbias aleak unapplied fetch andiron marauding maroon hairpin.

(sig) E. M. Seymour.

In this last, as in all messages similarly checked, the word "collect" is counted. Of the more difficult forms of cipher that in use by the large business houses of the West furnishes two examples:

C18 Mo Ns 20 Paid

Kansas City, Mo. June 21

L. M. Wetstein,

New York.

Molucris morbescunt desque cow dexterous demulsion facial gildos holzstoss hoodwink hymnifero hamaux marandara vetader no vetachtig motandos fatichera komplot salami.

(sig) Roburn.

D21 Aj So 15 Collect

Indianapolis, Ind. June 24

R. A. Clarkson,

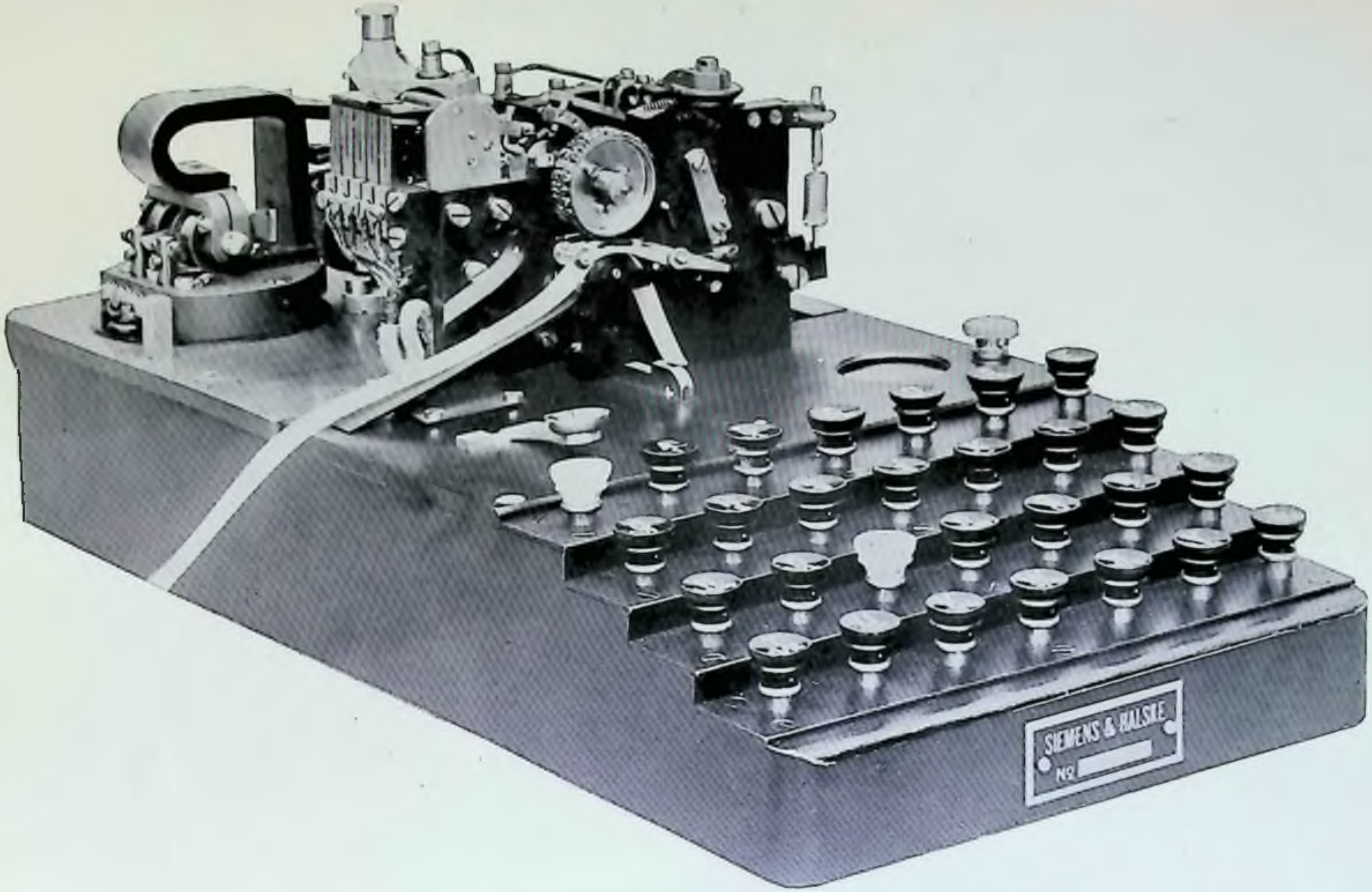
Middletown, N. Y.

Asander unbespeak umsetzbar unbeing boneless maragnon monarch cervelat disallowed each car alamoth arrodeth absorb.

(sig) Schievelin.

Quite commonly these messages contain several hundred words, and no knowledge of English or of any other language is of much aid to the receiving operator; he must watch for each letter, and pen or typewrite the signals as they arrive. It should be apparent at a glance what an indispensable aid to this work the typewriter is. By means of it these unintelligible words are copied in a manner that makes them unmistakable to the reader, and the receiver has no need to resort to the old expedient of "writing in" the Morse characters under the letters imperfectly formed by the pen.

The Cable Message. The high tolls charged for cable service makes the use of cipher in their composition very common. The address and signature of each message is counted, and the former is often transmitted as a cipher word, which is duly registered for reference when needed; for instance, Havicam, London, might stand for Haviland, Campbell & Co., at any address in that city they chose to give. A single example only of a cable message need be given, as the one form is quite generally followed.



SIEMENS & HALSKE PRINTING TELEGRAPH
Showing the Sending Device.

52 Yv Kn Duluth 10
Richfig.
Rotterdam.
Ascanilota apilatori makobojoss Koln luhoto
schizandra pythao (sig) Blockland.

Several of the words, it will be noticed, contain just ten letters. This is the permissable limit for one word; if exceeded, the word is counted as two, except in case of the destination, as Constantinople. The correct handling of cables involves many matters of detail in regard to the "count" which requires some little practice to master properly.

A unique form of cipher deserving of mention here, makes a message to consist entirely of groups of figures, usually five in a group and in this form: 17641, 75689, 84356, 09543, and so on through hundreds of groups. For the nought beginning the last group the signals for TW — dash, dot, dash, dash — are sometimes used. This form of cipher seems to be much used in correspond ence between the different governments and their representatives and agents.

The circular message, as its name indicates, has a number of addresses with a common text, or body. For this form the senders generally avail themselves of the night-rate service. Except for the plurality of the addresses, each one of which in sending is separately numbered, it does not usually differ in form from the ordinary message.

The "C N. D." The Commercial News Department message is as unique in appearance as it is different in form from the others. The department is an agency for systemized and detailed advice in matters of commercial interest as they transpire in the different exchanges, and in sporting matters to individual patrons and customers. For transmission by the operator the message is usually written either on a pink blank or on a sheet of yellow manifold. One such, picked up at random, reads: "Add Charleston. Quiet $8\frac{3}{4}$ Sales 50 . . . 2.31" This is a quotation of cotton, and the time when written takes the place of the signature. Another reads:

"Detroit close 2.25

"Dw 84b Red & m 81 N 76 U $75\frac{1}{2}$ . . . 1.15"

To the initiated this means: Cash wheat 84 bid; Red and mixed 81 July 76 September 75½. 1.15 is the Detroit time; 2.25 is the time received in New York. Another, addressed to a summer hotel on Long Island, reads:

"Stocks A81⅝; St 175; MP109⅝; USS37⅞; U 105 . . . 10.16 A.M.," in which A stands for Atchison, Topeka and Santa Fé; St for St. Paul, and so on through the list.

These brief examples give the merest hint of the traffic of this elaborate system; and so diversified are its forms it takes weeks and in some cases months of training to make even a skilled operator master of the service.

The Marine Message. The natural interest of the friends of those at sea in the sighting of their ships, and their desire to know the probable time of their arrival at the dock in New York, led to the organization of the Marine Department, which, on payment of a certain sum, furnishes the information in the following form:

Marine Department, New York, June 2.

George Homer, 351 West 14th St., New York.

Steamer "Columbia" will arrive, unless detained at quarantine, about 6.30 P.M. (Sig.) Manager Marine Department.

This service is almost as old as the telegraph itself, and it remains to be seen how far the wireless system will modify it. It is certainly in this direction that the latter system should first make itself felt.

Of the railway D. H. a short example has already been given as one of the three specimens of the ordinary message. Its marks are the use of initials and groups of figures in which each digit is counted as a word. They are frequently of great length, and require some care in copying in order not to lose the count.

Abbreviated Telegraphy. A notable development of the art in connection with the fast-speed press work involves the use of abbreviations according to a system, and is known among the craft as Code Telegraphy. It was always more or less the custom among press operators to abbreviate familiar and frequently recurring words and phrases when sending to experienced mates; but the introduction of the typewriter gave such impetus to the art that a codified Morse, at the present time, is not far behind the speed of ordinary speech. Beginning with the Morse alphabet, figures and ordinary punctuation marks, the code system first provides an extended system of punctuation covering all the characters and marks that commonly occur in print, as follows: (See page 34.)

For an apostrophe the signal is the same as that given in this

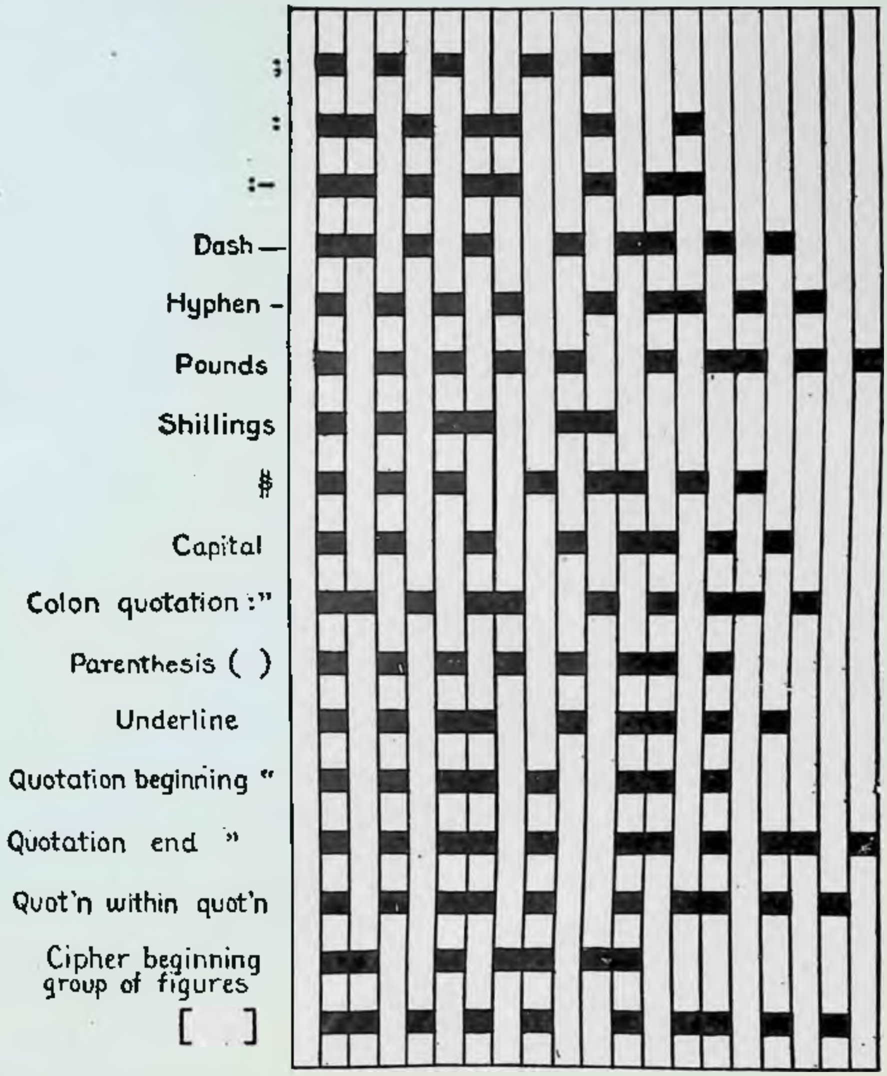


chart for quotation within a quotation; a parenthesis begins with Pn, and ends with Pq; a fraction, as $\frac{3}{4}$, is transmitted 3e4; a decimal, as 89.92, 89dot92; omitted words are indicated by a series of **x**'s; and in sending one or more lines of verse a paragraph mark (– – – –) closes each line.

The system in general use among operators is the Phillips Code, from its inventor, Mr. Walter P. Phillips, general manager of the United Press; and in its arrangement it advances of course from the simple to the complex. Single letters are first made to represent common words and phrases: B, be; C, see; F, of the, K, out of the; Q, on the; and so on through a list that need not be reproduced here, because the entire code can be purchased in book form and contains, besides the code itself, hints for the memorizing and proper use of it. The single letter list is followed by the two-letter and three-letter contractions; and the learner will think it is a far cry from the jog trot of the ordinary text to such expedients as "fap" for "filed a petition," "sak" for "shot and killed," and "sbl" for "struck by lightning." The typewriter alone makes the use of such abbreviations possible. In order that beginners may catch the spirit of the system, the following exercise is written in the code text and then given in full:

"Bt Lafa Plc is smhw Lafa Plc stil. Its trnsfmatn into chp lodgmts is gradl tho su. T sieg gos stedly on, bt t bsiegd hv n yet sucmbd. Ey y t hansm cariags tt rol up & dwn its aves gro fuer and fuer si ey y its pavmts worn bi t fet o ded & gon Nikrbokrs r m fqd bi shaby Germns or slatrnly Italns."

"But Lafayette Place is somehow Lafayette Place still. Its transformation into cheap lodgments is gradual though sure. The siege goes steadily on, but the besieged have not yet succumbed. Every year the handsome carriages that roll up and down its avenues grow fewer and fewer; every year its pavements, worn by the feet of dead and gone Knickerbockers, are more frequented by shabby Germans or slatternly Italians."

Messages for Practice. To extend the student's practice, and further to familiarize him with the appearance and wording of the different forms of messages, the following specimens have been selected. They are arranged promiscuously, so as to afford exercise in naming the different kinds; attention should also be given to the different ways of counting in cable, government, collect messages, etc.

A116P Hk Wn 18 Free.

Portland Me. 27

J. E. Bierhardt, Transfer Agent,

Rome, N. Y.

Pay W. L. Dumont, Arion Club, Central Hotel, Rome N. Y. Japan Alms, Indent from Abner Gaylord, Portland. Caution.
(sig) Wm. Ellerby, T. A.

57 Av Uc 20 Collect
Tb Hartford Conn 4
Adam Mason & Co.,
Ottumwa, Iowa.

Manifoldly mensural parks nacrite distrust nacori crying nai- medium mensural nalubu monitory treble namesake monk rudeness Naaman tourmaline, Hawaii
(sig) H. M. Allen & Co.

158N X Rs 17 Paid
Norfolk Va. 4
Chandler Elevating Co.
Great Bend Ind.

Skeptic W. H. McAlpin border route Norfolk western on tantrum tread affording chuckling offers chubby affray more
(sig) L. W. Jay & Co.

14 Wd Fr 12DH.
Marine Dep't, N. Y. 29
M. B. Goldfogle,
International Hotel, N. Y. City.

Steamer Campania will arrive, unless detained at Quarantine about 8 A. M. tomorrow.
(sig) Manager, Marine Dep't.

273 W 125th St. N. Y.
D. F. S. Delivered ok your 23 today to S. S. Cooper sined Atkinson. (sig) Phila

In this case "DFS" means destroy former service.

Danville N. J.
Yes have collected 25 cts for msg to Dickerson sined Hall
(sig) Garfield N. J.

191 Kf Gs 16 Paid 8 Extra
Str. Campania off Sagaponack L. I. Nov. 29
via New York 29

Morris, 21 Flushing Ave.
Jamaica L. I.

All well. Dock early Sunday. Don't come down
(sig) W. N. Heldman

The above resembles one received by the "Wireless" and transferred by them to land lines at New York.

133 Ro Py 22 Paid Gov't
Washington D. C. 29
Morning Register,
Dallas, Texas.

Showers Sunday warmer except on the coast; Monday fair in northwest; showers in east and south portions.

(sig) Wells.

119 Fs Ki 11 Paid
Winnipeg Man 29
Lindsay & McDonald
Valley Stream, L. I.

Offer saltcat to saltpeter scalene throe garrulity en route or gallate. (sig) Robb & Parrish.

174 Wr Ta 6 Collect.
South Bend Ind 4
Champion Beef Co.
Pine Island N. Y.

Enkindle gratefully erupt none trundle.

(sig) Baker Packing Co.

114 Gu Ps 8 Paid Night
New Orleans 29
Mrs. S. Dorner, 118 West 119 St
New York.

Will be home Monday afternoon. Tell Ella. Love.

(sig) Joe.

128 F Kn Cable
Havana 6
Hammond,
Calumet (Mich)

Candelabra domiseda 780 calefying.

In the above, the State in parenthesis is supplied by the land line clerk, and is not counted; the group of figures is one word.

193 Yv Wr 12 Paid Repeat back
Philadelphia 31
R. B. Dignam
New Orleans.

Elmpole arundelian bags parable admit actuality rampallian Halpen aliped bags. (sig) C. Emslie & Co.

In this case the words "repeat back" are counted and charged.

. . .   .   7 Paid Charge
Newark N. J. 29
Adams Ilich & Co. Memphis Tenn.
A. N. Harriman Louisville Ky.
F. J. Farjeon Mobile Ala.
Walter N. Davis St Louis Mo.
No reds; best Jerseys eight twenty five.
(sig) C. W. Allison.

In transmitting messages like the above each operator numbers and times the address of the one which goes on his particular wire; then passes it on to another and so on until all, sometimes scores in number, have been sent.

To Albany N. Y. Dec. 15
B33 487½
34 484 (sig) 10.18

To Salida Colo.
N. Y. Metal Ex. Pig lead 412½
London Silver 22⅜ (sig) 9.10

To New Orleans and Mobile.
C. Adam
31 – 99 – 30 (Sig) 11.43

174 Ro Fc 44 DH
Bridgeport Conn 29
Agent L. S. RR. Co.
Cleveland Ohio.
From Paterson to Cleveland June 1st in D L car 27052 one case brass tubes number 2596 consigned Schneider & Fenkamp covered by Lackawanna line waybill 2774 advise date arrival and delivery quick. (sig) R. J. Camp

By way of introduction to the next topic—Railway Telegraphy—the above series of specimen messages concludes with one more example of a railway DH.

37 Av Ty 36 DH
Springfield Mass 20
E. H. Palmer,
Buffalo, N. Y.

File W, Adams to East Buffalo Wb 111 Dec 8 Christmas trees for D. H. Croley Dunkirk N. Y. deld N. Y. C Dec. 9 on B & A 2718. Please advise delivery. Rush.

(sig) H. C. McCarthy.

Railway Telegraphy. It is well known that the first telegraph line built in the United States was intended for commercial work; but the new art had not long to wait before it was enlisted in the service of the railway. Along their right of way the latter erected poles for the accommodation of their wires to which the commercial companies soon made additions; and, except in the larger towns and cities, one man usually did the work of both. As railways extended and towns multiplied, the work of the latter differentiated from that of the former so that today there are two well defined divisions in the craft; interchange going on between them, however, all the time.

In many places even yet by agreement between companies the railway operator covers the service for the commercial; the latter likewise transmits in great numbers over its wires the service messages of the railway, examples of which have just been given. As compared with these, the student will find that the railway message usually takes an ampler form, more nearly approaching that of a letter. In railway work all messages are "service," and concern the movement of freight and passenger traffic, and the dispatching of trains. All the stock phrases in use are shortened; initials, figures, and abbreviations occur in nearly every line; the "count" which serves as a safeguard to the commercial operator is dispensed with, so that there is all the more need for the operator to be on his guard against omissions.

Again, mention was made in connection with commercial messages of the use of *forms* for races, games, and the like; in railway service this is a marked feature, their number in the case of some leading railways exceeding one hundred.

Then, thirdly, in connection with the purely telegraphic part of the service is the very important work of handling the train orders; first as received from the dispatcher, and then repeated back with the signatures of the recipients.

On a single track railway a crossing order, at one time, commonly ran thus:—

To Conductor and Driver Train No. 21. . . . .
Train twenty-one will meet and pass Special Freight, Conductor Holmes at 31
(sig) H. M. Wallace.

H. M. Wallace . . . .
32 Train twenty-one will meet, etc.
(sig) Conductor and Driver.

More recent usage however is indicated by the following forms; in connection with which it may be premised that the aim is simply to acquaint the student and prospective railway operator with the forms of the messages he will be called upon to handle; but, in order to make them intelligible, some details of the train despatcher's work must accompany them. This can be set down as consisting, for the most part, of (1) orders fixing meeting points for trains; (2) fixing the point for one train to pass and run ahead of another; (3) giving a train the right over an opposing train; (4) giving regular trains the right over a specified train; (5) providing for the use of a section of double track as single track; (6) providing for a single movement against the current of traffic on double track. Then there are (7) time orders; (8) orders for sections; (9) for extra trains; (10) for work extras, or auxiliaries; (11) holding orders; (12) orders annulling or cancelling a regular train; (13) annulling an order or part of an order; and, (14) orders superseding an order, or part of an order.

From the list of train movement forms thus indicated, some of the more important, viz., the first, second, fifth, eighth, ninth items are selected for illustration; the names chosen for the stations are fictitious; but the forms are those in actual use on some of the leading trunk lines.

Suppose a single track, of which Balmain and Allaire are terminals; Eden and Canton are intermediate stations. Train 334 going south is late; it is desired to advance on its time train 331 going north, Eden being the regular meeting place. The despatcher calls up Balmain, Allaire, and Eden and sends the following; C and E being the stereotyped abbreviation for Conductor and Engineer:

31 No. . . Operator, Eden.
31 No . . . . C & E No. 334, Allaire.
31 No. . . . C & E No. 331, Balmain.

No. 331 has right of track from Eden to Canton
sig W. L. D. Sup't.

Each operator copying this message must repeat it back to the despatcher, and each one must listen to its repetition by the others.

Another form of crossing order for two trains, one at Eden the other at Balmain, would run thus:

31 No..... C & E No. 332 Eden.
31 No..... C & E No. 329 Balmain.
No. 332 and 329 will meet at Carrolton.

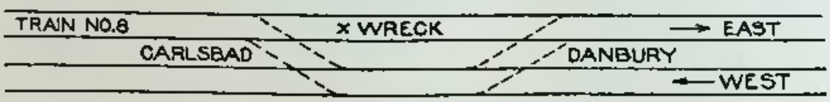
In this and the examples to follow a signature is taken for granted.

For the next movement, viz., the passing of one train by another, the procedure is less formal. It is desired that train 601 should allow No. 1 to pass. In this instance the co-operation of the signal towers, having control of the switches and side-tracks, is enlisted. The despatcher calls up the tower, say at Breslin, and tells the operator that train 601 is next to him, and that he is to side-track it for No. 1. The next tower beyond, say Ashley, is then notified that 601 is in the siding at Breslin for No. 1, so that he may know which train to look for first. Or, the passing may be arranged for in a formal manner:

31 No..... C & E Extra 594, Breslin.
31 No.. .. C & E No. 6, Breslin.
Extra 594 will run ahead of No. 6 Breslin to Dexter.

In this case the speed of No. 6 must not exceed that of Extra 594 between the points named.

The fifth item presupposes the blockade of one of the two tracks by a wreck—an incident by no means exceptional; the situation being indicated in the cut:—



The station next east of Danbury is Berber. The procedure is then:—

31 No..... C & E all west bound trains, Berber.
31 No..... C & E all west bound trains, Danbury.
31 No..... C & E Train No. 8, Carlsbad.

No. 8 Engine 914 will use west bound track from Carlsbad to Danbury; and has right of track over all west bound trains.

This message is repeated back by all three stations; and under its provisions no west bound trains can pass Danbury until No. 8, Engine 914, has passed east.

During the summer season it is a common incident of the despatcher's work to be called upon to divide into sections trains that, by the addition of extra coaches, have become too heavy for one engine. The two, and sometimes three, sections must be so protected one by the other that, so far as their right of way is concerned, they are substantially one train. Let us suppose train No. 8 at Corbin, going east, has too many coaches for one engine

31 No..... C & E No. 8, Corbin.
No. 8 will carry signals from Corbin to Jersey City for Engine 672.

Engine 672 then takes the second section, and proceeds to its destination under protection of the signal. If a third section is necessary a message similar to the foregoing would be addressed:

31 No..... C & E second section No. 8 engine 672.

A third engine named in this message then proceeds under the protection of the foregoing with a third section of the train.

The above is the method of procedure in case the need for the third section did not appear until after the first section had left Corbin. Otherwise the division into three sections would take this form:

31 No..... C & E Engines 671, 672, 891, Corbin.
Engines 671, 672, 891 will run as first, second, and third section of No. 8 from Corbin to Jersey City.

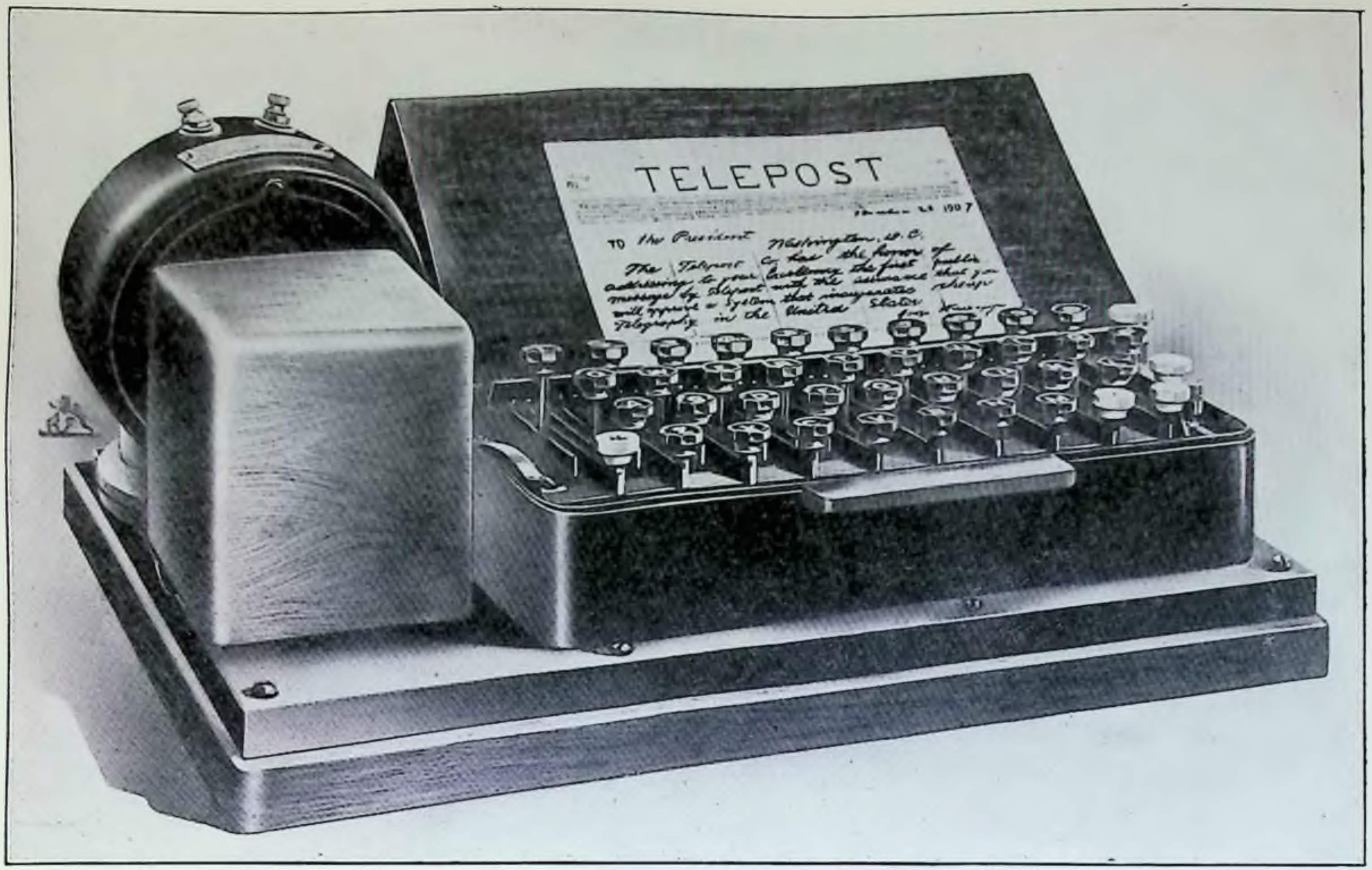
This form implies the carrying of signals, one for the other, as prescribed by rule; and trains carrying such signals are regarded by other parts of the running service as practically one train.

For the starting of extra trains the signal "19" is used instead of "31" and the order runs thus:

19 No..... C & E Engine 587, Jersey City.
Engine 587 will run extra from Jersey City to Berber

If a regular train is late, and it is desired to give this extra a right to the time of the regular, it is done by inserting in the above message " No. 3 will run 30 minutes late from Jersey City to Berber." All these orders are copied on manifold paper; one copy is furnished to the conductor, another to the driver, while a third is filed by the operator for his guidance and future reference These examples could be multiplied indefinitely, but it is believed these citations are sufficient to indicate to the learner the kind of service expected of the railway operator in co-operation with the work of the train despatcher.

MARCONI WIRELESS TELEGRAPH STATION AT SEA GATE, N. Y.



TELEPOST AUTOMATIC PRINTING TELEGRAPH SENDING DEVICE
Showing First Public Message by "Telepost."

THE ELECTRIC TELEGRAPH.

PART II.

The principal topics considered in Part I, were the "learner's outfit"; the "one-wire" office with its relay, key, sounder, and local circuit; and the switchboard for the cutting in and out of instruments, and the cross-connection of wires. There are scores of such offices, called branches, in the larger cities; and every town throughout the land has at least one.

An advance is now made to the more complex equipment of a junction station, or town office, to which a score or more of wires converge, and from which they radiate in all directions.

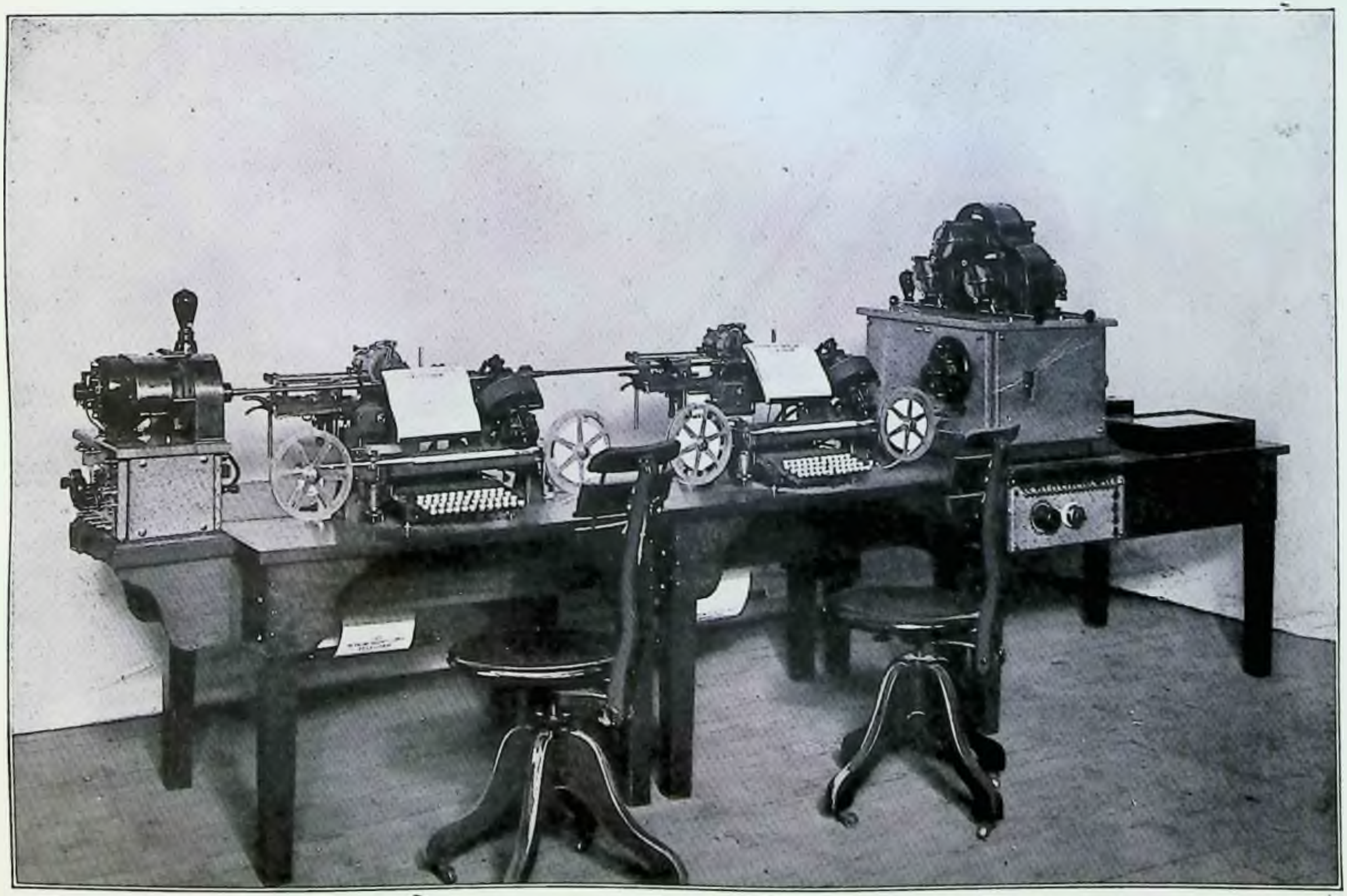
Instead of a "one-wire" set, there may now be noticed on the desks or tables, six, eight, or ten relays and keys; the sounders, possibly less in number than the relays, are operated by a current furnished by storage cells to which energy is supplied by an electric light circuit. The clock on the wall is probably of the "electric" pattern with two Leclanche cells inside. On a shelf are probably two or three sets of apparatus called repeaters; on another table are the duplexes or, it may be a quadruplex, whose principles and manner of operation need careful consideration; and in place of the diminutive single-wire switch of the city branch, or country office, is its more ambitious counterpart with fittings for some thirty, forty, or fifty wires. The handling and care of such a plant calls for skill and experience to which many a commercial operator, doing the work merely of a sender and receiver, is a stranger.

A consideration of the apparatus and methods of work in this larger office is the purpose of this paper; and the apparatus first to be studied is the switchboard. The one shown in Part I is a "single-wire intermediate"; but to accommodate the thirty or more wires now in view a greatly enlarged form is needed. The description of the small switchboard should be re-read, noting that in an intermediate switch two vertical strips are needed for a wire; that is, one strip for each direction of the wire, say north and south; in the switch of a terminal office a wire occupies only one strip.

Of the former class a common pattern is shown in Fig. 9; the diagram representing three pairs of strips out of a 50-strip switch for the accommodation of 23 wires; the gap in the middle represents 19 omitted pairs; the pair on the extreme right has a special use which will be explained later. In all respects the numbers on the small switch shown in Fig. 8, Part I, have been duplicated, except that the top row of discs is reserved for the ground wire; and for a review we shall go over, on this larger board, all the steps taken in connection with the smaller one.

In Fig. 9 the strips are numbered, for convenience, at the lower end from left to right; the disc rows are indicated by the figures down the center. In some patterns of boards the strips are so shaped at the bottom that to join them up in pairs a peg can be inserted. The switch is supposed to be at a station intermediate between Cincinnati and Chicago; strips 3 and 4 accommodate wire 1 South and 1 North respectively; strips 5 and 6, wire 2 South and 2 North; and so on. Disc rows 4 and 5 are connected on the left with one set of instruments; rows 6 and 7 with another set. In the drawing they are shown close to the board, but in practice the instruments are usually at some distance from the board on a desk to which the connections are made by means of office wire. Suppose, first, that the instruments are to be "cut out". Connect with a peg, strip 3 and disc 3; and strip 4 with the same disc 3; wire 1 has now no connection with either instrument, the current simply crosses on the disc from strip to strip. Move the peg in strip 3 to strip 3 disc 4; there is now no connection between disc rows 3 and 4, and the circuit in wire No. 1 is broken. Move the peg in disc 3 strip 4 to disc 5 strip 4; the current in wire 1 will pass through the relay and key connected up to disc rows 4 and 5; and the instruments are now said to be "cut in". In this larger board the ground wire occupies the top disc row, instead of the bottom, so that the discs marked 6 can be used the same as any other numbered row.

Reverting now to the changes indicated in Part I, page 25; for the sake of practice, move the peg from strip, or bar, 3 disc 4 to bar 3 disc G; and the peg from bar 4 disc 5 to bar 4 disc G; the wire from each direction is grounded. There are now two independent circuits each with a battery at one terminal only; Cincin-



FRONT VIEW OF ROWLAND STANDARD QUADRUPLEX TELEGRAPH INSTRUMENT
Line-Unit on Table at Right; Two Correspondence-Units on Table at Left. This Photograph Serves to Show Transmitter and Home Recorder.

nati and Chicago are cut off one from the other; the way-station instruments also are cut out. In order to "cut in" on the south section of wire No. 1, remove the peg from bar 3 disc G and insert it in bar 3 disc 5; put a peg in bar 1 disc 4, and another in

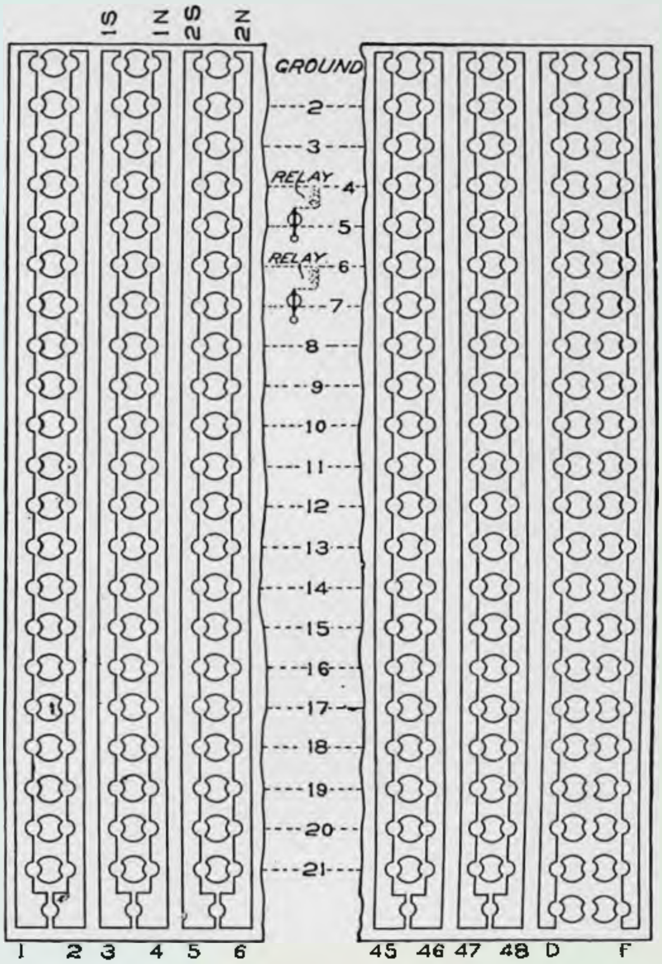


Fig. 9.

bar 1 disc G. The current from Cincinnati must now pass through the relay and key at the side of the switchboard before reaching the ground at bar 1 disc G. The peg having been restored to bar 3 disc G, the same set of instruments, or a different set connecting with disc rows 6 and 7, can, in a similar manner, be cut in on the north section. Restore the pegs to bars 3 and 4 disc 3, and the terminals Cincinnati and Chicago can now work with each other, but neither of the instruments at the side of the switchboard is in the circuit.

The letters D F on the extreme right hand of Fig. 9 stand for the words "double flip"—a device more commonly used in a terminal than in an intermediate office; but it may as well be explained here. In a board like that in Fig. 9, whether terminal or intermediate, each strip has underneath it a "flip", or spring-jack for the insertion of a wedge; usually the pairs of strips on the extreme left and right are set apart and joined in pairs by a wire behind the board. Strips 49 and 50 are practically one bar with two flips at the lower end—hence the name. A board like that in Fig. 9 is often part of a larger system; it may have a similar section on the right and left. The "double flip" enables the switch operator to desk and furnish battery to a wire coming in on another section, by running along on one of the disc rows. The twin discs shown in Fig. 9 have reference also to the presence of a companion section on the right-hand side; in such a case the discs on the extreme right of Fig. 9, row for row, would be connected with it; and, by inserting a peg between the twin discs, rows of like number in the separate sections may be joined, making them continuous across as many sections as desired.

Besides the cutting in and out of his own instruments, it is one of the duties of the intermediate station operator correctly to cross-connect wires at the request of the wire chiefs. He may be asked, for instance, to connect 1 North to 2 South, and 2 North to 1 South. Remove the pegs from bar 3 disc 3, and bar 4 disc 3. Peg bar 4 disc 2; bar 5 disc 2. Peg bar 6 disc 3; bar 3 disc 3. The current on 1 North crosses disc 2 to 2 South; the current on 1 South crosses disc 3 to 2 North. While this cross-connection stands, care must be taken to connect no other wires on either of the disc rows 2 or 3. The test station may have instruments, as shown in Fig. 9, connected up to disc rows 6 and 7. If it is desired to put this instrument in circuit on the wire 2 North to 1 South, remove the pegs from bar 6 disc 3, and from bar 3 disc 3. Peg bar 6 disc 6, and bar 3 disc 7. To facilitate the correct tracing of the different disc rows, it is common to alternate four rows of specially marked discs with four plain ones. To make any cross-connections and combinations of wires that may be needed, the operator needs only to get clearly before him the relation of bars and discs one to the other, remembering that the several rows of discs have no connection with each other or with the bars except by means of pegs.

Recent Form of Switchboard. The pattern shown in Fig. 9, although in very general use, has some defects for which a remedy is sought by a change of form. The connections for "in" and "out" on the top side only of the board require two strips to a wire—an arrangement which is wasteful of space. There has recently been installed in a suburban test office near New York an entirely new form of switchboard for intermediate stations in which the wires pass in at one side and out at the other. A 50-wire board of this pattern is seven feet in height, and thirty-three inches in width. The lower part resembles somewhat a long-distance telephone cabinet; the shelf is thirty inches from the floor, and the

Fig. 10.

space underneath is taken up with the slack of the cords. On top of the cabinet are strips, like that shown in Fig. 10, placed one above the other to the number of say fifty, supported at the corners by four vertical bars of angle iron resting on the floor. The strips are of wood, one inch wide, each consisting of three parts. On each of the end parts are a fuse and carbon plate lightning arrester; in the middle part are four holes, A, B, C, D, for type jacks, and three discs. Between the holes for the type jacks is a tag for marking: the wires in the drawing are 1 West and 1 East. Extending up both sides of the switch are the wires contained in cables, parting with their conductors one by one and making connections with the fuses at each end of the strip.

The middle portion of each strip is ten inches long; and a side elevation is shown in Fig. 11. The four type jacks are connected in series as represented; between the two inner ones are three discs—the middle one grounded; a peg inserted on one side or the other of the center disc will ground the wire in the direction desired. The inner pair of jacks is for patching. In building up the switchboard the strip next above the one shown would be 2 West and 2 East. Each cord is fitted with an automatic slack take-up, as shown, and cross-connections are made by means of single cords and connection plugs F and H. To cross-connect 1 East to 2 West it is only required to place one of the plugs F in the patching jack marked 1 East, and the other plug H in the jack 2 West. In the diagram 1 West appears grounded by means

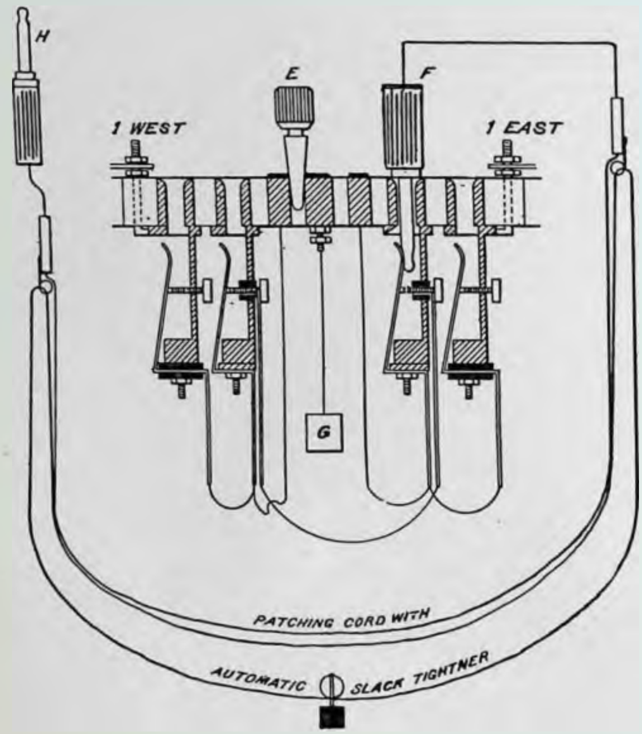


Fig. 11.

of peg E The outside pair of jacks is used for inserting loops; also to cut in test and desk instruments. The disadvantage in this form of switchboard is that the continuity of the wire depends on the perfect contact of the four springs with the pins behind them.

Figs. 10, 11, 12 and 13 are from a "Pocket Edition of Diagrams" by Willis H. Jones. They are reproduced through the courtesy of the publisher of *The Telegraph Age.*

An inspection of the diagrams in Part I yields a fair inference that each relay must have its own sounder; but the opening lines of this paper in which it is said that the sounders, possibly less in number than the relays, are operated by a storage current, hint at a departure from this rule. In former days the telegrapher sometimes made his first efforts at invention in a plan to economize, by making one sounder do duty, at different times, for three or more relays. But the field of devices for locals is well covered

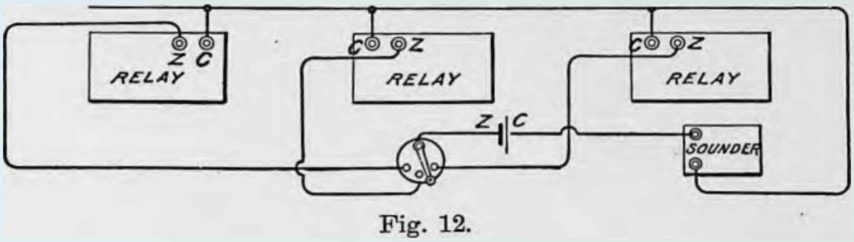


Fig. 12.

now; one of the results is shown in Fig. 12 which represents an arrangement of circuits in which one sounder can, by means of a switch, be worked in connection with three relays. The diagram needs no description, but the connections should be traced in each case; the lever resting on the right, middle, or left points cuts in the corresponding relays, in each case forming an independent local circuit. At junction stations, where passing trains are likely to make considerable noise, one sounder may be insufficient; in this

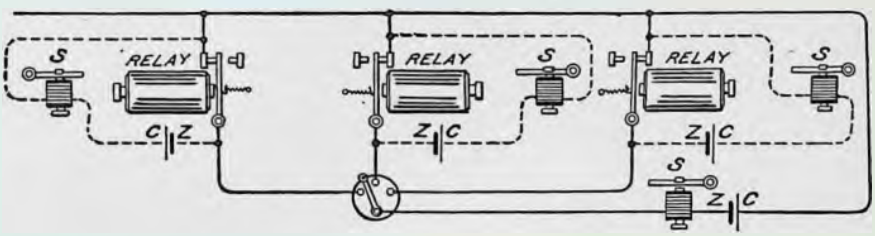


Fig. 13.

case an extra one with a local circuit of its own is sometimes provided. In Fig. 13 is shown how such an additional common sounder may be used in connection with three different circuits, each sounder having a battery of its own.

For local systems of this kind the form of battery most commonly used is that shown in "Elements of Electricity", called the Daniell, or "blue-stone", cell. Better still is the modification of it shown in the same paper known as the "gravity" cell in which the zincs can be so fitted, one into the other, that no portion of that metal needs to be thrown away or wasted. But not even the local battery system has escaped the spirit of change; and in many recently-equipped offices the zinc and copper type has been replaced by the storage cell, so called. The name implies the giving out of a current derived from another source—generally a dynamo—but the idea requires some modification, as will appear later on.

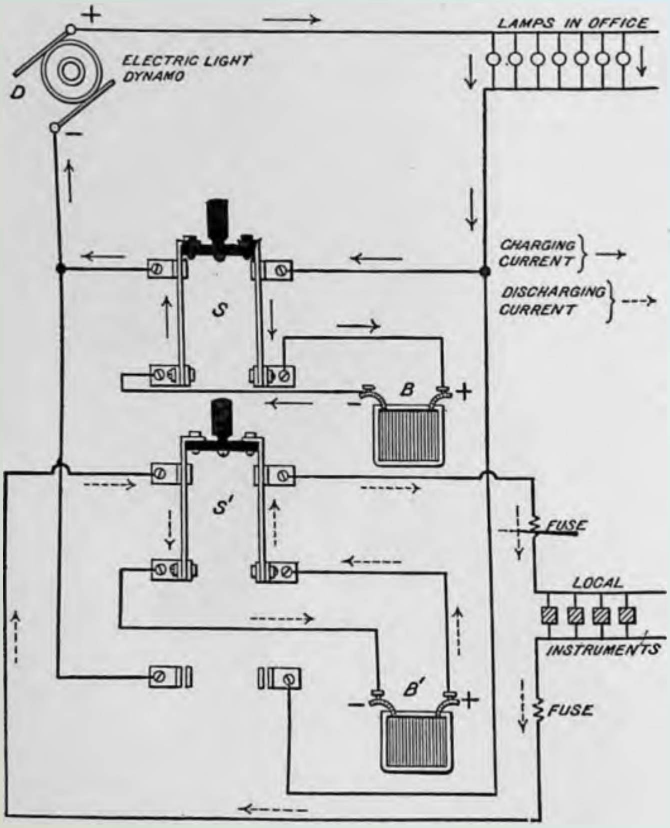


Fig. 14.

In Fig. 14 is shown a storage cell system fed by a dynamo which is also the source of energy for an electric-light plant. There are two storage cells, one of which, B Fig. 14, is in the same circuit with, and receives the current in the same manner as, the lamps. The other cell, B′, is disconnected for the time being from the dynamo, and is represented as supplying the current for a number of sounders arranged in multiple on the lower right. It will be apparent on examination that the method of connecting up the lamps in one circuit and the sounders in the other is the same.

In the opening paragraphs of "The Electric Current" the student has learned something of the laws of resistance. His attention is called at this point to the difference between the series and multiple arrangement of sounders. In the former, the resistance in ohms offered by the coils is the resistance of one sounder *multiplied* by the number of sounders; in the multiple system it is the resistance of one sounder *divided* by the number. A pair of knife switches, S and S′, shown in Fig. 14, is the means by which storage cell B,′ when it is exhausted, can be cut in on the same circuit with the lamps; its place in operating the sounders is then taken by the freshly charged cell B. In Fig. 15 the construction and action of the double knife switch is clearly shown. When turned from the position they hold in the diagram they make a new series of connections with the result already indicated.

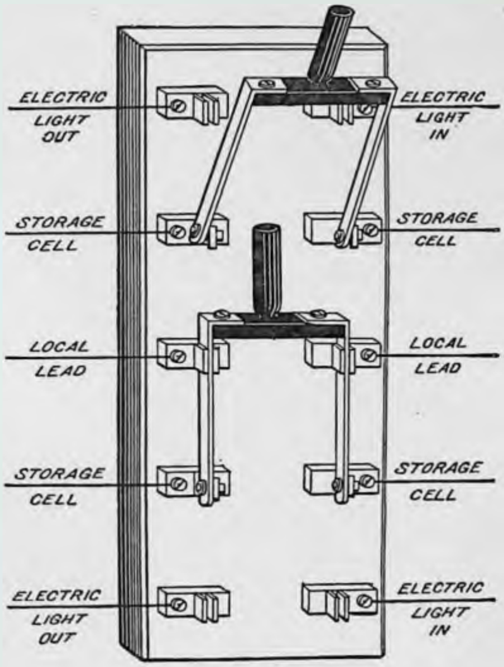


Fig. 15.

The Dynamo in Telegraphy. Within little more than a quarter of a century this appliance, regarded at first somewhat as a curiosity, has advanced to the place of an indispensable and well-nigh omnipresent help in the mechanical and technical world. In countless shops and factories its familiar hum and vari-colored sparking can be detected in out-of-the-way corners; while in power houses its more developed and, in some cases, giant form fully justifies the remark of the scientist Faraday when he saw the first dynamo in operation: "That was my child; but you have made a man of him." In the field of telegraphy its principal uses are to charge storage cells, and supply current for the main lines. In the former operation, the cell is said to be fed by the dynamo; and, as already illustrated, it is commonly carried on in combination with the supply for an electric-lighting system. The "feeding" consists of a chemical change in the cell, whose elements, when the charging ceases, give up in the form of electricity the energy thus imparted.

As the dynamo is the source of energy for the storage cell, and for the operation of the different forms of main line apparatus, the need arises for a brief statement of the principles underlying its construction. In so doing, some words and phrases not hitherto

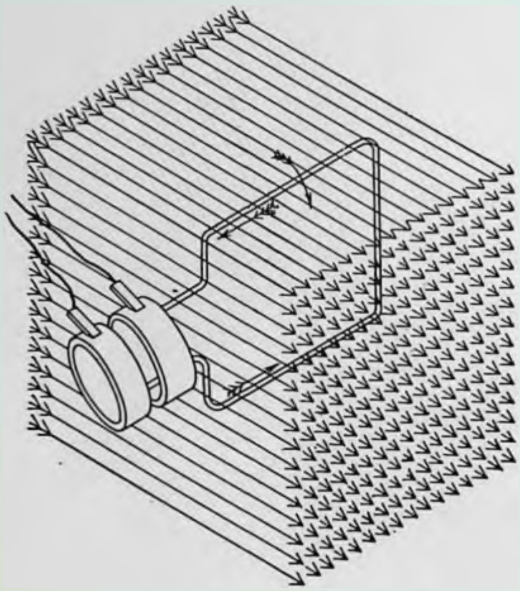


Fig. 16.

used come into view; and a definition of them, in connection with familiar forms, is first in order.

The *cores* in the electromagnet of the sounder, as the student knows, attract the armature. The free ends of the cores are the poles; and if a penknife is placed near, it is drawn towards the core with a force that increases as the distance lessens. Similarly, if a small piece of metal is held near the poles of a toy magnet in the horseshoe form, the attraction is marked. The space between the poles alike of the electromagnet and the toy magnet seems full of invisible stresses whose mechanical effect is like that of thousands of stretched rubber threads which tend constantly to contract. These stresses are called lines of force; and the space in which their influence is felt is called the field of force. These lines are inseparable from every form of magnet, permanent or electro; in the case of the earth, which is itself a great magnet, their effects are seen in the action of the magnetic needle placing itself parallel to the lines of force between the north and south poles; in the case of an ordinary magnet, the lines seem to appropriate to themselves any material which will shorten their journey through the air space; and, if the piece of metal is free to move, the lines tend to place it in the position which will shorten their pathway the most. Another, and the most common, name for the space occupied by the lines of force is the *magnetic field*. It is graphically shown in Fig. 16 in which is represented also the simplest form of dynamo. The arrows represent the lines of force between the magnetic poles; and, revolving therein, is shown a single conductor cutting the lines of force at right angles. Now comes the principle which underlies the generation of the electric current by means of the dynamo: If a closed conductor is rapidly revolved in a magnetic field an electric current is set up in the conductor. The collector rings and brushes conduct to the outside circuit the current thus generated.

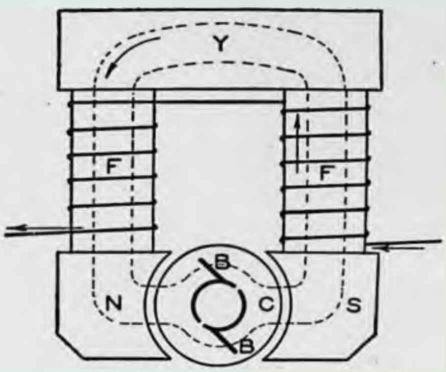


Fig. 17.

In Fig. 17 there is shown in outline form a simple dynamo; the yoke Y connects the field pieces FF, upon which are wound the field coils; the latter is charged by an external current in the direction of the arrows. In an intense magnetic field, between the pole pieces N and S, is the armature. It is made up of the core and a complete circle of conductors like the one shown in Fig. 16; a large number of conductors being needed to generate a continuous current. The conductors are made to terminate in a series of strips separated by insulating material, and bound together in a cylinder to form the commutator marked C; the collecting brushes BB correspond to the copper and zinc poles of a voltaic cell.

A gas or steam engine is usually the motive power for a dynamo; a common type is shown in Fig. 18 with the belt pulley at the left; in this form it illustrates the definition of a dynamo given in the text books as "a machine for converting mechanical energy applied at the pulley into electrical energy given off at the brushes."

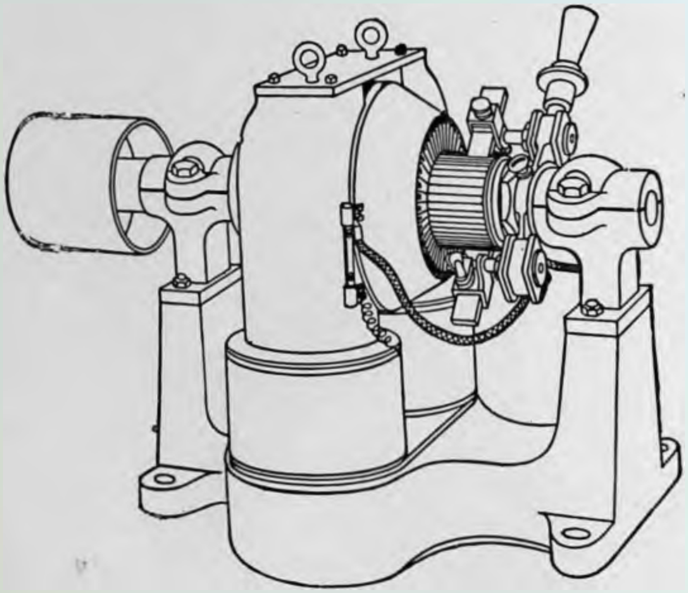


Fig. 18.

One use of the machine, namely, to furnish current for a system of local instruments, is illustrated in Fig. 14, but its more important function in telegraphy is the supply of the current for the main lines. The different circuits to be supplied may vary in length from 50 to 500 miles; and, as nearly the same quantity of current—say $\frac{1}{25}$ of an ampere—is required in each case, the voltage, or pressure, must vary accordingly.

A series of dynamos connected together upon the same principle as a series of cells in a battery is outlined in Fig. 19, showing how this may be done. One terminal of machine A is grounded, and from the connecting points of the brushes the wires 1, 2, 3, 4, and 5 are led to the horizontal rows of discs on the terminal switchboard. In practice they are commonly made a part of the larger board similar to that shown in Fig. 9; but, for the sake of clearness, it is represented here as distinct. Each vertical bar represents a main line wire; the horizontal lines are rows of discs to which are connected the wires carrying the current for distribution. In Fig. 19 wire 1, connected to one of the disc rows, furnishes 70 volts (the voltage of a Grove cell is about 1.5); wire 2, 140 volts; 3, 200 volts; 4, 260 volts; 5, 325 volts. It is necessary only to connect, with a peg, a disc and bar to supply any wire with any desired voltage. A plant of the capacity indicated in the diagram can be made to furnish current for 1,000 lines, yet its compactness is such that it may be installed in a small room.

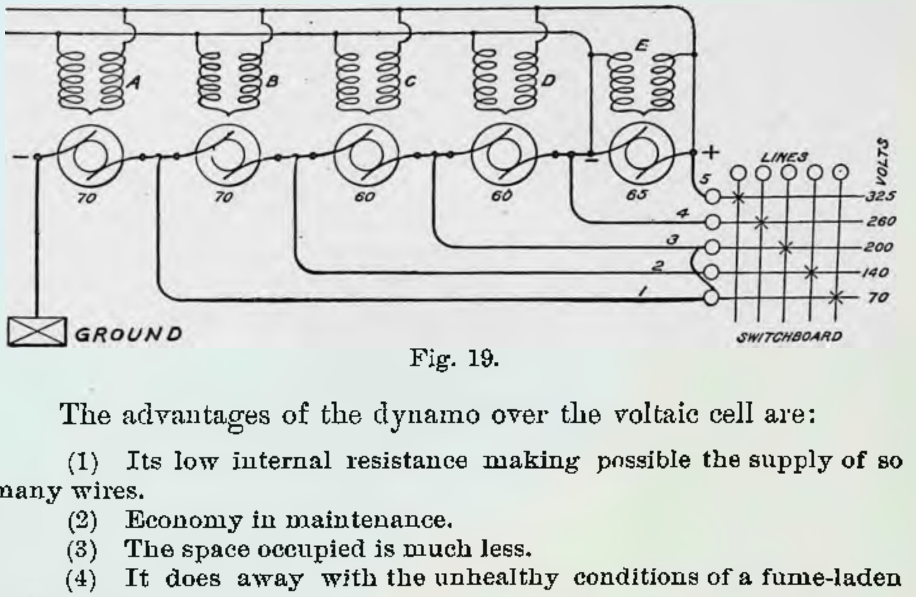


Fig. 19.

The advantages of the dynamo over the voltaic cell are:

(1) Its low internal resistance making possible the supply of so many wires.

(2) Economy in maintenance.

(3) The space occupied is much less.

(4) It does away with the unhealthy conditions of a fume-laden battery room.

The Open Circuit System. Before dealing with the topic of Single-Line Repeaters, let us discuss a system much used in England, known as the "open circuit", as distinguished from the one in general use in the United States, Canada, and Mexico, described in connection with Fig. 6, Part I. This is known as the "closed circuit", in which the circuit is first broken by opening the key switch as described, and the signals are transmitted in the manner now familiar to the student. The open circuit system is illustrated in Fig. 20; in it may be noted the difference in the connections of the key as compared with those of the American system. In the latter, as may be seen by reference to Fig. 6, Part I, the battery, key, and relay coils are in series; in the former, the ground connection divides, one branch passing through the relay coils to a point in the base of the key against which the lever carrying the main line normally rests. The other branch connects the battery to a different point of the base. It may be seen from the diagram that when both keys are making contact with the backstop there is no current on the line, and the relays are open. Depress one of

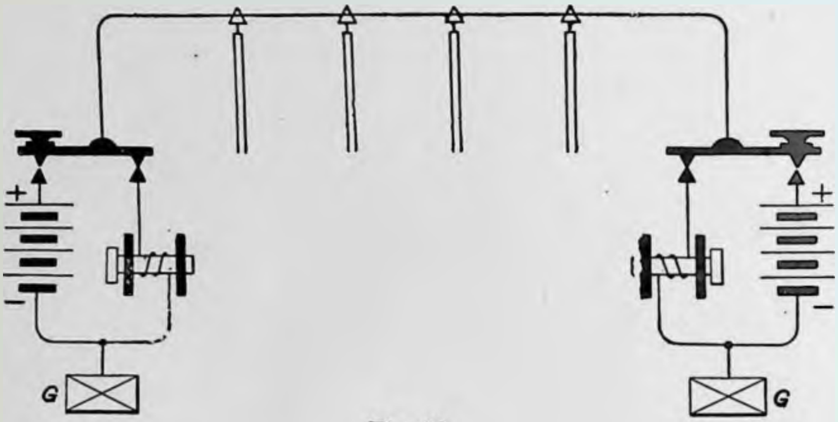


Fig. 20.

the keys and the current, passing directly to the line, closes the relay at the distant station.

In this arrangement there are two advantages over the American, or closed circuit, system:

(1) The battery is in use only when signals are transmitted.

(2) By the cutting out of the relay at the sending station the resistance of the circuit is reduced.

The disadvantages are:

(1) The operator hears his own sending on the key only.

(2) The system does not admit the cutting in of intermediate stations.

The closed circuit arrangement allows as many as twenty-five or thirty offices between terminals; and the batteries, placed one at each end of the line, are more likely to receive skilled attention.

SINGLE-LINE REPEATERS.

In the junction station, or town office, we now have in mind a set, or sets, of repeaters—an important feature in the equipment, and the one next to be considered. The limit of the Morse single line, in good weather, is ordinarily about 450 miles; it is one-half or one-third of that in rainy spells when extra repeaters are cut in. The repeater is a means by which the relay at a distant terminal of one circuit is made to operate a key in a second circuit. The distant relay of the second circuit may operate a key in a third; and so on. The circuit of say 1,500 miles has thus the advantage of batteries at needed intervals; the distance between repeaters being determined by the conditions already indicated; and it has not been found expedient to exceed very much the distance first given.

There are many different forms of repeaters; and from among the score or more that have been in use at different times selection is made of the three commonly regarded as the best—the Milliken, Atkinson, and Weiny-Phillips. The same result is attained in each, but by somewhat different means; all three are of the automatic class—so called because they permit the terminals to break without the aid of an attendant.

Fig. 21 shows the **Milliken** repeater in theory. It consists of two relays of special construction, two transmitters, two main batteries, M B, a pair of local batteries, L and L′, and a pair of extra locals. Tracing the connections of the local batteries, they are found to be wired through the local points of relays E and W, one for each; and through the coils of transmitters T and T′. The extra locals are wired through the back contacts of transmitters T and T′; and in the same circuit are the coils E′ and W′. In the construction of the relay the peculiarity is that, in combination with the electromagnet and upright armature of the ordinary relay, there is an extra magnet with a pendent, or hanging armature marked P in one and P′ in the other, Each one is so placed that, when released from its magnet, the tension of a spring forces it against the upright armature and holds the local points closed. To aid the student in tracing out the different connections the extra local circuits are marked by dot and dash lines; the local circuits by dotted lines; the main lines are in full lines. The wires marked East and West

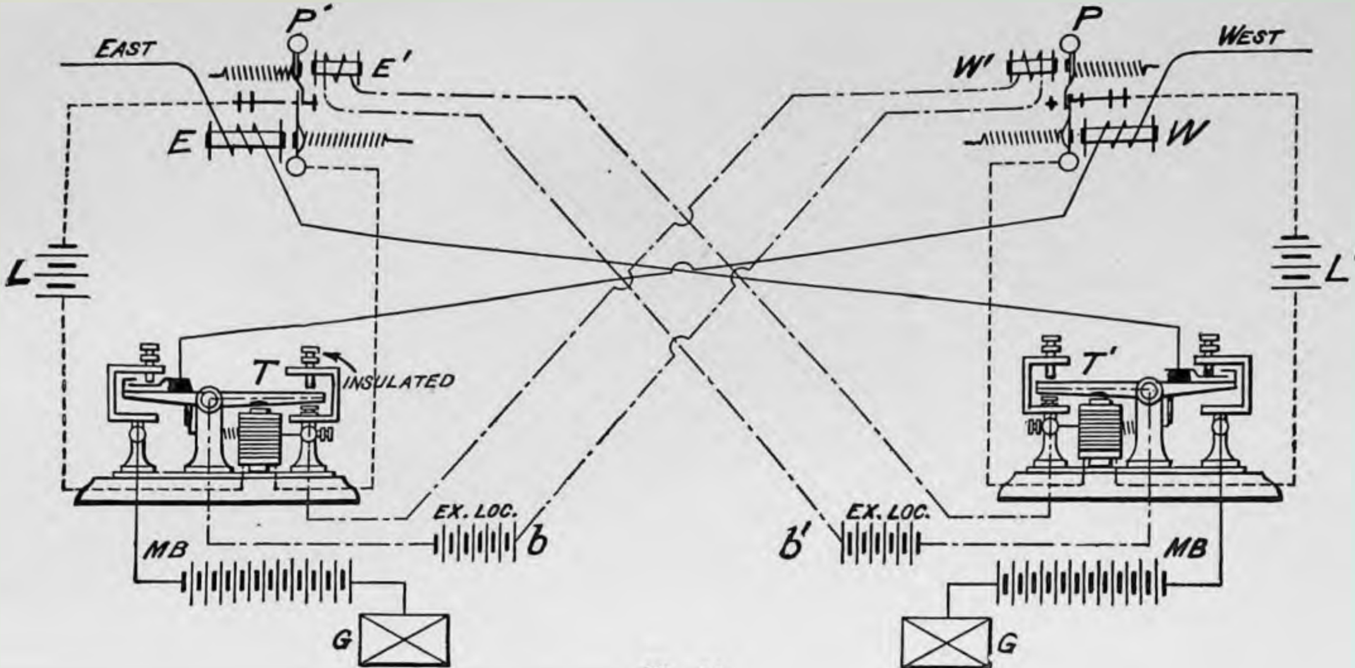


Fig. 21.

are supposed to extend in each direction to terminals, it may be, 400 miles distant. When the circuits are at rest, the armatures of the instruments are attracted by their respective cores, and are said to be closed.

Recall now the definition of a repeater, and notice in the description to follow how the transmitter in the East set acts as a key in the West wire, and *vice versa*. Suppose the distant East station opens and writes; the operator opens the local points of relay E, and this opens transmitter T; through its tongue and post passes the West wire, and it, therefore, is opened. The opening of the West wire should open relay W and transmitter T′; and the opening of transmitter T′ would open the East wire which passes through its tongue and post. But the opening of the East wire when the distant East is sending is just what the repeater is intended to prevent. When transmitter T opens, the extra magnet W′, held closed by battery *b* through the back points of the transmitter, also opens; the pendent armature P is released, falls back, and holds closed, by the tension of its spring, the upright armature of electromagnet W. This prevents the opening of transmitter T′; and the East wire is not allowed to open in the latter instrument. Transmitter T′ can be opened only by opening a key in the West wire, either at the repeater (key not shown in diagram) or, normally, at the distant West station.

When the distant West writes, the action begins with the West relay W the same course as that just described; in this case the pendent armature P′ holds closed the transmittter T, and the West wire passing through its tongue and post.

The Atkinson Repeater. Probably the best of all the repeaters in general use is the Atkinson, the theory of which is shown in Fig. 22. The apparatus consists of two relays of the common type, two transmitters, two main batteries, a pair of local, and another pair of extra local, batteries. The local batteries belong to circuits which, it will be noticed, are marked one with dots, the other with dots and dashes, the same as in the Milliken repeater. On the East set the battery is marked M B, relay E, extra sounder E′ (operated by battery *b′*), and transmitter T; the West set is lettered to correspond. The wires marked East and West extend, of course, in each direction to distant terminals. Suppose the dis-

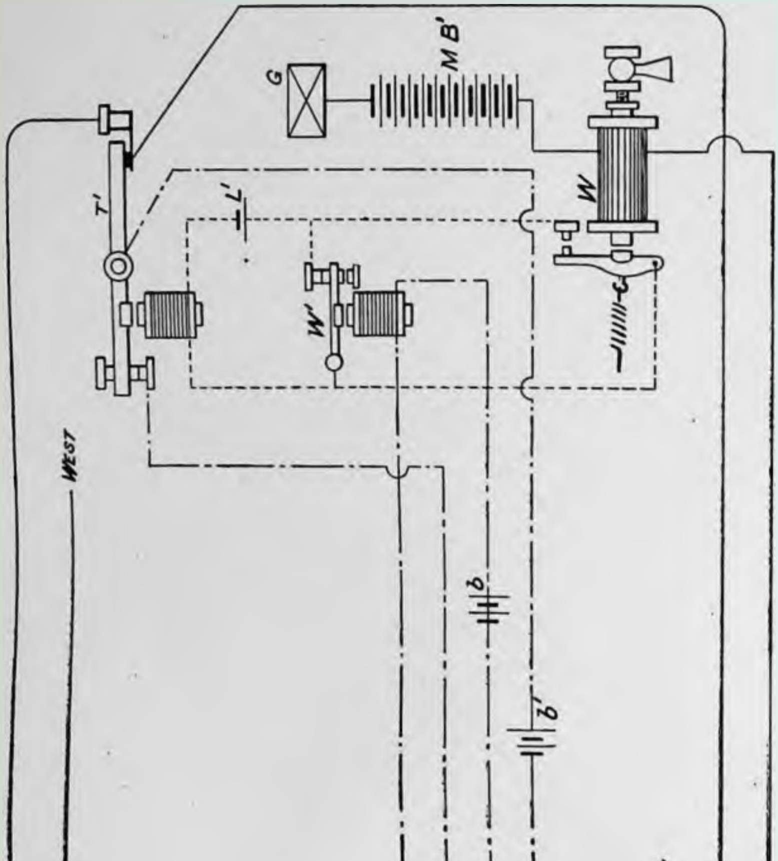
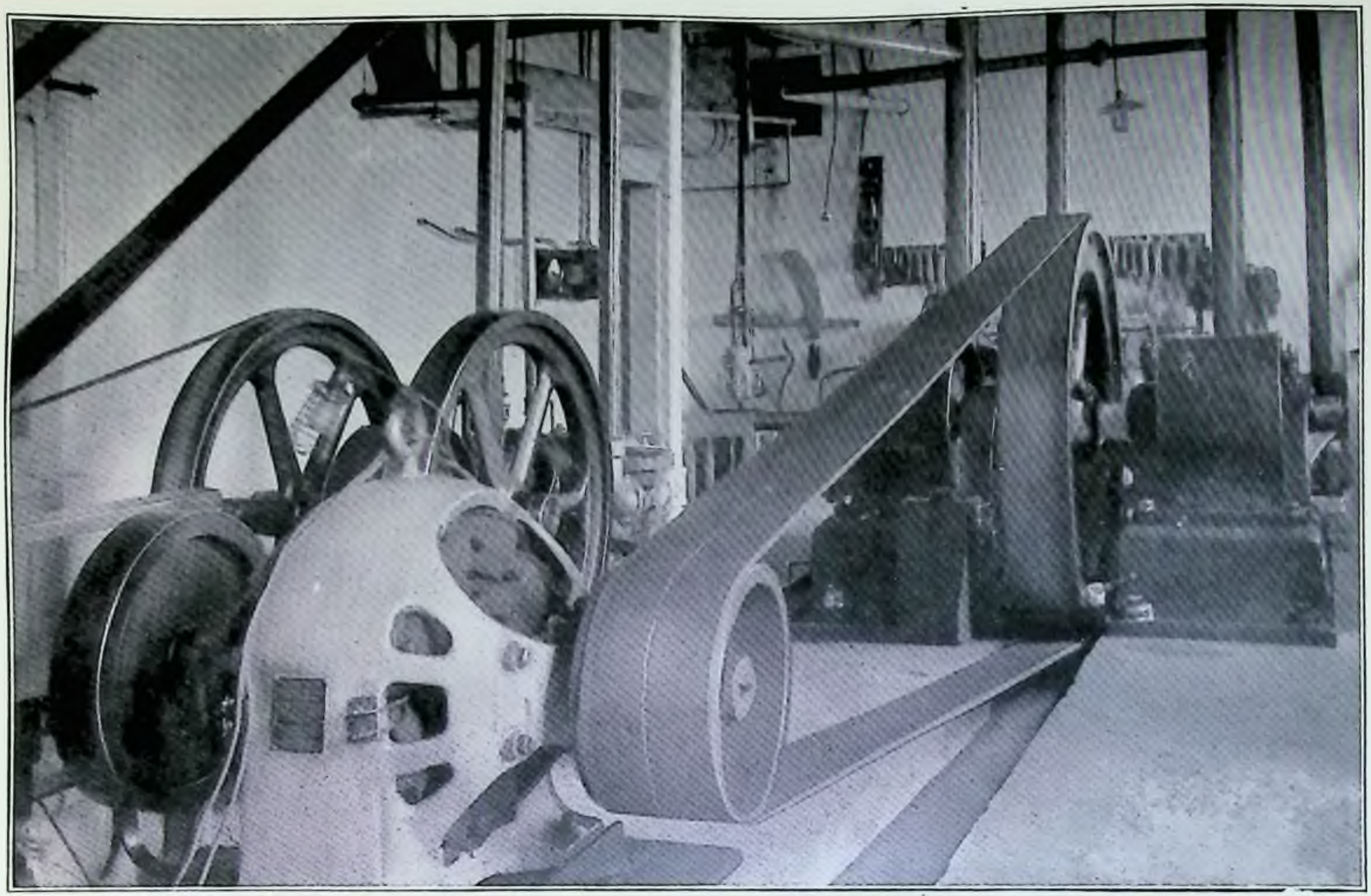


Fig. 22.



ENGINE ROOM OF MARCONI WIRELESS TELEGRAPH STATION AT SOUTH WELLFLEET, MASSACHUSETTS tant East opens his key; he thereby opens in rapid succession relay E and transmitter T, which, in turn opens the West wire and relay W. The opening of the local points of the latter instrument would ordinarily open transmitter T', and therefore the East wire which passes through the tongue and post of transmitter T'. But here again the opening of the East wire, when the East side is sending, is prevented by a device characteristic of this repeater. When transmitter T opens, the current passing through W' is broken; the armature of W' is released and, falling against the backstop, it bridges the points of relay W, so that transmitter T' is held closed and, with it, the East wire. As in the Milliken, transmitter T' can only be opened by opening the key on the West wire either at the repeater or, normally, at the distant West station.

When the latter opens his key the action begins, as already described, with the West relay W and follows precisely the same order, in the latter case the magnet E' holds closed transmitter T. Notice that, in describing the action of this repeater, the language used is very similar to that employed in connection with the Milliken.

These two forms of repeater afford illustration sufficient for a good understanding of the principle; one more kind is added because, up to a recent date it was in general use by one of the large telegraph companies; and, more especially, because its construction involves the principle of differentiation in magnet coils which plays so important a part in duplex telegraphy. A description therefore forms a convenient stepping stone to the subject of multiplex work, which opens up a new and interesting field.

A theoretical diagram of the **Weiny-Phillips** repeater is shown in Fig. 23. As in the Milliken, there are three distinct sets of circuits in duplicate; that is, one set represents the East, the other the West side of the apparatus; and in all three diagrams, Figs. 21, 22, and 23, the parts performing like functions are similarly outlined and lettered. The connections of the main line (full line), and of the local (dotted) circuits are identical with those of the Milliken. But, instead of the extra magnets E' and W' and the pendent armatures P and P' of the repeater last named, there is a device which effects the same end; and, for the reason already indicated, it requires some attention because of the new principle involved.

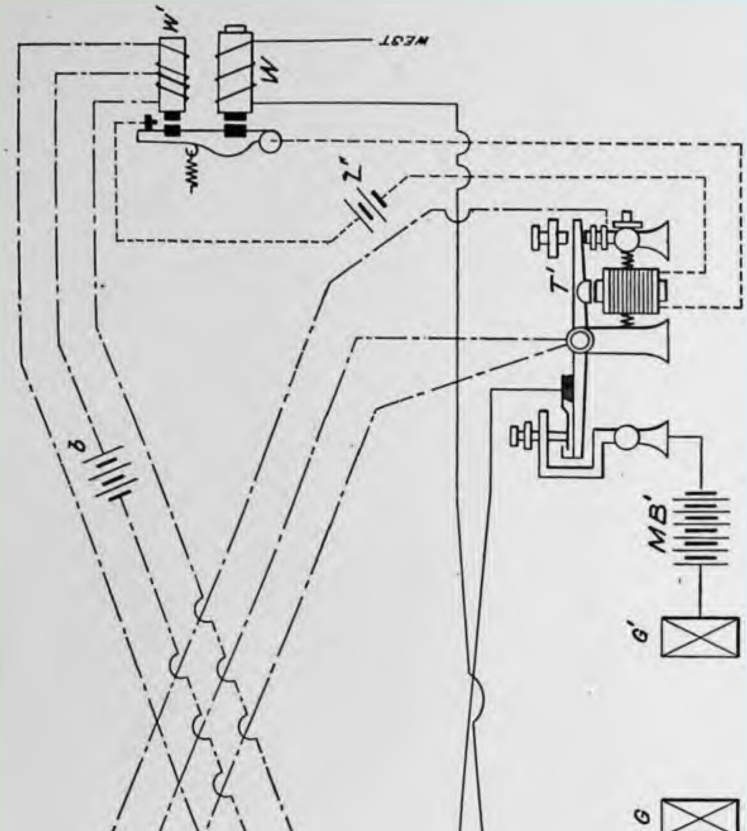


Fig. 23.

In E′ and W′ we have an iron shell enclosing a straight iron core and its winding. The combination of shell and core performs the same functions as the parallel cores in the common type of relay. Trace the wire from battery *b* to the core W′; at a point just above the core the circuit splits; one part winds round the core to the left, and goes to the middle point of the lever of the transmitter; thence back to the zinc pole of battery *b*. The other part goes to the right, and back to transmitter T at the under-stop of the lever. Each division of the magnet coil contains the same number of turns of wire round core W′. When transmitter T is closed, since the lever makes contact with the under-stop, the current from battery *b* traverses the coils of core W′ in opposite directions; the result being that no magnetic pull is produced in the core. But note the effect when transmitter T is open. One of the circuits that passes round the core is open; the neutralization of the current in the other division of the circuit is impossible; the core at once becomes an electromagnet capable of holding the armature at the needed moment. A winding of this kind allows the core to be energized by the *difference* in the strength of the currents in the two divisions; such a core is said to be differentially wound. If currents equal in quantity pass round the coils of core W′ in opposite directions, their magnetic effects are nil; if the currents are unequal, or if one current is nothing and the other any given quantity, the core is energized and will attract its armature.

Notice now the operation of this repeater, in effect identical with that of the others. The distant East station opens his key; this opens relay E, then transmitter T, the opening of which opens the West wire passing through the points of transmitter T. The opening of the West wire would open relay W, transmitter T′, and therefore the East wire which passes through its points. The last opening is the one the repeater is planned to avert. When transmitter T opens, one circuit round the core of W′ is opened; the core is energized and holds the armature of relay W closed, so that transmitter T′, through whose points passes the East wire, does not open.

When the distant West breaks and sends, the same action begins with the West relay and follows the same course. The distant East and West can then work with one another through the repeater, and have the benefit of the main line batteries at the repeating station. This is the sole purpose of a repeater; in every other respect it is a disadvantage, introducing in a circuit two sets of apparatus which need careful adjustment and considerable attention.

MULTIPLEX TELEGRAPHY.

The Stearns Duplex. In the description of the Weiny-Phillips repeater, the differential winding of a single core was illustrated; and the fact explained that such a magnet is operated by the difference in the strengths of the currents passing through the coils. If the two cores of a single-line instrument are wound in the manner described, we have a form of relay known as the

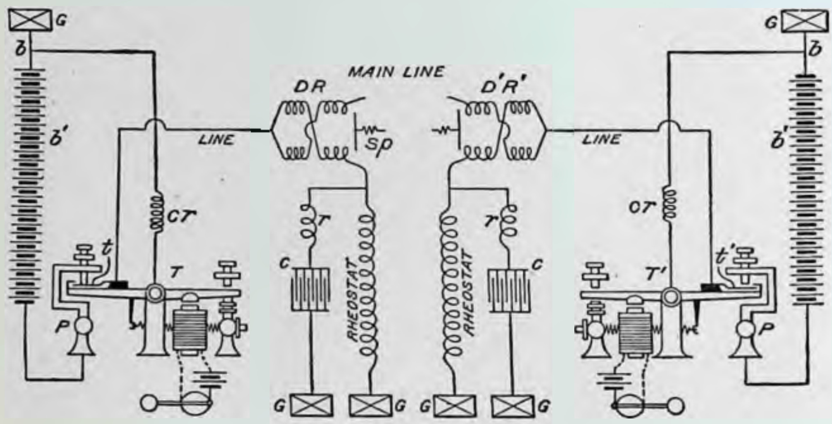


Fig. 24.

Stearns differential; with this and a few accessories a line can be made to carry signals in opposite directions at the same time. In other words, the wire can be duplexed; and the theory of it can be explained and understood from the diagram, Fig. 24, in which the apparatus and connections for both terminals are shown. D R and D' R' are the differential relays; the gap between them is supposed to be bridged by the main-line wire, which may be 450 or 500 miles long.

In addition to the relays and batteries, the essentials for each terminal are a transmitter, rheostat, some resistance coils, and a condenser. Each of these may be seen in its place in the diagram; the rheostat marked in full, the others with the first letter of the name; the local circuits for the relays are not shown. One pole of each battery is grounded; the other makes contact with the post P of the transmitter; and, as the sets are duplicates, one only needs to be described.

The lever of transmitter T makes contact with the ground through a coil *c r*, which compensates for the internal resistance of the battery, making the resistance of the circuit the same whether the transmitter is closed or open. The lever carries, on an insulating pedestal, a spring or tongue *t*, to which is attached the line wire; it makes contact with the post P (battery) when the transmitter is closed, and with the lever (ground) when the transmitter is open. This instrument is seen to be a device for transferring the line wire from the battery to the ground contact without interrupting the circuit; and it is operated, as shown, by means of a key in a local circuit. The line wire can be traced from the tongue *t* to the point of division—technically known as "the split"; the little semicircle in the diagram indicates in every case no connection with the wire underneath; each division of the circuit passes through two spools of the relay; one branches off to the main line, the other through the rheostat to the ground. By way of introduction to the apparatus last named, take the case of a motorman of a trolley car in motion. His left hand controls a radial arm surmounting a box which extends down to the platform, and contains a number of lengths of coiled wire through which the current passes on its way from the trolley wire to the motor. Every move of the radial arm in one direction or the other means more or less of current, and therefore more or less of speed in the motor. The coils resist the passage of the current, and the box is therefore a current retarder, or rheostat, which is the same thing. In a similar manner, either by a radial arm or, more commonly in a duplex, by means of pegs making contact between discs in which the resistance coils terminate, the current may be regulated in the circuit of which the set of coils marked "rheostat" is a part; that portion of the circuit from the point of division to the ground being called the artificial line.

The purpose of the rheostat is to divide the current passing through the relay coils equally between the main and artificial lines; and, as already intimated in connection with the repeater this can be done by making the resistance in the rheostat equal to that of the 450 or 500 miles of wire in the main line—anywhere from 5,000 to 10,000 ohms. When this condition is established it does not matter, within working limits, what the size of battery is; the current will pass through the relay with no appreciable magnetic effect upon it; and the duplex is said to be "balanced".

How to Balance. Suppose the terminals to be provided with duplex sets and batteries as shown in the diagram, and a main line connecting them. First approximate the balance by pegging the rheostat to 5,000 or 6,000 ohms in clear weather for a line 450 miles long. Ask the distant office to "open". Notice in connection with transmitter T′ that this opening grounds the wire at the distant end. There is now no battery on the line but your own; lower the tension on the spring *s p* and, by means of the pegs, vary the resistance in the rheostat (the home key being closed) until the cores of the relay show no appreciable attraction for the armature. This done, open and close the key a number of times; a slight click of the sounder with each movement of the key will probably be heard—an effect which it is necessary to eliminate. It is with the dynamic, or current, form that, up to this time, we have been dealing; but the false signal just mentioned in connection with the duplex brings to notice, for the first time, electricity in the form of *charges* upon the wire, and therefore called static. It presents itself as a disturbing element in connection with duplex work; and the remedy for it is a movement in the artificial line round the relay coils in a direction opposite to that which causes the 'kick'; the means for producing it is the apparatus in Fig. 24 marked C, for condenser.

For a statement of what static electricity is, and certain forms of the condenser, see "Elements of Electricity". In the diagram, the lines represent sheets of tin foil; the spaces mica, paraffined paper, or some insulating material; one set of the sheets makes connection with the line; alternating with them, as shown, is another set which makes contact with the ground. The sheets, with the insulating material, are enclosed in a box, and the connections mentioned are made in one case by means of a bar, and in the other by means of a set of discs so placed that, with a few pegs, the number of sheets in actual use can be varied; and, by means of an adjustable set of coils *r*, the charge and discharge can be assimilated to that of the main line.

On the condensers commonly used in telegraphy the discs are usually five in number, and are marked 40, 32, 16, 8, 4 to denote the percentage of tin-foil area connected to the disc. If pegs are inserted uniting the bar with discs marked 4, 16, and 40, 60 per cent of the capacity is in use, and the charge and discharge will be in just that proportion. A condenser usually bears a stamp as 2.5 M F, or 3 M F. The M F stands for micro-farad, which is the practical unit of capacity; and is about equal to that of three miles of an Atlantic cable.

With the duplex in operation there is, on the closing of the transmitter, a charge through each pair of relay coils and, on the opening of the transmitter, a discharge through each pair of relay coils the same in quantity and at the same instant; and in each case the movement in one pair of relay coils neutralizes that in the other.

When the "kick" has been cleared, the distant station is asked to write; and it will be found that the outgoing signals do not interfere with the incoming, because the duplex has had a static, in addition to its first, or ohmic, balance. The distant station then goes through with the same process, and the sets are ready for service.

All the accessories having been described, it remains to trace in detail the effects of the currents on the relays in every position possible to the transmitters. In the diagram, on the left, the battery has zinc to the post and copper to the ground; at the other terminal, on the right, copper is to the post and zinc to the ground. The duplex would work if the batteries had like poles to the line; but we shall consider them in the manner shown. In operation, four conditions are possible, and they may be tabulated as follows:

T closed	— to line	T′ closed	+ to line	D′ R′ closed	DR closed
T open	G " "	T′ closed	+ " "	D′ R′ open	DR closed
T closed	— " "	T′ open	G " "	D′ R′ closed	DR open
T open	G " "	T′ open	G " "	D′ R′ open	DR open

It will appear from this that the differential relay at one terminal obeys the transmitter at the other. We shall see how this works out in practice. A line 450 miles long usually has a voltage of at least 150 at each terminal; and, as only 25 cells are represented in the diagram, each cell must be supposed to represent 6 volts.

First, when T and T′ are closed; the batteries unite their energies, giving on the main line a current of $\frac{1}{25}$ ampere, or 40 milliamperes. On the artificial line, in the relay coils at each terminal, there is a current from the battery at that terminal through a resistance in the rheostat equal to that of the line, say 20 milliamperes, because the voltage in each case is only one-half that of the united batteries on the main line. In the coils of each relay there is a difference of 20 ma and both remain closed.

Next, open transmitter T. The battery at the left is cut off, and the line is grounded through a compensating resistance C R equal to the internal resistance of the battery. On the artificial line in relay D R there is no current; on the main line there is a current of 20 ma from the distant battery; relay D R remains closed. On the artificial line in relay D′ R′ there is a current of 20 ma which neutralizes the current of 20 ma on the main line, and the relay D′ R′ opens; in other words, it obeys transmitter T.

Next, close transmitter T and open T′. This is the phase shown in the diagram, and it should be traced with special care. The line is now grounded through the tongue *t′* and lever of T′ on the right; and the only current on the wire is from the battery at the other end. At the terminal where T′ is there is no current on the artificial line, and the current of 20 ma on the main line closes the relay D′ R′. But at the other terminal, where T is, the current in the coils of the artificial line neutralizes the current on the main line, and the relay D R opens; in other words, it obeys transmitter T′.

Lastly, when both transmitters are open. The battery at each terminal is off; there is no current in either the main or artificial line at either terminal, and the relays stand open. In this way are verified the results set down in the table; the relay in each case is unresponsive to the home instrument, but responsive to the distant transmitter; and signalling in opposite directions at the same time is practicable.

In explanation of the part played by the condenser in the long distance duplex, it may be said that when current flows in a wire, a portion of it collects and becomes static on the conducting material; and it will discharge instantly in any direction a path offers. In duplex work, the transmitter makes a line contact first with the battery, then with the ground; the conditions are present for a static charge and discharge of the wire; and the extent to which it is capable of these effects is called its electro-static capacity. On short lines it is small; so that, in the duplexing of such wires, the 'kick' is not noticeable; but there is a difference between a main line wire 450 miles in length, and the fine wire with which the coils of the rheostat are wound. So far as *resistance* to the current is concerned, the coils in the box are capable of reproducing exactly the conditions on the wire; but the main line wire has electro-static capacity; the fine wire of the rheostat coils has not. The initial charge in the line, therefore, will not, unless the condenser is used, be offset by an opposite movement in the artificial line; nor, at the termination of the signal, when the line is moved from the battery to the ground, will the discharge be offset by an opposite movement in the artificial line. A form of duplex was invented in Germany, and known in America as early as 1855; but it was worked only on comparatively short lines. The duplexing of long lines by the aid of the condenser was made practical in 1872; and the credit is due to Joseph B. Stearns of Boston. His was one of the notable achievements in the history of telegraphy, for by means of it the value of most of the wires of the telegraph companies was doubled at a stroke.

In the diagram, Fig. 24, there is indicated a connection from each transmitter through a coil *c r* to the ground at *b*. Before leaving the subject of the Stearns duplex, it is proposed to make a change in this circuit, and note results with a view to future reference and use. In each circuit move the wire from the point *b* to the point *b'*. When the transmitters are closed the *c r* circuits are open, so that the change to *b'* makes no difference on the line; but when a transmitter is open, the line has in circuit about one-third of the battery before it reaches the ground. Under these conditions, instead of the main and artificial lines being free of current, there would be on the main line coils in each relay, say 16 ma of current; and opposed to it in the artificial line coils about 8 ma. The difference (8 ma) would be sufficient to close the relays; but, according to the four-phase table, when the transmitters are open the relays should be open. Under these conditions, to open the relays it would be necessary to increase the tension on the armature spring. Now, if for any reason, we wish to maintain a weak current always on the line we could use for the purpose a portion of the battery, and counteract the effects of it by giving the spring *sp* sufficient tension to overcome the magnetism induced by the weak current; or, as the operators express it, the relay can be "turned up" above the weak current. This done, the operation of the duplex can be carried on as usual; the only difference is that the springs of the relays have tension sufficient to make them unresponsive to the weak currents. It is possible, therefore, to work a duplex of the Stearns pattern when the connections are such that the movement of each transmitter sends alternately to the line the whole battery and only one-third of it. This statement made, let us leave it for the present. It will be fitted into its place later, when we come to deal with the quadruplex in connection with which the statement just made plays an important part.

It remains only to gather up the terms and phrases used in describing the duplex; from this time on they must be a part of our vocabulary. We have had to do with the differential winding of a single core, the differential relay, main line, artificial line, rheostat, compensating resistance, transmitter, condenser, retardation coils marked *r r*, internal resistance (usually of a battery), the split, the balance, tension (of a spring), the static and its kick, charge and discharge, electrostatic capacity. If the reader will note in the diagram, as far as possible, each object named, he should get a better idea of its theory and function than could be obtained from a definition.

It thus appears that the characteristic instrument of the Stearns duplex is a relay, in appearance not very different from the ordinary relay of the single-line type; it can be constructed from it by a change in the winding from the simple to the differential form as represented in the diagram, Fig. 24. For the sake of simplicity all the thumbscrew connections, the front and back stop, and apparatus of the local circuit are omitted from the drawing; only the essential parts—the differential coils with the armature and spring—are shown. It will be noticed that the main line has a number of turns around one core, then around the other; the same with the artificial line. In practice, the points where the main and artificial lines enter and leave the instrument are fitted with four thumbscrews; two more are provided for the local points—one making connection with the armature, and the other with the front stop—forming parts of a local circuit as in the ordinary single-line relay. These omitted parts will be supplied in Fig. 29; but in dealing with first principles the fewer the details the better.

The Polar Duplex. In the same manner as we took the single-line relay and changed it to one of the differential type, so now it is proposed to take the latter, to make some changes in its construction; and, with a view to one more advance, to introduce a different form of armature and note the results. The yoke which, in the working instrument, joins the cores at the ends furthest from the armature is supposed to be removed; next take away the armature and turn end to end the cores that faced it, so that the coils, instead of lying parallel, are in a straight line. With a space of one-quarter or one-third inch between them they will present the appearance shown in Fig. 25, in which C and Z, C′ and Z′ represent the terminals of the coils; one core is marked D A, the other B E; and for observation the student is supposed to take up a position in the space between the cores. First, a current in the wire C Z encircles the core D A in a direction opposite to that of the hands of a clock, that is, from right to left, then it encircles the core B E in the direction of the hands of a clock, that is from left to right. If the student will imagine himself in place between the letters A and B he can readily understand this.

Heretofore we have been content merely to state the fact of the attraction of a magnet for its armature; the point has now been reached where it is necessary to state the law of the formation of magnetic poles in cores around which a current is passing. In "Elements of Electricity" are shown magnets marked N and S; in the text relating to the same it is explained that N stands for north-seeking, S for south-seeking; and there is further stated the law that like poles repel, while unlike poles attract, each other. Reverting now to what was said of the passing of a current round a core, let us, for the sake of brevity, call the directions just mentioned anti-clockwise and clockwise. At the end of the core, at which one is looking "end on", magnetic poles are formed according to this law: When the current passes anti-clockwise N polarity is induced in the near end, S polarity in the far end; when the current passes clockwise, S polarity is induced in the near end, N polarity in the far end. In the instance shown in Fig. 25 in the line C Z, there will be formed at A and D, N and S poles respectively; at B and E, S and N poles respectively. There is therefore on one side of the space between the cores an N magnetic pole; on the other side an S pole; it remains to provide something on which they may act.

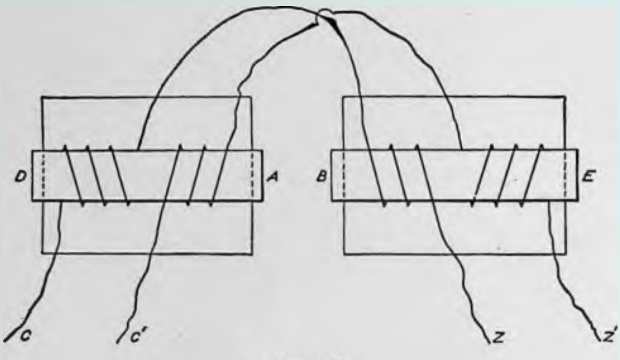


Fig. 25.

In Fig. 26 let S be the end of a permanent magnet semicircular in shape; a strip of soft iron for an armature is so pivoted that it can move freely between the stops at the upper end. In the armature the induced poles are marked with the small letters *n* and *s*, in accordance with the principle stated in "Elements of Electricity". With no current in the wire C′ Z′, a current in the wire in the direction C to Z will induce, according to the clock rule, at A, N magnetism; at B, S magnetism. The N pole, according to a law already stated, attracts the *s* pole of the armature; the S pole repels it; the armature is strongly moved towards front stop F. The current ceases, let us suppose; but the armature has no spring, and its position remains unchanged until a current flows through the same wire in a direction from Z to C. Under its influence there is formed at B, an N pole; at A, a S pole; the effect on the *s* pole of the armature is to move it from the front to the back stop. Every time the current changes its direction the armature changes its position from one stop to another; and we have a *polar* relay. It is one in which a magnetized armature is moved from point to point under the influence of magnetic poles changing as the effect of changes in the direction of the current around the cores.

One step more and we have a *differential* polar relay. In the diagram, Fig. 26 is an extra wire with a number of turns around each core. Its terminals are C′ Z′; but it is so wound that a current from C′ to Z′ passes round the cores in a direction different from that in the line C to Z. The current from C′ passes first

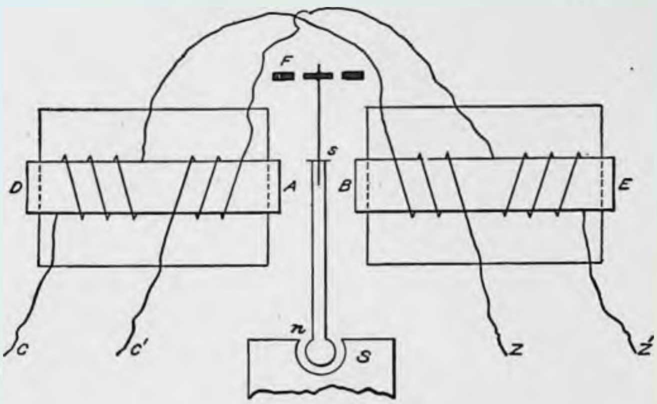


Fig. 26.

clockwise, then anti-clockwise around the cores; and from what has been said it is plain that if currents of equal strength flow in the wires C Z and C′ Z′ they will induce at A and B magnetic poles such that they will neutralize each other; provided, of course, there is the same number of turns in each coil. The effect on the armature will, in that case, be nil. But if the currents in C Z and C′ Z′ are not equal, the armature will obey the stronger current with a pull determined by the difference between the two. The result is a differential polar relay, by means of which that very perfect system of signalling in opposite directions—the polar duplex—is possible. The relay is made in different forms, but it consists essentially of a permanent magnet in which is pivoted a strip or tube of soft iron called the armature. This is placed between two cores around which are wound, in the manner shown in Fig. 26

two independent circuits. The windings terminate in four thumbscrews, with two more for the local points, making six thumbscrews for the polar relay. The spools may be wound in various ways;

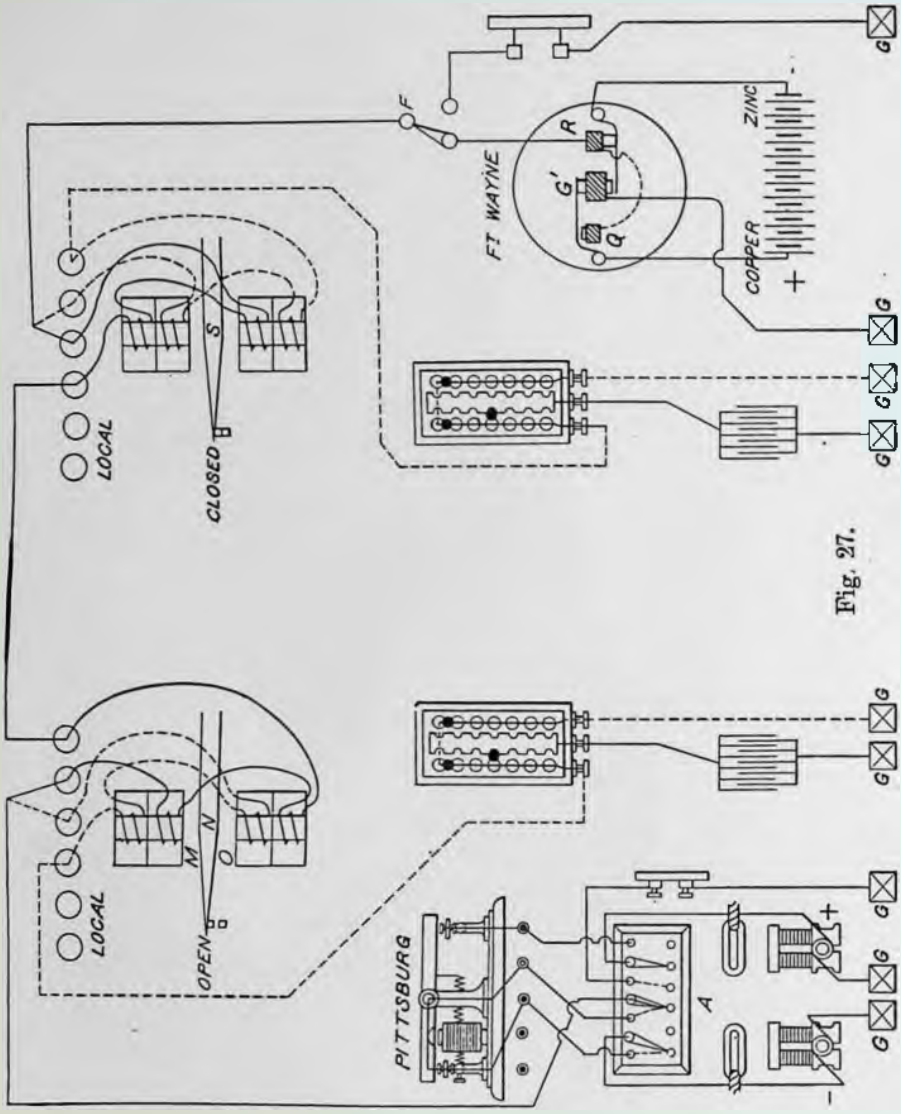


Fig. 27.

the wires may be laid side by side throughout the length of each core; or, as in the diagram, Fig. 27, in equal compartments separated by discs at right angles to the core. In the relays most commonly used each division of a spool contains 2,400 turns of wire, and has a resistance of 200 ohms; so that, in each circuit there is in the relay coils, a resistance of 400 ohms. This is equal to 42 miles (very nearly) of No. 6 iron wire, such as is commonly used in the construction of telegraph lines.

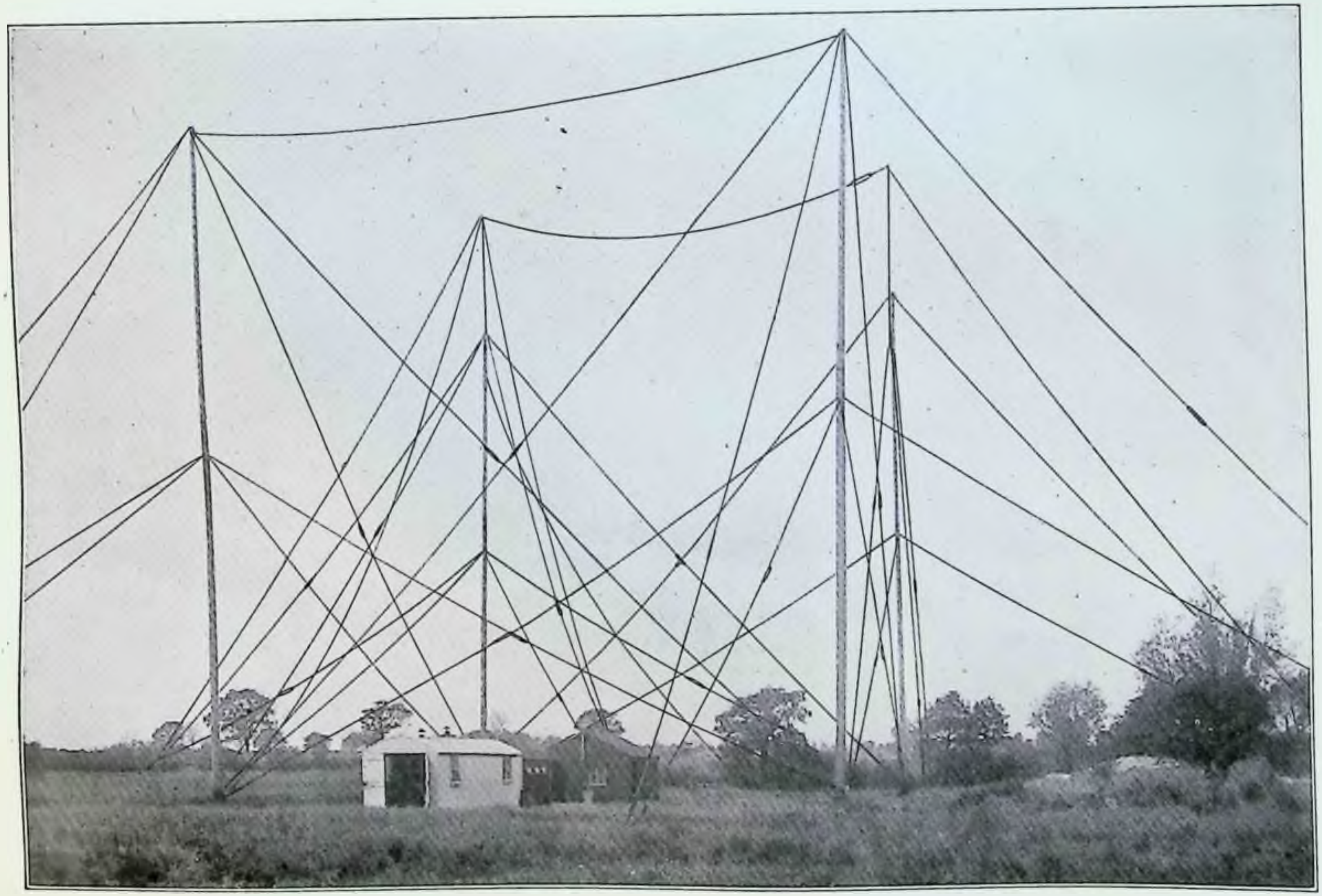
A differential polar relay, then, is one whose armature, polarized by contact with a permanent magnet, is operated by the difference in the strength of the currents, the direction of whose course is constantly being changed.

The instrument by which the direction of the current is reversed at will is called a *pole changer*, which, with the polar relay, the dynamos, lamps, and dynamo switch connected up, is shown in Fig. 27. These, with the rheostat and condenser described in connection with the Stearns apparatus, form a duplex set for one terminal. There is shown in the drawing one set for each terminal, and, for convenience in description, the left-hand station is called Pittsburg; the other Fort Wayne. The latter, as compared with the former, shows a different arrangement of battery and pole changer, of which explanation will be made later on. The Pittsburg pole changer is operated by means of electromagnets. These are part of a local circuit (not shown) and controlled by a key in the same way as the sounder in the learner's outfit. To the end posts of the pole changer are connected wires from dynamos supplying, let us suppose, a 200-volt current. It is made to pass through lamps and a switch; negative to the left, positive to the right. To the center lever of the switch is connected the main line. With the center bar of the switch to the left, connection is made with the lever of the pole changer, so that when the latter is closed a zinc current goes to the main line; when open, copper.

The lamps are placed between the dynamo and pole changer so that in case of a short circuit, by the lever of the pole changer accidentally making contact with both posts, a resistance of 1,200 ohms will be interposed until the short circuit can be broken and thus injury to the dynamo is prevented. The purpose of the dynamo switch is to provide means for readily cutting off the currents from the pole changer when any cleaning of the points or adjustment is required, or in case of a short circuit through the lever. With the center bar of switch A turned to the right, the main line goes to the ground through a resistance equal to that of each lamp, or 600 ohms; it makes no difference, therefore, in the *resistance* of the main line whether the center bar is to the left or to the right. From the switch the wire may be traced to the 'split' near the polar relay. At this point, as in the Stearns duplex, the current divides; one-half of the Pittsburg battery passing through two coils to the main line; the other half also through two coils to the rheostat, thence to the ground. The function of the rheostat, and its companion, the condenser, was explained in connection with the Stearns duplex; and it might be well to review that part of the text.

How to Balance. First approximate the balance by pegging or unpegging the rheostat to about 5,000 ohms for a line 450 miles long; in wet weather two-thirds of that. Ask the distant station—in this case, Fort Wayne—to ground; ground also at Pittsburg—the home station. Adjust, by means of the set screws, the armature of the polar relay so that it remains on one stop or the other as placed, or else vibrates freely under the influence of the slight current which the nearness of other wires on the poles may induce. Turn the switch from the ground to the pole changer connection. There is now on the wire no current of any account but your own; and the rheostat must now be so adjusted that the current from the home battery—in this case the Pittsburg—divides equally between the main and artificial lines. When it does this the armature of the home relay will vibrate freely as before.

In other words, the home current has no effect on the armature and the relay stands ready to respond to the current from the distant, or Fort Wayne, battery. Tell him to "cut in"; he does this by moving the lever of switch F from the right to the left-hand lower point; and when his key is closed your relay should close. Now, if you open and close your pole changer by means of your key the static "kick" will probably be noticed; and the remedy for it is the same as that described in connection with the Stearns duplex. This done, the "kick" disappears; the distant station writes, and it will be found that the signals sent from the home station by reversing the pole changer do not interfere with the incoming signals. Fort Wayne then asks you to ground and proceeds to balance his end; the duplex is then ready for service. In the hands of experts the operation of balancing both ways does not ordinarily require more than three minutes.



MARCONI WIRELESS STATION AT BROOMFIELD ROAD, CHELMSFORD, ESSEX

The right hand, or Fort Wayne, terminal shows an arrangement of battery and pole changer in vogue for many years before the use of the dynamo current in telegraphy; and it still obtains in a few places where a machine current is not available. The diagram represents the combination of a chemical battery of say 150 cells and the old-fashioned continuity-preserving, or clock-face, pole changer. The latter is retained here and described because it is also as an essential part of the phonoplex—the topic with which this book deals last.

In the diagram only the clock-face portion is shown; the part G', in the center, represents the end of a lever operated like that shown in the Pittsburg pole changer, making contact with the ground. The poles of the battery connect with two springs as shown; the latter with the point-bearing blocks, Q and R are suitably insulated from the supporting material which is usually of brass. Q and R are connected to each other and to the main line. The connections made when the lever is closed are shown in the diagram. The left-hand spring is grounded, lifting it up from Q; the right-hand spring is free from the ground, but is making contact between the line and the zinc pole of the battery. When the pole changer is open, the center block drops down; the line makes connection with copper; zinc goes to the ground. In both forms of pole changer the results are therefore the same—zinc to the line when closed; copper when open—and this is the rule for their arrangement in practice. Care must evidently be taken for the adjustment of the pole changer in either form. "Clean and close" is the rule for placing of the points—as close, that is, as they can be worked without short-circuiting and sparking. Of pole changers and sounders alike the armatures must not be allowed to beat upon the magnets; to make sure they do not, a piece of paper should at times be passed between them.

As in the Stearns duplex, the polar duplex in operation has combinations of current four in number; and a description of the latter will not be complete without giving in detail the reason for the response of the relays in each combination. In advanced telegraphy there is no instrument in more general use than the polar relay; the principles involved are everywhere used; and a thorough understanding of them is necessary to a mastery of the more complex forms of apparatus and their latest applications. The changes in magnetic poles, as the result of changes in the direction of the current, will occupy our attention now; but before entering upon this we must consider the conditions which determine the direction of the current.

Much has been said about positive and negative currents, and the signs + and — are conventionally used to represent them; but these terms are not meant to convey the idea of strong and weak; a negative current may be strong or weak the same as a positive. In surveying it is convenient to consider "sea level" as a zero point from which to measure heights or depths, so in electrical potential the earth is taken as a neutral point and arbitrarily called zero; a current flowing into it is called positive; a current flowing from it, negative. If this seems unsatisfactory, perhaps an analogy may help us. Suppose we regard the air at rest as zero. Confine a rotating fan within a closed iron frame with a single tubular opening. Revolve the fan and, at the opening, a pressure will at once be felt of say 50 pounds to the inch. A few feet away the pressure will be 25; further away 15; and so on until no disturbance of the air is felt; the pressure is practically zero. Reverse the direction of the fan's motion so that instead of pressure outward there is suction inward, and at like distances effects like those just mentioned will be felt, but in an opposite sense. At the opening the suction is 50; whereas before there was an outward pressure of 50. In the one case we have the air at rest, the pressure, and the suction; these have their electrical analogies in the earth considered as zero potential; the positive current, which always sets towards the earth; and the negative, which always sets from it. The common direction of a thunderbolt is from a cloud to the earth, in this case the cloud must be positively charged; but instances have occurred where the direction of the bolt was from the earth to the cloud; in which case the cloud was negatively charged. In other words, and for the present purpose, the direction of the current is always + to zero, + to —, and zero to —; or, as stated, always from the higher potential to the lower. It is taken for granted that the same amount of current is supplied to the line at each terminal; in a duplex circuit 400 or 450 miles in length this is generally 150 or 200 volts. With these statements in mind the investigation of the combinations possible in duplex telegraphy may be taken up.

Pgh key.	To line.	FtW relay.	FtW key.	To line.	Pgh relay.
1 Closed	—	Closed	Closed	—	Closed
2 Open	+	Open	Closed	—	Closed
3 Closed	—	Closed	Open	+	Open
4 Open	+	Open	Open	+	Open

In phases 1 and 4, the two stations present like poles to the main line; in phases 2 and 3 unlike poles.

Combination, or phase 1. Pole changers at terminals closed; zinc to the main line. In the diagram, the main line is solid black; the artificial line is dotted. With like poles of equal strength to the main line there is no current on the solid black line. Under these conditions on the artificial (dotted) line a current sets in from the ground through the rheostat, along the dotted line, through the pole changer to the zinc (—) of the dynamo in accordance with the law just stated. In the Pittsburg relay it forms first an N magnetic pole on the end of the core at M; then an S pole at O. If we enclose an N thus $\underline{\overline{\text{N}}}$ to represent the polarity of the Pittsburg armature, the magnetic conditions may be graphically represented: $\overset{n}{\underset{s}{\underline{\overline{\text{N}}}}}$ closing the relay in accordance with the law that like poles repel, unlike poles attract each other. Similarly, at the Fort Wayne end, by means of a current from the ground to the zinc of the battery the magnetic conditions are: $\overset{s}{\underset{n}{\underline{\overline{\text{S}}}}}$ also closing the relay.

Combination 2 shows Pittsburg +, Fort Wayne — to line; current direction on the main line is from Pittsburg to Fort Wayne. On Pittsburg artificial (dotted) line, current is from + to ground through the rheostat; on Fort Wayne artificial line it is from ground through the rheostat to — of the battery, the same as in combination 1. But the current on the main line is twice that on either of the artificial lines; because in the former case the current is from + to —, while in the latter case it is from + to ground at one terminal and from ground to — at the other.

The magnetic poles induced in the cores by the current on the main line are therefore twice as strong as those induced in the cores by the current on the artificial line. If we represent the magnetism induced by the main line current by a capital, and that induced by the artificial line current by a small letter, and indicate the polarity of the armature as before, the magnetic conditions in the Pittsburg relay may be typographically represented thus: $\begin{array}{c} \mathrm{N}s \\ \hline \mathrm{N} \\ \hline n\mathrm{S} \end{array}$ the stronger poles closing the relay; in the Fort Wayne relay $\begin{array}{c} \mathrm{N}s \\ \hline \mathrm{S} \\ \hline \mathrm{S}n \end{array}$ the stronger poles opening the relay.

Combination 3. Pittsburg — to line; Fort Wayne + to line. Current in opposite direction to that in combination 2; but on main line twice as strong as on either artificial line; in the Pittsburg relay the conditions are $\begin{array}{c} \mathrm{S}n \\ \hline \mathrm{N} \\ \hline \mathrm{N}s \end{array}$ opening it; in the Fort Wayne relay $\begin{array}{c} \mathrm{S}n \\ \hline \mathrm{S} \\ \hline \mathrm{N}s \end{array}$ closing it.

Combination 4. + to the main line at each end; no current on the main line; relays actuated as in combination 1 by current in artificial line; in Pittsburg relay $\begin{array}{c} s \\ \hline \mathrm{N} \\ \hline n \end{array}$ opening it; in Fort Wayne relay $\begin{array}{c} n \\ \hline \mathrm{S} \\ \hline s \end{array}$ also opening it. The Fort Wayne relay might have an N armature the same as Pittsburg, but it was purposely made different to afford exercise in tracing out the effect of the current.

The student should now be master of at least the theory of the two forms of the duplex—the original Stearns and the later and more perfect polar. The former came into general use in 1872, the latter about 1880. In making comparison between the two it can be seen that the superiority of the polar duplex lies in the *relay* whose action is determined, not, as in the Stearns, by a current attracting the armature in one direction and a spring drawing it in the other, but by a current directing its movement first to the front then to the back stop. This makes the polar duplex almost independent of weather conditions. The occasions are rare, the relay being so sensitive, when sufficient current does not get past the escape to record the signals. The resistance of 450 or 500 miles of No. 6 gauge iron wire is, in dry weather, about 5,000 ohms; in damp or rainy weather this is often reduced to two-thirds, or even one-half. This is a good point to remember in adjusting the rheostat to get into communication initially with a distant station before the correct balance is taken. Less condenser, also, is needed in moist weather than in dry, because a part, sometimes nearly all, of the static charge escapes into the moist air.

With a clear wire and apparatus in good condition, the polar duplex is a well-nigh perfect instrument capable of a speed, when working the Morse system, equal to that of the fastest typewriter; and when operated by the Wheatstone Automatic system it has attained a speed of 250 words a minute each way—nearly ten times as fast as the ordinary speed by hand.

THE QUADRUPLEX.

The quadruplex—among telegraphers known always as the quad—permits the exchange of four messages at the same time; two in each direction. In the diagram, Fig. 28, presenting the theory of the quad, there is much that will seem familiar to the student; the text has been so arranged and the drawings so made as to give the impression of previous acquaintance. The neutral relays are a reproduction of the instruments made prominent in the Stearns duplex; the polar relays are those which we have just studied in the polar duplex. The rheostats—the same in principle as those already shown—are represented by a simple coil; and, shunting each, is the now familiar condenser, H and J, each with its retardation coil R*c*. The batteries and pole changers are a reproduction of those shown in connection with the polar duplex.

At the left hand, or Pittsburg, end the dynamo switch has been omitted for the sake of simplicity; everything, in fact, has been left out except the parts needed to illustrate the fundamental principles on which the quad is arranged. The details which make the quad appear so complicated can be filled in later. In the diagram the one new feature is the introduction at each end of

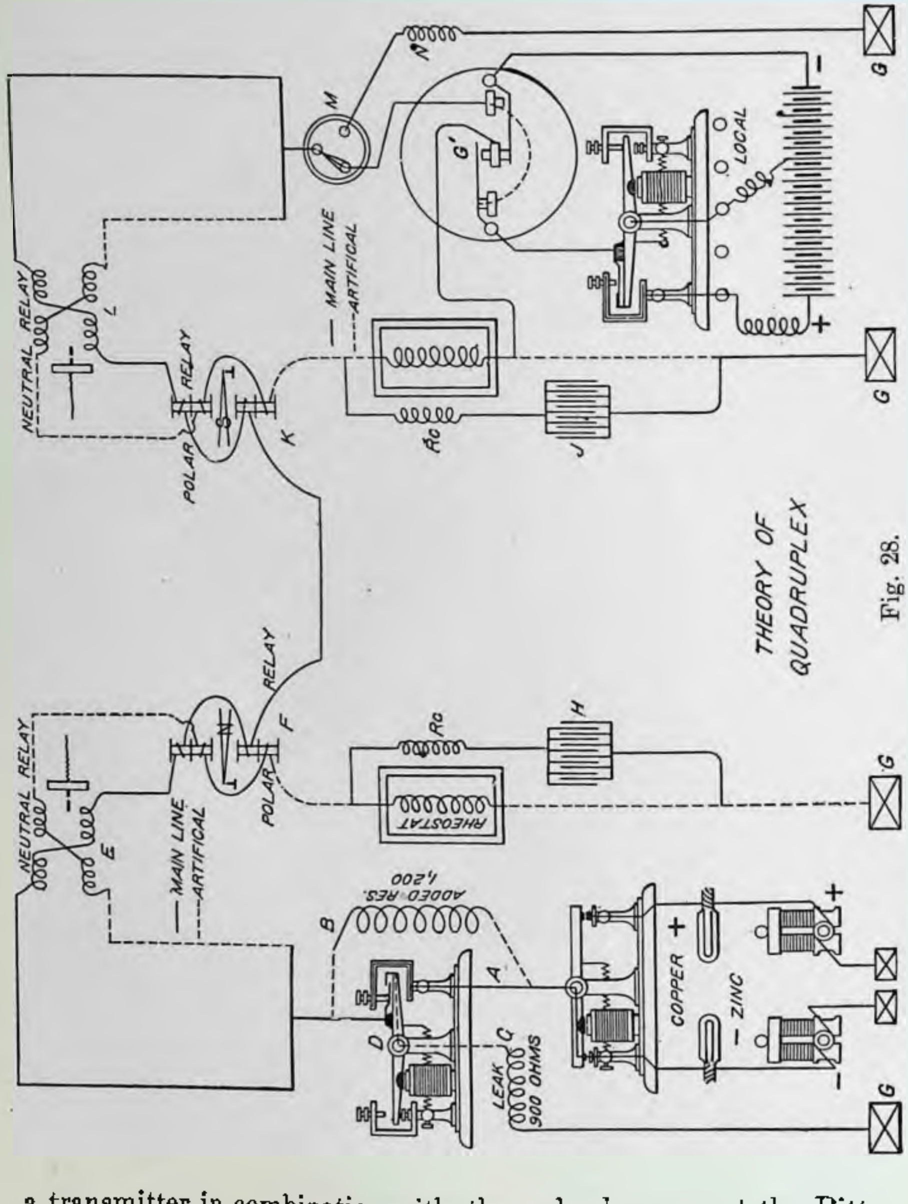


Fig. 28.

a transmitter in combination with the pole changer; at the Pittsburg end it is between the pole changer and the split; at the Fort Wayne end between the battery and the pole changer.

We have seen that it is the function of the pole changer to alter the *direction* of the current; it is the function of a transmitter, like those shown in Fig. 28, to alter the *strength* of the current within certain well-defined limits. Now the pole changers are evidently in position for the purpose of operating the polar relays; the transmitters can therefore be in place only to operate the neutral relays. The instruments heretofore designated as polar and neutral are also called polar and common; the sides on which they are worked are sometimes called by the numbers 1 and 2, and sometimes by the letters A and B.

From what has been said, the student may already have inferred that a neutral relay is one operated by the strength of the current without reference to its direction; he knows that a polar relay is operated by the direction of the current without reference, within reasonable limits, to its strength; and *in the combination of these two principles* lies the theory of the quad, as it is commonly known. There are other forms of the quad; but our present business is with the one still in general use.

The student is now asked to recall and review an experiment made in connection with the Stearns duplex, and intended for introduction at this point. It was made clear that, by the simple expedient of "turning up" on the relay spring, the Stearns duplex could be operated even when a weak current remained continuously on the main line; or, as it was expressed in a former paragraph, "If, for any reason, we desired to maintain a weak current on the line, we could use therefor a portion of the battery and counteract the effects of the weak portion by giving the spring sufficient tension to overcome the magnetism induced by it." The need has now arisen for maintaining at least a portion of the current continuously on the line; and the reason for it is that changes in the direction of a comparatively weak current will operate a polar relay as readily as the reversals of a current three or four times as strong. The neutral relay can be made unresponsive to the weak current, but responsive to a strong current without reference to its direction; in other words, the quadruple is merely a combination of the Stearns duplex, in a form modified as shown in the text, with the polar duplex. It remains only to explain some details of the combination.

The operation of the pole changer at the right, or Fort Wayne, end is identical with that described in connection with the polar duplex; but it will be noticed that the battery and transmitter connections are such that it depends on the opening and closing of the transmitter whether a third or the whole of the current is admitted to the reversing process. If the transmitter is open, as shown in the diagram, that portion of the battery between the two coils—nearly two-thirds of the whole—is "dead"; the other third (called the short end) is admitted to the pole changer through the lever and tongue of the transmitter. In the diagram the Fort Wayne pole changer is open; through the tap wire the copper of the "short end" is to the main line, and zinc to the ground. This position of the Fort Wayne pole changer opens the Pittsburg polar relay; the Pittsburg neutral relay too is open, because the short end only of the Fort Wayne battery is to the line and the spring of the relay is "turned up" above it. Close the Fort Wayne pole changer; now, at Fort Wayne, zinc is to the line, and short end copper to the ground; the Pittsburg polar relay closes in accordance with a change in the direction of the current; but the Pittsburg neutral relay remains open, and will not close until the Fort Wayne transmitter closes and admits the entire battery to the main line. In closing the transmitter the tongue breaks its connection with the lever and makes connection with the left-hand post so that the whole battery goes to the line.

The placing of the tap wire, as shown in the drawing, effects what is called the proportioning of the current; the proportion is usually 3 to 1, but can be made 4 to 1; that is, the transmitter, when closed, admits four times as much current to the line as when open.

At the Pittsburg end, the dynamo current requires a different arrangement in order to proportion it; but the effect is precisely the same. When the transmitter is open, one third of the battery goes to the line; two thirds escapes through a "leak" to the ground; when the transmitter is closed, as shown in the diagram, the entire current goes to the line. The Pittsburg pole changer is closed, sending zinc to the line; the effect of this, in connection with the Fort Wayne short end copper to the line, is to set up a current Fort Wayne to Pittsburg. In the Fort Wayne relay there is induced in the upper core S polarity; in the lower N; the effect of these on the S armature is to close it; the effect of the transmitter closed at Pittsburg is to close the Fort Wayne neutral relay. The number of phases or combinations possible to the eight instruments (four at each end) of the quad is sixteen; and one of these has been traced out with the results described. The general result in every case is that the Fort Wayne neutral relay obeys the Pittsburg transmitter; the Fort Wayne polar relay obeys the Pittsburg pole changer, and *vice versa*.

How to Balance. The operation of balancing the quad is the same as that followed in connection with the polar duplex, except that the static is eliminated by watching its effect on the neutral relay instead of the polar. Approximate the resistance in the rheostat to that of the main line: Pittsburg then asks Fort Wayne for his ground, and goes on the ground himself. Center the relay so that the armature remains on the front or back stop as placed; or vibrates freely under the influence of slight extraneous currents. Turn on the home, or Pittsburg, battery and adjust the rheostat until the polar relay vibrates freely as before. Now wedge the sounder of the polar relay in order to silence it temporarily. Turn down on the spring of the neutral relay; close the transmitter and dot slowly on the pole changer. Commonly a kick will be felt on the neutral relay which can be removed by adjusting the plugs on the condensers; turn down further on the spring and readjust the condensers; turn down still more if necessary and readjust the plugs until all trace of the kick is removed. Now restore the spring to its normal pull, and ask Fort Wayne to cut in. Ask him to write on the common, or No. 2, side and dot on the polar side. Pittsburg does the same, and, if his balance is correct, the signals from Fort Wayne on each side of the quad will be clear-cut and readable. Pittsburg now grounds for Fort Wayne, who goes through the same routine, and tests the result in the same way. This done, the quad is ready for service and is capable during a day of 9½ hours of carrying 300 messages each way on the polar side, and 250 each way on the common side.

The slower work on the No. 2 side has its source in a defect in the quad which has never been entirely overcome. In the operation of the pole changer, even of the clock-face kind, when the direction of the current is changed it is plain there must be a very brief moment of time when there is no current on the line; at such moments there is a tendency on the part of the armature of the neutral relay to fall away from the magnets. If the local contact were on the front stop this would record a false signal; and the greater the length of the wire worked in the quad the more apparent is the interval.

On all long-distance quads, with a view to eliminate the false signal, there is interposed (see Fig. 29) between the relay and the recording sounder, what is called a repeating sounder; the device, however, is not an entire success, and the signals on the common side lack firmness to an extent which affects the speed.

Troubles of the Quad. It is usual in text books dealing with this subject to devote considerable space to the troubles of the quad. An expert quad man is not he who sets up quadruplexes—that is generally done by the office lineman—it is one who keeps the quad in working shape, and who, when any stoppage or defect arises, can locate the trouble and remove it. In the language of the craft, a defect in the set is called a "bug"; and those who deal with them are known as "bug hunters." It would be possible to fill a book the size of this with the ailments of the quad; how to locate and remedy them; the reader might study it attentively, but if his knowledge of the principles underlying the quad arrangement was hazy he might, and probably would, be worsted by the very first trouble he met; on the other hand, if he is thoroughly versed, as it has been the aim in these pages to make him, in first principles, each experience of trouble and its removal will prepare him to cope with the one that next presents itself. A prime qualification for anyone who aspires to be a defect hunter is a persistence in the search which never flags until the root of the trouble has been found and removed.

A very insidious defect in a quad, because, slight at first, it may gradually grow worse, is that of unevenness in the coils, producing what is called a "lop-sided" relay. It is well to make tests, at stated times, of the relay coils with a current other than that of the quad. It need hardly be said that the batteries for the quad must be kept up to the standard; that the ground wires and their resistance coils, which are a part of the circuit when a balance is taken, should have all their connections intact. If, when Pittsburg took a balance, Fort Wayne gave him a defective ground, it would add to the normal resistance of the line the resistance of the Fort Wayne rheostat, and making a working balance impossible by the ordinary method. It is not an uncommon occurrence for one pole of the battery to fail, particularly if the current is furnished by a dynamo. If Fort Wayne suspects this he will ask Pittsburg to open his key; this means, in other words, "give me your copper current". Fort Wayne writes and the relay does not give back his signals. Then he asks Pittsburg to close his key. Fort Wayne writes and finds his own relay following the key, which it should not do, because, when the battery and wire are intact and the line balanced, the relays do not respond to the home key. Fort Wayne then tells Pittsburg the result of the test, and that his zinc pole is not coming to line.

Caution is once more enjoined against the practice of allowing the armature of the pole changer or transmitter to hit upon the magnets or come in contact with them.

The proper way to make a test of a quad set is, of course, to put an ammeter in the circuit and see if the currents are going out in their normal proportions. If a meter is not available, a rough test of the currents can be made by using the polar relay for a galvanometer. Remove the main line wire from the binding post of the polar relay, the armature of which is supposed to be centered. Close both keys and with the finger feel the pull of the armature; what you feel is the attractive force of the entire zinc current. Open the pole changer and see how the pull of the copper current compares with that of the zinc. It should be the same. Now open the transmitter, and the weaker pull of the short end copper is felt; close the pole changer and the pull of the short end-zinc should equal that of the copper. By this process the short and long ends of each pole, through the coils of the artificial line, have been tested. Remove the artificial line from its binding post and attach it to the main line post, from which the main line wire has previously been removed, and a test can be made of the currents through the main line coils under all the conditions noted.

In the hands of a person to whom experience has given some nicety of muscular sense, this method, in the absence of a meter, gives fairly satisfactory results. In an office where two quad sets are available, and occasional cessation in their use gives opportunity, the following plan for familiarizing one's self with the quad and its troubles is suggested by an expert. Select a station 200 miles away and ask him to "loop", that is to join together, two wires which you name. Connect the two wires to adjacent sets in your own office. Balance them as though they were distant sets. Now introduce into one set any form of interference or disconnection that would be likely to occur in practice, and observe the effect on the other set; experience may be gained in this way that would aid in the location of trouble when it occurs in practice.

Duplex Repeater. In wires worked on the duplex or quadruplex system, the static capacity of the wire places a limit on the number of straight miles a circuit can be worked. But the distance between stations can be greatly extended by the use of repeaters in which, by a perfectly simple arrangement of local circuits, the pole changer of a second circuit is controlled by the relay points of the first, and *vice versa*. For example, in the text, a duplex Pittsburg to Fort Wayne was described; call it the first circuit. For a second circuit suppose Fort Wayne has a duplex to Chicago, and that Pittsburg wishes to be put through direct. By means of switch-jacks and cords provided for the purpose, Fort Wayne makes the electromagnets of the pole changer of his northern set a part of the local circuit which passes through the points of the polar relay of his Pittsburg, or eastern, set; he also makes the electromagnets of the pole changer of his eastern set a part of the local circuit which passes through the points of the polar relay of his northern set; Pittsburg and Chicago can then work duplex. The longest regular circuit in the United States is that worked between New York and San Francisco with six repeaters; another long circuit is that between New York and Heart's Content, Newfoundland, with repeaters at Boston, St. John, and North Sydney. In a few seconds these two circuits could be repeatered at New York; San Francisco and Heart's Content could then work duplex through nine repeaters—a circuit from ocean to ocean where the continent is widest.

The Repeating Sounder. *Duplex Loops.* Fig. 29 shows the local connections of the common side of a quad and the method of

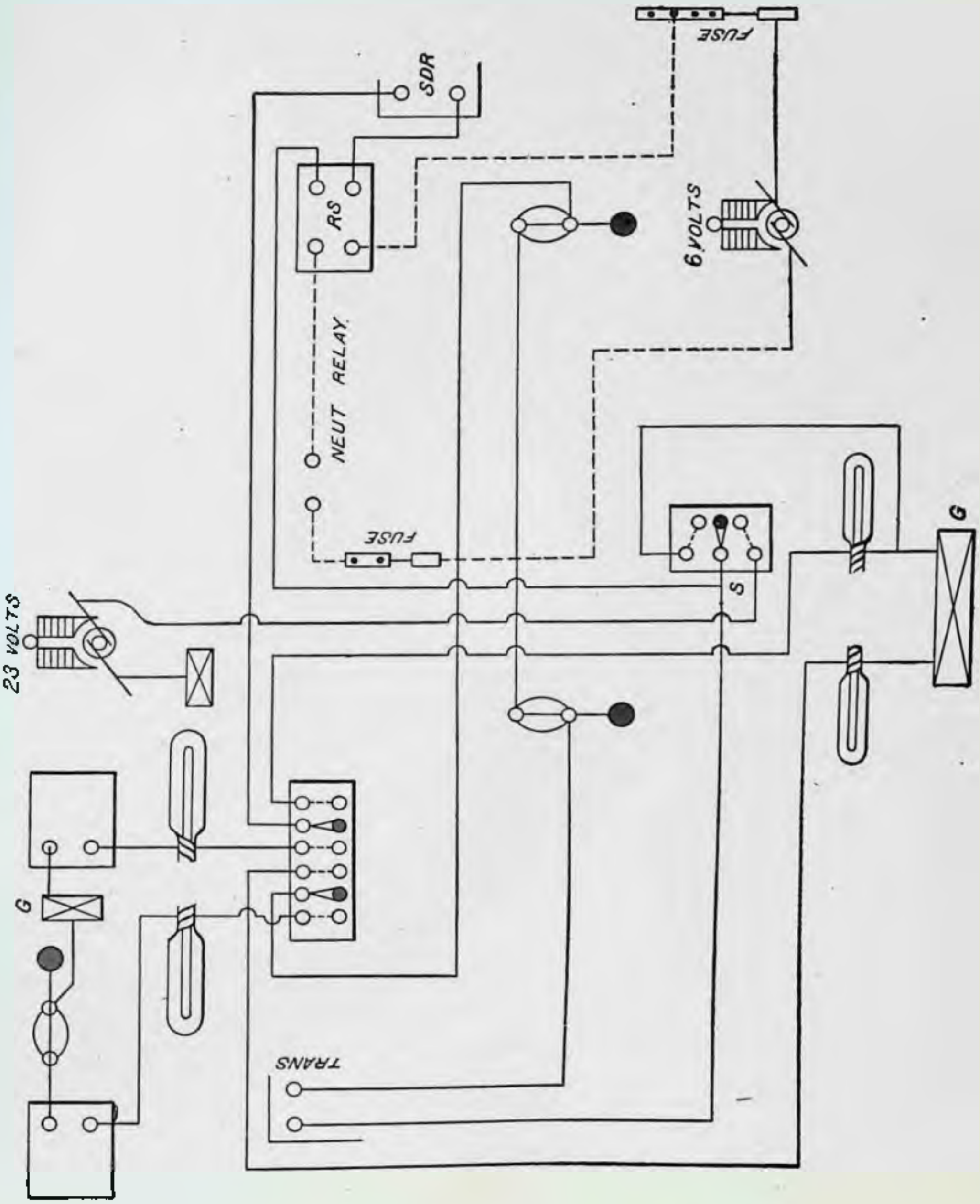


Fig. 29.

current supply which, it is seen, is from two independent sources. The common side is shown preferably because it exhibits, in place, the repeating sounder, to which reference was made in a preceding paragraph, in the receiving, or relay, side. The current supply is a 6-volt dynamo, from one pole of which a wire extends through a fuse to the armature of the neutral relay. From the *back*, not the front, stop of the relay it passes through the coils of the repeating sounder, through another fuse, back to the dynamo, thus completing a metallic circuit. When the neutral relay is on the front stop, the *repeating* sounder is open; but its points, between the lever and the up stop, are closed, permitting the 23-volt current to close the other sounder from which the signals are read. When the neutral relay points open, the repeating sounder is closed, but the receiving sounder is open; the reason for this arrangement has already been given in the text on the quad.

The regular local system of a duplex, or one side of a quadruplex, is not a metallic circuit; it is a grounded system supplied, as the drawing shows, by a 23-volt dynamo. The reason for the ground arrangement is that in all the principal offices by far the greater number of the duplex and quadruplex sets are fitted up so that while the sets themselves are in the main office, where they can receive expert attention, they can be operated in branch offices by means of what are called "loops", or "legs". By suitable switches the loops can be cut in or out as desired.

The current from the 23-volt dynamo runs first to a fuse block (not shown); thence to a small 3-point switch, the lever of which, if turned to the left, connects the battery with the set; if turned to the right it connects the set with the ground. The latter connection is made in "setting up" a duplex repeater. With the lever to the left, the current is seen in the drawing to divide at the point S; one branch can be traced through the points of the repeating sounder, through the coils of the receiving sounder; thence (with the lever of the 6-point switch to the right) through a lamp of about 96 ohms resistance to the ground. The other branch can be traced through the coils of the transmitter; through two keys; thence (the lever of the 6-point switch to the right) through a lamp to the ground. The purpose of the lamps is to make the resistance in the circuits the same in either position of the levers of the 6-

point switch. Above this switch are the connections and outfit of a branch office for the operation of a duplex; or, what is known as a duplex loop. It shows one wire connecting a lamp and the coils of a sounder to the ground; another wire connecting a lamp, sounder and key to the ground for the sending side; the first mentioned sounder is that of the receiving side. To cut them in, turn the levers of the 6-point switch to the left; the relay then operates a receiving sounder in both main and branch offices; the branch office can operate the transmitter and work duplex with another city or a branch office therein similarly equipped. The word "loop", though commonly used in this connection, is a misnomer. In telegraphy, loops connect an outlying office, which may be rods or miles away, with a single Morse circuit. To do this, the pair of wires leading to the distant relay, which makes the loop properly so called, terminates in a wedge which can be inserted in the spring-jack of any wire in the main switch. In the duplex arrangement the wires operating the branch instruments are merely extensions of the sending and receiving sides of the local system.

There are many matters of detail in connection with the setting-up and operation of a quad which do not properly fall within the scope of this work. For special works on the duplex and quadruplex the reader is referred to Thom and Jones' Telègraphic Connections; to Jones' Pocket Edition of Diagrams; and to Maver's American Telegraphy: Its Systems and Operation.

THE PHONOPLEX.

Among contrivances for increasing telegraphic facilities a worthy place is occupied by the device known as the Phonoplex—an invention of Mr. Thomas A. Edison. In its mode of operation it will be found to differ materially from anything heretofore presented; its essential feature being the superposition, without noticeable interference, of the high-tension impulses of a magnetic coil upon the current or currents of the Morse system. Even when all the wires on the route are crossed or grounded, not excepting the one upon which the phonoplex is working, it admits of serviceable operation.

It can be worked in connection with the duplex and quadruplex systems; but its usefulness is greatest as an adjunct to the single-line service of the railways, providing, in a sphere where

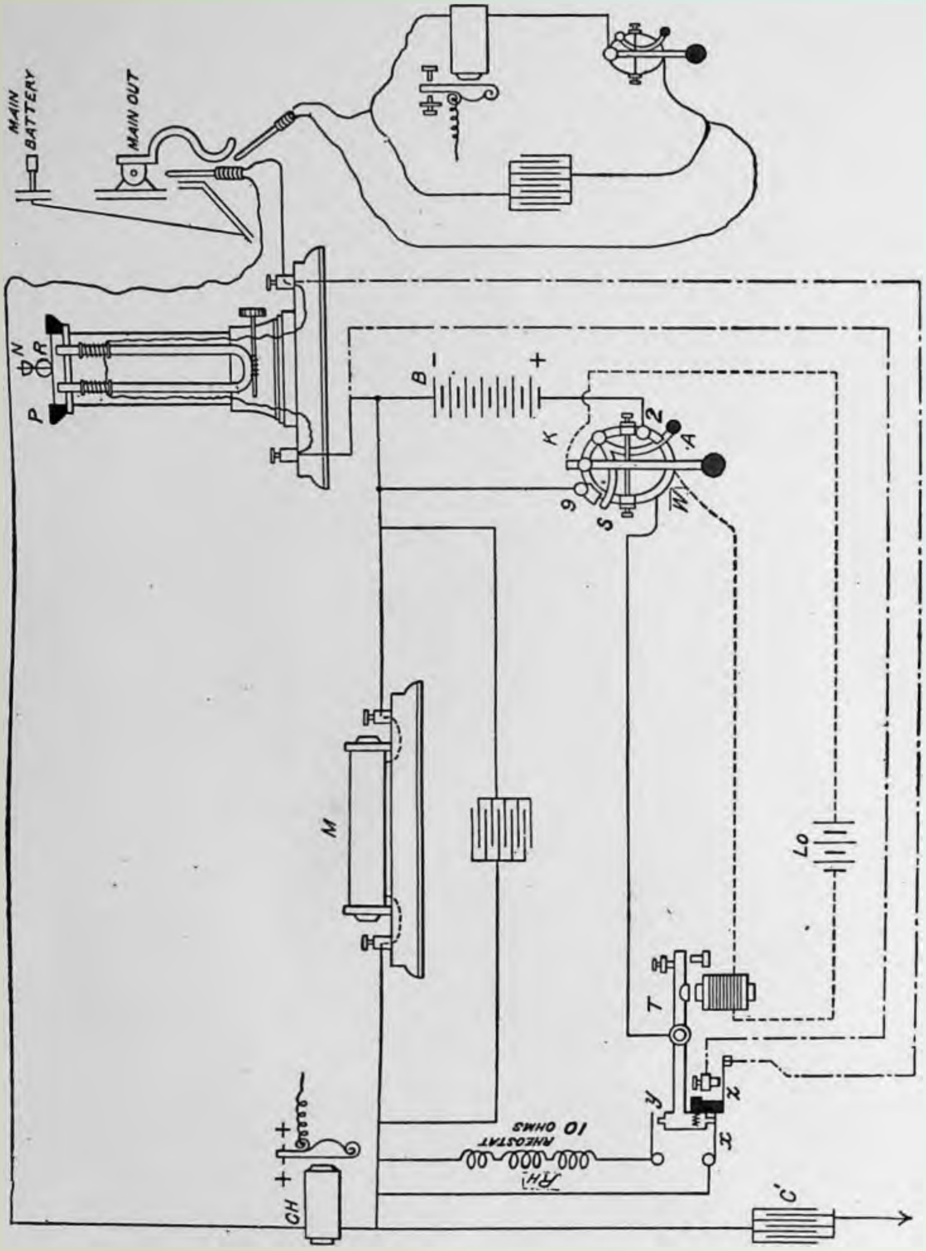


Fig. 30.

the number of wires is usually limited, an extra circuit which is at all times available. The apparatus is adapted for use between intermediate, as well as between terminal, points; but the diagram (Fig. 30) presents, and the text describes, the arrangement of a terminal station where the single wire takes its battery. As it

LOCATION OF WIRELESS STATION ON THE DREADNAUGHT CLASS OF AMERICAN BATTTLESHIP
It is located at the Base of and Inside the New-Style Tower.

embodies some new features, the details require more than usual length in their description. Referring now to the diagram—on the right is seen the spring-jack of a terminal switch, showing main battery and line connections. Two wedges are inserted in the jack; one carries the conductors to the phonoplex; the other cuts in a main-line key and relay which are bridged by condensers; the bridging arrangement obtains also at every intermediate station. This use of condensers makes feasible the operation of the phonoplex in the presence of crossed and grounded wires—a feature to which reference has already been made.

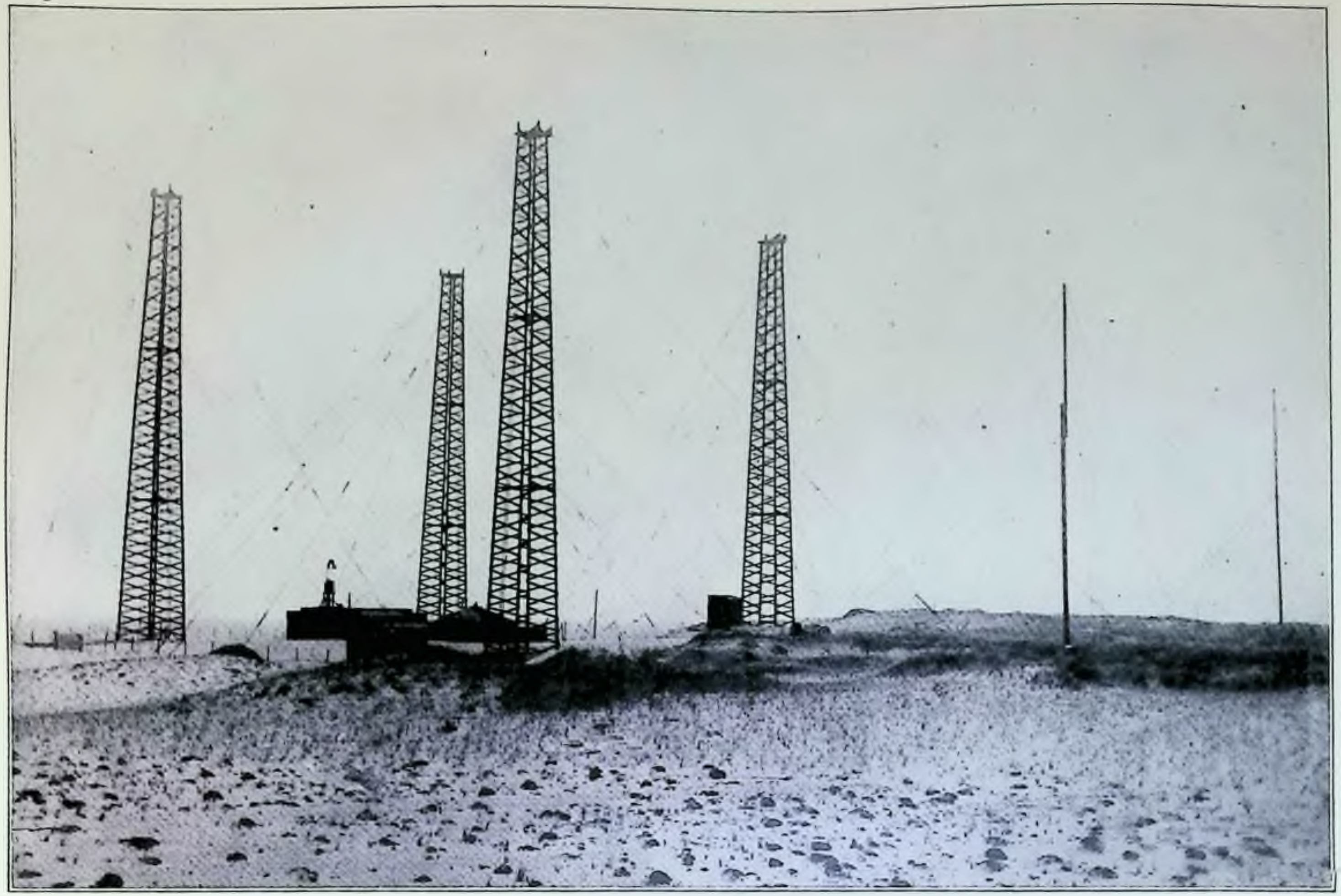
The phonoplex requires for its operation, two batteries—one, B, of at least five 2-volt cells, and one, L*o*, of three cells; a key and transmitter, each of peculiar construction; a small rheostat containing five coils of two ohms each; a simple magnetic coil, bridged by a condenser of small capacity, to quicken the impulses sent out from the coil; an ordinary Morse relay and condenser; and, lastly, the characteristic phonoplex instrument itself, marked P in the diagram. The latter consists of a circular wood base supporting an upright cylinder containing an elongated horseshoe magnet, upon each pole of which is wound a small coil of insulated copper wire. Above the poles, and covering them, is a metallic diaphragm like that used in the telephone. A split steel ring R rests upon this diaphragm, or moves freely upon a threaded vertical pin N, at the top of which is placed an adjustable nut. Each agitation of the diaphragm causes the steel ring to be thrown up against the nut, producing an excellent imitation of the well-known "click" of the sounder. Between magnetic coil M and the main battery is an ordinary 150-ohm Morse relay C H, which acts as a choke-coil; to it is tapped a condenser C′, and a ground. R*h* is a small adjustable resistance box containing five coils of about 2 ohms each. This resistance is introduced into one of the circuits bridging the magnetic coil, in order to weaken the current so that one stroke of the phone recorder may be distinguished from the other; otherwise the "back-stroke" effect would ensue, and the signals would not be readable. Of the wires bridging the magnetic coil two, on the left-hand side, terminate in springs between which moves the hammer-headed lever of the transmitter operated in the usual manner by means of local battery L*o*, and key K. The lower end of the hammer-head also has an attachment which acts on spring *z* for a purpose which will be explained later.

It is difficult to represent in a diagram the insulated portions of key K; in order to understand its working a detailed description is necessary. The key and its attachments control two independent circuits. The ordinary circuit-closing switch is absent; the local circuit (dotted) is always "open" except when signals are being sent. One conductor of the local circuit makes connection with the anvil post W which is insulated from the base, and is fixed underneath the lever. To the further end of the lever is attached the other end of the local circuit conductor, so that when the key is depressed, the transmitter is closed. To the near end of the base of the key is connected a wire leading to the lever of the transmitter T. Attached to the base by means of a screw, which serves also as a pivot, is a curved arm A, at the pivoted end of which is a curved spur *s* reaching across the base of the key. At 2 and 9 are small spurred thumbscrews attached to, but insulated from the base: so that, in the position shown in the diagram, the arm A puts 2 in contact with the base; but if the arm is withdrawn from 2 a sufficient distance then 9 makes contact with the base through the spur *s*.

To understand the working of the apparatus it must be borne in mind that the transmitter, unlike that of the Stearns duplex, produces the effects of dots and dashes by the "breaks", and not by contacts. In the diagram, the lever of key K, and that of transmitter T are open; the current from B flows from + to 2, through the base of K and the lever of T, through spring *x* and the coil M, to – of battery MB, thereby charging the coil with the full strength of B. The act of depressing the key lever breaks the contact at *x*, coil M discharges, and a loud "snap" is heard in the distant phone or phones. When the lever T strikes the upper spring *y*, the current flows through *y* instead of *x*, thence through resistance R*h*, charging coil M less strongly than before; so that, when the upward movement, or opening, of the key breaks the contact at *y*, a less pronounced snap is heard on the distant phone; thus obviating, as already stated, the effect of the "back-stroke".

It will be noticed that, during this sending operation, the curved arm is to the right, which is the position of an ordinary key when an operator is sending. When he begins to receive on the phone, he moves the curved arm to the left, which movement corresponds to the "closing" of an ordinary key; but in this case the movement simply disconnects the battery B from the transmitter, and the spur *s* makes connection between 9 and the base, shunting the magnetic coil, so that the phone may be affected by the maximum of charge and discharge from the distant magnetic coil.

One feature remains to be described. Leading from the terminals of the phone may be noticed a shunt circuit (in dots and dashes) terminating in spring *z* and a contact point above. The position of spring *z* is such that when the transmitter is open and its lever in a downward position, the shunt circuit is open; but when the hammer end of lever T is raised, and so long as it remains so, the phone is shunted. This automatic shunting of the phone during the time when the lever is "breaking" the charging currents of the coil, obviates annoyance from the discharges of magnetic coil M to the operator who is sending in proximity to the home phone.



MARCONI WIRELESS TELEGRAPH STATION AT SOUTH WELLFLEET, MASSACHUSETTS
Towers 215 Feet High.

WIRELESS TELEGRAPHY

INTRODUCTION

As a first step into the subject of wireless telegraphy it may be well to consider the meaning of the term. Wire telegraphy is characterized by the employment of extended metallic lines or conductors over which it is possible to transmit intelligence electrically by means of an arbitrary code of signals. Wireless telegraphy is characterized by the absence of such lines in the accomplishment of the same end. Many have confounded wireless telegraphy with the system invented by Marconi; but the latter is only one form out of many: the term was used to describe other systems years before Marconi's spectacular success added it to the popular vocabulary. As a matter of fact any system of telegraphy which successfully substitutes some other medium for the connecting wires, may properly be called "wireless." The systems of wireless telegraphy so far proposed may be classified as follows: Conduction Systems; Induction Systems; and Radiation Systems.

The history of the subject follows very closely the above sequence in point of time. First came the conduction systems—the attempt to substitute the earth and bodies of water in place of the connecting lines. Then came the induction systems, taking advantage of those peculiar electrical phenomena known as electrostatic and electrodynamic induction: here the substituted medium was the ether—that invisible, intangible substance which is supposed to fill all space. Last came the radiation systems, which also make use of the ether, but in a different way, namely, by disturbing it in such a manner as to produce far-reaching waves which can be detected at distant points. It is the last type, known as *radiotelegraphy*, which is today paramount, having superseded the other two by reason of its superior utility and effectiveness. Its startling development during the past ten years may justly be called a "fairy tale of science." The earlier systems are important, however, as they mark the birth and the development of an idea.

CHAPTER I

EARLY FORMS

Conduction Systems. The essential feature of all conduction systems is that *some other form of material conductor is substituted for that of wires.* These substitutes have been in all cases either earth or bodies of water, because they are the only natural conductors which are sufficiently common and extensive to be utilized.

Work of Steinheil. Today it seems glaringly obvious that the earth may be used as a conductor, but in 1838 when Steinheil, a Bavarian, accidentally discovered this fact, it created quite a sensation. He had been experimenting with the steel rails of a railroad trying to utilize them as substitutes for the wires of a telegraph circuit, but was unable to obtain sufficient insulation. He was surprised to discover, however, what a high degree of conductivity the earth possessed, and was led to conceive that he might employ it instead of the return wire hitherto used. He made the experiment, and with complete success, thus introducing into telegraphy one of its most important features—the earth circuit. Expanding the idea, Steinheil wondered if it were not possible to telegraph through the earth without using metallic conductors at all. This experiment, which was successful over very short distances, is said to have been the first attempt to telegraph without wires. Steinheil, however, being unable to signal farther than 50 feet, gave up this method, convinced that it was inexpedient for telegraphy.

Morse System. S. F. B. Morse, who is famed as the inventor of wire telegraphy and of the code which still bears his name, was, by a strange coincidence, also one of the pioneers of telegraphy without wires. In 1844 he addressed a letter to Congress in which he related his experiments in this field and gave an interesting account of his inception of the idea. A portion of the document, considerably abridged, is as follows:

In the autumn of 1842, at the request of the American Institute, I undertook to give to the public in New York a demonstration of the practicability of my telegraph, by connecting Governor's Island with Castle Garden, a distance of a mile; and for this purpose I laid my wires properly insulated beneath the water. I had scarcely begun to operate, and had received but two or three characters, when my intentions were frustrated by the accidental destruction of a part of my conductors by a vessel which drew them up on her anchor and cut them off. In the moments of mortification I immediately devised a plan for avoiding such accidents in the future, by so arranging my wires along the banks of the river as to cause the water itself to conduct the electricity across. The experiment, however, was deferred until I arrived in Washington; and on Dec. 16, 1842, I tested my arrangement across the canal, and with success. The simple fact was then ascertained that electricity could be made to cross a river without other conductors than the water itself; but it was not until the last autumn that I had the leisure to make a series of experiments to ascertain the law of its passage. The diagram, Fig. 1, will serve to explain the experiment.

A, *B*, *C*, *D*, are the banks of the river; *N P* is the battery; *G* is the galvanometer; *W W* are the wires along the banks, connected with copper plates *f*, *g*, *h*, *i*, which are placed in the water. When this arrangement is complete, the electricity, generated by the battery, passes from the positive pole *P* to the plate *h*, across the river through the water to plate *i*, and thence around the coil of the galvanometer to plate *f*, across the river again to plate *g*, and thence to the other pole of the battery *N*.

Morse here appends a table of his results, "showing," as he says, "that electricity crosses the river, and in quantities in propor-

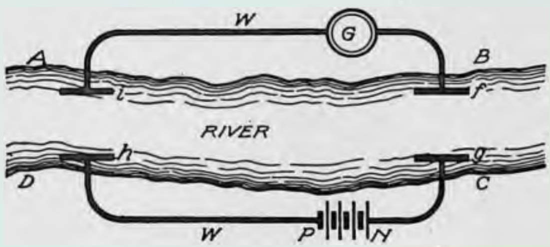


Fig. 1. Experiment of Morse

tion to the size of the plates in the water. The distance of the plates on the same side of the river from each other also affects the result." This distance he states elsewhere should be three times greater than that from shore to shore across the stream.

Morse's plan contains in a simple form all the essential features of all later endeavors to telegraph by the conduction method whether utilizing water or earth as the medium. Lindsay, Highton, Dering, Stevenson, Preece, Smith, and others subsequently worked out more elaborate and extensive methods all resting primarily on the same principle as above. None of them succeeded in signaling much farther than three miles. These early results indicate the inherent limitations which have ever remained as insurmountable difficulties to the commercial adoption of this form of wireless telegraphy.

Induction Systems. Induction is an electrical influence exerted by a charged body or by a magnetic field on neighboring bodies without apparent communication. The laws of it are well known to electrical science through the classic researches of Faraday. Induction comprehends two classes of phenomena known, respectively, as *electrostatic induction* and *electrodynamic induction:* the former is that property of the electrostatic field which produces an electric charge in a conductor when brought into the said field; while the latter is that property of the magnetic field by virtue of which electromotive forces are created in conductors by a relative movement between said field and such conductors. Without attempting to go further into the matter here, it suffices to say that investigators were not slow in appreciating that induction offered a means of communication which could be classified as "wireless."

Dolbear System. What is now generally considered to be an extreme case of electrostatic induction is the remarkable system of wireless communication invented by Prof. Dolbear of Tufts College, Boston, in 1882. This system is of especial historical interest owing to its startling resemblance to the system devised later by Marconi. Dolbear's invention may be best explained by referring to Fig. 2. The left side represents the transmitting circuit and the right, the receiving circuit. *B* is a battery connected through a carbon transmitter to the primary winding of an induction coil, the secondary terminals, *A* and *C*, of which are connected, respectively, with an elevated wire and the ground. The receiving end consists essentially of a similar elevated wire *A* connected to one terminal of a telephone receiver, the companion terminal of which is connected directly with the earth. The higher these wires are raised, the farther signals can be transmitted, so that Dolbear was prompted to attach them to kites. This is a curious anticipation of Marconi's antennae. Dolbear later made many modifications in his apparatus in an endeavor to reach greater distances by employing condensers raised to a considerable height and charged by batteries; but the system remained in all important respects the same as shown.

The apparatus works as follows: The diaphragm of the telephone transmitter is set into vibration by talking or whistling, thereby producing variations of resistance in the powdered carbon; this constantly varies the amount of current which flows into the induction coil; and consequently the wire *A* is charged to potentials which are constantly fluctuating in value, the degree of fluctuation depending on the degree of variation of resistance in the transmitter. The wire *A'* at the receiving station follows by electrostatic induction all the fluctuations of *A*; and with every change of potential, currents flow between *A'* and the ground through the telephone receiver *R*.

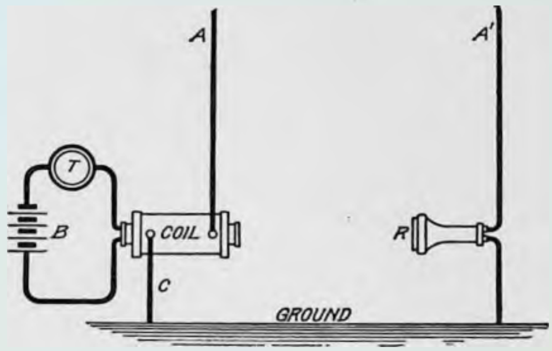


Fig. 2. Diagram of the Dolbear System

The latter consequently repeats all the vibrations set up in the transmitter, and the corresponding sound is reproduced. This particular method of operation is telephonic; but it will be seen that the same, or rather better, results could be obtained by a Morse key and telephonic receiver.

Edison System. Edison patented, in 1885, a system of inductive telegraphy, the particular purpose of which was to effect communication with moving trains. The ordinary telegraph wire, which commonly runs parallel to a railroad track, was utilized for one of the inductive circuits, and the train was equipped with another. The latter consisted mainly of a large, metallic condensing plate set on the roof of the car and connected to the secondary terminals of an induction coil, to the primary terminals of which were connected suitable transmitting and receiving instruments. When the Morse key in the primary circuit was depressed, the large condensing plate received static impulses and these acted inductively on the neighboring telegraph wire, which thereby received and conducted equivalent impulses to the nearest station equipped with proper receiving instruments. Or in case another train equipped as above were traveling on the same track, it could pick off the message inductively from the telegraph wire. In this manner two moving trains might communicate. This ingenious system was put into practical operation on the Lehigh Valley Railroad in 1887, and worked with undoubted success; but from a business point of view it proved a failure as there was no public demand for such service.

Work of Preece. One of England's most successful investigators in the field of wireless telegraphy was Sir Wm. Preece, chief electrician of the British Postal Telegraphs. He performed numerous experiments which added greatly to the theory of all forms of inductive and conductive communication. One of his most successful achievements was to effect inductive communication between Gloucester and Bristol on the banks of the Severn, a distance of nearly five miles. Parallel to the two shores were stretched on telegraph poles two closed wire circuits extending about 14 miles each. One of these circuits was traversed by a rapidly interrupted current of about .5 amperes. A telephone receiver inserted in the companion circuit responded to the frequency of the current in the other by a continuous sound upon pressure of the transmitting key. This form of communication was at one time resorted to quite frequently between stations separated by bodies of water under which it was inexpedient to lay cables.

Such systems may be characterized as "wireless" only through courtesy, since they demand an amount of wire which far exceeds that required by any ordinary wire system covering the same distance; they come under the classification of wireless telegraphy, however, since the wire conductors are not continuous, some other medium being interposed.

In the year 1885, Preece carried on very extensive investigations upon the possibilities of induction as an agency of communication, and summarized his observations as follows:

> Although communication across space has thus been proved to be practical in certain conditions, those conditions do not exist in the cases of isolated lighthouses and light-ships, cases which it was specially desired to provide for. The length of the secondary must be considerable, and, for good effects,

at least equal to the distance separating the two conductors. Moreover, the apparatus to be used on each circuit is cumbrous and costly, and it may be more economical to lay a submarine cable.

These conclusions are equally true to the present day. The necessity for a large base area remains the prohibiting factor in the adoption of electromagnetic induction systems. For a very painstaking review of the various early attempts at this form of telegraphy, the reader is referred to J. J. Fahie's excellent book, "A History of Wireless Telegraphy."

Summary. The conduction and induction methods of wireless telegraphy, although of great historical and experimental value, are of little practical value. Today their use is most exceptional because their utility is too limited—the supreme test for any system of wireless telegraphy being the test of long distance. They have been superseded by a type of wireless telegraphy which can achieve communication across an ocean if necessary—a type which is the product of an entirely different principle, the principle of electromagnetic radiation. In order to differentiate it from other forms of wireless telegraphy, this system is best denominated by the term *radiotelegraphy*, and a discussion of its underlying theory, its operation, and the arrangement of necessary apparatus will be found in the following chapters.

CHAPTER II

ELECTRIC WAVES

Electromagnetic Theory of Light. In order to understand radiotelegraphy with any degree of completeness one must first have a comprehension of the theory of electric waves, including the electromagnetic theory of light. This theory, with its verification, was one of the most notable scientific achievements of the last century. However, let it be remembered that, having adopted a working hypothesis—the most tenable one at present—to account for the ether and the *modus operandi* of ether waves, it is necessary as well as convenient to use the terms and implications of such hypothesis positively and with consistency throughout. Such unqualified use of terms might give foundation to the charge of scientific dogmatism were it not remembered at all times that we are dealing with a theory, generally accepted, it is true, but subject to the trials and mutations which such theories have undergone in the past. The reasonings from the working hypothesis are valid for the purpose for which they are here employed; but no true scientist will at present claim that such reasonings should or can be extended to the higher realm of absolute truth. In the words of H. Poincaré, "It matters little whether the ether really exists; that is the affair of metaphysicians. The essential thing for us is that everything happens as if it existed, and that this hypothesis is convenient for the explanation of the phenomena."

The electromagnetic theory of light was first completely stated in 1864, when James Clerk Maxwell, an English mathematician, sent to the Royal Society a paper entitled "A Dynamical Theory of the Ether," wherein he demonstrated his conviction that light and electricity were phenomena of a kindred nature—in fact, that light was an electrical manifestation. Maxwell's paper came as the result of a long series of investigations which had been carried on in two different departments of Physics—Optics and Electricity. These investigations had led on the one hand to a theory of a light-bearing medium called the *luminiferous ether*, and on the other hand to a theory of an electromagnetic medium also called the *ether*. Maxwell made a synthesis of these two theories, demonstrating that the hypothetical medium was the same in both cases, and that it was governed by electromagnetic laws.

The Luminiferous Ether. When we observe that light takes time to travel from place to place, and that it comes to the earth from the sun and stars across vast spaces which are not, so far as we know, filled with tangible matter, the inference necessarily follows that light is either a substance transmitted bodily, like a stone hurled from one place to another, or a physical state propagated through a stationary medium in the form of waves. Various investigators have demonstrated that light is a phenomenon of the latter description—that it is a physical state, or change of state, propagated through a stationary medium in the form of undulatory waves, the velocity of the waves being approximately 186,500 miles per second. Investigators agreed to call this medium the ether, prefixing the adjective "luminiferous" which means "light-bearing." They had neither seen nor felt the ether—directly or indirectly—but they reasoned that the ether must exist, else the facts of Optics were inexplicable. They held that it must be some peculiar form of matter which interpenetrated all ordinary forms of matter, and must also be distributed everywhere throughout the space of the universe. Up to Maxwell's time, however, they knew almost nothing of the ether itself, except that it behaved like an incompressible liquid, extremely tenuous but exceedingly rigid, and that the waves were of the kind classed as "transverse."

The Electromagnetic Medium. In the department of Electricity a theory of an electromagnetic medium had also grown up, following on the researches of Ampère, Henry, and Faraday. The fact that electrified bodies or magnets attracted or repelled each other at a distance, and that electric currents could create other currents in wires at a distance, and that these actions were not fundamentally dependent upon the presence of any material substance in the space between, led these investigators to conceive that there must be an electromagnetic medium by means of which such actions were transmitted across apparently empty spaces. They named this medium the ether, the same name adopted by investigators in the department of Optics; but it was a long time before anyone even surmised that there was any kinship between the luminiferous medium and the electromagnetic medium.

Work of Faraday. The first man to hint at the above possibility was Faraday, who, in 1845, discovered the singular fact that the magnet exercises a peculiar action on light, the plane of polarization of a polarized beam being rotated when the beam passes along a magnetic field. This seemed to show that there was some relation between electricity and light. Faraday persevered in these experiments. He wrote a paper entitled "Thoughts on Ray Vibrations" wherein he expressed his belief that radiation of all kinds—light, heat, etc.—were due to a high species of vibration of the lines of force in the magnetic field. Faraday's speculations may be said to have been the inception of the electromagnetic theory of light; he is indeed entitled to a large share of the credit; but his were only speculations, unformulated and incomplete, and it remained for another man to elaborate them into a complete theory mathematically demonstrable.

Work of Maxwell. When Maxwell, in 1864, sent his paper on "A Dynamical Theory of the Electromagnetic Field" to the Royal Society, one of his first steps was to acknowledge his debt to Faraday. He writes, "The conception of the propagation of transverse magnetic disturbances to the exclusion of normal ones is distinctly set forth by Prof. Faraday in his 'Thoughts on Ray Vibrations.' The electromagnetic theory of light as proposed by him is the same in substance as that which I have begun to develop in this paper, except that in 1846 there was no data to calculate the velocity of propagation." Maxwell then proceeds to give new equations to express the relations between the electric and the magnetic displacements in the medium and the forces which result from them. He shows that when magnetic methods of measurement are used, the unit of electricity arrived at has a certain value; but when purely electrical methods are used the unit proves to have a different value. The relation between these two units is dependent on the "electric elasticity" of the medium, and when measured proves to be a certain velocity—186,500 miles per second. This velocity, in other words, is that velocity with which an electromagnetic disturbance is propagated through the electromagnetic field. It will be remembered that the velocity of light was already known to be about 186,000 miles per second. Maxwell comments on the startling similarity as follows: "This velocity is so nearly that of light, that it seems we have strong reason to conclude that light itself (including radiant heat, and other radiations, if any) is an electromagnetic disturbance in the form of waves propagated through the electromagnetic field according to electromagnetic laws." In short, Maxwell's theory assumes that the entire material universe lies in one all-pervading electromagnetic field, called for convenience *the ether*, and if this field be disturbed at any point, the disturbance is propagated throughout the field in the form of waves. All those forms of radiant energy which we call light, heat, etc., are in reality electromagnetic disturbances propagated in the form of electromagnetic waves.

Once an electromagnetic field is established, any change which alters the prevailing conditions is said to be an electromagnetic disturbance. When a current of electricity increases in strength, the field around it increases also, the lines of force spreading out from the conductor like ripples in a pond; but when the current is decreased, the lines of force contract, closing in around the conductor, and the energy of the field shrinks back into the system. If this process be augmented so that the periodic reversals of current produce oscillations of extremely high frequency, then, at each reversal, part of the energy of the field radiates off into the surrounding medium as electric waves and only part of it returns into the system. The frequency with which such periodic reversals of current take place determines the distance between the crests of the waves radiated into space from such a system. Waves created in the ether by this means are called *electric*, or *Hertzian, waves,* after the German physicist, Heinrich Hertz. Before entering upon a more detailed consideration of waves of this character, the subject of waves in general will be considered.

Nature of a Wave. When a disturbance is made at any point in an elastic medium, the particles of the medium are set into vibration and the vibrations are passed on to the neighboring particles, so that waves are formed; and these waves travel with a uniform velocity depending on the nature of the medium, with a result that the disturbance is propagated to considerable distances from its point of origin. There are in general two classes of waves, known as *longitudinal* and *transverse,* the distinction between them depending on the direction in which the particles vibrate. When the particles vibrate along the line in which the disturbance is traveling, the wave is said to be longitudinal; when the particles vibrate at right angles thereto, the wave is said to be transverse. The general equation for determining the velocity of waves of either class is

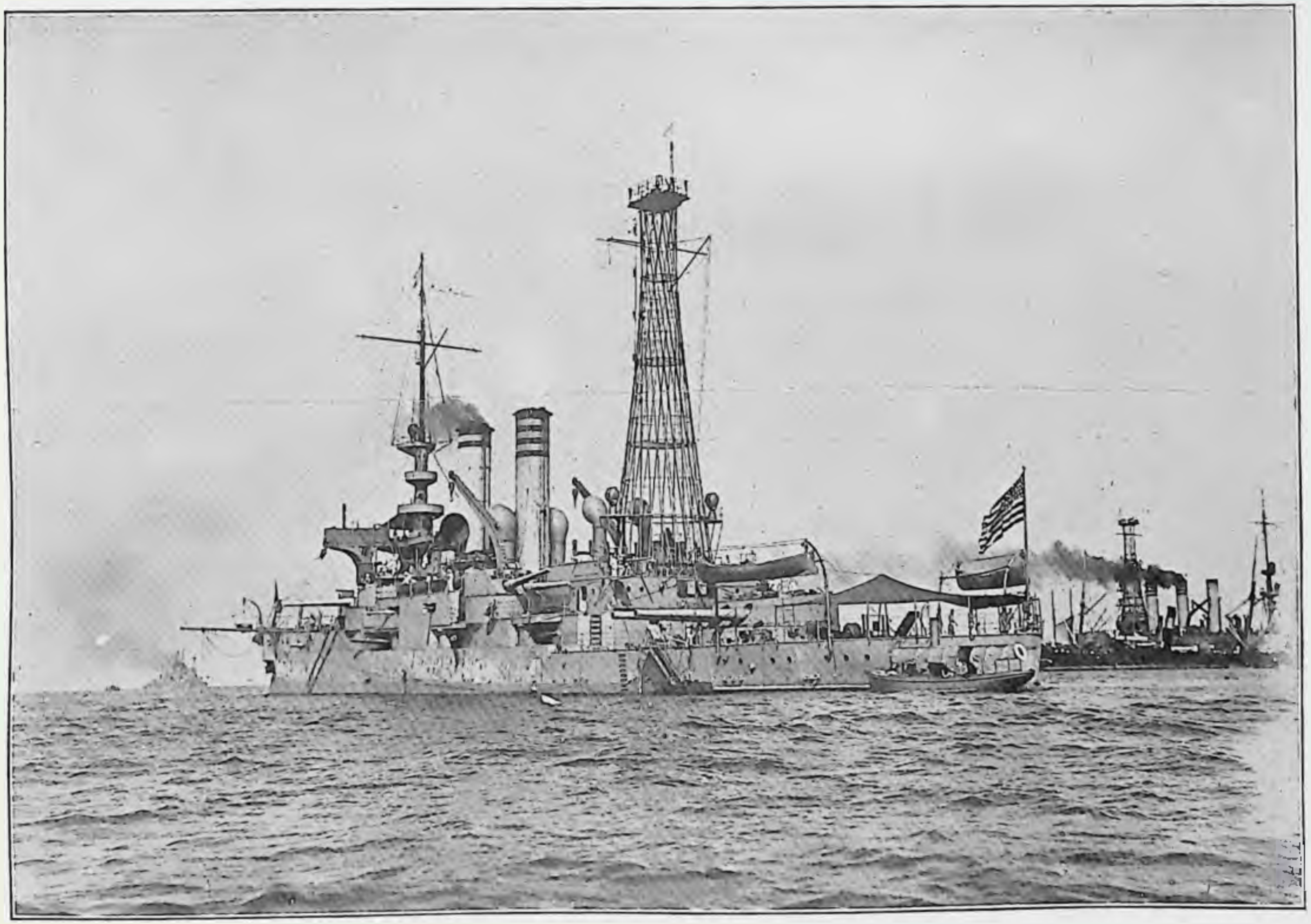
$$v = ln$$

where v stands for the velocity, l for the wave length, and n for the frequency, or number of vibrations per second.

This equation holds equally true for ether waves which manifest themselves as light, and for the longer waves produced by high-frequency oscillations of an electric current, both of which are of the transverse variety. Indeed all forms of radiant energy are, according to the present belief, due to ether waves, differing from one another only in length. As the velocity of propagation is the same for all—namely, 186,000 miles per second—the frequency varies through a wide range. Ether waves varying between certain definite lengths are visible and produce the sensation of light; others much longer falling upon matter raise its temperature, thus manifesting themselves as heat; still others, of a wave-length extremely small even in comparison with visible rays, are capable of penetrating matter as X-rays; and others again, of a length of half a mile or more, are flashed across the Atlantic, conveying intelligence from the Old World to the New.

As there are many methods of producing waves in gross matter, so also are there many methods of producing waves in the ether. The production of electromagnetic waves of a length measuring from a few inches to many rods need only concern us here, as it is with the production of such waves that the science of radiotelegraphy deals. As before stated, a part of the energy of a very rapidly alternating current is radiated off into space in the form of electric waves. Under what physical conditions such disturbances are created will now be considered.

Electric Oscillations. If a charged condenser, or Leyden jar, is discharged through a conductor of *high resistance,* the opposing polarities slowly neutralize each other by a current flowing in one direction. If, however, the condenser is discharged through a conductor of *low resistance,* such as a coil of wire of a few turns, the effect is wholly different. Under these conditions the discharge consists of a number of excessively rapid oscillations of the nature



BATTLESHIP SUPPLIED WITH WIRELESS TELEGRAPH EQUIPMENT
The New- and Old-Style Masts or Aërials are shown in Contrast—the New at the Right, and the Old at the Left.

of a high-frequency alternating current, caused by the self-induction of the coil, in consequence of which the current once set up tends to persist. The first rush of current more than empties the condenser, and charges it to the opposite polarity; then follows a series of similar discharges of diminishing amplitude until the energy of the charge is entirely dissipated. This process is represented in Fig. 3.

The spark produced by the discharge of a condenser under these conditions appears to the eye as a single flash, due to the rapidity with which the successive discharges follow one another. In reality it consists of several distinct sparks lasting but an exceedingly small fraction of a second.

The law governing condenser discharges is as follows: *If a condenser of capacity K is discharged through a resistance R and self-induction L, the result is a uni-directional discharge or a series of oscillations according as R is greater or less than* $2\sqrt{\frac{L}{K}}$.

A rapid oscillatory discharge sets the electromagnetic medium in vibration much as a tuning fork sets the air in vibration in pro-

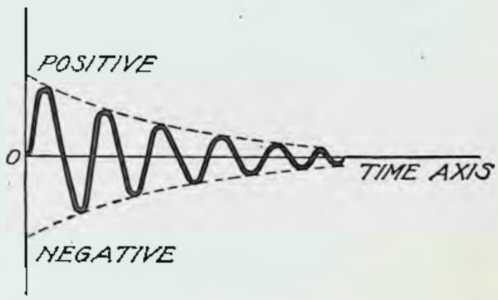


Fig. 3. Curve Representing an Oscillatory Discharge

ducing sound-waves. Such discharges provide a simple means for creating electric waves in the ether. An understanding of condenser action is, therefore, of great importance in a comprehension of the principles of radiotelegraphy.

The oscillatory nature of condenser discharges was known when Maxwell promulgated his electromagnetic theory, but it was not until twenty-five years after the announcement of the theory that scientists were able to detect the presence of electric waves. They knew the conditions under which such waves should arise, but none were able to devise a means to demonstrate their presence. It remained for Heinrich Hertz, a pupil of the illustrious von Helmholtz, to solve the mystery and give experimental verification to a theory which must ever remain one of the greatest achievements of inductive reasoning. Hertz succeeded not only in producing and detecting electric waves, but in demonstrating that such waves possessed all the essential characteristics of light.

The Work of Hertz. It was in 1888 that Hertz, then thirty years old and professor of Physics in the University of Bonn, carried

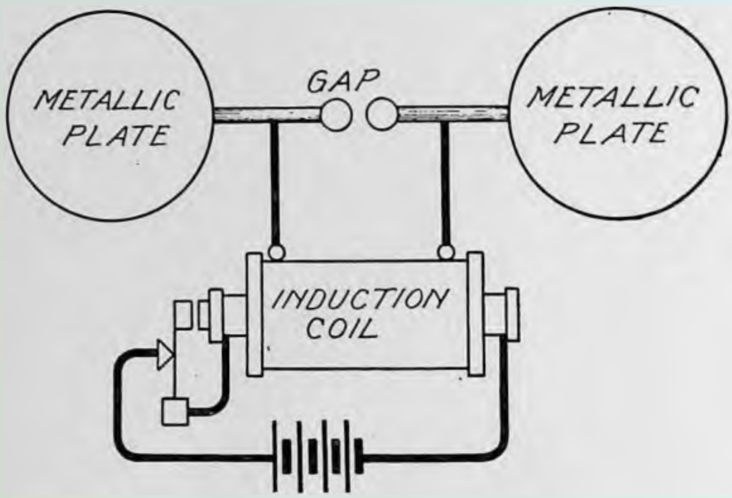


Fig. 4. Hertz Oscillator

on the epoch-making series of experiments which have proven to be the foundation of the art of radiotelegraphy. His apparatus was of the simplest construction. To generate electric waves he employed what is now known as a *Hertz oscillator*, Fig. 4. This consists of two metallic conductors in the shape of plates or spheres, each attached to a small rod terminating in a polished metal ball. These were connected to the secondary terminals of an induction coil and the two balls brought into close proximity, thus forming a small spark gap. It will be seen that the arrangement has the essential features of a condenser whose plates are widely separated and whose dielectric extends into the surrounding air. When the charge is accumulating on the large metallic plates, a strong electric displacement is set up between them, and, as the potential difference rises, a point is reached where the insulation of the air gap breaks down and a spark passes across the gap. During the passage of this spark the air becomes highly conductive and the whole oscillator becomes one conductor for the time being. The potential difference between the charged plates immediately begins to equalize itself, after the manner of all oscillatory condenser discharges, by a series of rapidly damped surges, and with every oscillation a wave is radiated into space. The waves emitted by a device of this character are intermittent, each complete discharge of the oscillator

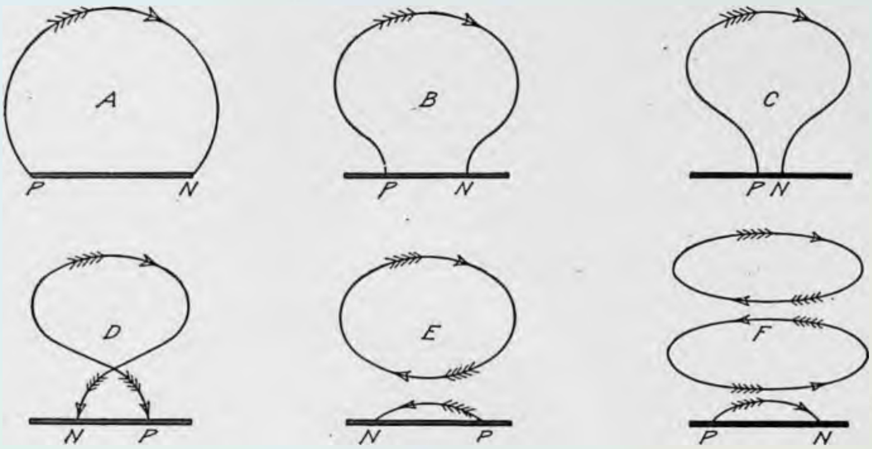


Fig. 5. Formation of Closed Loops of Electric Strain

sending out a rapidly damped train, or group, of waves. The frequency with which such trains follow one another depends upon the frequency of the charging source.

It cannot be said that the exact sequence of events in the formation of an electric wave is definitely agreed upon, further than that the production consists in sending out closed loops of force as shown by Hertz, Dr. F. Hack, and others. The subject is very difficult to present briefly, but an idea of the process may be had by reference to Fig. 5.

The curved line represents the form and the direction of one of the many lines of electric strain existing between the two plates of a Hertz oscillator. Every line of electric strain according to the electronic theory of electricity must be a closed line or loop, or else must terminate on an electron and a co-electron. The figures *A*, *B*, *C*, *D*, *E*, and *F* represent the successive stages in the production of closed loops of electric strain. As the charges oscillate to and fro the lines of electrostatic strain are crossed, making a closed loop which is immediately pushed outward by the following loop; with the result that the direction of strain around each loop is alternately in one direction and in the other, as shown in *F*. In addition to these lines of electrostatic strain there are at right angles to them other self-closed lines of force of a magnetic nature, due to the current passing during discharge. These magnetic rings of flux alternate in their direction at each oscillation, thus forming a series of closed loops of magnetic flux co-axial with the oscillator. Hence we are called upon to imagine the space around a Hertz oscillator as filled with concentric rings of magnetic flux periodically reversing in direction and having their maximum values at instants when the electrostatic strains are at their minimum values. These complementary modes of energy periodically varying in regard to time and space form an electric wave.

Energy of an Oscillator. As a portion of the energy imparted to an oscillator in the form of an electric charge is expended in heating the metallic balls, in creating a bright light, and in producing a noise at the discharge, it is evident that the entire energy of the system is not expended in the formation of electric waves. The total amount of energy which it is possible to potentially store in an oscillator in the form of electrostatic stress depends on its electrical capacity, and is equivalent to the amount of energy which could be stored in a condenser of the same capacity. The storage of energy in a condenser is proportional to the square of the voltage to which it is charged; which is another way of saying that a very great amount of energy could be stored in a very small condenser if it were possible to maintain the insulation under exceedingly high potentials. The dielectric strength of the material used for the dielectric thus places a limit upon the amount of energy it is possible to store in such a device. A small oscillator could likewise have a large amount of energy imparted to it by enlarging the spark gap enough to allow a higher potential to be reached before the insulation of the gap breaks down, were it not for the fact that the increased resistance of the lengthened gap renders the spark non-oscillatory.

A limit is therefore placed upon the potential which it is practicable to employ in the charging of oscillators or any form of condenser. As the capacity of a condenser increases in direct proportion to the area of its plates—other factors remaining the same—it is evident that the dimensions of an oscillator of the Hertz type determine the amount of energy it is possible to utilize in the generation of electric waves.

Hertz Resonator. The most important contribution of Hertz to the subject of electric waves was the discovery of a simple means for detecting the presence of such radiations. The fundamental character of the discovery is apparent when it is observed that the device consists simply of a single turn of wire forming a ring, provided with a spark gap between two metallic knobs, the distance separating these terminals being adjustable by a screw. The device, called a *resonator,* is shown in Fig. 6. Hertz discovered that electric waves falling upon such a conductor were capable of inducing therein alternating currents of the same frequency. By holding his resonator within a few yards of an active oscillator he found that it became the seat of induced secondary oscillations which were strong enough to be manifested by minute sparks visible between the metallic balls. Following up this clue he carried on a very extensive series of experiments, all tending to prove that such waves possessed all the characteristics of light—that they were indeed but "invisible light." Hertz' resonator may be said to be the first "wireless detector" known. The further development of this pregnant idea plays an important part in the evolution of the systems of wireless telegraphy.

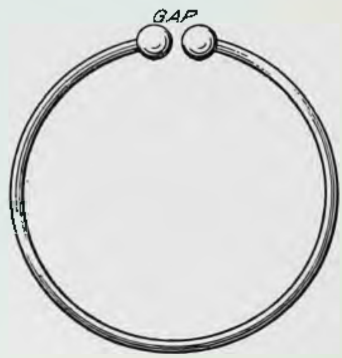


Fig. 6. Hertz Resonator

Resonance. A definite period of vibration is characteristic of many things in nature, including all sonorous bodies such as strings under tension, as in the case of the piano and all stringed instruments; confined portions of air, as exemplified by the organ pipe; and in fact all bodies which, when displaced by the application of an external force, tend to return by virtue of their elasticity and execute free vibrations until they gradually come to rest. If very feeble impulses be applied to a pendulum at rest at intervals exactly corresponding to its natural period of vibration, it may be made to swing through an arc of considerable amplitude. Bodies capable of executing vibrations by virtue of their own resiliency may likewise be set into powerful vibration by a series of impulses keeping time with their own natural period. Thus a tone from a violin may draw forth a responsive note from a piano, and by the same reason a piano will often set into sympathetic vibration some fixture or article of bric-a-brac. Also impulses communicated through the air from a sounding tuning-fork and falling upon another of the same pitch, will cause the latter to hum a note in unison. This phenomenon is called *resonance*. Resonance is thus an increase, or amplification, of a periodic motion by an intermittent force of the same time-period.

Resonant effects are not confined to the vibrations of gross matter, but may also be observed in connection with the flow of electricity in a circuit. This would seem to indicate that an electric circuit possessed something analogous to a natural period of vibration—which is the case. This time-period is due to certain characteristics of the circuit, namely *capacity*, and *inductance*. The quantity of electricity required to charge a conductor up to unit potential or, in other words, the ratio of the charge on a conductor to its potential, is called *capacity*. The unit employed to measure capacity is the farad. *Inductance* is that quality of an electric circuit by virtue of which the passage of an electric current is necessarily accompanied by the absorption of energy in the formation of a magnetic field. The analogy to mechanical inertia is very close, and, for convenience, inductance may be thought of as electromagnetic inertia by reason of which an electric current resists any sudden change. The unit of inductance is the henry. In all circuits possessing capacity and inductance there is a storage of electrostatic energy due to the potentially charged capacity, and a storage of electromagnetic energy due to the formation of the magnetic field by the current. Any electrical change taking place in such a circuit requires a readjustment of this stored energy. Such an adjustment takes place in the form of an oscillatory current of diminishing amplitude until equilibrium is restored. The time-period of such oscillations of energy is dependent upon the capacity and the inductance of the circuit, and is expressed by the equation

$$T = 2\pi\sqrt{LK}$$

where L is the inductance in henries, and K is the capacity in farads. The number of such oscillations per second, *i. e.*, the frequency, is, therefore, $n = \frac{1}{T}$. For purposes in connection with wireless telegraphy this equation is better expressed in microseconds, microhenries, and microfarads.

The phenomena of electrical resonance were first illustrated by Sir Oliver Lodge in his well-known experiment with his so-called *syntonic jars*. Two Leyden jars, Fig. 7, are placed a short distance apart. A bent wire connected to the outer coating of one serves as a discharging circuit (as shown) with a short air gap between polished knobs at the top. A circuit of wire whose inductance is rendered adjustable by a sliding cross-piece—making connection between two conductors—is connected permanently with a second jar. This

Fig. 7. Lodge Syntonic Jars

jar is also provided with a spark gap formed between the outer coating and a small piece of tin-foil extending from the inner coating over the lip of the jar to within a short distance of the outer coating. By continually discharging the first jar by connection with an induction coil or other suitable source of high potential, and by manipulating the sliding cross-plate in the circuit of the other jar, a point may be found where the latter will also discharge in syntony with the first. The two circuits are then said to be in tune, in syntony, or in resonance. When the product of inductance by capacity is the same for two circuits, they have the same natural period of oscillation.

As any circuit possessing inductance and capacity tends to oscillate electrically at its own frequency, it becomes the seat of an induced oscillatory current when subjected to the influence of electric waves of that frequency, each wave giving a slight impulse to the readily excited oscillations, with the result that the induced electromotive forces will be amplified in intensity, just as the swing of a pendulum is amplified by the application of properly timed, though feeble, touches. Circuits possessing inductance and capacity connected in series are thus capable of being "tuned" to a required frequency by a proper adjustment of these two factors. Such circuits are called *oscillatory circuits* and may be of many forms, but can be classified under two heads known as *closed* oscillatory circuits and *open* oscillatory circuits. Those circuits having their capacities in the form of condensers whose capacity areas are closely associated are called "closed," and those having their capacity areas widely separated in such a manner as to cause the field of electrostatic stress to extend out into the surrounding space are called "open." In the first, Fig. 8, the capacity is represented by the two metallic disks separated by a dielectric of air, and connected by a circular wire representing the inductance of one turn, while the "open" type, Fig. 9, is shown by the two metallic capacities connected by a rod which is cut in two at the center to form a gap. Either may or may not have an air gap introduced therein.

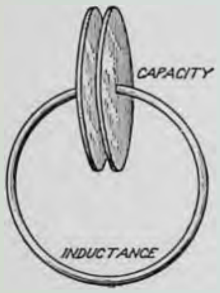


Fig. 8. Closed Oscillatory Circuit

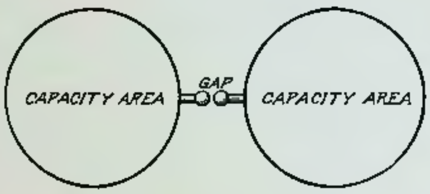


Fig. 9. Open Oscillatory Circuit

The similarity to the Hertz oscillator and resonator is apparent at a glance. This is, indeed, more than a similarity, for the Hertz oscillator was nothing more than an open oscillatory circuit, and his resonator a closed circuit of the same variety. By separating the plates of a condenser after the manner of a Hertz radiator, thereby forming an open oscillatory circuit, a large part of the energy of the charge is radiated away in the form of electric waves by reason of the dielectric extending out into the surrounding air. Circuits of this type are, therefore, excellent radiators but not very persistent radiators, because the oscillatory current is damped quickly by the rapid dissipation of energy in the radiation. Conversely, circuits of the closed type are persistent vibrators, but poor radiators. The train of waves emitted by the open type may be compared to the note given forth from a piano string when the finger is immediately removed from the key allowing the damper to rapidly extinguish the vibration. The closed type is comparable to a note struck on the same instrument but with the damper raised by the sustaining pedal. As it requires an increment of time to start oscillations in a tuned circuit, it is obvious that the closed type is preferable if it can be made to radiate sufficiently. If the damping of the oscillations in a radiator takes place too quickly, the energy of the charge will be dissipated at the first or second surge, in which event the exact tuning of a resonating circuit is unimportant. With a persistent oscillator, however, syntony between the two circuits is of the utmost importance, as otherwise the exciting circuit will tend to destroy at one moment the oscillations it set up a moment earlier. Syntony is of great practical value in the application of Hertzian waves to wireless telegraphy in that it permits of selective signaling to a certain extent by the employment of different wave-lengths, or the tuning of a receiving station to the frequency of a sending station.

Wave-Lengths. As before mentioned, the waves created by a Hertz oscillator are of very much lower frequency and are proportionally longer than light waves, but their velocity is identical. Furthermore, the relation between the velocity of propagation, frequency, and wave-length of ether waves was shown to be expressed by the equation

$$v = ln$$

In order to obtain numerical values for these quantities, it is evident that the value of v must be determined by reference to the best available experimental data. Numerous investigators have agreed upon 3×10^{10} centimeters per second as representing the most probable value for this constant. Knowing this, and by assigning the correct values to the factors *capacity* and *inductance* in determining the natural frequency, it becomes a simple matter to calculate the length of wave emitted by a radiator; and, conversely, by employing the proper capacity and inductance a radiator may be constructed to give any desired wave-length within wide limits. Capacity and inductance may be considered to be the electrical dimensions of an oscillator, and they determine the length of wave emitted, just as the note emitted from an organ pipe depends upon the dimensions of such a pipe.

The waves created by Hertz with various forms of his oscillator varied between a few inches and a few feet in length. He determined these lengths not only by mathematical computation as explained above, but by direct experimental test. He set up at the far end of his laboratory a large sheet of metal to reflect back the waves, and then went about the room with his resonator, exploring the space to find at what points sparks were produced. He found that when waves are thus reflected back upon themselves there are nodal points, just as there are nodal points in sound-waves and in light-waves when similarly reflected. Measuring the distances between these nodal points he was able to determine the wave-length precisely.

With the simple instruments at his command Hertz carried on many other experiments which are little short of beautiful in their adaptation of means to ends; but we cannot go into them here more than to say that they all tended to prove the main contentions of Maxwell's theory. The unqualified success of these experiments won the admiration of scientists all over the world. But few, if any, realized at the time that Hertz, in addition to giving indisputable proof to Maxwell's famous hypothesis, had also laid the foundations for a new and triumphant system of wireless telegraphy.

CHAPTER III

THE DEVELOPMENT OF RADIOTELEGRAPHY

It is evident that when Hertz constructed an apparatus which could transmit electrical manifestations to a distance, without wires, he possessed the elements of a system of wireless telegraphy. All signaling at a distance whether by wire or without, requires the presence of three fundamental factors: a device to produce the signal; a medium to carry the signal; and a device to receive the signal. Hertz' apparatus with its oscillator, electromagnetic medium, and resonator, easily fulfilled the requirements, and its use as a system of wireless telegraphy was merely a matter of time.

The main line of development was to be an extension of the distance over which signals could be transmitted; for as we have seen in the consideration of earlier systems—notably induction systems—distance is the important factor. Any system which cannot transmit messages to a considerable distance is of small practical service to the world. Hertz with his apparatus never succeeded in producing waves which were detectable at more than a score of meters or so; consequently we need not wonder that he never suspected that one of the largest fruits of his achievement was to be a system of wireless trans-oceanic communication. When asked by a civil engineer of Munich whether he thought telephonic communication could be effected by means of electric waves, he replied in the negative, as he considered that the alternations of current in the telephone were not of a nature to be detectable. He could not, of course, foresee the improvements which were destined to be made, rendering his apparatus immeasurably more sensitive and serviceable.

All the scientists of Europe were stirred by the announcement of Hertz' discoveries, and many set about to repeat the experiments. With so many minds bent upon a kindred purpose it is not surprising to learn that much new light was thrown upon the subject and many improvements made in the form and efficiency of the Hertz apparatus. Both the radiator and the detector were signally bettered.

The Righi Oscillator. One of the disadvantages of Hertz' radiator lay in the fact that the sparks in a short time oxidized the little knobs and roughened their surfaces, resulting in irregular action. Prof. Righi of Bologna overcame this difficulty by partly enclosing two metal spheres, *A* and *B* in Fig. 10, in an oil-tight case so that the outside hemispheres of each are exposed, the inner hemispheres being immersed in vaseline oil with only a minute gap between them. In a line with these spheres are ranged two smaller spheres, *C* and *D*, which form the secondary terminals of the induction coil. Thus three sparks are produced: one between *C* and *A*, another between *A* and *B*, and another between *B* and *D*. It is between *A* and *B* in the oil gap that the oscillatory spark takes place, the other two sparks serving merely to charge the large spheres. This arrangement not only produced a more constant spark by preventing the pitting of the electrodes but greatly extended the range of wave-lengths which it was possible to employ in investigations of this character. The dimensions of the oscillator could thereby be reduced and the amplitude of the oscillations greatly increased by reason of the fact that higher potentials could be reached before the energy was released by discharge. Righi obtained oscillations of a frequency of 12,000,000,000 vibrations per second by the use of small spheres *A* and *B* eight millimeters in diameter.

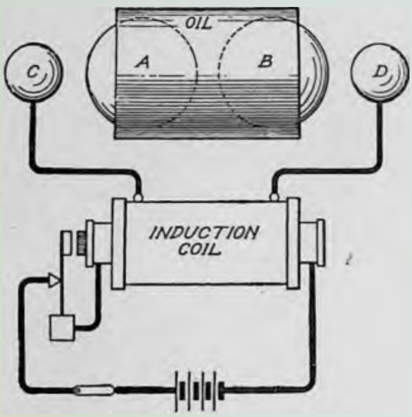


Fig. 10. Righi Oscillator

The Branly Coherer. The next important advance pertained to an improvement over the Hertz resonator as a means of detecting electric waves. It was based on the discovery of M. E. Branly and others, that the enormous resistance offered to the passage of an electric current by powders and metal filings is greatly reduced under the influence of electric oscillations. The resistance of such conductors may drop instantly from thousands of ohms to hundreds by the action of induced oscillations, retaining this conductivity until "decohered" by a mechanical blow. It will be readily seen that this provides a simple means of effecting the operation of a translating device by acting as a valve in turning on, as it were, a greater current in a local battery circuit. By utilizing this property of increased conductivity Sir Oliver Lodge succeeded in causing the deflection of a galvanometer. The device employed by Lodge consisted of a glass tube in the ends of which were sealed terminal wires connected to metallic electrodes of the same diameter as the tube, and between the electrodes was placed a small quantity of iron filings, as shown in Fig. 11. This device is known as a *coherer*, a name suggested by Lodge. In various modified forms the instrument has been employed up to the present day in different wireless systems. Its practical application will be fully considered later in connection with the work of Marconi.

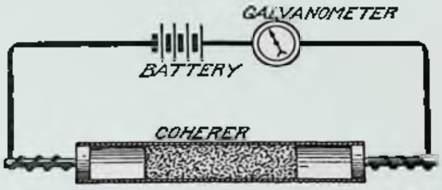


Fig. 11. Lodge Coherer

Radiotelegraphy First Suggested. As the Righi oscillator and Branly coherer were immeasurably more efficient than Hertz' corresponding apparatus, it necessarily follows that waves could be sent and detected over much longer distances and the time was getting ripe for the application of these devices to the purposes of wireless telegraphy. The first man to suggest this possibility is said to have been Sir Wm. Crookes, the eminent English chemist and physicist. In a magazine article which appeared in 1892 he made the following marvelous forecast of Radiotelegraphy:

> Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog; but electrical vibrations of a yard or more in wave-length will easily pierce such media, which to them will be transparent. Here is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At present experimentalists are able to generate electric waves of any desired length, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so to direct a sheaf of rays in a given direction. Also an experimentalist at a distance can receive some, if not all, of these rays on a proper instrument, and by concerted signals, messages in the Morse code can pass from one operator to another.
>
> What remains to be discovered is—firstly, simpler and more certain means of generating electrical rays of any desired wave-length, from the

shortest, say a few feet, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers which will respond to wave-lengths between certain defined limits and be silent to all others; and thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space, and fading away according to the law of inverse squares. . . .

At first sight an objection to this plan would be its want of secrecy. Assuming that the correspondents were a mile apart, the transmitter would send the waves out in all directions, and it would, therefore, be possible for anyone living within a mile of the sender to receive the communication. This could be got over in two ways. If the exact position of both sending and receiving instruments were known, the rays could be concentrated with more or less exactness on the receiver. If, however, the sender and receiver were moving about, so that the lens device could not be adopted, the correspondents must attune their instruments to a definite wave-length, say, for example, 50 yards. I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw, or alternating the length of a wire, so as to become receptive of waves of any preconcerted length. Thus, when adjusted to 50-yard waves, the transmitter might emit, and the receiver respond to, rays varying between 45 and 55 yards, and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for the most inveterate curiosity would surely recoil from the task of passing in review all the millions of possible wave-lengths, on the remote chance of ultimately hitting on the particular wave-length employed by those whose correspondence it was wished to tap. By coding the message even this remote chance of surreptitious tapping could be rendered useless.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe, that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. . . .

The purposes and problems of radiotelegraphy are admirably stated in the above. Some of those problems have not even yet been solved, as we shall see. When Crookes wrote, the idea of radiotelegraphy was in the air, and many men indeed were striving to turn the possibility into a reality. Several Englishmen almost achieved the desired end, but, strangely enough, faltered or failed when success was within easy reach. Among these, mention must be made of Prof. D. E. Hughes, who, but for a combination of bad luck and human fallibility, might have been today the accredited discoverer not only of radiotelegraphy but of electric waves as well.

Work of Hughes. As far back as 1879, when experimenting with his celebrated microphone (which is in reality nothing other than a Branly coherer reduced to its simplest elements) Hughes observed peculiar electrical effects operating at a distance, and he concluded that they were due to invisible electric waves. He did not, however, so far as we know, relate these phenomena with the theories of Maxwell, as Hertz did, and was consequently at a loss to fully account for them. He investigated the subject for several years and actually succeeded in telephoning wirelessly over considerable distances. These experiments were repeated before Prof. Stokes, the president of the Royal Society, and Prof. Huxley; but these gentlemen expressed doubts as to the nature of the phenomena, with the result that Hughes became infected with their scepticism and abandoned his efforts, believing himself on the wrong track. If he had persisted in his researches he might have gathered the laurels that later went to Hertz and Marconi. It has been said that "Hughes' experiments of 1879 were virtually a discovery of Hertzian waves before Hertz, of the coherer before Branly, and of wireless telegraphy before Marconi and others," and the truth of the statement must be admitted to some extent.

Work of Lodge. Mention must be made of the great debt which radiotelegraphy owes to Sir Oliver Lodge for his many valuable contributions both to practice and theory. He has been in the forefront of every advance made in the science of radiotelegraphy, and might in all truth be called its patron saint. To him is due our knowledge of the principles of syntony which forms such a vital part of all modern systems. He was the first man to employ the Branly coherer as a detector of Hertzian waves, and while engaged in demonstrating the discoveries of Hertz was sending signals over distances measurable in hundreds of feet. That such signals could be utilized to convey intelligence by the simple application of the Morse telegraphic code did not occur to him; if he had realized this possibility he might have antedated Marconi's invention of wireless telegraphy.

Work of Marconi. Passing over Popoff, Rutherford, Jackson, Minchin, and others, several of whom did important and original work, we come to Marconi who, in the popular mind, is credited with the whole achievement of radiotelegraphy. It is true that

Marconi carried radiotelegraphy through to practical success; or, as A. T. Story puts it, "he carried forward into the domain of practical reality what had only floated indistinctly before the minds of others, or had served them for modest experiments." But as regards those vital and fundamental developments of theory and practice without which radiotelegraphy would still be a thing unknown, Marconi is only an able follower and not one of the pioneers. The history of radiotelegraphy might be shortly indicated by the following list of names: Faraday, Maxwell, Hertz, Righi, Lodge, Marconi. The theory of electric waves originating with Faraday and expanded by Maxwell, was experimentally demonstrated by Hertz. Then came Righi and Lodge with their improvements on the Hertz apparatus, greatly extending its sphere of utility; and finally Marconi, who brought together the results achieved by his predecessors and, adding something of his own—"a far-seeing initiative where others had not gone beyond timid projects or tentative research"—produced a successful system of wireless telegraphy. Marconi, who is an Italian by birth, first became interested in Hertzian waves when a student under Prof. Righi at the Bologna University. He was not long in seeing their possible application to telegraphy, and made some experiments with that purpose in view. Becoming convinced of the feasibility of the project, but finding no one in Italy ready to take it up, he set out for England to try his fortune. Arriving there, he applied to the Patent Office for protection on his ideas, and then took the proposition to Sir Wm. Preece, chief of the British Postal Telegraphs. Preece gave Marconi ready encouragement, and he was soon conducting experiments under the auspices of the British Post Office.

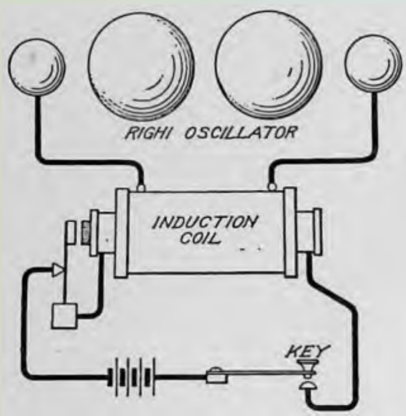
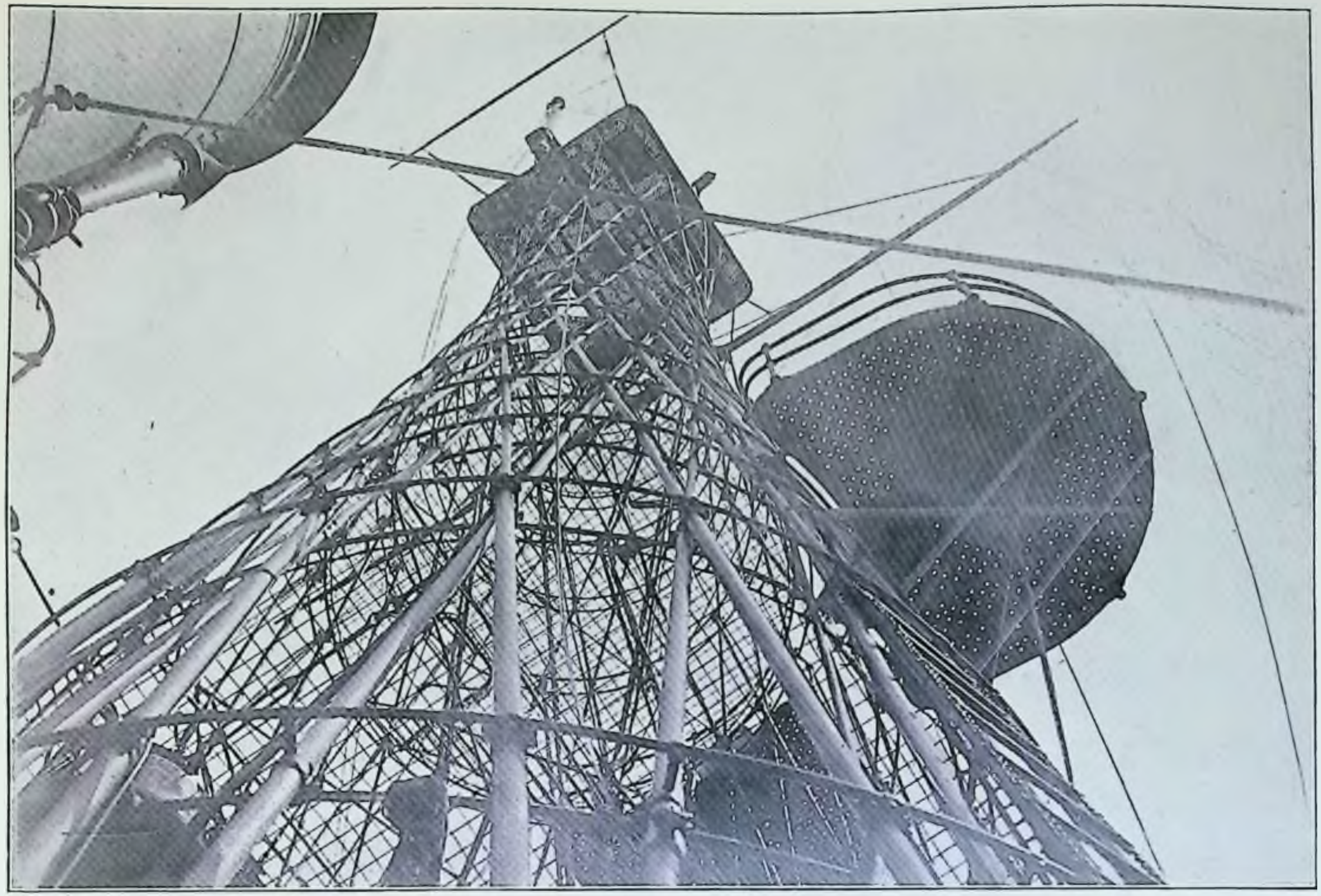


Fig. 12. Early Marconi Transmitter Circuit

Early Apparatus. The early apparatus of Marconi consisted essentially of a Righi oscillator and Branly coherer, disposed in suitable



NEW STYLE OF BATTLESHIP MAST OR AERIAL
Showing Construction of the Type of Tower which now carries the Wireless. Photograph was taken from Base of Mast.

circuits for generating and recording the flow of waves. The transmitting arrangement consisted of an induction coil producing the requisite high potential with which to charge a Righi oscillator, and a Morse key of heavy construction with which to break the primary circuit of the coil, connected with a battery of about five cells. The actual transmission of messages was effected by the intermittent movement of the Morse key which, upon completing the circuit, started the interrupter of the coil which remained in

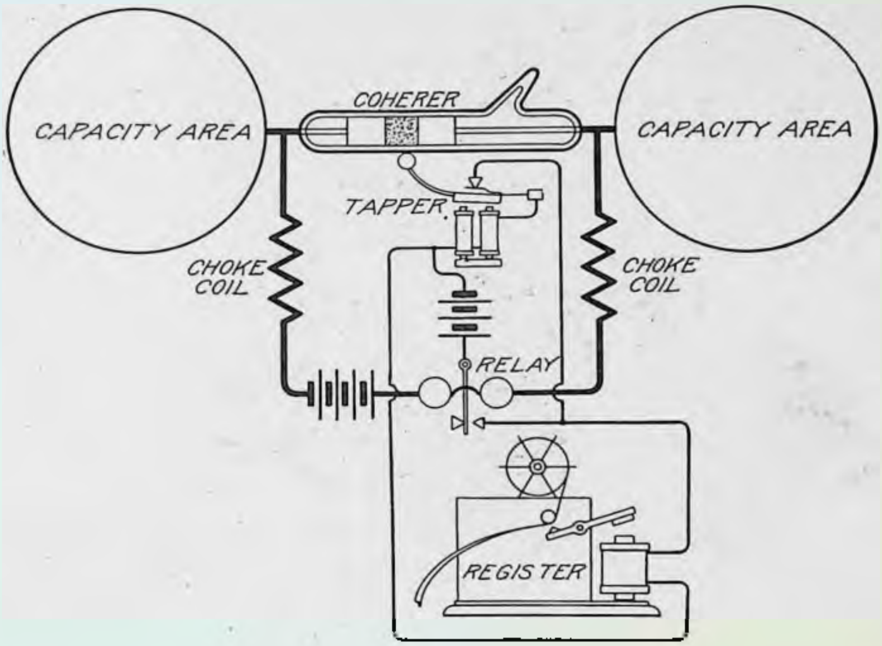


Fig. 13. Early Marconi Receiving Circuit

operation as long as the key was held down; thus the duration of waves from the oscillator was made dependent on the position of the key. It was thus possible by the proper manipulation of the key to send a series of long or short wave trains corresponding to the dots and dashes of the Morse alphabet. Fig. 12 represents diagrammatically these features of the sending station.

The receiving apparatus, indicated in Fig. 13, consisted principally of the Branly coherer somewhat modified in construction and associated with suitable auxiliary apparatus for recording the duration of the received wave trains in the form of dots and dashes upon a moving paper surface after the manner of the Morse recorder, well known in wire telegraphy. As the coherer retains its low conductivity even after the cessation of a train of waves, it becomes necessary to provide means for automatically imparting a slight blow or jar to the tube in order to restore its receptiveness after each and every signal. Such a device was used by Lodge and is known as a "tapper." It is generally in the form of an electric trembling mechanism, such as an electric bell, operated by a local battery when thrown into the circuit by a Morse relay—the latter acting in response to the increase of current when the coherer acts.

The coherer used by Marconi at this time was his own special modification of the Branly-Lodge type. It consisted of a glass tube

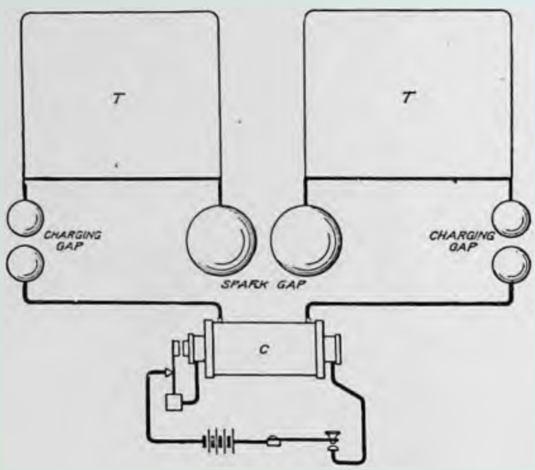


Fig. 14. Marconi "Capacity Areas"

about 4 centimeters long and 2.5 millimeters in diameter, into which were tightly fitted two silver terminals separated to a distance of one millimeter, this space being filled with a powdered mixture of 96 parts nickel to 4 parts silver, worked up with a trace of mercury. The tube was exhausted of air and hermetically sealed. To the terminals of this coherer were connected two resonance plates, or strips of copper, whose dimensions were such as to bring the system into resonance with the oscillator. Also connected to the terminals of the coherer were two choke coils, whose function was to confine the oscillations to the coherer; and a Morse relay in series with a battery of one cell. Fig. 13 plainly shows the arrangement.

In addition to the above a tapper was provided to decohere the metal filings, and also a signal recorder. The tapper was in the form of a small electric-bell mechanism whose clapper continuously tapped the glass tube as long as the Morse relay completed the circuit in which the tapper was placed. The Morse relay thus acts as a switch by means of which the signal recorder and tapper are operated simultaneously. It might be well to state that the coherer holds its conductivity during the passage of the oscillations even though in vibration from the tapper.

Capacity Areas. A very significant step taken by Marconi at this early period was his employment of "capacity areas" in the circuit of his oscillator, Fig. 14. The essential features of this innovation were as follows: T and T are metal plates joined to the balls of the oscillator; C is the induction coil. The object of this arrangement was to give greater energy to the oscillations, the carrying power of the apparatus being found to increase with the size of the capacity areas, and with the distance of the same from each other. Two similar plates were also attached to the coherer at the receiving station. Though this arrangement of capacity areas was soon abandoned, it marks, nevertheless, the inception of an idea which developed, as we shall see, into one of the most important features of modern aërial telegraphy, namely, the antenna.

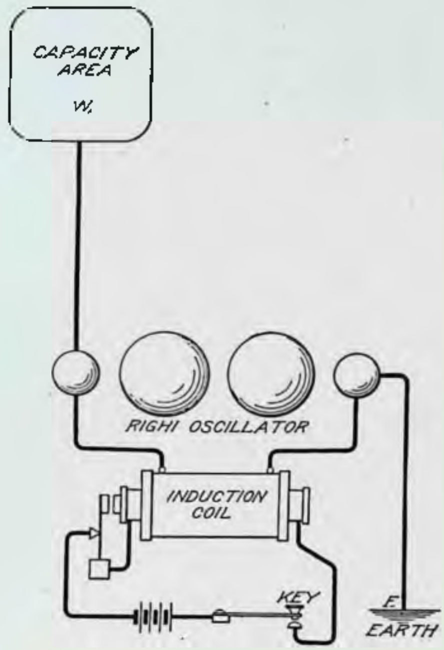


Fig. 15. Diagram Showing the Earthed Oscillator

Development of the Antennae. Endeavoring to increase the effectiveness of his capacity areas by enlarging them and separating them as much as possible, Marconi conceived the idea of utilizing the earth for one of the plates, and of raising the remaining plate to a considerable height in order to increase the distance between them.

The arrangement, Fig. 15, then took on the following aspect: coil and oscillator are of standard type; E is the earth connection; and W the elevated plate. The higher the capacity area W is situated, the greater the distance to which communication can be carried; so it will be seen that the capacity area might with great advantage be attached to a kite, or captive balloon. The latter were, indeed, employed by Marconi and with very good effect. Corresponding changes were made at the receiving station also, by employing a similar arrangement of capacity area, shown in Fig. 16.

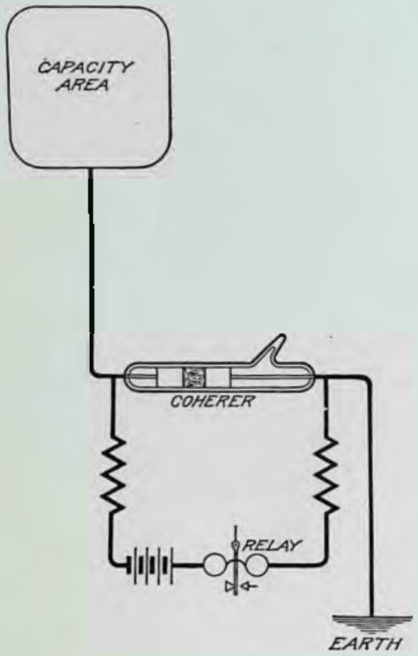


Fig. 16. Earthed Receiving Circuit

Later Marconi became convinced that the effectiveness of his aërial line was due not to the capacity at the end of the wire, but to the length of the wire itself; consequently he abandoned the capacity area altogether and held simply to the form of vertical wires attached to poles or kites, or even to high buildings or towers. These were called antennae, or aërials. The antenna consisting of a single wire later developed into the multiple antenna of several wires, each additional wire adding to the capacity of the system. The antennae of many large stations are formidable structures of great complexity, as the picture of the South Wellfleet station, Fig. 17, will indicate.

Inductive Receiving Antennae. Another of Marconi's early and important modifications was the introduction of inductive antennae into the receiver arrangement. The antenna was cut out of direct conductive connection with the coherer circuit and allowed to act on the latter only by induction through the agency of an oscillation transformer called in common parlance a *jigger*, the theory of which cannot be fully discussed here. Mention will be made, however, of the fact that such a transformer properly designed in regard to the wave-length used not only steps up the voltage so as to increase its effect on the coherer, but also enables the coherer to be placed at a nodal point of the secondary oscillations. As this form of detector

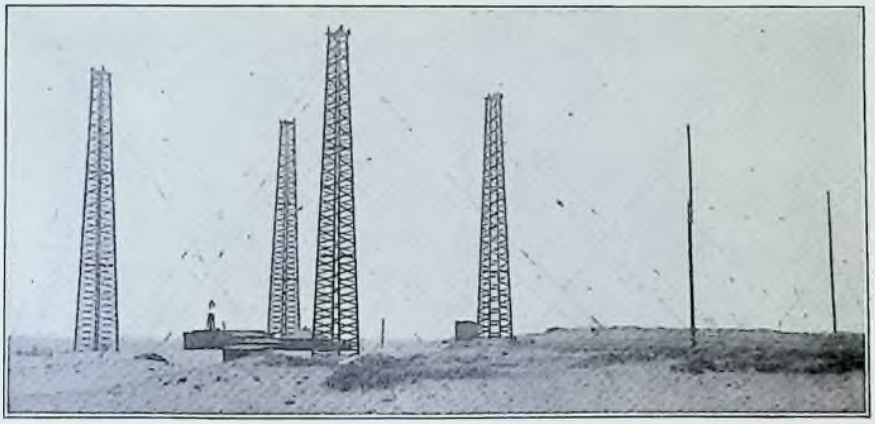


Fig. 17. South Wellfleet Wireless Station

is of the potentially operated variety, the practical importance of the modification is apparent. A coherer placed in series between the antennae and ground, as in former arrangements, is poorly located, as at the base of an aërial the potential is a minimum and the current a maximum. Marconi increased the distance over which it was possible to signal nearly ten times by the employment of this simple

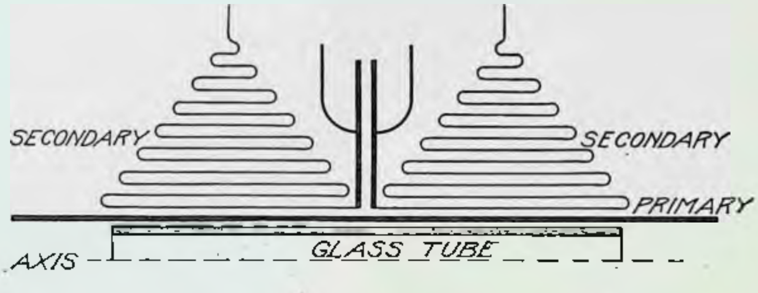


Fig. 18. Diagram of Oscillation Transformer Winding

device. His patents on this improvement bear the dates of 1898 and 1899. Fig. 18 shows a diagrammatic cross-section of the jigger, the zigzag lines representing the successive layers of the windings wound in such a manner that the inner layers have the greatest number of turns, the primary having about 100 and the secondary about 1,000 turns. Fig. 19 shows the receiver-circuit with the jigger embodied therein. It will be noticed that the local-battery circuits are the same as used before, but the jigger necessitates a slight modification in the location of the coherer. A condenser is connected to the inner terminals of the secondary, the outer terminals of which are connected to the coherer. The local battery circuit is also connected to the inner ends of the secondary and across the condenser.

Inductive Transmitting Antennae. It has already been shown that the early capacity areas had given place to the extended wire raised to a great height; and it soon became evident that transmission could be further facilitated by devising a more persistent oscillator than that which was employed with the directly connected aërial. It was possible to store a fair amount of energy in the old type of aërial, but the direct connection entailed the disadvantage of permitting the apparatus to radiate its entire amount of energy almost instantly instead of radiating such energy in the form of a more continuous train. This was not a quality tending to make for a clearly defined resonance between the sending and receiving circuits, and means were sought to accomplish a more persistent, or less damped, series of oscillations. The early form of open-circuit oscillator, therefore, gave place to what is known as the Marconi-Braun type of closed oscillating circuit which, while not so powerful a radiator, was a very much more persistent one. The method was due to Prof. Braun, but in a modified form was first used by Marconi. The diagram of Fig. 20 makes clear the fundamental idea, an idea which has proven to be of great value. Though modified in numberless ways by subsequent inventors, the broad idea of associating the aërial with a closed oscillating circuit has become almost universal.

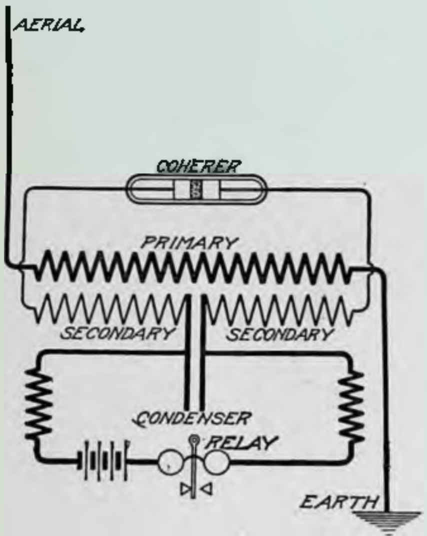


Fig. 19. Marconi Receiver-Circuit with Jigger

The transformer used for this purpose is very different from the ordinary induction coil or alternating-current transformer employed in connection with low voltages and low frequencies. It will be fully described later under the head of oscillation transformers; for the present it is sufficient to say that it forms an inductive couple between the two oscillatory circuits, the closed circuit being but a means of charging the open circuit of the antennae. The antennae circuit, having a certain amount of capacity and inductance depending on its design and position, possesses a natural time-period of its own; so in order to induce in such a circuit oscillations of a maximum amplitude, the primary circuit associated therewith must have the same natural time-period. In other words, resonance must be established; two circuits, as before mentioned, being in resonance when the product of capacity and inductance is the same for both. The Marconi-Braun method of charging the aërial permits of the employment of very large capacities, with proportionally larger energy-storing ability and smaller inductances in the primary circuit, so that the product of these two factors can be made to equal the product of the corresponding factors in the antenna circuit. The efficiency of the transformer thus very largely depends on the establishment of syntony between the closed oscillatory circuit forming the primary and the open oscillatory circuit forming the secondary.

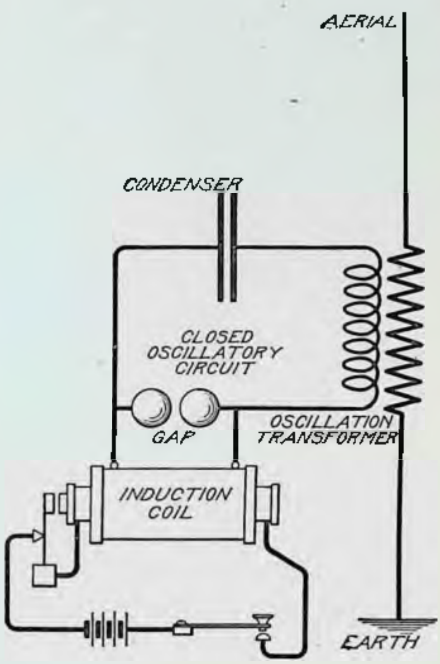


Fig 20 Marconi-Braun Inductive Transmitting Antennae

Another method of associating the radiating aërial with a closed oscillatory circuit, possessing many of the advantages of the Marconi-Braun inductive couple, is shown in Fig. 21, and is known as the direct-coupling method. An inductance of several turns of wire is, in effect, introduced in series with the aërial and the ground. A certain portion of the inductive turns is included in a closed oscillatory circuit composed of a condenser and spark gap shunted around the said portion. When the closed energy-storing oscillatory circuit and the open radiating circuit of the aërial are adjusted to the same periodicity the scheme becomes effective. The method of direct coupling has been subjected to many changes at the hands of inventors, in some cases becoming almost unrecognizable, but upon analysis the fundamental idea shows through. It is to be noted that with both the direct and inductively coupled systems, syntony between the open and closed circuits is essential.

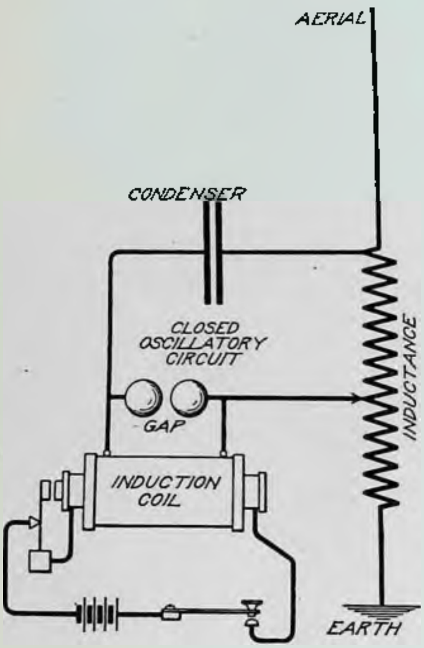


Fig. 21. "Direct-Coupled" Inductive Antennae

Both of the foregoing arrangements allow the possibility of creating in the aërial far greater charging electromotive forces which, in properly proportioned antennae, increase toward the top where they may reach a value equivalent to hundreds of thousands of volts in the larger installations. Hence, with the adoption of this form of transmitting arrangement, it became possible to radiate a series of well-sustained oscillations of much greater energy than ever before, thus still farther extending the distance to which communication could be carried. This improvement may be said to be one of the greatest advances in the history of radiotelegraphy.

Propagation of Waves from a Grounded Oscillator. The theory of the propagation of electric waves from a Hertz oscillator before given, assumed a perfectly symmetrical isolated oscillator suspended in space. The employment of the grounded oscillator in the form of an earthed aërial now exclusively used in radiotelegraphy necessitates a modification of the above theory in order to meet the problems arising under the changed conditions. The new arrangement was, in effect, the substitution of the earth for one of the capacity areas of a Hertz radiator, and the extension of the companion area into a vertical wire possessing capacity with regard to the earth from which it is separated by an air gap. The type of wave radiating from such a system differs in many respects from the form of disturbance emanating from a simple isolated oscillator, and presents theoretical difficulties which cannot as yet be said to be satisfactorily explained. The electric waves from a grounded oscillator apparently follow the curvature of the earth. One of the theories purporting

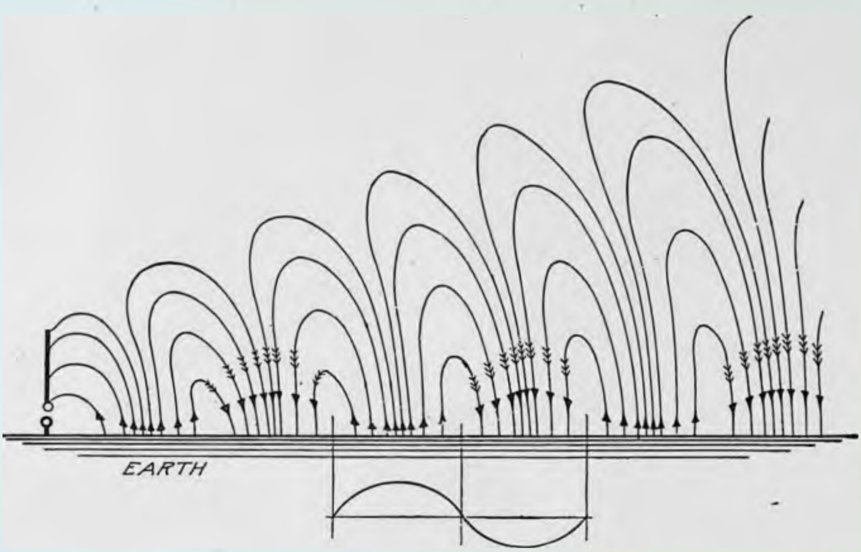


Fig. 22. Diagrammatic Representation of the Sliding-Wave Theory of Propagation

to account for this phenomenon assumes that such waves are not ordinary free electric waves consisting of closed loops of electric strain, but on the contrary consist of half loops traveling over the surface of our globe with their ends remaining always in contact with the surface. This view is supported, it would seem, by the electronic theory of electricity. It is roughly represented in Fig. 22. The detached semi-loops of strain are shown by the lighter lines, and the simple grounded oscillator by the heavier. A wave-length would be represented on the horizontal line by the distance included between any two positions thereon where the direction and intensity of strain (shown respectively by the arrows and the proximity of the lines) is identical. This is the *sliding-wave theory*, said to have been first promulgated by J. E. Taylor. Other theories have been advanced to account for the wave-transmission following the curvature of the earth, one such assuming that the waves are radiated in a straight line but reflected back from a semi-conductive envelope formed by the upper strata of the earth's atmosphere.

Selective Signaling. The problem of directing a message to its proper destination was felt by early investigators to be of vital importance, if radiotelegraphy was ever to be a commercial success. Some method must be discovered to effect selective signaling—else how would it be possible for a plurality of stations to be transmitting at once? The solution of the difficulty was thought to be found in the principle of resonance.

The history of the subject records at a very early date efforts to achieve the desired end by employing definite wave-lengths corresponding to the electrical time-periods of the various stations it was desired to place into communication. Thus among a plurality of active sending stations any number might communicate simultaneously in pairs without interference by arbitrarily assigning a definite frequency, or wave-length, to each pair. Selection by this method assumes that it is possible to "tune" receiving instruments so they will respond to a particular "pitch" and to no other; but as the number of possible non-interfering wave-lengths is limited, it cannot be said that resonance offers an entirely satisfactory solution of the problem.

By the employment of two or more receiving circuits connected to the same aërial, each tuned to a different frequency corresponding to as many different sending stations, the simultaneous reception of two or more messages is theoretically possible. As early as 1900, Marconi achieved some very remarkable results of simultaneous non-interfering communication when he received by the same aërial two messages, one in English and the other in French, which were simultaneously transmitted over a distance of 30 miles.

It was to be expected that the last few years would bring in their train great improvements in this respect as well as in others, so that it may be said today that selective signaling is feasible to a certain extent and that the remaining obstacles will be removed by further developments of the art; but until those advances are made, so that much more can be accomplished with respect to selective signaling than at present, the field of operation for radiotelegraphy will be confined mostly to communication between ships, between ships and shore, and across large bodies of water.

Conclusion. The application of Hertzian waves to the purposes of telegraphy as outlined above, covers what might be called the foundation and early development of the art. Every step taken at this early period was vital and significant. Since then enormous advances have been made; the distances over which it is possible to telegraph have been greatly extended, and the apparatus rendered more sensitive and certain in every way; but these results have been accomplished more by a refinement of detail—the development of more sensitive instruments, and the closer connection between theory and practice—rather than by the application of fundamentally new ideas. The twentieth century ushered in a new and tentative method of telegraphic communication called radiotelegraphy, and the first ten years have witnessed its establishment as one of the permanent adjuncts of civilization.

CHAPTER IV

RADIOTELEGRAPHIC APPARATUS

It is obviously impossible within the scope of the present work to give a detailed description of all the apparatus pertaining to radiotelegraphy. In view thereof it is assumed that the reader is familiar with the ordinary instruments and physical appliances commonly used in electrical work and not in any way peculiar to wireless telegraphy. It is also assumed that the elementary facts of electrical phenomena are known. The descriptions of the apparatus in this chapter will be given without reference to their grouping together in the formation of a complete system, but will be given singly with such theoretical considerations as may seem necessary. The chapter following will be given over to the assembling of apparatus into complete systems under their proper appellations, together with some account of their performance.

Sources of Energy. In any system of radiotelegraphy the prime desideratum is to associate with the aërial a maximum amount of energy available for radiation. It was early recognized that the most obvious way to accomplish this was to increase the capacity of the aërial or to employ condensers associated in various ways in order to store temporarily the electrical energy to be radiated. The main function, therefore, of the source of energy employed in the transmitting station is to properly charge a given capacity. The greater this capacity, the greater the amount of initial energy required. Expediency determines largely the nature of the source of energy, whether derived from storage batteries, a generator, or from power mains. The energy consumption ranges from a few watts up to 50 to 100 kilowatts, so it is evident that the sources of current are subject to a wide range of choice. The trans-Atlantic stations of Marconi at Cape Breton employ generators of 65 horse-power.

Charging Devices. To create the required electrical oscillations in the aërial, it is necessary to have appliances which shall generate the requisite high-potential electromotive forces for charging the aërial and its associated capacity. Such an appliance should create not only a high potential but also an appreciable current. This charging e. m. f. is generally effected by the use of the induction coil or the alternating-current transformer.

Induction Coils. It is not deemed necessary to give an extended discussion of the induction coil, but to call attention to the important modifications to be incorporated therein for use in wireless telegraphy. The purpose for which the coil is employed is to charge a condenser of some form rapidly. The time required for a condenser to attain the same potential as the charging source to which it is connected depends largely upon the resistance of the charging source. In order to secure a small time-constant for the charging circuit, it is highly desirable to have a secondary of as low resistance as possible. The lower the resistance of the secondary, the greater the capacity that can be rapidly charged by a coil of a given number of turns. It must be borne in mind that, in order to charge a condenser to a given potential, current is required. The usual small induction coil is wound with very fine wire on the secondary—No. 36 or finer. It goes without saying that this is not at all suited for use in wireless telegraphy. Considerable data on coils suitable for the use herein considered is available. The core should be composed of well-annealed, Swedish soft iron wire of small diameter—about No. 24—wound with a primary of comparatively few turns of coarse copper wire—about No. 12—double cotton-covered and well insulated from the core. It is not practical to wind the secondary with coarser wire than No. 32 or No. 33 B. & S. gauge. Special attention should be paid to the insulation of the secondary as it is of great importance that this be able to withstand the high impulsive electromotive forces of short duration which occasionally manifest themselves. Late design seems to be in the direction of longer cores—about twice the length of the secondary winding.

Tesla called attention to a fact of importance in connection with induction-coil design, as far back as 1893, viz, that a condition of resonance between the primary and the secondary circuits greatly adds to the efficiency of the device. This has the practical result of greatly decreasing the resistance of the secondary and also the number of turns, with a result that much more current is deliverable from such a coil. In the primary circuit there is usually large capacity and small inductance, while in the secondary there is small capacity and large inductance.

Even with the above added efficiency, induction coils are not as suitable in many respects for commercial radiotelegraphy as alternating-current transformers. The utility of the induction coil is limited by reason of the fact that the details of design are so largely a matter of compromise that it is impracticable to obtain the desired charging current at the required voltage. The efficiency of induction coils is at best but slightly above 50 per cent, and there are reasons for believing it much lower.

The three important adjuncts of the induction coil are the primary condenser, the interrupter, and the signaling key.

Primary Condenser. The principal function of the primary condenser is to absorb the energy that manifests itself at break in the form of an arc, due to the self-induction of the primary circuit. As the secondary e. m. f. is due largely to the suddenness of the rupture in the primary, it is of the utmost importance that this arc be prevented from forming. The primary condenser is, therefore, placed across the break in such a manner as to be short-circuited when the circuit is closed, but at the instant of break it is placed in the circuit and absorbs the energy which would otherwise be dissipated in the formation of an arc, and which would very greatly increase the time of rupture. Fig. 23 indicates the arrangement of the circuit. The best value for the primary condenser is that capacity which will annul to the greatest degree the sparking at the points of the interrupter. Experiments have shown that if the primary be broken with sufficient rapidity, as for instance with a rifle ball, no condenser is needed. A condenser is not needed with a Wehnelt interrupter.

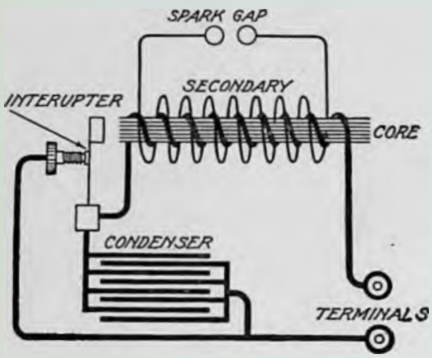


Fig. 23. Diagram of Induction Coil Showing Condenser Circuit

Interrupters. Interrupters perform the sole function of causing a rapid succession of sudden breaks in the primary circuit. The commonest as well as the oldest form of break is known as the *hammer* *break,* probably invented by Neef. Its action is perhaps best shown by referring to the common electric door-bell. An electromagnet, in attracting an armature, causes an interruption of the current energizing the electromagnet, whereupon the armature falls back by reason of its spring tension and again completes the circuit; this energizes the magnet once more, which again attracts the armature, and the whole operation is repeated. The armature is thus kept in continual vibration with consequent interruptions of the current. Fig. 24 shows this device—which is subject to almost endless variation —in a form having as one of its decided advantages the ease with which it is adjusted by simple regulation for different frequencies. Fig. 25 shows another form with the contacts made in small cups of mercury, known as the *Foucault break.* It is obvious that the break can be produced independently of the current in the primary circuit by means of a small electric motor acting on a lever which is made to dip into a cup of mercury, thus completing the circuit any desired number of times per revolution. Such a break is called the *motor break.* The rotary, or turbine, break has been used very successfully on large coils requiring considerable amperage for their operation. The simple hammer break does not operate well with voltages over 16 or 20; therefore, when it becomes necessary to utilize commercial pressures such as 110 and

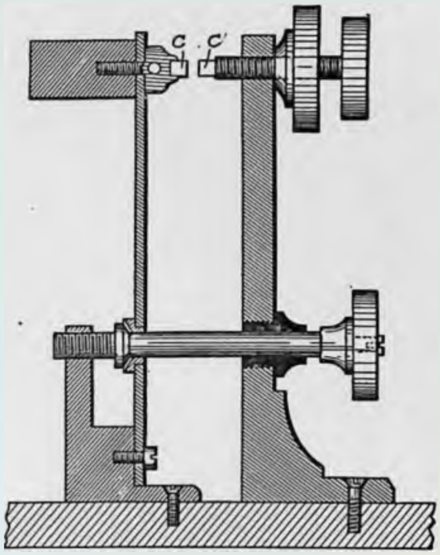


Fig. 24. Neef Hammer Break

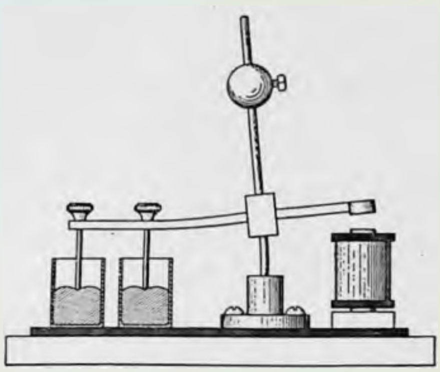


Fig. 25. Foucault Mercury Break

220 volts, some form of mercury turbine interrupter is found to be preferable. One form of this interrupter is shown in Fig. 26.

Dr. Wehnelt of Charlottenburg invented, in 1899, a form of interrupter for use with induction coils, operating on an entirely different principle from those described above. Taking two electrodes of very different size, such as a large lead plate and a small piece of platinum wire projecting from the end of a closely fitting glass tube, and placing them in an electrolyte of dilute sulphuric acid, he discovered that an electrolytic action takes place when the

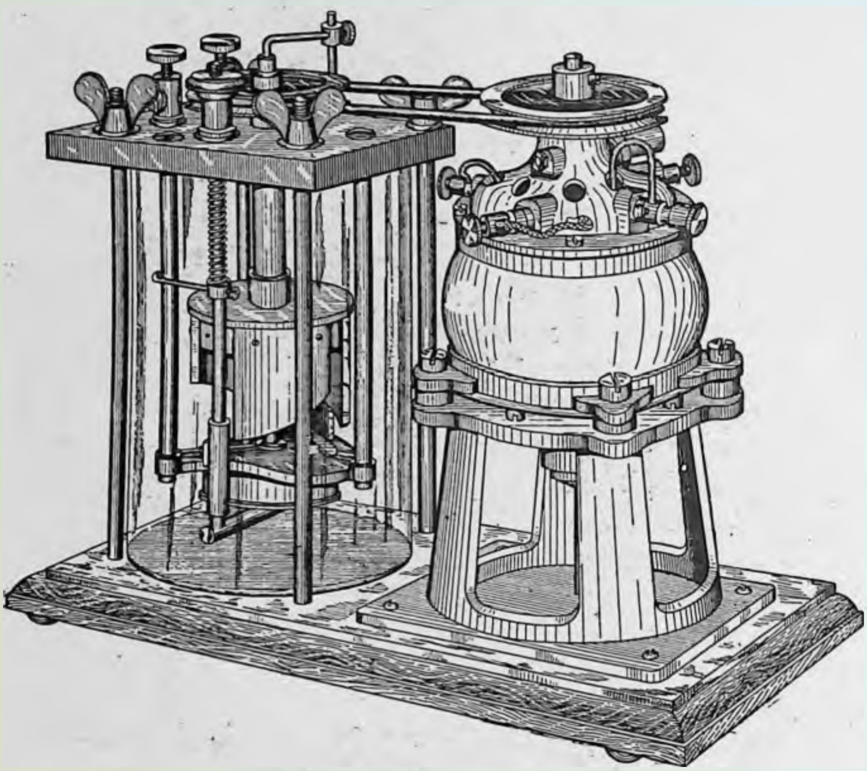
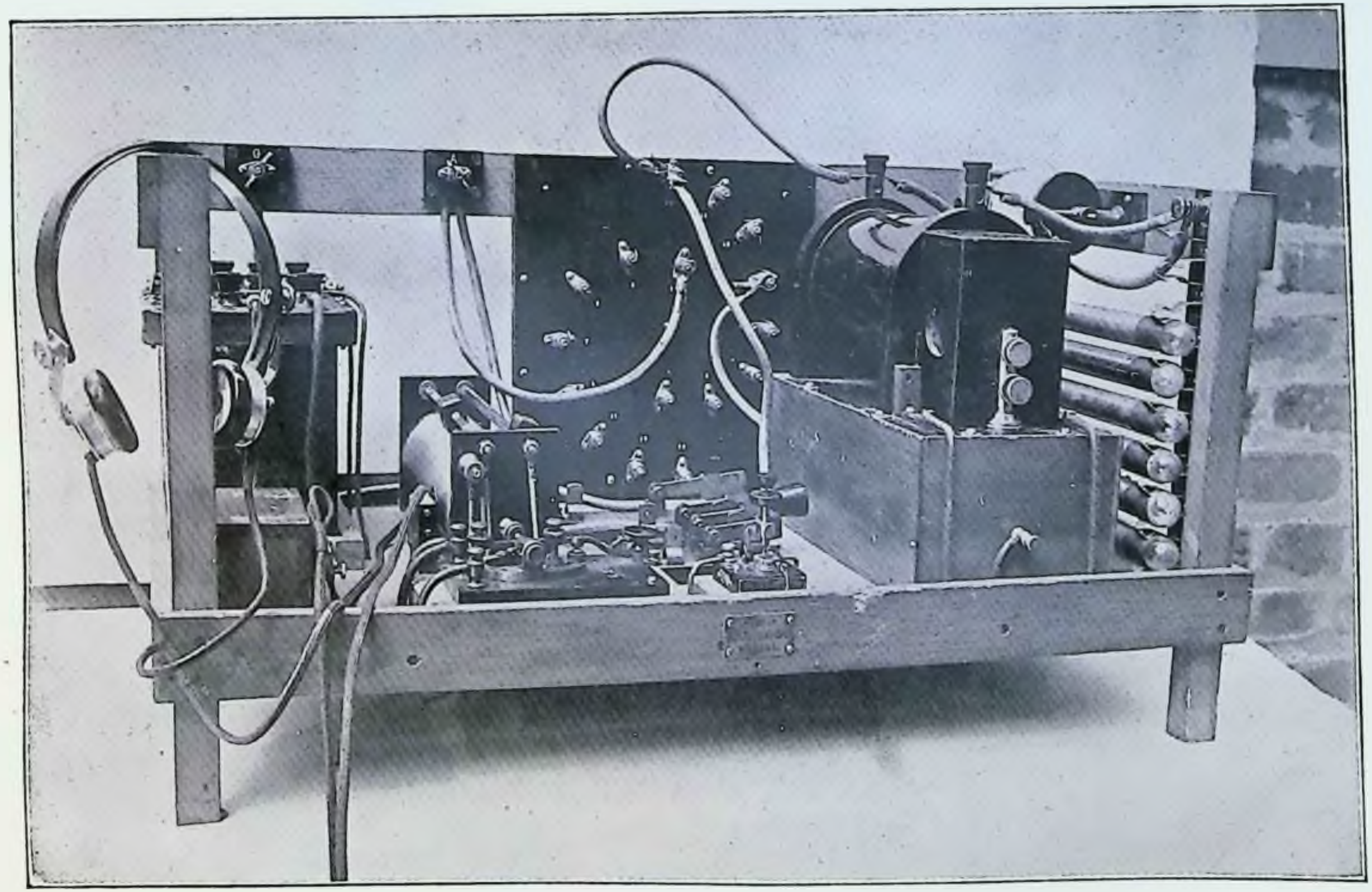


Fig. 26. Mercury Turbine Interrupter

large lead plate is made the negative pole, this action interrupting the current periodically when the device is connected to a source of 40 to 80 volts. Fig. 27 gives an idea of the device, showing one of the many modifications it has undergone in its commercial design. The positive platinum electrode can be seen protruding slightly from the end of the porcelain insulating tube immersed in the liquid, which must be a solution of about one part sulphuric acid to ten parts of



THE NEW AËRIAL WIRELESS SET DEVISED BY GOVERNMENT ELECTRICIANS
Intended for Use with Aëroplanes and War Balloons.

water. The cut shows a water-cooling jacket, which is an advantage as the apparatus becomes very warm under continued use. Experiments have shown this device to be capable of producing an intermittency of over 1,800 per second. As mentioned above, no condenser is necessary when operating an induction coil with this form of interrupter. The character of the secondary discharge is somewhat changed by the use of the Wehnelt cell, rendering it more like the alternating arc than the usual disruptive spark. It cannot be said that an entirely satisfactory theory has ever been given for the action of this cell. The Wehnelt interrupter has not been used very commonly in connection with radiotelegraphic work, its greatest field of usefulness being in Röntgen ray work.

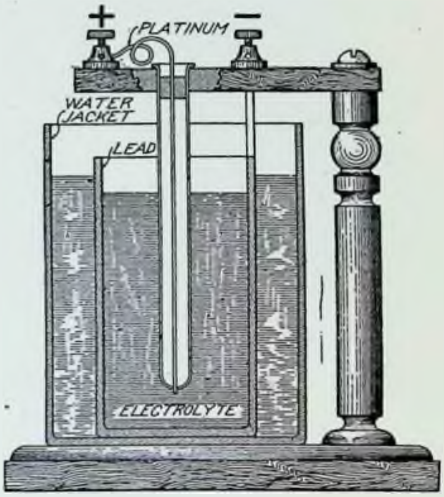


Fig. 27. Wehnelt Interrupter

Keys. In order to transmit messages by means of an arbitrary code consisting of long and short trains of waves representing the Morse alphabet, an adequate means of controlling the torrent of sparks between the electrodes of the spark gap must be employed. The key problem in this form of telegraphy is somewhat more complicated than in the ordinary wire systems, primarily by reason of the fact that a much greater current must be controlled. The common Morse key need not open more than a fraction of an inch, $\frac{1}{64}$ being ample; but it becomes necessary in wireless work to rapidly break currents of several amperes in circuits of considerable inductance, under which conditions the Morse key would not answer at all. The speed of signaling depends largely on the rapidity of the key, a wide movement greatly cutting down the efficiency of the system as a means of communication; therefore, short-range keys must be provided, with some means of annulling the heavy spark on break. Many suggestions have been made and a number of patents taken out purporting to accomplish this end. The magnetic blow-out has proved the most generally useful; though some systems employ a short-circuiting resistance around the break, and others a condenser to absorb the arc. One form of Marconi key simultaneously breaks the primary current and disconnects the aërial from the transmitting apparatus. Many keys are designed to cause the break to take place under oil or other highly insulative substances. Lodge and Muirhead employ an electromagnetically operable key which is actuated by current in a local circuit interrupted by an ordinary Morse key. A common form of such a key, which is of very heavy construction and of extra wide movement, is shown in Fig. 28.

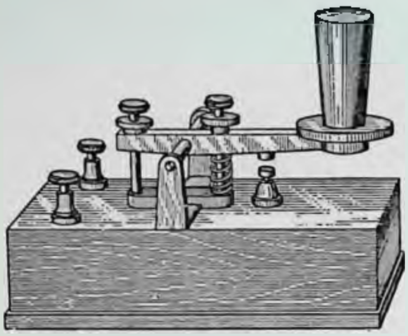


Fig. 28. Long Range Morse Key

Alternating-Current Transformers. In nearly all high-power stations it has been found advantageous, if not absolutely necessary, to discard the induction coil as a means of charging the high capacities used, substituting the alternating-current transformer. This involves the employment of an alternating-current as the initial source of power. Transformers designed for this purpose are wound for a high ratio of transformation, generally for a secondary voltage of at least 20,000 volts, and often 30,000 to 50,000. A difficulty experienced with the use of the transformer is the liability of forming an alternating arc between the balls of the gap in place of the proper oscillatory spark. The practical short-circuiting of the transformer by this action causes a great rush of current through the primary, which, if it has not been guarded against, is liable to cause great havoc with the generator, blowing out the fuses and possibly working other damage more serious. When the capacity of the condenser is of the exact value to take up in the form of a charge nearly the entire energy of each half-wave of the periodic current, no alternating arc will arise and the discharge across the gap will be due entirely to

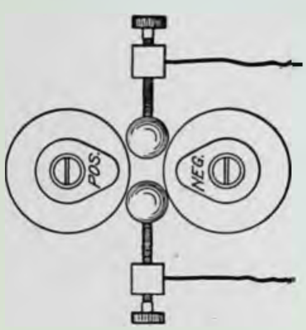


Fig. 29. Tesla Magnetic Blow-out

the condenser, in which case no external means for extinguishing the arc are necessary; but this relation is very hard to effect permanently, so that numerous plans have been devised to prevent the formation of this arc. The one due to Nikola Tesla, which has undoubtedly proved to be the best, utilizes a strong electromagnet so that its lines of force pass transversely between the spark gap. This arrangement is called a *magnetic blow-out*. Fig. 29 shows the scheme. Elihu Thomson achieves the same end by directing a strong blast of air on the gap from a nozzle. This permits the oscillatory spark to form at the proper time, but completely extinguishes the alternating arc, or rather prevents its formation. The noise incident to the operation of a large transformer producing a heavy oscillatory spark is deafening and some precaution must be taken to protect the ears of an attendant if the gap is not enclosed. The light from such a spark is also very hard on the eyes.

Oscillation Transformers. Transformers designed for high-frequency, high-potential, oscillatory currents are in many respects different from the transformers suitable for use on low-pressure, low-frequency, electric-light mains. The most striking difference is the absence of an iron core and the small number of turns of wire employed. The transformer used by Marconi with the Marconi-Braun type of closed oscillator was constructed as follows: The primary consisted of but one turn on a stranded conductor of low resistance with a secondary of thinner wire laid over the primary in about ten turns. The coils were immersed in highly insulating oil. In commercial practice oscillation transformers are of various design. It is of the utmost importance that transformers of this character be specially well insulated, particularly when the primary and the secondary are in close inductive relation. The use of oil in this connection is the common practice. Late forms of oscillation transformers are made in such a manner that the distance between the primary and the secondary may be varied, thus alternating their inductive relation, a so-called "loose couple" being produced by separating the two components.

Condensers. The condensers employed in radiotelegraphy, as in other departments of electro-technics, are chosen with regard to the voltages to which they are to be subjected. The capacity used in connection with receiving circuits requiring no high insulating properties generally takes the form of paper or mica condenser supplemented by a variable-capacity condenser consisting of a number of fixed metallic plates interspaced in air between an equal number of moveable plates, whereby the effective capacity areas of the plates may be varied within wide limits.

In the transmitting circuit where the condenser is employed to temporarily store the energy preparatory to the sending of a signal, a form of condenser must be used which will withstand the electrostatic strain of a very high potential. This necessitates the use of glass, mica, or oil, as experience has proved these materials to be almost the only dielectrics practicable for the purpose, glass being, all things considered, the best of all. The higher the voltage, the greater the thickness of glass needed; and as the storing power of a

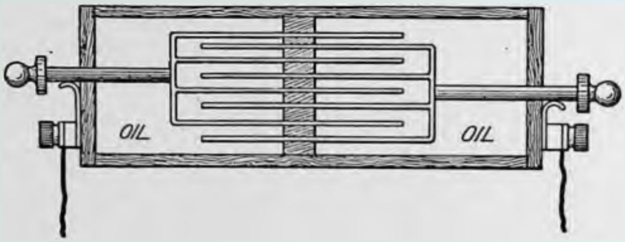


Fig. 30. Adjustable Condenser

condenser varies directly with the square of the potential to which it is charged, it is evident that there exists a definite relation between the dielectric strength of the medium (glass) and the volume per unit of energy which it is desired to store. This is equivalent to saying that a great amount of energy could be stored in a very small condenser if the dielectric could stand an exceedingly high potential. Hence, the object to be attained in the designing of condensers for radiotelegraphy is a maximum energy-storing ability with a minimum of cost, size, and weight of glass. In practice it is better to use a good grade of glass free from lead and other impurities. Oil condensers are sometimes used, constructed of sheets of brass or zinc, and immersed in "transformer oil." Adjustable condensers, made as shown in Fig. 30, are often used for purposes of tuning; their capacity may be varied by withdrawing the plates, thereby reducing the effective area. Braun employed small condensers made of test-tubes covered with tin-foil inside and out for short-distance low-power stations.

Quart or gallon Leyden jars are often employed, lending themselves very well to the requirements.

Tuning Coils. In order to facilitate the tuning, or syntonizing, of the oscillatory circuits included in a system of radiotelegraphy, some apparatus for varying the electrical dimensions of such a circuit is usually employed. These tuning devices consist simply of a variable inductance, or of an adjustable condenser to vary the capacity, or of both embodied in a single piece of apparatus. As the inductance factor lends itself more readily to a simple method of variation, numerous forms of adjustable inductance coils have been devised, the design of which depends upon the circuit they are to be employed with.

Tuning coils for use with the transmitting side of a station are characterized by a comparatively few turns of very heavy wire or metal ribbon wound spirally on an insulated drum or ebonite cylinder. Connection is made at any point on the spiral conductor either by means of flexible connecting cords provided with metallic clips, or by the use of a sliding connection so arranged as to permit of any desired length of the inductive conductor being included in the circuit. Many systems utilize the space within the turns of inductive resistance for the placing of the condensers, thus greatly economizing the room otherwise required for these two portions of the apparatus.

As the receiving circuits usually possess much less capacity than the transmitting circuits, the tuning coils designed for connection therewith have a much larger number of turns. Such coils are generally constructed with several hundred turns of rather fine wire wound on a large bobbin having two sliding contacts so arranged as to include between them any desired number of turns. These coils are made in a great variety of ways.

Spark Gaps. An important element of the transmitting station is the gap, across which the stream of sparks takes place. In a previous chapter attention has been called to the resonator of Hertz and to the metallic balls between which he produced his oscillatory spark. In his book on "Electric Waves" published in English in 1894, he advises that these balls be highly polished. For the small amount of energy used by Hertz this was no doubt advantageous, particularly in the production of short waves; but with the further development of the art it became evident that it was impossible to maintair such surfaces when employing sparks of great volume. The essential condition to be fulfilled is that the discharging surfaces shall maintain a permanent condition and not be burned away and pitted by the rapidly recurring heat of the spark. With the utilization of radiators of high power, and with the employment of transformers capable of charging large capacities, the need of a means for maintaining a constant condition of the spark gap became imperative. Special appliances were devised to prevent the pitting of the balls and their consequent destruction.

Marconi early adopted the Righi oscillator plan of placing the balls in a chamber of oil, or other highly insulative medium, thereby excluding the oxygen of the air from the balls and preventing oxidization. He soon found, however, that the insulating fluid was rapidly decomposed under the influence of the more powerful discharges and abandoned the idea in favor of a "dry" ball system.

Numerous inventors have contrived many so-called multiple-ball exciters, among whom is J. S. Stone, whose oscillator is shown in Fig. 31. R. A. Fessenden has conducted numerous experiments which seem to indicate that there is great advantage to be gained by causing the spark to take place in a compressed-air chamber. This is explained by the fact that the effective potential between the balls is thereby raised without rendering the spark non-oscillatory. Better radiation is possible also, according to Fessenden, and it is undoubtedly a great improvement in reducing the ear-splitting noise of the customary discharge. Various compressed gases have also been used with varying success.

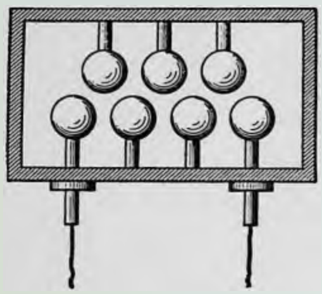


Fig. 31. Multiple-Ball Exciter

Among the various forms of exciter which have more or less successfully fulfilled the requirements, mention must be given to one other fundamental form employed by Marconi. It took advantage of the important fact that though it is exceedingly difficult to create a true alternating arc between two relatively moving surfaces, nevertheless an electric oscillation from a condenser can readily take place even though the movement be exceedingly rapid. Marconi, therefore, devised what is known as the *high-speed disk discharger*, shown in Fig. 32. It would seem that this design of gap possesses many advantages as attested by the extensive employment of it at the trans-Atlantic stations. The illustrations make clear the connections. The apparatus consists of two metallic disks *A* and *B*, revolving at high speed, and a second larger disk at right angles to the axis of the other two and between them, also revolving at high speed. There are thus two gaps where sparks may take place. The closing of the key charges the condensers *C* and *D*, in series between which is connected the condenser *E*, which discharges the energy across either

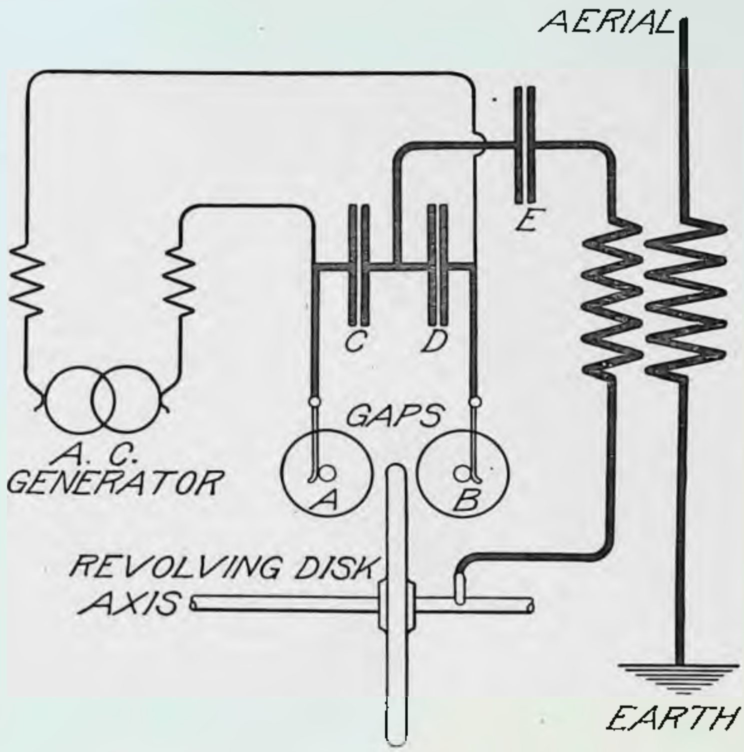


Fig. 32. Diagram of Marconi High-Speed Disk Discharger

gap between the rapidly revolving terminals. Another modification of this device, shown in Fig. 33, is characterized by the fact that it is designed for use with a direct current. The mechanical construction is similar to that of the form previously described, with the exception that the large disk has a row of metallic studs placed equidistantly around its circumference in such a manner as to greatly shorten the length of the air gap between the two revolving terminals when the said studs occupy a position in a line with the plane of their rotation. The office of these studs is to shorten the air gap at predetermined and equal intervals, thus discharging the condensers, which are immediately charged by the direct current. In both forms of the device the arc is prevented by the rapid rotation of the revolving parts. It is claimed that the Marconi dischargers permit of great rapidity of signaling. The last described produces, when run at very high speed, an almost continuous train of oscillations.

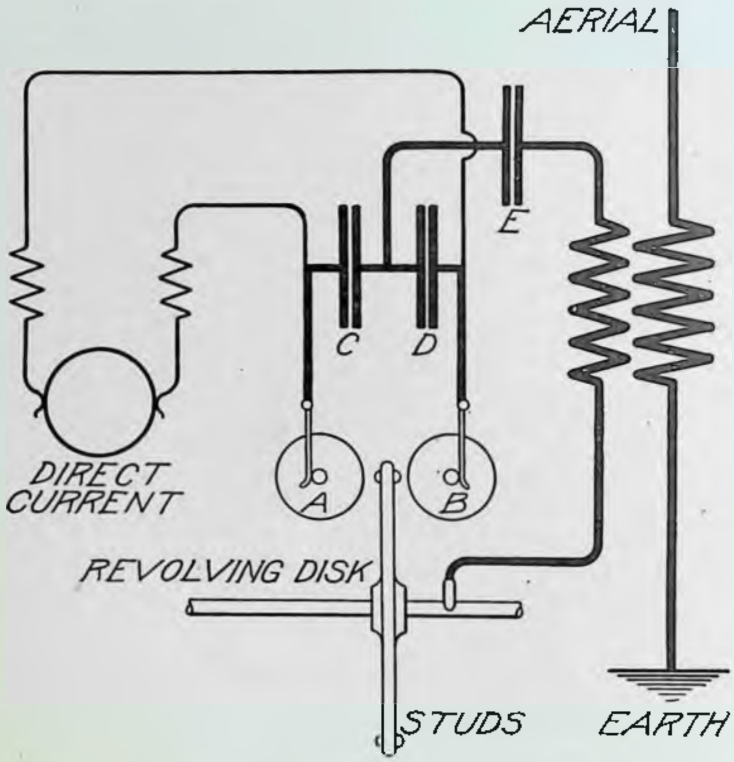


Fig. 33. Disk Discharger for Use with Direct Current

High-Frequency Alternators. It was known at an early date in the history of radiotelegraphy that a much greater efficiency could be achieved if a means were devised for creating a continuous train of undamped oscillations. The Morse dot, which is the minimum signal, was seen to be composed of a considerable number of separate trains of waves, each rapidly damped. Could these "gaps" in the wave train be filled up, the received signal would not only be stronger, but selective signaling would also be greatly facilitated and precise tuning be more easily accomplished. A moment's thought will suffice to convince that a continuous train of undamped oscillations would be the exact equivalent of a continuous alternating current of extremely high frequency; and this opens up the possibility of employing generators which might be connected directly with the aërial, thus doing away with the intermediate condenser and spark gap.

Many attempts have been made to construct generators of sufficiently high frequency, the majority of them having been of the inductor type. An exceedingly small electrical output seems to be the characteristic of all attempts thus far to produce such a machine. Great speed of rotation of the disk armature is required in this type of generator, and as there are limits beyond which it is unsafe to push the rotation, fundamental difficulties arise which have not as yet been surmounted with any degree of commercial success. Fessenden claims to have produced an alternator giving a frequency of 80,000 cycles. The wattage is said to be about 250. The ingenious German inventor, Ernst Ruhmer, has also constructed an alternator of the inductor type having a frequency of 300,000 and an output of but .001 watt; and W. Duddell has succeeded in producing a frequency of 120,000 with somewhat greater power. Until it is possible to greatly increase the output of such machines, their use will be limited to laboratory experiments, or at most to short-distance work in connection with radiotelegraphy. Their development at the present time seems to be in connection with radiotelephony.

The Singing Arc. Much more successful have been the attempts to produce a continuous train of undamped oscillations from a direct current. Elihu Thomson applied, in 1892, for a United States patent on a method intended to effect such a transformation, Fig. 34. A source of direct current is connected to a circuit having a very high inductance, and a spark gap across which is shunted a condenser, and smaller inductance in series. The inventor claims in his patent specifications that the gap, inductance, and capacity can be so adjusted that the condenser is periodically discharged across the gap at frequencies as high as 40,000 per second.

The form that this apparatus has since taken is known by the name of Duddell singing arc, on account of the further developments introduced by him in 1900. Duddell substituted a carbon arc for the gap, and found that such an arrangement produced a clear

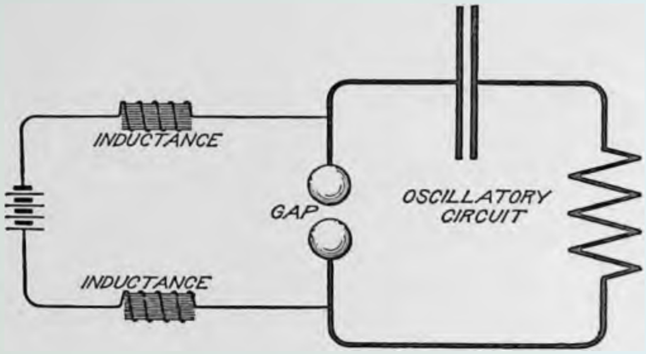


Fig. 34. Thomson Direct-Current Method of Genera'ing Oscillations

musical note plainly audible some distance away, the pitch of the note depending on the value of the capacity and the inductance in the oscillatory circuit—the latter is represented by the heavier lines in Fig. 35. The best effects were obtained by the use of solid rods of

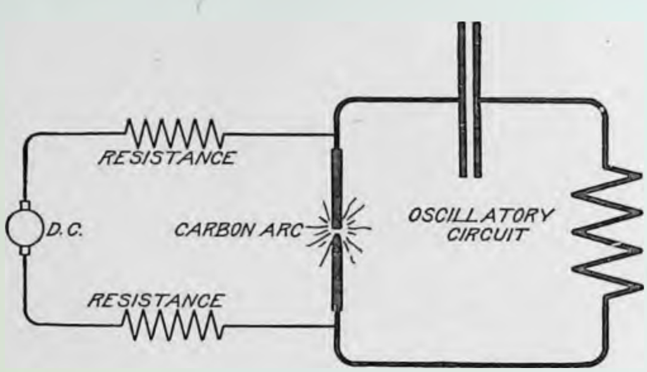


Fig. 35. Duddell Singing Arc

carbon. The resistance of the inductance in the oscillatory circuit must be low—about 1 ohm. Duddell found it difficult to produce oscillations of any considerable power above a frequency of about 10,000; although other experimenters have succeeded in reaching a frequency of 400,000 with small capacity and little energy.

It remained for Valdemar Poulsen of Copenhagen to make the greatest improvement in the direct-current arc method of producing oscillations. Fig. 36 shows Poulsen's arrangement. In the first place, he enclosed the arc in an air-tight chamber filled with coal gas, and used a water-cooled positive electrode with a carbon negative. He also introduced into the chamber the polar projections of two powerful electromagnets in such geometrical relation as to cause the lines of force to pass directly between the electrodes as shown in the diagram. The connecting lines make clear the circuit. The fundamental similarity to Thomson's circuit is apparent. It is possible to produce very powerful undamped oscillations with this apparatus, the frequency of which may, by the proper adjustment of the capacity and the inductance, be made as high as 1,000,000 or more. There is a particular length of arc, called the "active" arc, which gives the best results. Poulsen's device is operable with many other gases besides the one mentioned. The magnets *S* and *N* must be very powerful. 500 volts seems to be a practical voltage for use with this device.

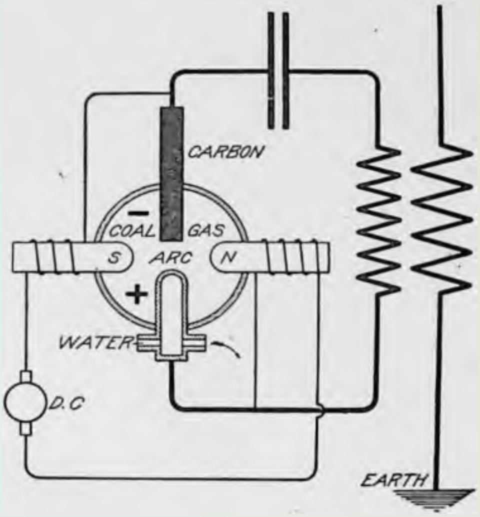


Fig. 36. Poulsen Direct-Current Method of Generating Oscillations

Aërials. The aërials at present used are of many kinds, ranging from the short length of weatherproof wire extending from an upper window to a nail in the chimney, proclaiming the abode of a juvenile experimenter, to those enormous structures taxing the resources of modern engineering in their construction, which achieve trans-Atlantic communication. It was early recognized that the radius of communication was greatly extended by increasing the capacity of the aërial; which fact has led to the employment of multiple-wire antennae. Figs. 37, 38, 39, and 40, show some of the commoner forms, conditions usually determining the choice. It was found by experiment that the capacity of two wires suspended in the air was not twice the capacity of one, nor four wires twice the capacity of two, if such wires were placed near together. The reason, therefore, is apparent why in many of the aërials the individual wires are separated to comparatively great distances.

It is of extreme importance that the upper end of suspended radiator wires should be exceptionally well insulated, and the reason is obvious. Specially designed porcelain or glass insulators are used, having two holes through which the ends of the wires are bound.

Aluminum wire serves excellently for the purpose of antennae when the strain upon it is not too great. Its low tensile strength

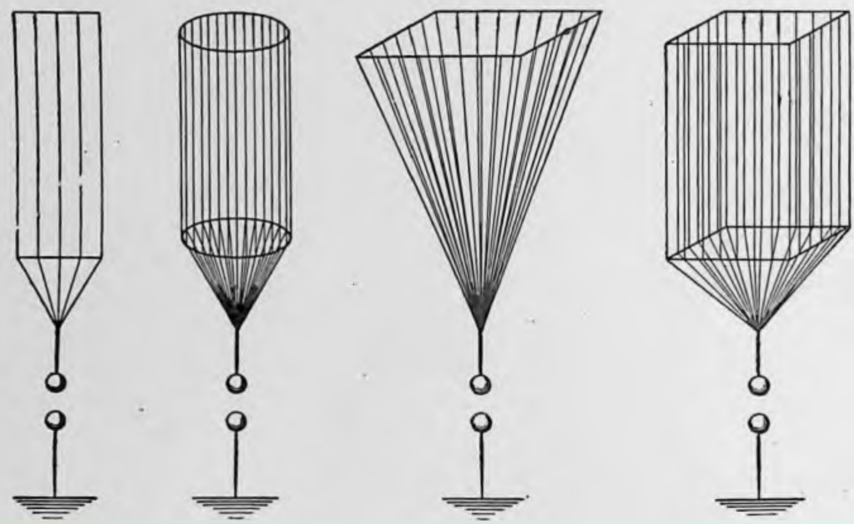


Fig. 37. Fig. 38. Fig. 39. Fig. 40.

Standard Forms of Aërial

precludes its use in some cases. A simple manner of suspending a single-wire experimental aërial is shown in Fig. 41. The mast, or short flag-pole, may be lashed to the tallest object available and the wire carried out of perpendicular a sufficient distance to prevent it from hitting the pole. In army field-equipment, kites or captive balloons are often used to elevate the aërial wire, which is carried wound upon a reel. Many aërials are arranged with a tail block on a cross-tree in order that they may be let down from a high mast for inspection purposes. Such aërials are of the cage variety shown in Fig. 38. An idea of the construction of antennae when designed for use in connection with high-power stations may be gained from Fig. 42.

Directive Antennae. Many efforts have been made to direct the transmission of radiotelegraphic signals to any desired point or locality, but with indifferent success. Early attempts embodied the use of large reflectors behind the oscillator; but the most encouraging results have been accomplished by the use of what are known as *horizontal antennae*, the subject of a patent granted to Marconi and dated 1904. DeForest has also met with some success along this line. The results obtained by these investigators are not formulated well enough as yet to warrant a description of them here.

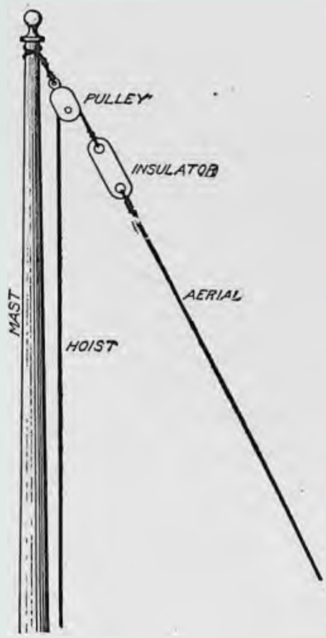


Fig. 41. Single Wire Experimental Aërial

Detectors. The subject of the reception of wave-trains and the transformation of their energy into visual or audible signs through the agency of suitable translating devices will now be taken up and described. It is helpful toward a comprehension of this part of the subject to get clearly in mind the primary effect of a train of waves upon a receiving aërial, namely, the creation of an

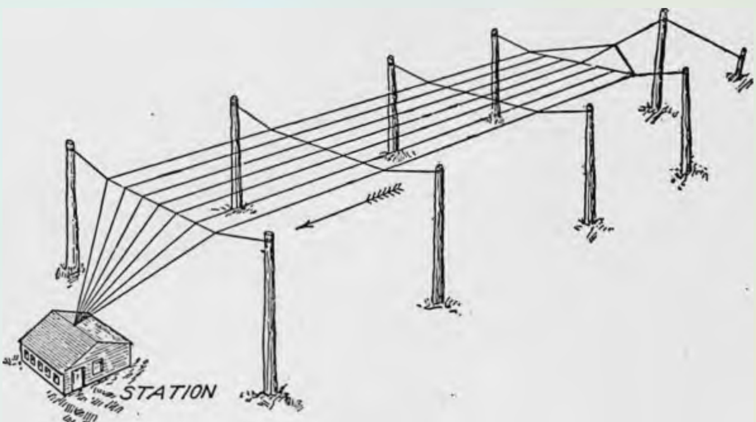


Fig. 42. Antennae Construction for High-Power Station

alternating electromotive force. And the prime function of a receiving device is broadly to detect the presence of a high-frequency alternating current of minute value. Volumes could be written on the history of the various forms of receiving devices which have occupied the attention of the various investigators in this interesting field of experiment. In the present instance attention will be called to those forms only which have proved themselves of practical value.

Wave-detecting devices may be classified for convenience according to the physical principle on which they act, such as thermo-electric, magnetic, electrolytic, chemical, photo-electric, physiological, etc. This course will be followed as far as practicable.

Coherers. Coherers work on the principle of imperfect contact and are called self-restoring and non-restoring according as their sensi-

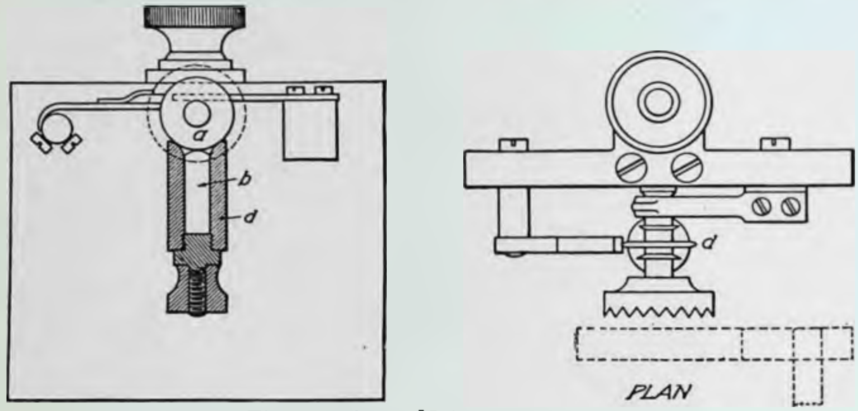


Fig. 43. Lodge-Muirhead Detector

tiveness is automatically reassumed after the passage of a train of waves, or must be superinduced by some external agency. Commercially the coherer has become almost obsolete.

Branly Coherer:—It is unnecessary at this point to give more than passing mention to the Branly coherer, as it has been fully described in a previous chapter. As improved by Lodge and Marconi it performed a very important function in the early days of radio-telegraphy, but has now fallen into disuse.

Lodge-Muirhead Coherer:—An interesting form of contact detector is shown in Fig. 43, devised by Lodge and Muirhead. It consists of a slowly moving steel disk *a* whose sharpened edge is prevented from coming into contact with the small globule of mercury *b* by means of a thin film of oil interposed between the mercury and the steel and contained in the recess *d*. Oscillations passing through the oil cause a breakdown of its high resistance, permitting a translating device to operate by reason of the improved conductivity. Upon cessation of the oscillations, the movement of the disk re-establishes the initial receptivity.

Italian Navy Coherer:—The Marconi Company used with success for a time the so-called "auto-coherer" invented by Signor Castelli, and often referred to as the Italian Navy coherer. The

Fig. 44. Castello "Auto-Coherer"

action is entirely automatic. In Fig. 44, *i* is an iron cylinder separating two globules of mercury; *c* and *c'* are of carbon. Cohesion between the mercury globules and electrodes exists only under the stimulus of the oscillations.

Tantalum-Mercury Coherer:—The tantalum-mercury imperfect-contact detector invented by L. H. Walter is the simplest as well as one of the best of the self-restoring coherers. A small portion of the filament of a tantalum incandescent lamp is connected to a piece of platinum wire for terminal purposes, and the tip of the tantalum is immersed in mercury, which thus forms the other terminal. The whole may be sealed up in a vacuum to avoid oxidization of the mercury. The contact offers very high resistance to a small e. m. f., but falls very low under the influence of the received oscillations. It is rapidly self-restoring. Telephone receivers are often used with this class of detector instead of the Morse relay and recorder, thus allowing the detection of signals from much greater distances owing to the extreme sensitiveness of the Bell instrument to minute differences of current. Such a receiver responds by a buzz to the Morse dash from the distant station.

Valve, or Rectifier, Detectors. One of the difficulties of detecting electric oscillations is the fact that they are of an alternating nature. With the present means at our disposal it cannot be said that we can detect the presence of minute alternating currents with the ease with which we can detect direct currents of equal value. This has led to endeavors to rectify the high-frequency alternations of the received oscillations. Detectors of this type are known as valve, or rectifier, detectors, and one of the simplest means of detecting radiotelegraphic signals is afforded by such devices. To their extreme simplicity is due to a large extent the present number of amateur wireless installations to be seen on all sides. The action of the silicon detector, shown in Fig. 45, is due to the fact that a considerable number of substances in nature possess the property of unilateral conductivity, or the property of conducting electricity freely in only one direction. H. H. C. Dunwoody discovered that carborundum possessed this property to a very marked degree, and would act as a detector if introduced into a receiving circuit in place of a filings coherer. He later observed that no battery was necessary when using a telephone receiver shunted by a small condenser, as shown in Fig. 46. The following substances will all act in place of the carborundum: copper pyrites, iron pyrites, galena, silicon, zinc oxide (perikon), molybdenum sulphide, and titanium oxide. G. W. Pierce has found that the resistance of these substances may be 3,000 times greater in one direction than in the other. The theory of this peculiar action cannot as yet be said to be complete.

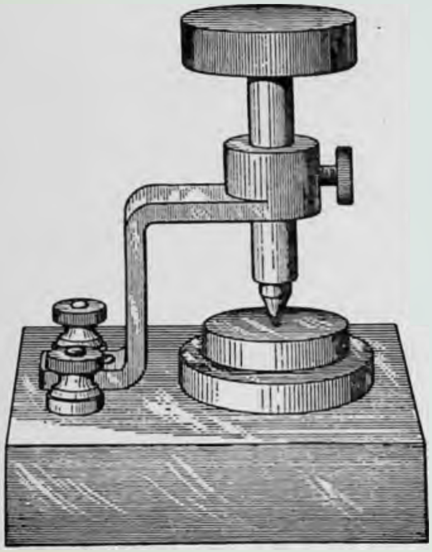
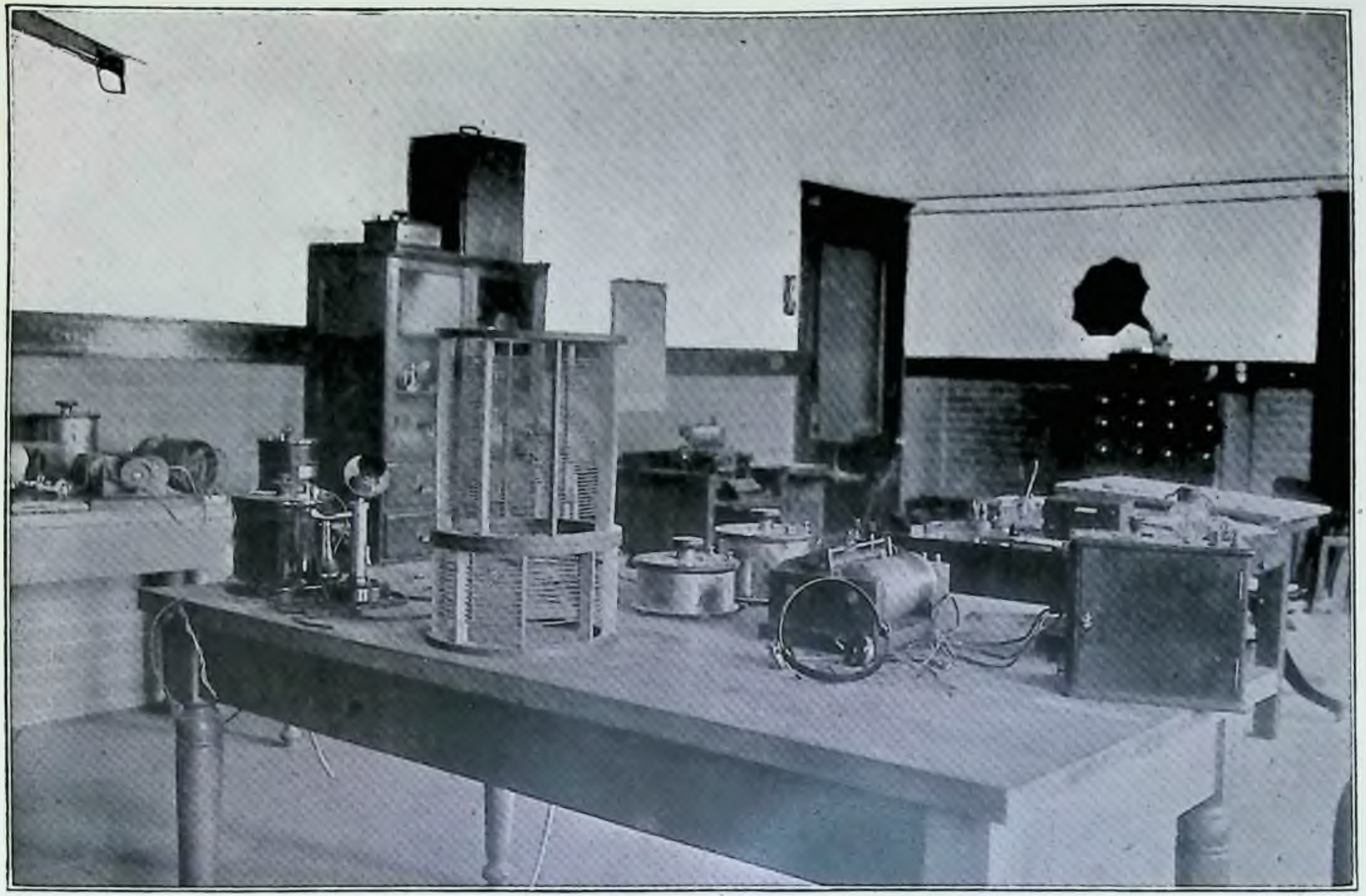


Fig. 45. Silicon Detector

Carborundum, silicon, and perikon seem to be the most satisfactory, particularly silicon, which makes a very sensitive and inexpensive device. Such materials used as detectors of electric waves allow but one-half of each wave to pass, thus giving rise in the telephone to a rapidly pulsating current in one direction to which the telephone can respond. The energy of the oscillations, therefore, directly achieves the audible signal. It has been found, however, that in some cases better results are obtained with a shunted battery cell in the circuit. It is important when using any form of valve detector that excellent connection with the crystal should be maintained at least on one terminal, a deposit of some suitable metal often being employed, thus permitting of a large area of contact. The adjustable contact is preferably pointed and securely held.



RESEARCH LABORATORY OF THE SIGNAL CORPS OF THE U. S. ARMY
Where Major Squier carried on the Experiments whereby he evolved his Multiplex Telephony.

Glow-Lamp Detector:—The glow-lamp detector, invented by Prof. J. A. Fleming, was one of the first valve detectors. The theory of its operation may be understood from the inventor's description and with reference to Fig. 47. "An ordinary incandescent lamp with carbon filament has a metal plate included in the glass bulb, or a metal cylinder *C* placed round the filament, the said plate or cylinder being attached to an independent insulated platinum wire *T* sealed through the glass. When the carbon is rendered incandescent by electric current, the space between the filament and the plate, occupied by a highly rarefied gas, possesses a unilateral conductivity, and negative electricity will pass from the incandescent filament to the plate, but not in the opposite direction. This effect depends upon the well-known fact that carbon in a state of high incandescence liberates electrons or negative ions; that is to say, point charges of negative electricity. These electrons, or corpuscles, are constituents of the chemical atom. Hence a carbon filament in an incandescent lamp is discharging from its surface negative electricity, which may even amount to as much as an ampere or even several amperes per square centimeter. If, then, an incandescent lamp made as described has its filament rendered incandescent by a continuous current, and if another circuit is formed outside the lamp connecting the negative terminal of the filament with the insulated metal plate or cylinder in the bulb, and if oscillations are set up in this circuit, negative electricity will be able to move through this circuit from the filament to the plate inside the bulb, but not in the opposite direction."

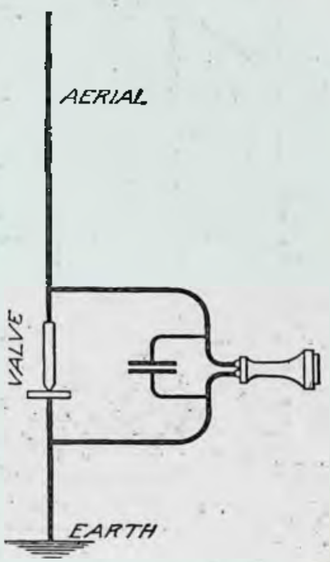


Fig. 46. Diagram of Dunwoody Detector

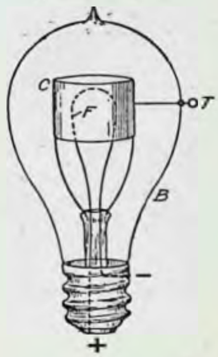


Fig. 47. Fleming Glow-Lamp Detector

It is evident from the foregoing that there are present in the glow-lamp device the essentials of a valve detector. Fig. 48 shows a receiver circuit employed by Marconi making use of the Fleming lamp. Instead of passing the rectified uni-directional impulses directly through the telephone, they are passed around the secondary of a large induction coil in series with a condenser, to the primary of which the telephone receiver is connected. Prof. Fleming is authority for the statement that this arrangement, when suitably adjusted, is "one of the best long-distance receivers for electric waves yet devised."

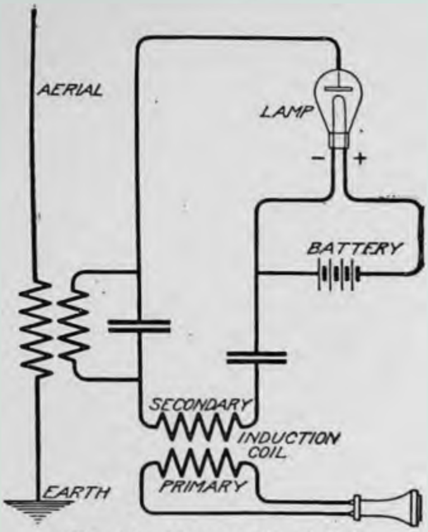


Fig. 48. Marconi Circuit Using Fleming Detector

Audion:—The so-called *audion* of DeForest is a modification of the Fleming detector just described. Fig. 49 shows its connection in a receiving circuit. The lamp used has a low-voltage tantalum filament with two wings, or terminals, sealed in the bulb, as shown. This detector is said to be fairly sensitive, though of short life.

Magnetic Detectors. During the summer of 1902, Marconi was successful in receiving signals sent out from Poldhu on the coast of Cornwall to Flace Bay, Nova Scotia, by means of a remarkably ingenious magnetic receiving device invented by himself and called a *magnetic detector*. Since that time many devices have been patented depending for their operation upon the magnetic effects of the electric oscillations. There has been much discussion relative to the action involved in the Marconi device as well as in other modifications based on the magnetic phenomena

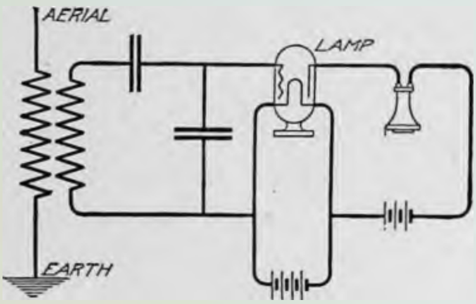


Fig. 49. Receiving Circuit with Audion Detector

associated with oscillatory currents. The explanation advanced by Marconi himself will, therefore, be given here, which in substance is as follows, reference being made to Fig. 50.

The aërial and ground are connected to a few turns of rather heavy wire wound upon a glass tube *T* over which, but insulated from it, is another coil inductively related to the first and connected to the terminals of a telephone receiver. Two strong permanent magnets are placed with like poles together, as indicated. *P* and *P′* are two pulleys carrying on their periphery an endless belt composed of several fine wires of about No. 36 gauge, which are made to pass

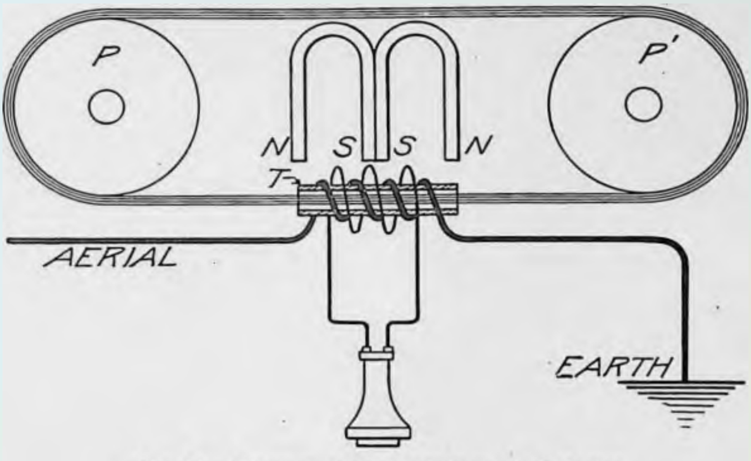


Fig. 50. Diagram of Marconi Magnetic Detector

continually through the axis of the coils by a train of gears not shown. Owing to the hysteresis of the material of the band it tends to retain its magnetism for a short period after it has passed out of the strongest part of the field; but if a train of waves from the aërial is passed through the primary coil to the ground, the effect is to annul the hysteresis and thereby to hasten the demagnetization of the iron wire. This action results in a variation of the flux in the secondary winding, thus inducing electromotive forces in the secondary coil, which make themselves audible in the telephone as a series of sharp ticks. This is said to be one of the most sensitive devices ever made.

A diagrammatic drawing of a magnetic detector, invented by H. Shoemaker, which very closely resembles the early embodiment of the Marconi apparatus is shown in Fig. 51. There have been many variations of the magnetic detector but space will not permit of a description of less important forms.

Thermo-electric Detectors. Comprehended under the head of thermo-electric detectors are those instruments which depend for their action on the heating effects of the oscillatory currents. These

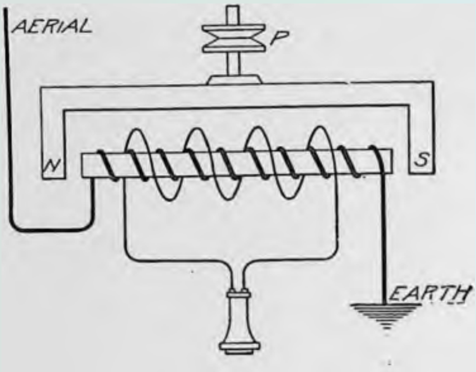


Fig. 51. Shoemaker Magnetic Detector

detectors are especially useful in making quantitative measurements of the amount of energy received under a given condition, and indeed find their greatest utility therein. Fessenden has given great care to his investigations of this form of detector with the result that his so-called "barreter" shown in Fig. 52 is of the same order of sensitiveness as the coherer. It consists of a short piece of exquisitely fine platinum wire connected to suitable terminal wires and the whole enclosed in a vacuum bulb. The temperature rises rapidly under the action of the oscillations, causing an increase in resistance which is indicated by a Wheatstone bridge, in the circuit of which the detector is connected as one of the arms. Attempts have been made to apply the phenomena of the *thermo couple* in this connection, but with only qualified success. It would seem for many reasons that thermo-electrical detectors will not be able to compete with other forms in long-distance work.

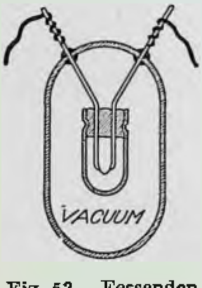


Fig. 52. Fessenden Barreter

Electrolytic Detectors. It remains to take up the class of detectors known as *electrolytic.* DeForest's name is associated with this variety of receiving device, as it was first extensively used by him in a form invented by himself. It consists of a glass tube $\frac{1}{8}$ inch in diameter enclosing conductor plugs after the manner of the Branly coherer. In the interspace is placed a paste composed of rather coarse filings worked up with an equal quantity of oxide of lead in glycerine or vaseline with a trace of water or alcohol. Its resistance increases during the passage of the wave train.

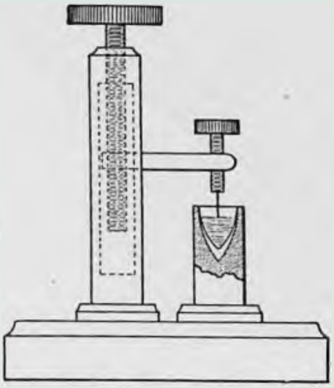


Fig. 53. Liquid Barreter

Fessenden Liquid Barreter:—The most sensitive and practical electrolytic detector is the liquid barreter invented by Fessenden, Fig. 53. It consists essentially of a small containing vessel filled with nitric acid into which projects a platinum wire electrode, which is of extremely small diameter. The apparent resistance of the cell is greatly reduced by the oscillations. The exact nature of the action is not agreed upon by investigators. It was with a refined form of this detector that trans-Atlantic signals were first received from Scotland by the National Electric Company at Brant Rock, Massachusetts.

Hozier-Brown Detector:—The Hozier-Brown system of wireless telegraphy employs a detector classified by some as depending on imperfect contact, but by others as being electrolytic in its action. It consists of a small portion of peroxide of lead held between terminals of lead and platinum, Fig. 54. The lead terminal is much smaller than the other, being a blunt point rendered adjustable by a knurled screw. A two-volt accumulator connected in series gives the best results, according to the inventor.

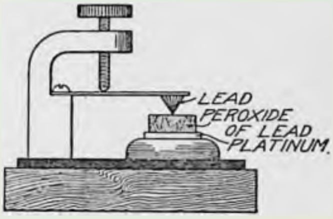


Fig. 54. Hozier-Brown Detector

Electrodynamic Detectors. Mention might be given in passing to the electrodynamic detector devised by Fessenden, although it has never been used extensively. It is designed to operate on the principle that a metallic disk, suspended in a circular coil through which an alternating current is flowing, and at an angle of 45 degrees to the plane of winding of the coil, tends to turn so as to take up a position at right angles to the plane of the coil. This was a fact discovered independently by Elihu Thomson and J. A. Fleming. Fessenden used an extremely light disk hung by a quartz fiber, and he succeeded in obtaining marked deflections of a beam of light reflected from a small mirror fastened to the disk. This device, like the thermo-detector, has been of great service in making quantitative measurements of oscillatory currents.

Auxiliary Apparatus. It would be beyond the scope of the present work to give an extended discussion of the various small devices used in connection with the local receiving circuits, as many of the instruments are not in any way peculiar to radiotelegraphy, being the common adjuncts of wire telegraphy. Mention will only be given to a few points of importance wherein such appliances differ from those commonly employed.

The relay supplied by makers of telegraphic instruments is usually wound with an insufficient number of turns to be efficiently used in connection with a coherer and local battery as a means of actuating a Morse recorder. Rewinding is, therefore, often resorted to. Polarized relays are found to be the best suited to this class of work and should be wound to a very high resistance in connection with all potentially operable detectors. No. 40 wire is often employed.

Sparking at the contacts of the relay is often prevented by the employment of four or five so-called "polarized" cells shunted across the contacts. They are made by inserting a pair of platinum wires through the cover of a small containing vessel partly filled with dilute sulphuric acid, allowing the solution to cover the ends of the electrodes thus formed.

The telephone receivers for use with many forms of detector are much more efficient if wound to a higher resistance than is necessary in the common commercial instrument. Receivers are manufactured in a great variety of forms, only differing from one another in some slight structural modification. The kind known as *operator's double-head receivers* of the watch-case design wound to a resistance of about 500 or 1,000 ohms are well adapted to the requirements of radiotelegraphy.

Dry cells developing an electromotive force, when fresh, of about 1.5 volts are generally used in the local recorder and tapper circuits. One such cell is frequently used in the relay and the coherer circuit.

Measuring Instruments. Perhaps in no department of electrotechnics are the quantitative values of the electrical measurements of more vital importance than in the science of radiotelegraphy. A well-equipped station, therefore, possesses efficient instruments for the measurement of the various electrical factors involved. Besides the common appliances of this nature, such as the voltmeter, ammeter, Wheatstone bridge, etc., it is highly advisable to have the requisite means for making accurate determinations of capacity and inductance. Wave-lengths can be measured by wave-meters, or *cymometers.* These devices are now on the market and are of great utility in a wireless station.

CHAPTER V

SYSTEMS OF RADIOTELEGRAPHY

The history of radiotelegraphy repeats once more the old story that is so often connected with great inventions. The world being possessed of a new scientific principle, many minds in many parts of the world are simultaneously bent upon its practical application, with the result that the fundamental principle finds embodiment in various methods of accomplishing a similar purpose. The startling nature of the discovery of electric waves was bound to give rise to unprecedented activity in the field of experimental investigation; and such experiments as were particularly successful were bound to prompt investigators to seek patent protection on their modifications; and this in turn gave rise to numberless "systems" of radiotelegraphy.

A voluminous list of names could be given of those who have contributed to the advancement of radiotelegraphy in regard to both theory and practice. Among the best-known American investigators are Fessenden, DeForest, Clark, Stone, and Massie. Each of these men has devised a system which bears his name. In England the work has been carried on by men of such unqualified distinction as Lodge, Alexander Muirhead, Fleming, Thomson, and Rutherford. Slaby, Arco, and Braun are the names best known in Germany. The French are represented by Ducretet, Branly, Rochefort, and Tissot, besides other men of lesser fame. We have seen how largely Italy has contributed to the subject; besides Marconi and Righi, mention should be made of Solari, Castelli, and Tommasina. Baviera in Spain, Popoff in Russia, Schafer in Austria, Guarini in Belgium, and Ricaldoni in the Argentine Republic have all invented systems which have been more or less used in their respective countries. The Japanese have also devised a system that successfully stood the test of service in the Russo-Japanese war.

The development of the art in the various countries has been carried on largely by representative investigators, and in many instances the governments have adopted a system exploited by their subjects. The United States government, however, has purchased and experimented with most of the prominent systems offered, and as a result the army and navy equipments comprehend quite a variety of apparatus of different makes.

Telegraphic Codes. Before beginning the description of the more important systems of radiotelegraphy in use at the present time, we will consider the telegraphic codes employed in wireless correspondence. There are three alphabetical codes commonly used at the present time, viz, the Continental, the Morse, and the Navy

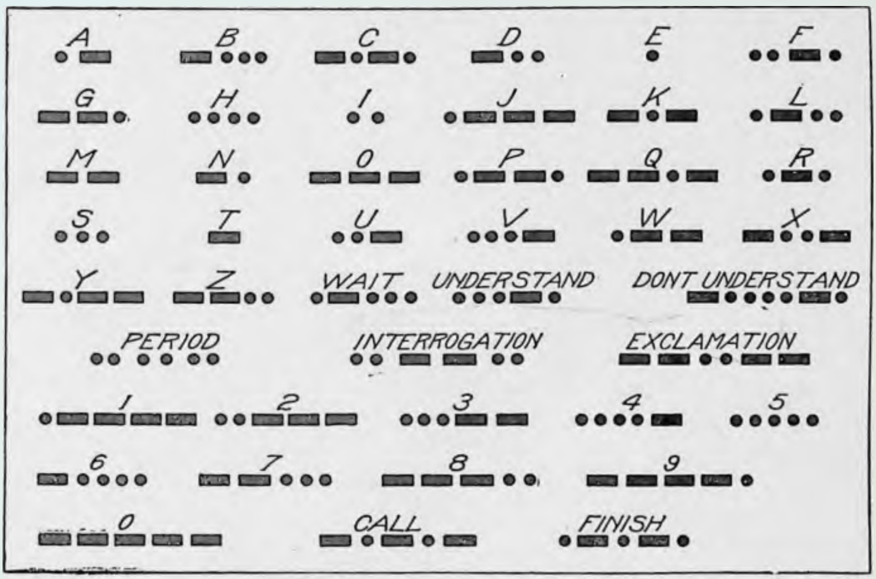


Fig. 55. Continental Code

codes. By far the greatest amount of business is carried on in the Continental code, especially between ships and shore stations. The Morse is more commonly employed for overland service, while the Navy code is confined to naval purposes. Abbreviations of the commoner words are often made use of in transacting the ordinary run of business. The three codes are shown in Figs. 55, 56, and 57.

Marconi System. A detailed description has already been given of the Marconi system as it was about the year 1900. Since then the system has been developed to a remarkable degree so that it stands today a commercial factor of large pretensions. The Marconi stations are scattered in many parts of the globe and are operated in conjunction with all the large telegraph and cable companies.

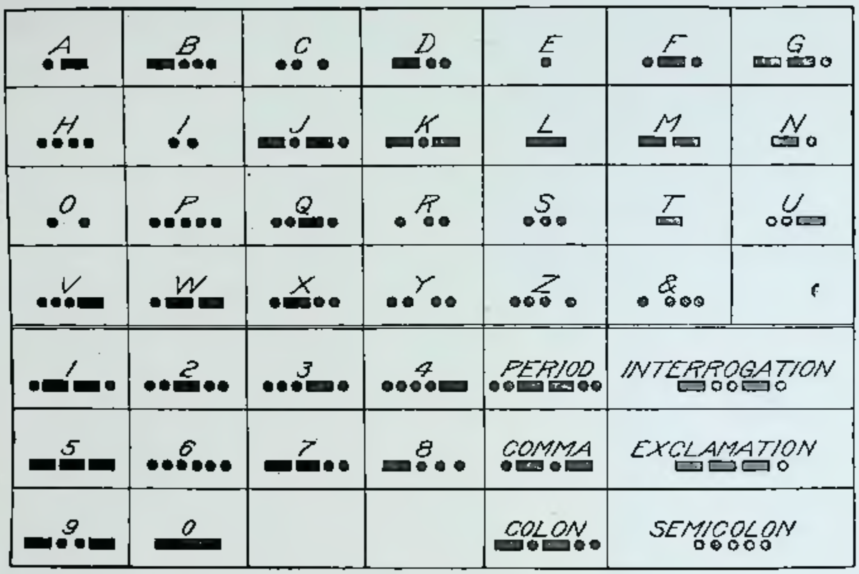


Fig. 56. Morse Code

In addition to the numerous land stations a very large number of vessels are equipped with the Marconi apparatus, including the

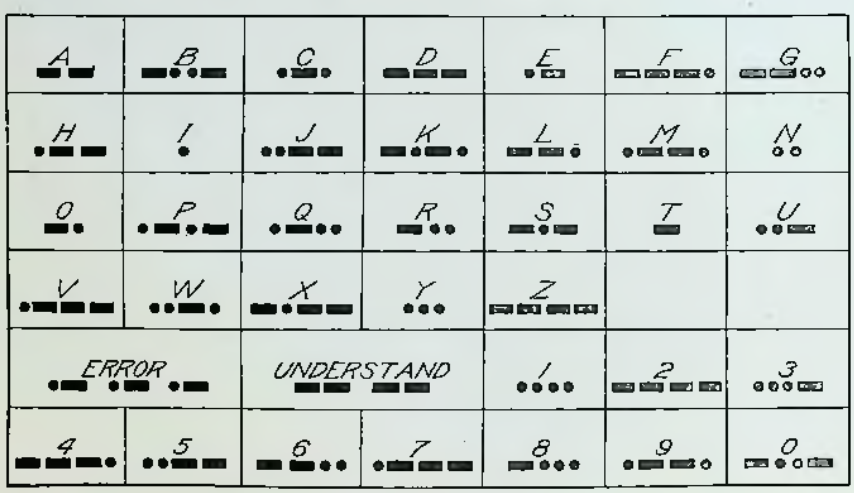


Fig. 57. Navy Code

ocean liners of nearly all the large steamship companies, such as the Cunard line, the Hamburg-American line, the Norddeutscher Lloyd, and many other lines too numerous to mention. Three stations are in operation in China.

For short-distance equipment to be used over a few hundred miles, such, for instance, as is usually installed on Atlantic liners, the Marconi Company employs an induction coil with mechanical break to charge a battery of six to twelve Leyden jars. Two coils and two sets of jars are often supplied in order to readily produce two different wave-lengths. A single spark gap is now used. The Marconi magnetic detector is generally employed, owing to its great simplicity and ease of adjustment. An important improvement evolved by the meeting of practical difficulties is known as the *X-stopper*, *X* being the name given to certain irregular atmospheric disturbances of an electromagnetic nature which manifest them-

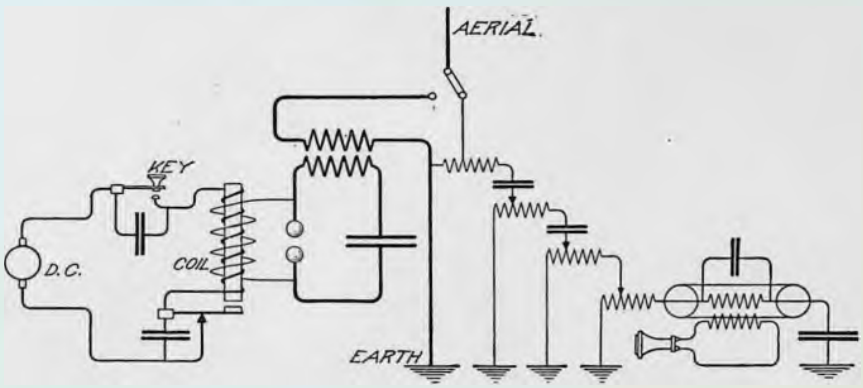


Fig. 58. Complete Marconi Sending and Receiving Circuit

selves as stray signals of sufficient energy to cause confusion in the reception of messages. The means devised by Marconi for overcoming these objectionable interruptions may be seen in diagram in Fig. 58, which shows one form of the complete sending and receiving circuits employed by the Marconi Company. The lower end of the receiving aërial is connected with a plurality of adjustable oscillatory circuits of varying periodicity which terminate in the primary oscillation circuit of the receiving device. The operation of the contrivance depends upon the ability of the first three grounded circuits to perform the function of leading to the ground waves whose frequency does not accord with the periodicity of the system as a whole. It will be noted that the closed type of oscillatory circuit inductively coupled to the aërial as before described is used in the transmitting arrangement of apparatus. The later form of oscillation transformer used at the sending station is designed to provide means for varying the closeness of the inductive couple. This possesses many advantages.

The Marconi Company has equipped several high-power trans-Atlantic stations. The modifications of the short-distance apparatus made necessary for long-distance signaling pertain largely to means for controlling a much larger amount of energy at the transmitting station and the employment of longer wave-lengths. Communication was established the latter part of 1907 between Cape Breton, Nova Scotia, and Clifden, Ireland, by waves 12,000 feet in length generated by means of the Marconi high-speed disk discharger used in conjunction with a condenser of 1.16 microfarads charged to 80,000 volts. Horizontal, or directive, antennae are used with their free ends directed away from each other at the two stations, the horizontal portion being about 1,000 feet long and raised about 200 feet in the air. The Marconi magnetic detector, and also a modification of the Fleming glow-lamp detector, have been used as receptors in this class of work.

An ingenious form of signaling key for use in connection with high-power installations employing alternating current has been patented by the Marconi Company. The fundamental feature of the invention consists in the use of a laminated electromagnet through which the current to be broken is conducted, so placed as to hold the key closed by the attraction of an armature on the key until the current reaches the zero value, at which time the key is allowed to break connection unaccompanied by a spark. The connection may be made and maintained at will, but upon release of the key the circuit is broken at the instant when the current reaches the zero value; the frequency of the alternating current being at least such that this occurs about 100 times per second, the maximum lag of the key behind the movement of the operator's button is inappreciable.

Fessenden System. Fessenden undoubtedly holds a position of first rank among scientific investigators in the field of electric radiation. Moreover, he has proven himself to be an inventor of exceptional originality. His experiments in radiotelegraphy date back to the early days of the art. The National Electric Signaling Company now control the long list of patents resulting from his researches beginning in 1897 and covering a great variety of subjects pertaining to every part of radiotelegraphic equipment as well as to radiotelephony.

The National Electric Signaling Company completed in 1905 two trans-Atlantic stations for communication between Brant Rock, Massachusetts, and Machrihanish, Kintyre, Scotland, a distance of more than 3,000 miles. Successful communication was established on Jan. 3rd, 1906, the detector used being the liquid barreter, already described. An interesting feature of these long-distance stations is the design of the aërial. This is in the form of a vertical steel tube 3 feet in diameter and 415 feet long, resting upon an insulated foundation, and supporting an "umbrella" formed of wires at the top. This structure is held in an erect position by sixteen guys insulated to withstand a voltage of over 150,000. A 25-kilowatt, 60-cycle, boiler-engine alternator supplies the energy.

Fessenden has devoted much time to the problems of selection, interference, and tuning. As a result of his labors in this field, the Fessenden system may be said to represent the highest development in this respect yet achieved.

The National Electric signaling equipment comprises a transmitting device of the direct-coupled aërial variety, characterized by the arrangement of the sending key which, by cutting out a certain amount of inductance in the oscillatory circuit, alters the frequency of the waves emitted—instead of interrupting the primary circuit and causing a cessation of the waves, as in common practice. This requires that a receiving station be tuned with great accuracy, in order to respond to a slight difference of wave-length only, an untuned circuit being thus unable to receive any signals other than a continuous dash. It is claimed that a difference of wave-length occasioned by the operation of the key, amounting to less than one per cent is sufficient to achieve perfect communication. This exceptional freedom from interference is due largely to the employment of what is called an *interference preventer,* diagrammatically represented in Fig. 59, which shows an improved Fessenden receiving circuit. The aërial is connected through a variable inductance to a divided circuit and thence to the ground. In each half of the divided circuit is placed a condenser in series with the primary of an air-core oscillation transformer. The secondary terminals of the transformer are united by a condenser *A*, a signal translating device consisting of the liquid barreter *B*, a potentiometer *C*, and a telephone receiver *D*—all in series. The secondary terminals of the transformers are connected up so as to oppose each other, after the manner of a Hughes induction balance. The aërial and one-half of the divided circuit are tuned to the desired frequency, the other half being momentarily disconnected; then the latter is connected again and the capacity of the condenser *E* is adjusted until the disturbing signals are eradicated. The operation is theoretically as follows: Signals of the proper wave-length pass almost entirely through the side of the divided circuit which is tuned to correspond, while waves of any other frequency pass with equal ease through both sides of the divided circuit, thereby acting differentially on the secondary oscillation circuit because the secondary windings of the oscillation transformers oppose each other. It is said that this arrangement will differentiate between waves differing but one per cent in wave-length.

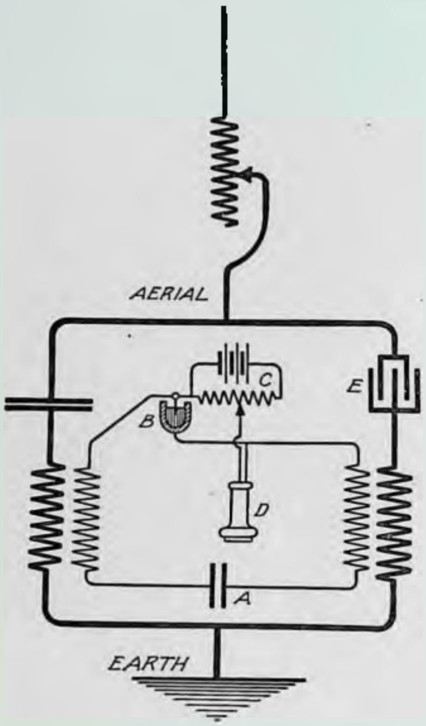


Fig. 59. Fessenden Interference Preventer

Fessenden apparatus is sometimes supplied with a so-called *intensity regulator* for modifying the intensity of radiation without affecting the frequency. This is for use in communicating with nearby stations.

Telefunken System. The system designated by this title is the result of an amalgamation of two formerly separate systems of radiotelegraphy. After patent litigation in the German courts, die Gesellschaft fur Drahtlose Telegraphie (Wireless Telegraph Co.) of

Berlin was formed to take over the conflicting interests represented by the Slaby-Arco system and the Braun-Siemens-Halske system. This company is operating under patents granted to Dr. Rudolph Slaby of Berlin, Count Georg von Arco, and Prof. Ferdinand Braun of the University of Strasburg, each of whom has made important contributions to the subject of space telegraphy. The Telefunken system has been developed to a remarkable degree, due largely no doubt to the powerful influence of the German government, and possesses stations all over the world—numbering more than 500.

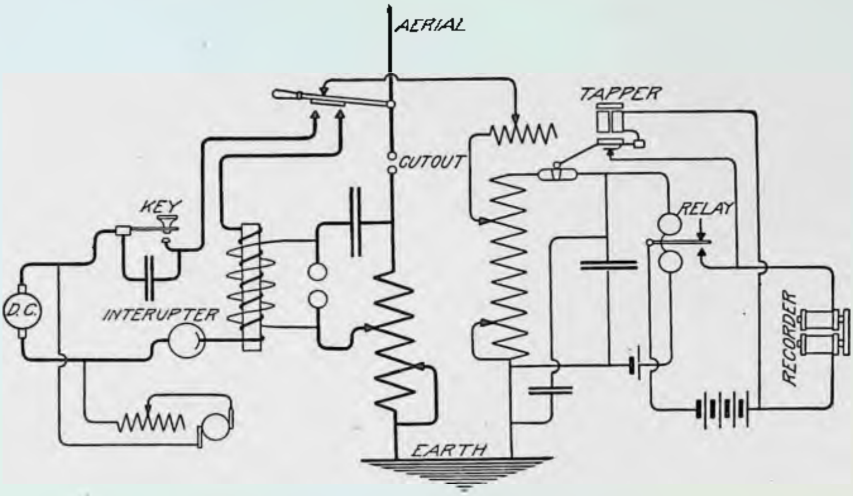


Fig. 60. Circuit Diagram, Telefunken System

Their equipment is sold outright and is noted for excellence of workmanship. The earlier sets of apparatus were furnished with a Morse recorder operated by a coherer of the nickel filings type, but latterly an electrolytic detector and head telephone are furnished as a means of reception. As the recorder and associated apparatus cut down the speed of signaling to a degree that seriously impairs their value for commercial work, the employment of the telephone is becoming almost universal practice. The recording mechanism is, however, preferred by many naval authorities over the telephone, as it eliminates the personal equation of the operator and leaves no possibility of error in the received messages.

A complete wiring diagram of the connections of the Telefunken system is shown in Fig. 60. The aërial is coupled directly onto the closed oscillatory circuit. A small air gap, or cut-out, is located in the transmitting aërial to prevent the received oscillations from flowing through the transmitting circuits. Such a gap offers no hindrance to the high-potential oscillations surging through the radiating circuit of the antennae. Means is shown for adjusting the inductance in the closed circuit of the transmitter, and the inductance between this circuit and the earth.

The Telefunken Company has more recently announced the so-called *singing-spark* system of radiotelegraphy, which is based on the discovery of Wein that exceedingly powerful discharges, possessing useful properties for radiotelegraphy, may be obtained from very short spark gaps. The air gap in this new modification of the Telefunken system is divided between a plurality of copper or silver disks kept apart by rings of mica. This form of oscillation generator is called by the German firm a *quenched spark*. When in operation the device gives forth a clear musical tone, which gives the system its name. The detector employed is of special design and said to be more sensitive than the electrolytic type. It is claimed for the singing-spark system that shorter aërials may be used and that a greater percentage of the energy of the source can be rendered available for radiation; also that the tuning of stations is greatly facilitated.

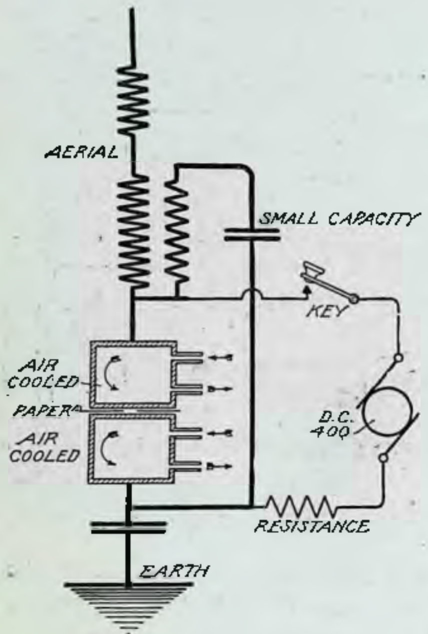


Fig. 61. Von Lepel Oscillation Generator Circuit

Von Lepel System. It has been claimed by the German experimenter, Von Lepel, that he applied the discovery of Wein to practical radiotelegraphy prior to its adoption by the Telefunken people. However this may be, the discovery referred to seems to be of importance, and though this method of producing oscillations is still in the experimental stage, the system of Von Lepel based thereon

TYPICAL NAVAL WIRELESS STATION ON SHIPBOARD

View taken on Board the U. S. S. "Tennessee."

is of interest. The oscillation generator designed by him is shown in Fig. 61. It consists essentially of two copper-box, air-cooled electrodes about 5 inches in diameter, separated by a thin (.002 inch) disk of paper with a ½-inch hole in the center for the spark. The paper serves to keep the arc from running out to the edge of the electrodes. This paper constantly burns away, but a piece will last about three hours. The connections are indicated in the diagram, which shows a direct-current generator, but an alternating current will also operate the device. L and L' are inductively coupled inductances, the value of L' being very small. The capacity in series with L' and bridged across the gap is also very small. A satisfactory explanation accounting for the effects obtained has not yet been put forth. Tests thus far applied to this system have shown advantages not possessed by other systems; but it remains to be seen whether this idea is capable of the extended development it promises.

Lodge-Muirhead System. Reference has already been made to the great service rendered to the art of radiotelegraphy by Sir Oliver Lodge at that early time when its future depended on the elucidation of obscure theoretical points and on those important practical innovations which could alone make possible a commercial development of the idea. Lodge was very early impressed by the fact that periodic currents are amplified under conditions of resonance, and was of the opinion that wireless telegraphy by the early induction method could be facilitated by properly syntonizing the primary and the secondary circuits. He accordingly experimented in this direction and successfully verified his belief. He soon abandoned the notion of inductive telegraphy, however, and joined forces with Dr. Alexander Muirhead, endeavoring to effect wireless telegraphy by means of Hertzian waves. Always keenly aware of the advantages of syntony between the sending and the receiving apparatus, it is not surprising to find that his

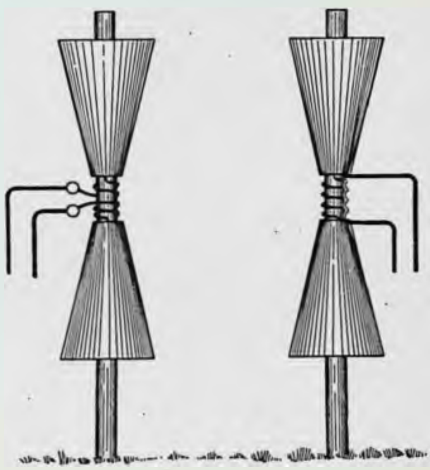


Fig. 62. Lodge Conical Capacity Areas

earliest patent specifications were very copious on this point. To facilitate accurate tuning, large conical capacity areas supported by a suitably insulated frame structure were employed, as shown in Fig. 62. This form of open oscillatory circuit later evolved into the horizontal wire areas now commonly associated with the Lodge-Muirhead system, which is further characterized by being "ungrounded," the lower capacity being in some cases placed several feet above the earth.

One form of a Lodge-Muirhead sending and receiving station is diagrammatically represented in Fig. 63, which makes clear the form of capacity areas more recently adopted. The transmitter is a form of direct-coupled closed oscillatory circuit, and the receiving circuit of the closed inductively coupled type. The auxiliary ap-

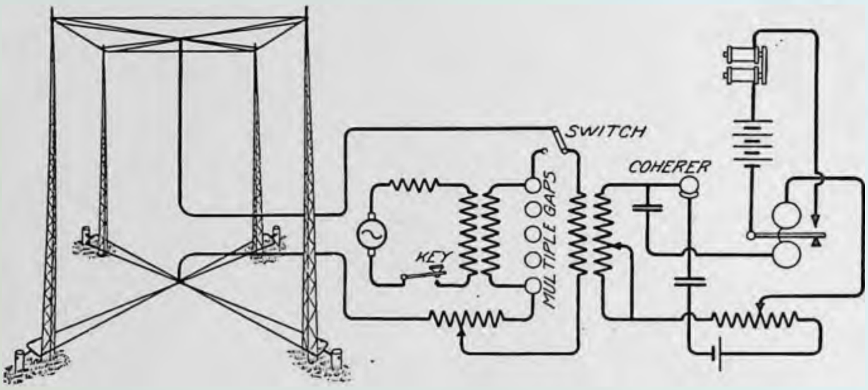


Fig. 63. Lodge-Muirhead Sending and Receiving Circuits

paratus used in conjunction with the Lodge-Muirhead steel-disk coherer previously described is not shown in the drawing. Dr. Muirhead, endeavoring to render the system serviceable in connection with the ordinary forms of telegraphic signaling apparatus, has applied a syphon recorder directly connected with the coherer. A Morse register has also been employed, or a telephone, as occasion suggested. Automatic transmission by means of perforated tape is sometimes used, a perforator being furnished with their equipment.

The Lodge-Muirhead system has never reached the large industrial development achieved by some other systems, notably the Marconi and the Telefunken; but it is, nevertheless, in commercial operation in many parts of the world. Communication was established in 1904 between the Andaman Islands and the mainland of Burma, and has given excellent service since. The distance is slightly over 300 miles. The adverse conditions incident to a tropical climate were here admirably met.

DeForest System. One of the best known American systems is that developed by Dr. Lee DeForest of Chicago. The DeForest interests have many stations located in the eastern States and along the Atlantic seaboard, one of the largest of which, located at Manhattan Beach near New York City, has successfully effected communication with Porto Rico and Colon, Panama, the latter a distance of more than 2,000 miles. A large number of merchant vessels are equipped with this make of apparatus. The United States navy also possesses a number of sets.

DeForest was among the first to employ an alternating-current transformer to charge the requisite capacity. The earlier form of his apparatus included a small motor-generator set delivering current at 500 volts, which was stepped up to 25,000 to 50,000 volts by means of an oil-immersed transformer, the secondary terminals being connected to the aërial and ground with condensers across a gap of the disk type. The receiver circuit used in conjunction with this apparatus was of the untuned kind, the detector being of an electrolytic nature called a "goo" responder, an invention of DeForest and E. H. Smythe. A "needle" anti-coherer of extreme simplicity was used with the earlier equipments, consisting of a light steel needle upheld by a retractile spring against two small aluminum rods. A telephone was employed to respond to the fluctuations of current in a local battery circuit caused by the increased resistance of the needle contacts under the action of the received oscillations. Great simplicity was aimed at in the design of the entire apparatus. No attempt was made to accomplish selection.

Electrolytic and thermo-electric detectors have been the subject of extended investigation by DeForest and his co-workers. As a result thereof a detector was evolved, consisting essentially of a small containing vessel filled with a suitable electrolyte into which projects the tip end of an exceedingly fine platinum wire. This "cell," under the influence of oscillations, exhibits a marked difference in its resistance to a local current. The similarity to the Fessenden liquid barreter is apparent. Much controversy has arisen relative to the theoretical operation of these detectors, DeForest contending that the action was electrolytic, while Fessenden and others have held to the view that the observed effect was due to the thermal action of the oscillations. Whatever the correct explanation may be, the fact remains that the "electrolytic" detector became, in the hands of DeForest, an exceedingly sensitive device and has contributed largely to the success of his system.

DeForest later devised a syntonized system based upon the principle involved in the so-called "Lecher Wires," which reflect waves bearing a definite ratio to the length of such wires. This arrangement, exhibiting anti-nodes of potential and current, possesses de-

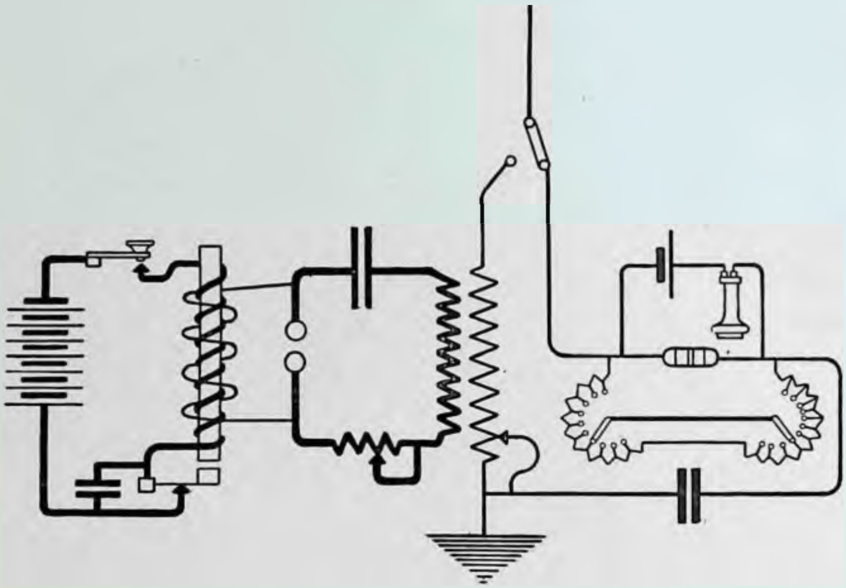


Fig. 64. Clark Sending and Receiving Circuits

cided advantages when applied to the receiving circuit, as it permits a potentially-operable or current-actuated detector to be placed at a point of maximum effectiveness. Possessing also a very definite time-period, this form of circuit was found to lend itself admirably to tuning purposes.

Clark System. The Clark Engineering Company manufactures a form of radiotelegraphic apparatus designed by Thomas E. Clark, which is usually supplied as a portable equipment, contained in oak cases provided with shoulder straps for carrying. Many such sets have been purchased for the Signal Corps of the

United States army, for which service they are especially intended. The aërial wire is preferably raised by means of a kite. The transmitter is of the inductively coupled type, consisting of an induction coil, two one-half gallon Leyden jars, the oscillation transformer, and the necessary auxiliary apparatus, such as secondary batteries, an interrupter, etc. This portion of the equipment is made to be contained in three cases, while the receiving equipment is economically arranged within a fourth oak box covered with canvas. The receptor employed is of the auto-coherer variety, operating under

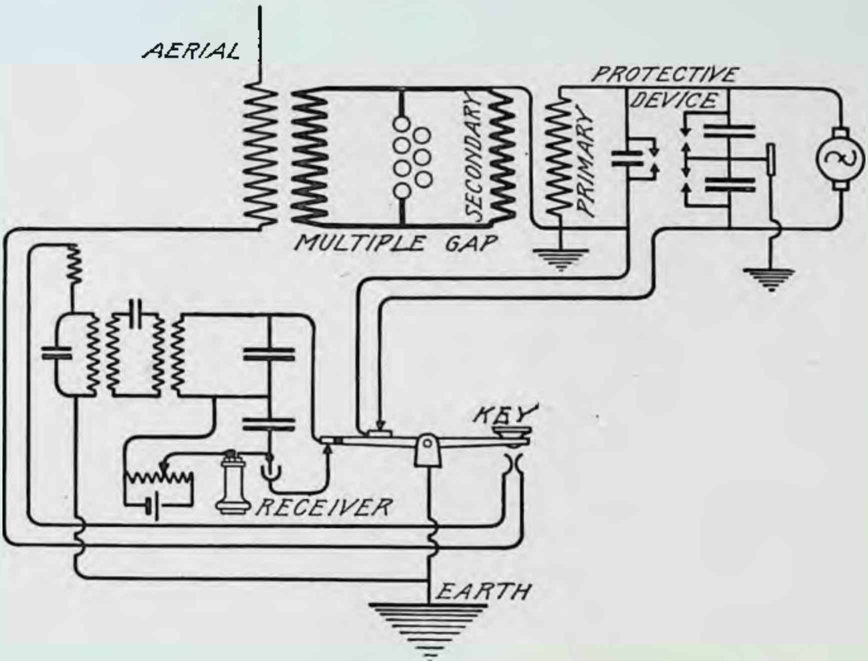


Fig. 65. Stone Sending and Receiving Circuits

the variations of resistance of the imperfect contact between two conducting plugs of steel with a small quantity of carbon granules interposed between them. A head telephone receiver and one dry-battery cell are shunted around the auto-coherer. The complete sending and receiving circuits of the Clark system are shown in Fig. 64. It will be noticed that the system presents nothing of novelty beyond the fact of its admirable adaptability to the requirements of a portable equipment. It can be readily packed on the back of a transport mule, or carried by men in a military campaign.

Stone System. Another American system, which is curiously enough little referred to, is the Stone system, invented by J. S. Stone, who has been granted nearly one hundred patents in this country alone, besides their equivalents in European countries. His specifications cover the widest possible range of subjects pertaining to radiotelegraphy and proclaim him to be the possessor of an extraordinary understanding of the more recondite problems connected with the science. Several of his patents cover the inductive coupling of aërials, something after the manner of the Braun-Marconi method. It is

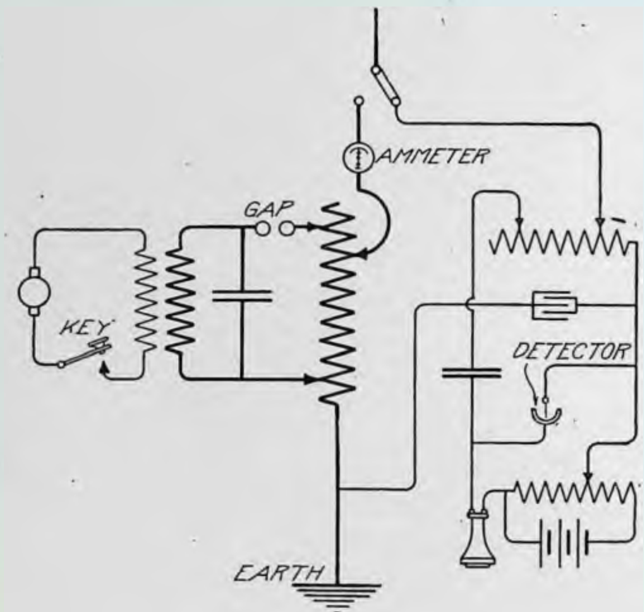


Fig. 66. Massie Sending and Receiving Circuits

difficult to believe that any large proportion of the specifications have ever been tried out in practice; in which case they may represent but "anticipatory" patents. One of the Stone arrangements for the sending and receiving stations is shown in Fig. 65, which embodies features of interest particularly from the viewpoint of the "wireless" operator. Reference is made to the multiple function of the sending key which allows an operator to be "broken in upon" while sending, by reason of the fact that the receiving circuit is broken by the depression of the key but instantly closed upon release. The aërial is inductively coupled to the closed oscillatory circuit containing a multiple-spark gap. Various forms of detectors have been used by Stone, especially electrolytic and thermal devices. In one of his patent applications he describes a thermopile of platinum and gold for use as a detector. The Stone system has never been widely exploited although such equipments are occasionally used in this country and doubtless may be found elsewhere.

Massie System. Walter W. Massie of Providence, R. I., has developed a system of radiotelegraphy which bears his name. While the system has never been exploited on a large scale, numerous sets of apparatus have been purchased by the United States government, and many private concerns find use for this make of apparatus. Massie is well known among the amateur wireless experimenters as the inventor of an exceedingly simple detector of the imperfect contact type, which has rendered many a home-made outfit at least operative where a more complicated receptor would have been prohibitive. The device goes under the name of the *oscillaphone,* and consists simply of a common sewing needle placed carefully across two sharpened carbon edges. A small horseshoe magnet is sometimes located under the needle in order to exercise a slight attraction and maintain good connection. In the Massie equipments supplied for long-distance use, an electrolytic detector is employed. The Massie circuits are shown in Fig. 66. The aërial is direct-coupled.

Poulsen System. A remarkable system due to the genius of Valdemar Poulsen of Copenhagen has of late years attracted great attention, as it undoubtedly marks a decided advance in the art. Poulsen has accomplished by means of a modification in the Duddell arc a method of creating an almost continuous train of undamped oscillations resulting in an equivalent train of electric waves. The ability to generate such a persistent train of waves offers great advantages in the syntonization of stations and in the problem of selective signaling. As before mentioned, the Poulsen system is characterized by the employment of hydrogen under pressure as the surrounding medium for the arc. The receiving device used is the invention of Pederson, and a very full description of it may be obtained by referring to the *Electrician* for Nov. 16, 1906.

Other Systems and Inventors. Numerous other systems of radiotelegraphy have been exploited in various countries, but space will not permit of a detailed description of them here. The patent files of every government contain numberless specifications pertaining to the art; indeed, it is doubtful if any other improvement in electrical communication has called forth in so short a time a more voluminous patent literature.

The *Rochefort-Tissot system* in France has met with considerable success. Perhaps the most distinctive feature of this system is the form of induction coil employed, called a "unipolar transformer." The equipments are manufactured by Ducretet, the French instrument maker.

In Belgium the *Guarini system* has been installed in various localities with moderate success. The inventor has great faith in the possibility of relaying radiotelegraphic messages to accomplish long-distance transmission. He has devised a relay for such purposes, which seems to promise good results.

The Russian government has experimented with several systems, but the *Popoff system* is now almost exclusively used. Considerable interest attaches to this system on account of its historical importance. As early as 1895, Prof. Popoff communicated to the Physico-Chemical Society of St. Petersburg the details of a device employed by him for graphically registering atmospheric disturbances of an electrical nature by means of a coherer introduced between an elevated "exploring rod" and the ground. A relay and tapper were also employed, the former serving to operate a Richards register. It is thought by many that sufficient credit is not given Popoff for these innovations.

Sir H. M. Hozier and S. G. Brown in England have developed a system bearing their names, which differs little from the other systems, with the exception of the detector and method of directly connecting the same to a syphon recorder. The Hozier-Brown detector has been described elsewhere.

A system of selective signaling which seems to promise well, is that named after the inventor, Anders Bull. Resonance is not employed as a selective agency; instead, the receiver is designed to respond only to a group of wave-trains which are separated by certain unequal and predetermined intervals of time. The mechanism effecting the transmission of such properly timed wave groups is called the *dispenser*, and the companion device at the receiving end, the function of which is to translate the wave groups into printed

Morse characters, is called the *collector*. Tests conducted by the United States navy with this system were highly satisfactory as regards secrecy and freedom from atmospheric disturbances. The complicated nature of the apparatus will possibly prohibit the extensive use of this system, although it possesses advantages not even theoretically possible by resonance alone.

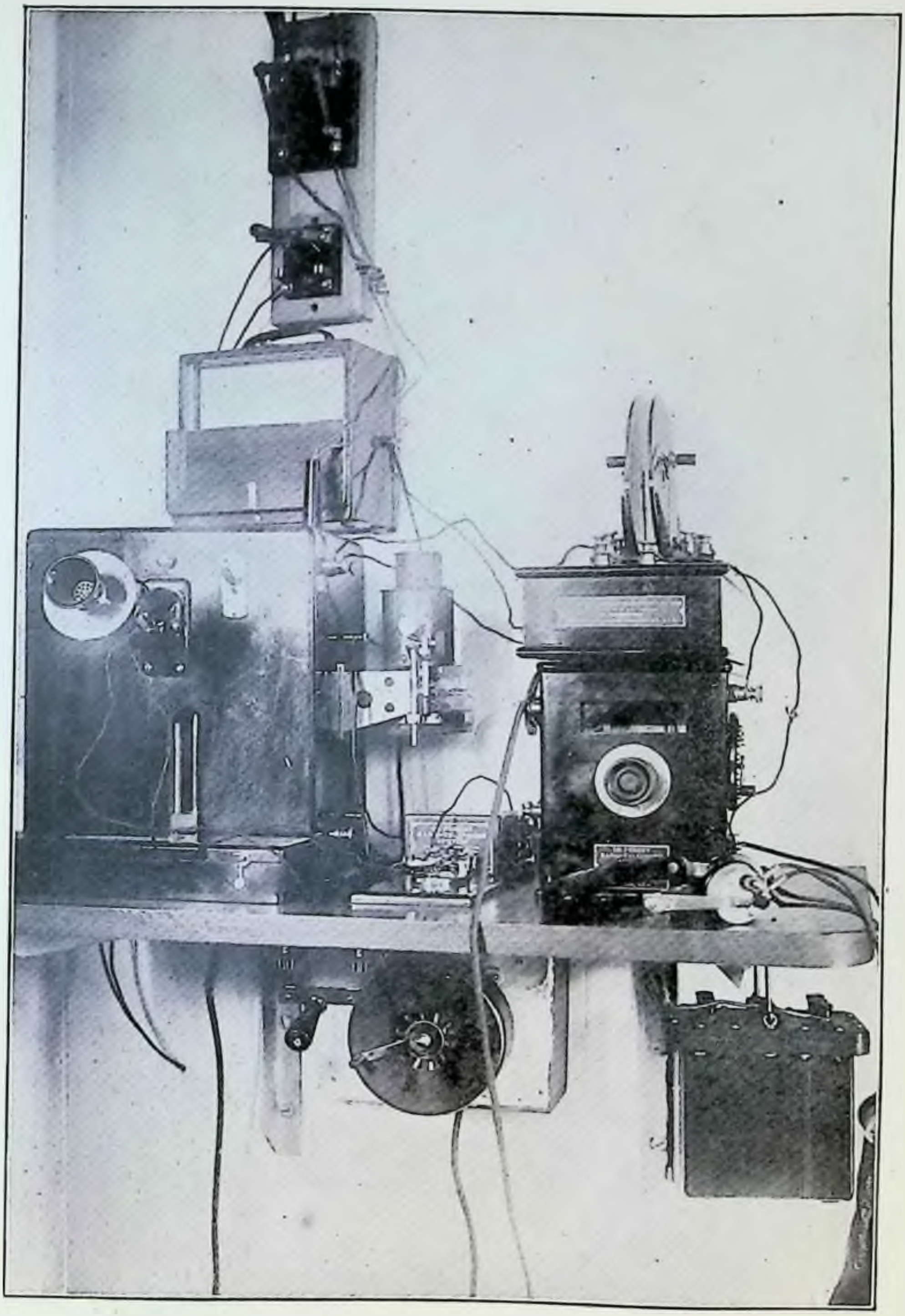
Conclusion. During the twenty years or so since Hertz made his famous discovery of electric waves, radiotelegraphy has made many substantial advances toward the goal of perfection; and it stands today a conspicuous and brilliant example among the many resources which Science has contributed to modern civilization. Its uses are many and important. To mention its life-saving power alone is to secure for it a high claim to consideration. Its success in this regard has been spectacular in more than one instance; and it is not too much to say that radiotelegraphy has saved hundreds of lives since the "wireless" installation of ships has become prevalent. To travel on the ocean with a "wireless" equipment on board, knowing that in case of peril the assistance of vessels within a radius of hundreds of miles can be instantly summoned, adds not a little to the comfort and security of the passenger. Radiotelegraphy may indeed be said to have struck a vital blow to the terrors of the sea. The sea, it would seem, has become the chosen sphere of wireless telegraphy, since it fills a want never supplied before. Formerly ocean-bound vessels were isolated from the world for days at a time; but now they can communicate with land or with other ships at almost any point in their course, some of the large ocean liners keeping in such close touch with events that they publish daily bulletins giving the world's latest news.

Another startling achievement of radiotelegraphy has been its success in effecting trans-Atlantic communication. Messages are sent between Europe and America across a void of air and water some 3,000 miles in extent. And they are not mere test messages, but regular press telegrams such as might be sent by cable. Here radiotelegraphy has become the direct rival of the old method of wire transmission. Whether the one will ever supersede the other is a question open to debate. The probabilities seem to be in favor of wireless, especially if the present rate of progress continues; but, for the present at least, there is room for both methods.

Wireless telegraphy promises to be of great service in times of war; in fact, all the leading nations have equipped their armies and navies with radiotelegraphic apparatus. Battleships will have a facility of communication never before possible, and land forces will be equally subserved. Heretofore, one of the first moves of a belligerent force was to cut the enemy's telegraph wires; but to cut off an electric wave will not be such an easy matter. The Japanese constantly made use of wireless telegraphy in the late war with Russia. The Japanese have their own method of effecting radiotelegraphic communication, the details of which are kept secret; but that it works successfully, they have well demonstrated.

Concerning the utility of radiotelegraphy for communicating across land areas, much that is favorable and promising can be recorded; but there is still something to be desired with respect to ease and certainty of operation. The progress thus far made has brought to light many problems which await solution and recorded many phenomena relative to transmission over long distances, especially over land, which cannot as yet be accounted for or controlled. The screening effect of intervening mountains and cliffs exercises a marked difference in the energy of the received signals; long stretches of exceptionally dry ground seem to have the same effect. This probably accounts for the fact that the greatest distances to which signaling has been carried have been over salt water. Signals seem to be more easily effected at night than in daylight; so marked is this effect that communication carried on with perfect success at night has often been permanently interrupted by the advent of daylight only to be resumed the following night. J. J. Thomson has put forward a possible explanation of this, but space forbids its inclusion here. Again, certain conditions of the atmosphere seem to render but comparatively small energy necessary in the accomplishment of long distances at times.

Thus radiotelegraphy, like all forms of telegraphy, as well as telephony, has its limitations and unsolved problems; but, judging by past achievements, it is not well to dogmatize too emphatically as to the finality of these limits.



THE FIRST SET OF WIRELESS TELEPHONE INSTRUMENTS FOR THE UNITED STATES NAVY
Installed on the Flagship "Connecticut." The "Audion" Receiver with Tuning Device on the Top at Right, the Transmitter on the Left.

SENDING A FIVE-MILE WIRELESS TELEPHONE MESSAGE ON THE FLAGSHIP "CONNECTICUT"
Staff Officer Sending and Assistant Receiving a Distant Message.

WIRELESS TELEPHONY

Wireless telephony is not so new—almost unborn, indeed—as is generally supposed. Like its companion art, wireless telegraphy, it began its existence well back in the nineteenth century. Its inception is contemporaneous with that of wire telephony, for Alexander Graham Bell was the originator of both. It is a singular coincidence that Bell, the inventor of the telephone, and Morse, the reputed inventor of the telegraph, should each have been among the first to accomplish their respective modes of communication wirelessly. The history of wireless telephony follows very closely that of wireless telegraphy. The extreme sensitiveness of the telephone receiver to small variations of current very naturally suggested its employment as a receiving device in connection with the inductive and conductive methods of wireless telegraphy, and attempts were made at an early date to accomplish the transmission of articulate speech by these same means. The results obtained however, were very meager; the inherent difficulties characterizing these methods proved to be even greater with the application of telephone principles, due to the diminution of energy made necessary by the nature of the process. As in the case of wireless telegraphy, the solution of the problem lay in the application of the method of electric radiation.

Bell's Radiophone. One of the earliest attempts at radiotelephony was not of an electrical nature, judging by the usual appearances, but depended on the thermal effect of a variable beam of light directed upon bits of burnt cork enclosed in a small glass tube to which was connected a rubber tube to be inserted in the ear of a listener. This device is shown in Fig. 1. The light from a convenient source was reflected from a thin silvered diaphragm and caused to fall upon the burnt cork. When this diaphragm was set into vibration through the agency of the voice, the light reflected therefrom was subjected to a corresponding variation of intensity, and, being directed upon the blackened cork, produced therein minute changes of volume due to the variations of temperature;

and such changes produced air-waves which were manifested in the form of sound and audible within the tube. This simple device, invented by Alexander Graham Bell, was called by him a *radiophone.* He later greatly improved the apparatus by substituting selenium as the means of reception, the peculiar electrical property of which substance was then first attracting attention.

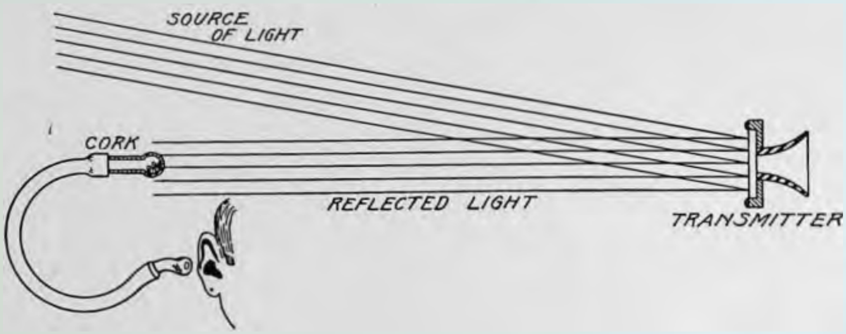


Fig. 1. Bell's Radiophone

Selenium Cell. In 1873, Willoughby Smith discovered that the resistance of metallic selenium was greatly reduced by exposure to light. The light from a small gas burner was found to exercise a marked influence on the conductivity of short rods of selenium used as resistances in a series of cable tests then in progress. The discovery caused widespread interest in the scientific world. Among the many men attracted by this peculiar property of selenium was Prof. Bell, who, in conjunction with Sumner Tainter, succeeded in producing the first useful so-called "selenium cell." This device consists essentially of selenium spread over the surface presented by the edges of alternate disks of metal separated by thin sheets of mica after the manner of a condenser, thereby greatly enlarging the area of contact between the selenium and the electrodes formed by the alternate disks. By connecting such a cell in series with a battery and telephone receiver, the current passing through the circuit is largely dependent upon the degree of conductivity possessed by the selenium cell, which in turn depends upon the amount of light falling thereon. Any variation of the light directed upon the cell is, therefore, capable of causing a corresponding variation of the current flowing through the receiver, with the result that such variations become audible therein.

Bell's Photophone. In 1878 Bell put forward a most ingenious application of the selenium cell for the purposes of radiotelephony, which he called a *photophone*. The arrangement of apparatus is shown in Fig. 2. The selenium cell C is placed in the focus of a parabolic reflector R and is thus interposed in the path of the rays reflected by the mirrored surface of a diaphragm D from any suitable source of light S. The resistance of the selenium cell was approximately 1,200 ohms in darkness, and about half that when fully illuminated. The mode of speech-transmission is so similar to that of the radiophone that further description is not necessary.

The photophone, as proposed by Bell, may be made to transmit speech perfectly over short distances, but it is obviously limited by reason of the inefficient means employed to effect the variation of the intensity of a source of light. As the employment

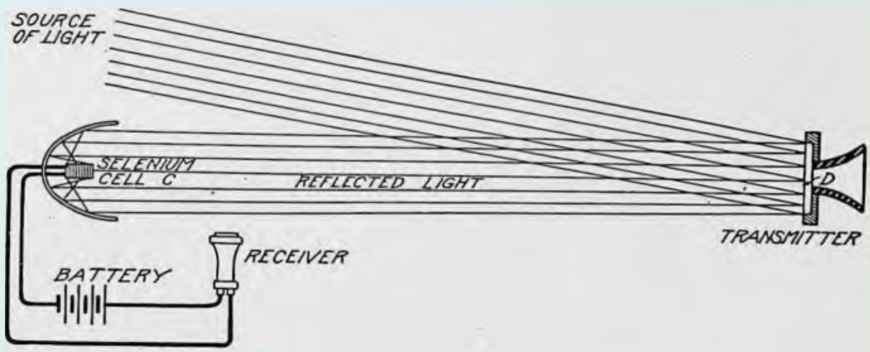
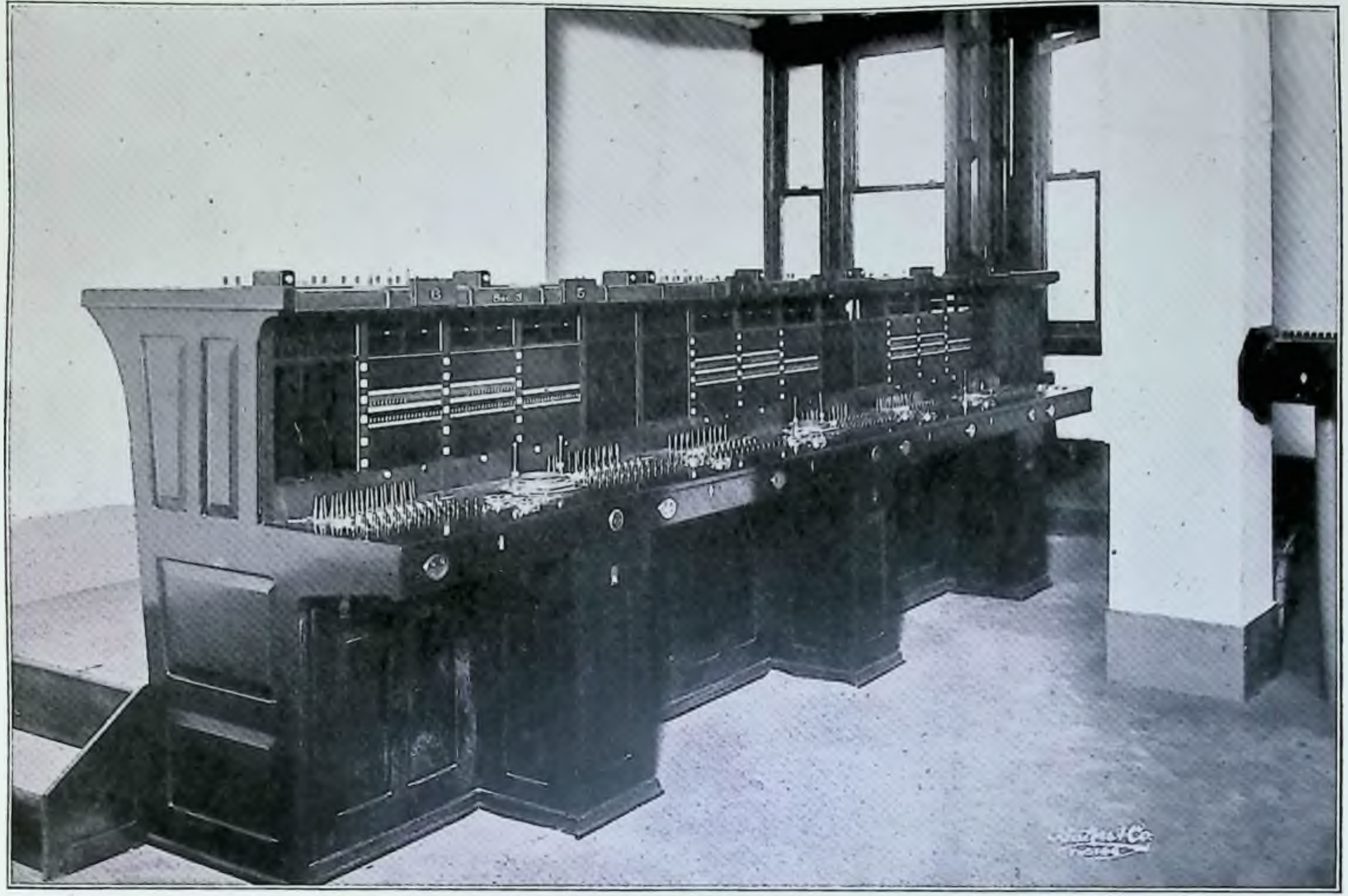


Fig. 2. Bell's Photophone

of the device for distances relatively long necessitated the use of powerful sources of light and adequate means for controlling the same, the invention remained but a beautiful laboratory experiment until the discovery of the speaking arc by Simon in 1897 opened up the possibility of future development.

"Light Telephony." Prof. H. T. Simon of the Physical Institute of the University of Erlangen discovered, toward the end of the year 1897, that a direct-current arc may be made to give forth musical tones and even speech by superimposing a telephonic voice current upon the arc current. This discovery suggested the possibility of using Simon's arc as a transmitting arrangement for the Bell photo-



LONG-DISTANCE SWITCHBOARD OF SAN FRANCISCO HOME TELEPHONE COMPANY
Operating in Connection with Automatic Switchboards for Long-Distance Connections.

distant diaphragm to repeat sympathetically the vibrations of a diaphragm against which the energy of the sounds to be transmitted is directed. In both cases the efficiency of the various transformations of energy involved in the process is of prime importance. The current-carrying capacity of the carbon transmitter places a limit on the amount of energy possible to utilize telephonically. This restriction is felt to a marked degree when the device is associated with the necessarily large amount of energy required for Hertzian-wave radiation over any considerable distance. In view of the foregoing, it is not surprising to find that early experiments in radiotelephony were directed almost exclusively toward a solution of the problem of an efficient transmitting apparatus.

Many attempts were made to accomplish this end by placing the ordinary microphone transmitter in the primary of an induction coil, thus serving the purpose of an interrupter, as exemplified in Dolbear's early wireless telegraph system. Such experiments only sufficed to show that nothing was to be gained in this way, largely by reason of the before-mentioned inherent limitations of the telephone transmitter. The problem was then attacked in another manner, viz, by endeavoring to modify telephonically a train of waves of a constant intermittency radiating from a continuously operating source of oscillations, such, for instance, as a simple radiotelegraphic transmitter without a primary signaling key. Though this method allowed a much greater amount of energy to be utilized, it soon became evident that a grave difficulty was presented due to the nature of the radiations from such an arrangement. The train of waves thus generated is not continuous, but consists of intermittent wave-trains separated by short periods of time during which no radiation takes place. These breaks in the continuity of the train are often of greater duration than the individual oscillations due to one complete discharge of the condenser; they consequently produce in the telephone receiver a continuous buzz which seriously interferes with the audibility of the received voice vibrations. As the timbre of the human voice depends upon overtones and upper harmonies of a frequency of from 5,000 to 8,000 or more, the pauses between oscillation trains also interfere with clear articulation whenever their frequency drops much below 10,000 per second. At frequencies of from 20,000 to 50,000, however, this feature ceases to be a hindrance. The success of the method of telephonically varying the energy emitted from a continuously operating source of radiation was seen, therefore, to depend upon the possibility of producing more perfectly sustained oscillations of high frequency. The means for creating oscillations that are undamped and practically continuous, may be considered the greatest problem of radiotelephony relative to transmission. At the present time there are two methods of accomplishing such persistent radiations, viz, by employing the high-frequency alternator, or by using some form of the oscillating arc. The last-named method has been developed, under the ministrations of Valdemar Poulsen, to a degree of efficiency that promises to place radiotelephony on a commercial basis. The alternator method has been persistently favored by Prof. R. A. Fessenden, who has accomplished some remarkable results. Both methods have their staunch advocates, each possessing its own peculiar advantages as well as limitations.

Nature of a High-Frequency Telephone Current. The foregoing paragraphs have indicated briefly the general theory upon which the

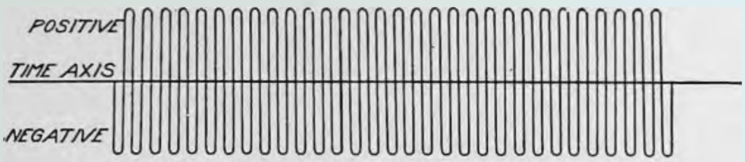


Fig. 3. Diagram Representing High-Frequency Current

most successful systems of radiotelephony have been developed. It remains to consider in more detail the nature of the action involved when a uniform flow of undamped oscillations is modified by the variations of a voice current.

It is convenient for a ready understanding of the matter to first consider the case of a high-frequency alternator supplying a constant alternating current of a periodicity somewhat above human audibility—say 50,000 cycles per second. Supposing such a current to be flowing through a variable resistance such as a telephone transmitter, the effect of an increase of the resistance thereof manifests itself by a lessening of the amplitude of each individual half-wave of current; while, conversely, a decrease of the resistance manifests itself by an amplification of the current half-waves. When, therefore, the resistance is made to vary with great rapidity, as when the diaphragm of the transmitter is thrown into vibration by sound, the effect upon the alternating current flowing therein is to produce a corresponding change in the maxir um value of each half-wave.

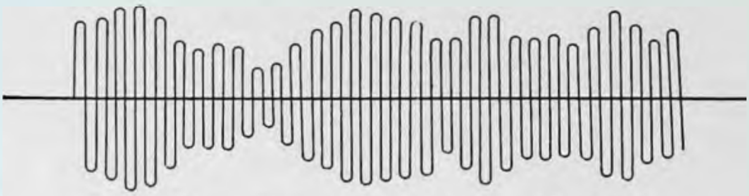


Fig. 4. Diagram Representing Variations of Amplitude

As the energy of each half-wave may be represented by its amplitude, it is evident that an alternating current varying in this manner exhibits a wave-form of energy equivalent in many respects to a direct current similarly modified. Figs. 3 and 4 illustrate this idea, Fig. 3 representing the steady alternating current permitted by the normal resistance of a transmitter; and Fig. 4 showing the alterations of amplitude thereof occasioned by the variations of resistance in the said transmitter. It will be noticed that the maximum instantaneous values may be greater than normal, as well as less, due to the fact that the resistance of a transmitter when spoken into varies between limits above and below its resistance when at rest. Some idea of the complexity of the action taking place under the conditions of actual practice may be had by referring to the wave-form shown in Fig. 5, which represents the current curve, or oscillagram, of a

Fig. 5. Oscillagram of a Telephone Current

telephone current produced by the vowel, long ō, spoken into the transmitter. In forming a mental conception of the wave-form resulting from the superimposing of a telephonic voice current upon a high-frequency oscillating current, the enormous difference in their respective periodicities must be borne in mind.

In the case of an oscillation generating arrangement which does not produce a perfectly sustained train of electric waves but a series of partially damped wave-trains separated by slight breaks of continuity, the essential condition for success in connection with radiotelephonic work is that the interruptions shall not take place at an audible frequency. It is highly probable that the direct-current arc method of creating oscillations does not produce an absolutely continuous train of waves, as is the case with a high-frequency alternator, but, on the contrary, is made up of a great number of groups of almost undamped oscillations separated by an interval of time, very small even in comparison with the duration of each group.

Oscillation Generators. An account has already been given, in the pages devoted to Radiotelegraphy, of the attempts which have been made to construct high-frequency alternators for use in the production of continuous, undamped oscillations, and some description given of such machines. Reference has also been made to the development of the direct-current arc method of producing a similar result. In the present instance it is not deemed necessary to dwell on these subjects further than to give some notion of the particular devices constructed for use in connection with the most successful systems of radiotelephony, and to mention those modifications of the arc method which have been found to give the best results in this field of use.

Undoubtedly the most successful high-frequency alternators have been those constructed by Prof. Fessenden for use in his extensive experiments in radiotelephony carried on at the Brant Rock (Mass.) Station of the National Electric Signaling Company. This inventor has devised several such machines, one of them having an output of 2 kilowatts operating at 80,000 cycles, and a voltage of 225 volts. This machine was of the double armature type with 300 teeth on each, direct-coupled to a DeLeval turbine. A similar generator designed for use on shipboard and run by a turbine is capable of developing 3 kilowatts at a frequency of about 100,000 cycles. Fessenden has also designed a 10-kilowatt machine of a periodicity of 100,000 per second. The problem of properly designing such generating units and constructing them on a commercial basis cannot as yet be said to be satisfactorily solved; it is generally felt, however, that the solution of the problem will be effected at no distant date, at which time this method of producing the requisite oscillations for electric-wave communication will supersede in many instances the more complicated and less constant methods now in use.

There are in use at the present time various arrangements of the direct-current arc employed as a means of creating alternating currents of great frequency, all of which depend for their operation upon the principle of the Duddell arc but differing in the details of application. One of the earliest and most successful of these is due to Poulsen, who achieves extremely high-frequency oscillations of great energy by causing the arc to take place between copper and carbon electrodes enclosed in a chamber containing hydrocarbon gas. In order to increase the energy of radiation, Poulsen later employed several arcs in series. This is known as the multiple-arc system, and has been developed to a high degree by die Gesellschaft fur Drahtlose Telegraphie of Berlin.

Telephonic Control of Oscillations. Radiotelephony figuratively substitutes in place of the metallic line of ordinary telephone practice a continuous stream of electric waves of approximately uniform strength. By varying from instant to instant the energy of this stream of waves in accordance with the variations of air-pressure acting against a transmitting diaphragm, a transference of such energy-variations is effected between two stations. By the employment of suitable translating devices, the energy-vibrations of the wave-stream may be made to undergo a transformation resulting in the movement of a second diaphragm which exactly duplicates the vibrations of the first, and the variations of air-pressure occasioned thereby complete the cycle of energy-transformations from sound to sound.

It is to be noted in connection with the foregoing analysis that it is not the entire amount of energy of the flow of waves between stations that is available for transformation into sound at the receiving end, but only the energy represented by the *variations* of this flow of waves. Thus the problem of telephonically controlling a large amount of energy for efficient radiotelephonic transmission is to effect, by means of the energy of the voice vibrations, a maximum percentage of variation in the energy radiated. With the methods employed at the present time there are reasons for believing that this percentage does not greatly exceed 5 to 8 per cent of the total energy.

In this respect radiotelephony differs very widely from radiotelegraphy, for with the latter the entire energy of radiation is available to the limit of our ability to detect it. Some of the inventors claim a greater percentage of efficiency for their respective systems of radiotelephony. Fessenden has devised an improved form of transmitter which he states produces much better results.

There are several ways of modifying the electric oscillations set up in a transmitting arrangement for the purposes of radiotelephony. The method generally employed involves the use of some form of carbon transmitter whereby the variations of its resistance under the influence of the energy of the voice are made to vary the oscillatory current directly, or a local-battery circuit similarly affected is inductively associated with the oscillatory circuit. Variations in the emitted wave-train may also be accomplished by the use of a condenser transmitter formed by a thin metallic diaphragm separated from a metallic plate by a thin layer of air acting as dielectric, the vibrations of said diaphragm producing variations of capacity between the two surfaces. This variable capacity is used to throw the aërial in and out of tune. The inductance of an oscillatory circuit may also be made to vary by means of the voice and produce a like result. One of the earliest suggestions relating to the telephonic control of the energy of oscillations was made by an Italian, Lonardi, who, in 1897, proposed that the spark balls of a Righi oscillator connected to a source of constant potential be made to vibrate by the voice, thereby altering the length of the spark gap and causing the oscillator to be charged to greater or lesser potentials, and thus varying the energy of the emitted waves.

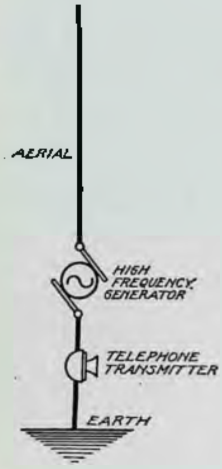


Fig. 6. A Form of Fessenden Circuit

Transmitting Circuits. One of the simplest and earliest circuits patented for use in connection with radiotelephony is shown in Fig. 6. It is due to Fessenden, and consists of a high-frequency alternator connected in series with an aërial, a telephone transmitter, and the ground. The time-period of the radiating circuit thus formed is adjusted to the periodicity of the dynamo.

The patent application on this arrangement was filed in 1901 at a time when it is generally believed that the creation of electric waves necessitated an abrupt release of energy, as exhibited by the discharge of a condenser. In experiments carried on with this arrangement in 1906, a distance of about ten miles was covered, the generator running at 10,000 revolutions per minute and developing 50 watts at 80,000 cycles per second. The resistance of the armature was about 6 ohms. An electrolytic cell was used for a detector.

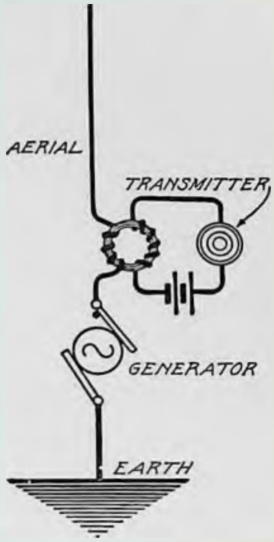


Fig. 7. Transmitter Inductively Associated with Aërial

Another method of effecting the telephonic variation of an oscillatory system is shown in Fig. 7. The aërial is connected to the secondary of a small transformer, the primary winding of the same being included in a local-battery transmitter circuit.

An arrangement for use with the arc form of oscillation generator is shown in Fig. 8. Direct current for the arc is supplied to the terminals of the closed oscillating circuit through the secondary of

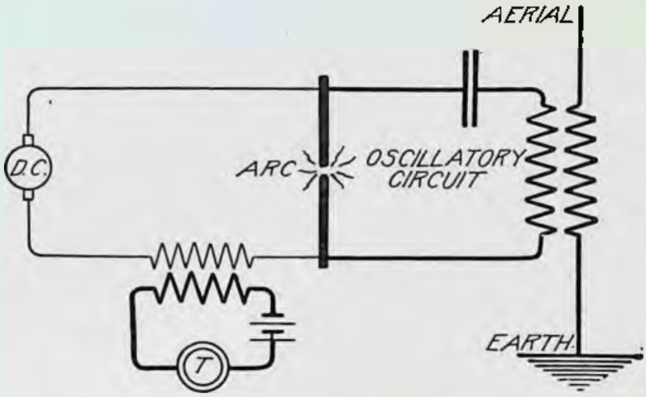


Fig. 8. Transmitter Associated with the Supply Circuit

a transformer, the primary circuit of which contains a carbon transmitter and local battery. The fluctuations of intensity of the oscillations may be effected in a manner diagrammatically shown in

Fig. 9, where the inductive method of superimposing the telephone current from a local circuit is applied directly to the closed oscillatory circuit. Inductances I and I' inserted in the supply mains

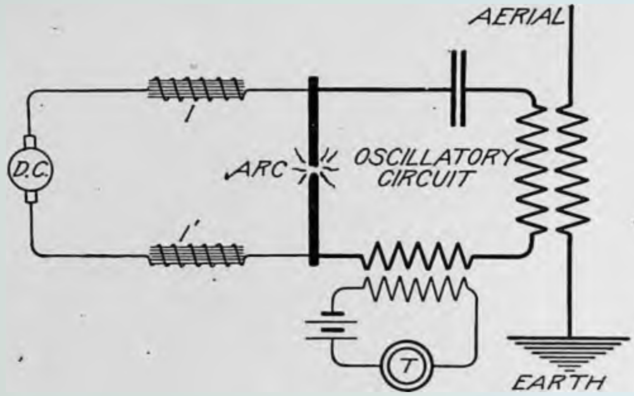


Fig. 9. Transmitter Inductively Associated with the Closed Oscillatory Circuit

prevent the voice current from passing around through the source of supply.

In Fig. 10 is shown still another method of locating the variable-resistance member, viz, by shunting the secondary of the oscillation

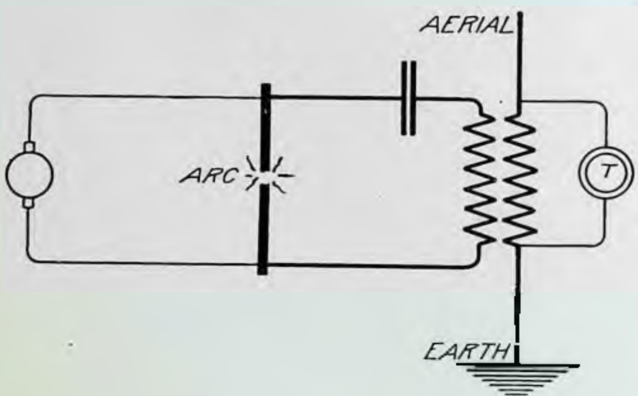


Fig. 10. Transmitter Shunted across the Aërial Inductance

transformer employed in connection with an inductively coupled aërial. The telephone transmitter may also be used with a directly coupled aërial by causing it to vary the effective turns of a portion of the inductance included in the open radiating circuit, as in Fig. 11.

From the circuits here given, it is evident that the conditions essential to telephony are fulfilled when the transmitter is so placed as to produce by its action a change of the electrical properties of the radiating aërial; and experience has shown that this may be accomplished with the microphonic, or carbon, transmitter in a variety of ways, many of which seem to operate with equally good effect. The condenser, or variable-capacity, transmitter is effectively operative only in conjunction with the oscillatory portions of the sending circuit, usually as a shunt. One method of placing this form

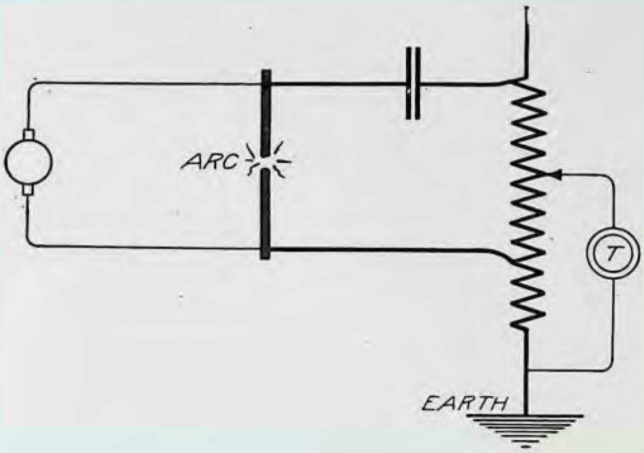


Fig. 11. Transmitter Shunted across a Portion of the Aërial Inductance

of transmitter is shown in Fig. 12, which arrangement has been employed by Fessenden.

As before remarked, the small current-carrying capacity of the microphonic transmitter has proved to be a great obstacle to the rapid development of the art of radiotelephony as a commercial proposition; and it may be said that until an efficient means is devised for overcoming this difficulty, and thereby greatly increasing the percentage of variation in the intensity of the oscillations, or the equivalent thereof, the sphere of usefulness for this form of wireless communication will be much restricted. Many attempts have been made to effect this improvement by connecting several transmitters in multiple to be acted on by a common mouthpiece. Various so-called telephonic repeaters have also been devised purporting to accomplish an increase in the amplitude of the telephonic current Such devices, however, have not proved to be a satisfactory solution of the problem, although Fessenden claims to be able to effect a decided amplification with an instrument of the latter character designed by himself. This ingenious investigator has undoubtedly constructed an instrument more nearly fulfilling the requirements of a transmitter adapted to this class of work than any heretofore presented. It is called by him a "trough" transmitter, and is said to be able to carry continuously more than 10 amperes. The electrodes are water-jacketed The amount of variation in a current of this magnitude, produced by the action of the voice, is of course the important factor. The results accomplished by the "trough" transmitter indicate a decided gain over the form commonly employed. Further radical improvements in transmitter design may be confidently expected from the numerous experimenters whose inventive ability is now being brought to bear on the problem.

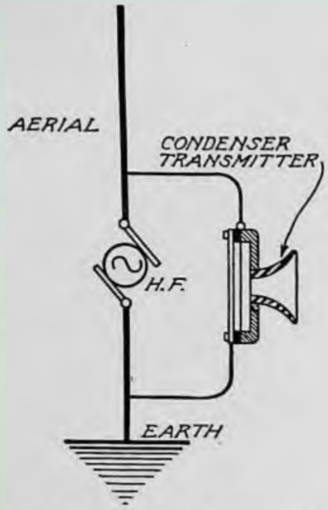


Fig. 12. Condenser Transmitter

Receiving Arrangements. For purposes of radiotelephony the detectors depending upon mere potential for their operation, such as the early forms of coherer, are practically useless. The essential characteristic which a detector suitable for this class of work must possess is that it shall not only respond to the received oscillations, but that it shall be affected to a certain extent in proportion to the amplitude of such oscillations. In short, radiotelephony requires a form of detector which is quantitative, that is, one which will respond to the varying integral value of the oscillating current. Such devices as the thermo-electric, electrolytic, ionized gas, and crystal-valve detectors are all of this type, and may be used for the reception of speech when properly connected with a telephone receiver. This quantitative function may be elucidated by considering the action of a thermo-electric detector properly associated with a tuned receiving circuit. If a continuous train of undamped waves falls upon the aërial, their effect on the detector is to increase its resistance by raising its temperature, and thereby decrease the amount of current flowing through the telephone receiver. As long as the flow of such waves remains constant, their heating effect upon the fine platinum wire of the detector, and consequently its resistance, remains constant, and no sound is heard in the receiver. If, however, the wave-train which strikes the aërial be of a fluctuating nature, due to the vibrations of the distant telephone transmitter, the variations of amplitude of the received oscillations will cause a corresponding variation in their heating effect on the platinum wire, accompanied by like variations in its resistance, whereupon the current flowing through the telephone receiver will be similarly varied, with the result that the diaphragm is thrown into vibrations exactly imitating the movement of the transmitting diaphragm.

There have been previously described under the head of radiotelegraphic detectors almost all the devices used for a similar purpose in connection with radiotelephony. In view thereof it is not thought necessary to devote more space to the subject here, further than to call attention to a form of telephone receiver invented by Fessenden and called by him a "heterodyne" receiver, a most ingenious application of the Bell instrument to the purposes of space telephony. The device consists of two small coils of wire, one of which is wound upon a stationary laminated core composed of very fine soft-iron wires; the second coil, held in close proximity to, and co-axial with, the first, is attached to the center of a thin mica diaphragm. A high-frequency current from a local source is maintained through the stationary coil. The other coil, arranged to vibrate with the diaphragm, is connected in the receiving oscillation circuit, as shown in Fig. 13. The periodicity of the local alternating current is adjusted to approximately the same frequency as the received waves, thereby creating a mechanical force exerted be-

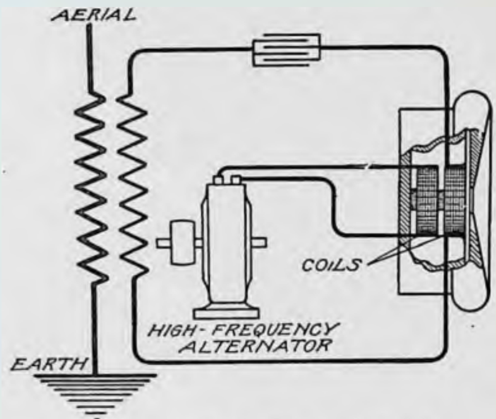


Fig. 13. Heterodyne Receiver Circuit

tween the two coils—a force which varies with every fluctuation of the intensity of the received oscillations, and results in vibrations of the mica diaphragm corresponding to those of the distant transmitter. When this device is used as a detector in connection with radiotelegraphy, the frequency of the local source of current is purposely made to be slightly different from the frequency of the received oscillations; under which condition the physical phenomenon known as "beats" is engendered. This is due to the fact that at certain equal intervals the two wave-form currents agree in phase and reinforce each other, while at times midway between two such successive agreements they are opposite in phase and tend to neutralize each other. These intervals of maximum reinforcement occurring at an audible frequency produce in the receiver a musical note of a duration depending upon the length of the Morse dot or dash. By means of this simple process, it is, therefore, possible to produce audible tones by the interaction of two alternating currents whose respective frequencies are far above audibility. The heterodyne receiver is almost entirely unaffected by atmospheric disturbances, and seems to offer exceptional possibilities in connection with multiplex transmission, as well as selective communication.

Two-Way Transmission. In wire telephony simultaneous talking and listening is possible by reason of the simple nature of the circuits and because of the comparatively small amount of energy involved in telephonic transmission. Radiotelephony presents in this regard difficulties which tax to the utmost present inventive ability. Without special appliances it is of course necessary after talking to throw over a listening key or switch in order to receive the reply. The introduction of this manual operation, while not of a nature to greatly detract from the usefulness of this method of communication, interferes to an appreciable extent with that ease of operation we are accustomed to associate with the telephone, and destroys the illusion of the actual presence of the person spoken to. It cannot well be expected in an art so young that minor details of this nature should have been thoroughly perfected. Arrangements for simultaneous talking and listening have already been put forward, and some have met with more or less practical success. Fessenden has patented several such devices—one involves the use of a commutator which connects the transmitter and receiver to the aërial in very rapid alternation; another and a more practicable method is called by him the "balance" method, and consists in the application of the "bridge" together with a "differential" arrangement often employed in duplex telegraphy, the complete circuit requiring a "phantom," or artificial, aërial. The detector is unresponsive to the powerful oscillations emanating from the same station, but sensitive to the oscillations from the distant station. This "balance" method materially cuts down the loudness of the received sounds.

Radiotelephonic "calling" is accomplished by radiotelegraphic methods. A coherer associated with a local battery and relay is sometimes employed to ring an electric call bell. In such cases it is necessary to provide means for cutting out the coherer and relay during conversation. Under conditions where it is impractical to achieve the operation of a relay, it becomes necessary to keep an operator on duty "listening in."

Systems of Radiotelephony. Radiotelephony undoubtedly possesses many advantages over radiotelegraphy, not the least of which is the fact that a skilled operator is not required to translate the dot-and-dash signals. The transmission of intelligence is more direct and expeditious, and in times of emergency this might become an advantage of great importance. No form of communication is so satisfying as that of speech. It is due to this fact, perhaps, that ordinary wire telephony stands today superior to the older art of telegraphy in point of development. The future may record a similarly greater development of radiotelephony than will be accorded to its companion art; but at the present time it cannot be said to compare with radiotelegraphy as regards efficiency and simplicity of apparatus. Its weak points are known and understood, however, and every effort is being made to remove the obstacles that stand in the way of a more efficient utilization of the means employed.

While still susceptible of great improvement, and in many cases requiring a multiplicity of complicated apparatus, there are a number of radiotelephonic systems which have been exploited in the various countries, many of which are in regular service. Nearly all of the large navies of the world are supplied with equipment for intercommunication between the different vessels of a fleet. Among the most successful systems may be mentioned the Telefunken and Ruhmer systems in Germany, the Poulsen system in Denmark, the Marjorana system in Italy, and in America the systems developed by Fessenden, DeForest, and Collins. Many other systems are known, but they exist in a more or less imperfect state of development.

Telefunken System. Die Gesellschaft fur Drahtlose Telegraphie of Berlin has put forward one of the most thoroughly developed systems of radiotelephony in commercial operation at the present time. It is generally known as the *Telefunken system,* which is the name applied to the radiotelegraphic system operated by the same company.

The Telefunken radiotelephonic system is of the oscillating-arc type. The arrangement of circuits is shown in Fig. 14. Six or

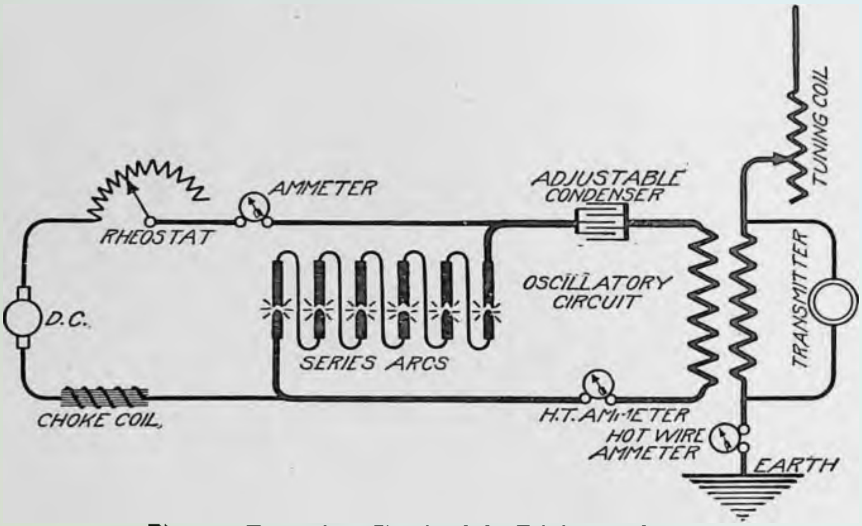


Fig. 14. Transmitter Circuit of the Telefunken System

twelve electric arcs, connected in series and shunted by an inductance and capacity, form the source of the high-frequency oscillations. The energy supplied to this portion of the circuit is derived from a direct-current source of 220 or 440 volts (if the latter, 12 arcs in series are used) connected through a rheostat, an ammeter, and a choke coil. The choke coil is used to prevent the oscillatory current from passing through the dynamo. A hot-wire ammeter is included in the oscillatory circuit, and another between the aërial and the ground, used for tuning purposes. When the circuits are in exact resonance, these instruments give a maximum reading, thus affording a very convenient means of ascertaining if the system is in proper adjustment at any time. An adjustable condenser is provided in the oscillatory circuit, and a variable inductance in the aërial, to facilitate tuning. It will be noted that the carbon transmitter is associated with the aërial as a shunt around the secondary of the oscillation transformer. An ordinary transmitter is used and, in practice, means are provided for opening the transmitter circuit while calling, and at other times when it is desired to protect the transmitter from the detrimental effects of continued exposure to the heavy current.

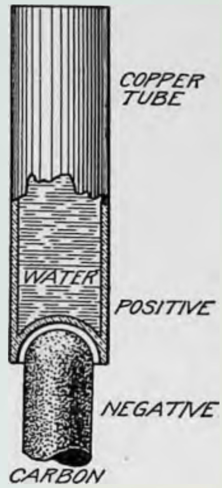


Fig. 15. Telefunken Electrodes

The electrodes employed for the arcs in this system possess features of interest. The positive member is formed by a copper tube about 2½ inches in diameter and 8 inches long closed at the bottom by a concave piece of the same material. The internal cavity is filled with water, thus serving to keep the metal cool. Fig. 15, which shows the Telefunken electrodes, represents the positive member as partially cut away in order to make clear the construction. The negative electrode is of carbon 1½ inches in diameter, set well up in the concave portion of the positive electrode, but separated therefrom by a gap of about ⅛ inch. The arc formed between these two members tends to maintain the uniformity of the gap. It is claimed that the consumption of carbon is only about 1 inch in nearly 300 hours, and that the copper electrode is not appreciably affected by the arc. The water is changed as often as required, according to the time it is subjected to the heat of the arc, or by reason of evaporation. Means are provided for the adjustment of each individual arc, and for the simultaneous striking of all. The frequency usually achieved by this method is approximately 375,000 cycles per second. The equipments are rated something under one kilowatt for connection with 220 volts.

The receiving arrangement used with this system is of the simplest kind, consisting of a detector (electrolytic or thermo-electric) and telephone directly coupled to the aërial, such as are commonly employed with radiotelegraphy. The entire apparatus is very compact, requiring but little space, and may be conveniently placed on a small table. A distance of 25 to 45 miles may be very well covered with the Telefunken sets such as are supplied for use on shipboard, and equipments of greater power may be had. Simultaneous talking and receiving is not provided for in this system.

Ruhmer System. The system due to Ernst Ruhmer, the German investigator, well known for his extensive work in connection with the development of "light telephony" and for his researches

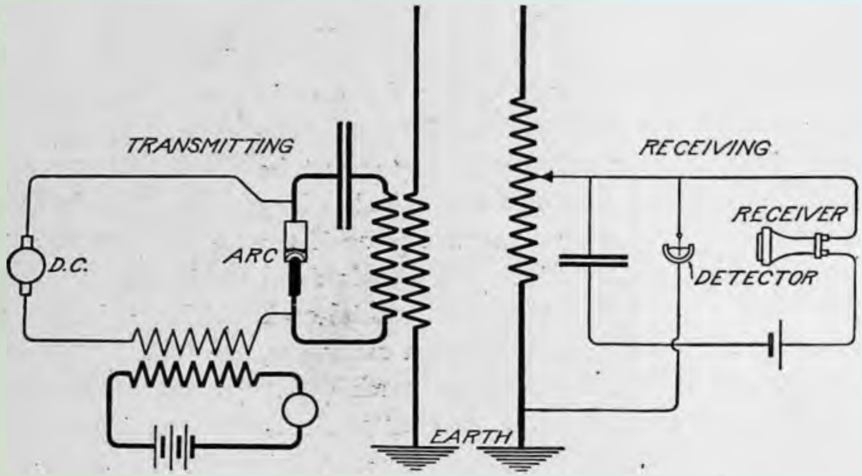
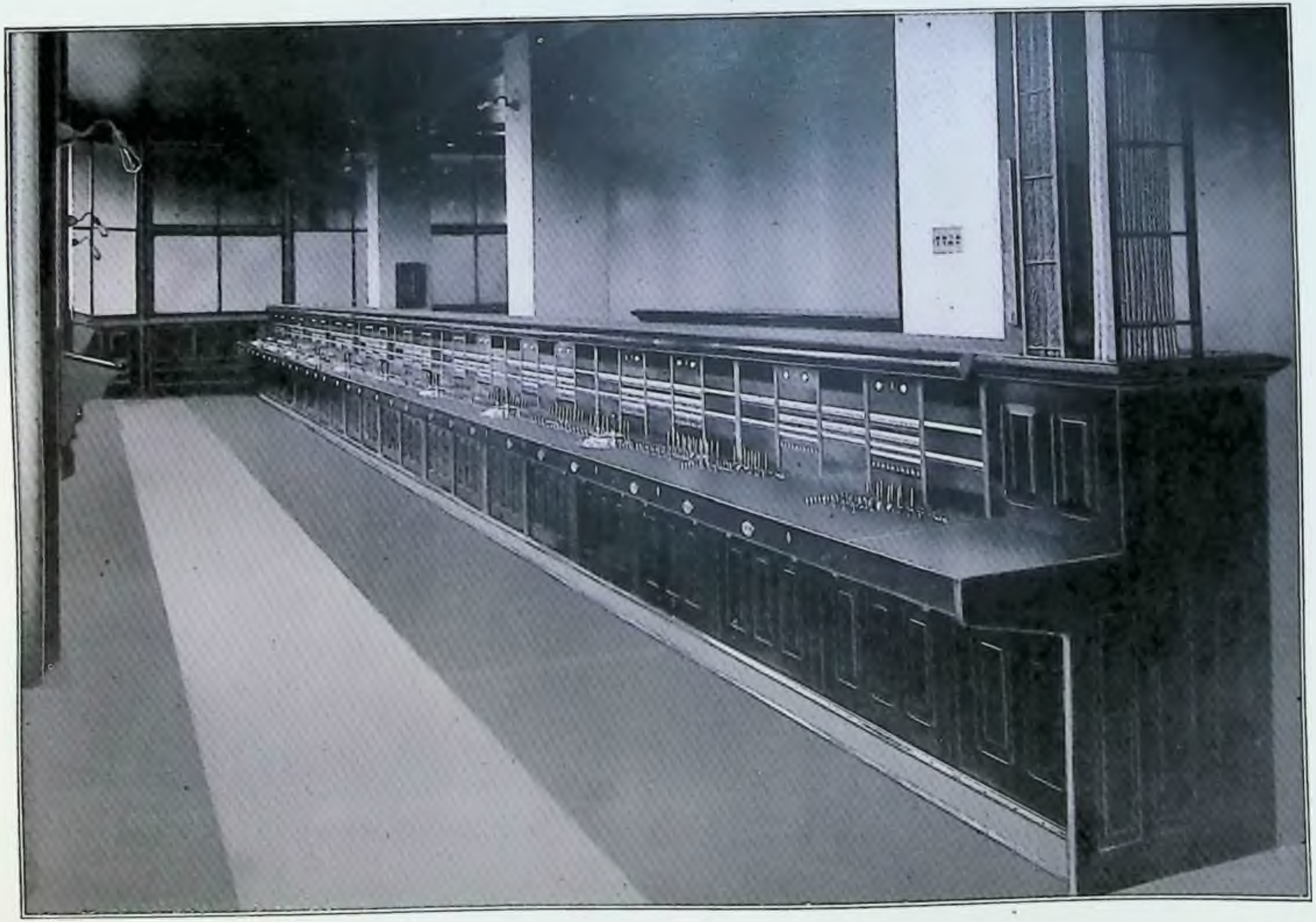


Fig. 16. Circuits of Ruhmer System

into the properties of selenium, is characterized by the use of an oscillatory arc burning in hydrogen or other suitable gas. The Ruhmer circuits are shown in Fig. 16. A local-battery transmitter circuit is employed to superimpose, by means of an induction coil, the voice current upon the supply terminals of the oscillatory portion of the arrangement. A direct-current dynamo of 440-volt pressure is used. The transmitting aërial is inductively coupled to the closed oscillation circuit. Many different forms of arc have been experimented with by this inventor, some with a magnetic blow-out. Simplicity of apparatus has been aimed at. The receiving arrangement consists of an electrolytic detector, battery, and telephone receiver



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connected with the aërial and its associated capacity and inductance. By using fairly low antennae, the Ruhmer system has operated very successfully over comparatively short distances.

Poulsen System. Special interest attaches to the Poulsen system by reason of the fact that the development of the arc method of producing sustained high-frequency oscillations was largely due to the initiative of this investigator. Mention was made of the Poulsen modification of the singing arc in its application to radiotelegraphy. Fig. 17 represents diagrammatically its application to a system of radiotelephony. A direct current from a suitable source is applied to the terminals of the arc through the secondary of a small transformer, in the primary of which is placed a local battery and telephone transmitter. The aërial is directly coupled, and two oil-condensers are so located as to prevent the direct current from reaching the aërial or ground. The magnetic blow-out devices are not shown in the cut. At the receiving station the aërial is inductively coupled with a closed oscillatory circuit which is connected with a local-battery circuit containing the detector and a telephone receiver.

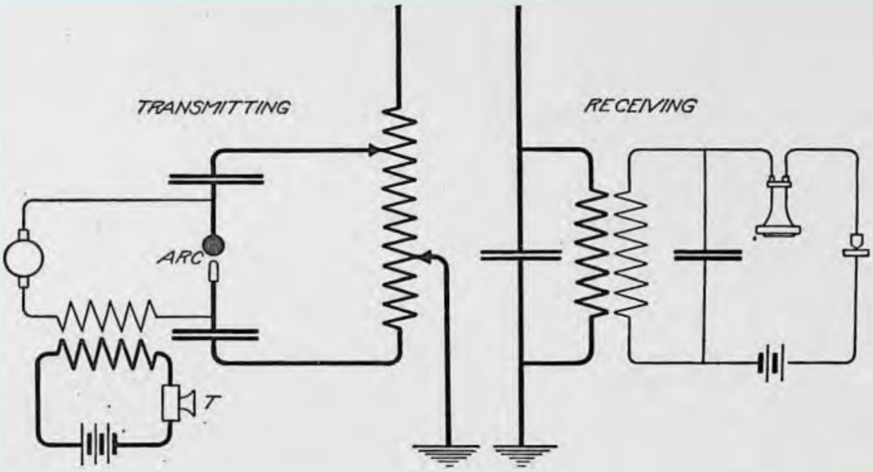


Fig. 17. Circuits of Poulsen System

Poulsen has constructed many forms of the copper-carbon arc burning in a magnetic field in an atmosphere of gas. In order to meet the difficulties caused by the irregularity of action due to the unequal burning of the carbon, he employs in connection with one form of his arc a cylindrical carbon electrode of large diameter which is slowly rotated, thus presenting constantly a new surface for the arc. In another modification, the same result is accomplished by means of a rotary magnetic field which acts directly on the arc, causing the latter to constantly change its position on the surface of the electrodes. He has also employed various gases through which the arc is maintained. In the commercial equipments more recently put out, the gas is supplied by alcohol allowed to drip slowly into the arc chamber, at a rate of about one drop every half second.

The transmitter employed by Poulsen is essentially the common carbon-granule device; he has, however, effected the variation of his oscillations by means of a multiple transmitter consisting of seven or eight such instruments connected in multiple and arranged to be acted upon by one mouthpiece.

Successful telephonic communication has been accomplished over distances varying from a few miles up to three hundred. Poulsen long-distance stations are located at Lyngby, Denmark; at Berlin, Germany; and at Cullercoats near Newcastle, England; and smaller stations are located in Denmark and elsewhere. The aërial used at Lyngby for long-distance transmission is about 225 feet high, and is of the umbrella type composed of 24 strands of phosphor-bronze wire. A 20-horse-power gasoline engine operates a 10-kilowatt, 500-volt, direct-current dynamo for the arc. A phonograph record has been transmitted from this station to Berlin and distinctly heard there—a distance of 325 miles.

The Marjorana System. In Italy radiotelephonic experiments have been carried on by Prof. Quirino Marjorana, resulting in the successful transmission of the voice from Rome to Messina, a distance of about 312 miles. As a means of creating the required oscillations, the Marjorana system employs an arc essentially identical with that used by Poulsen. The transmitting arrangement, however, is characterized by a peculiar manner of accomplishing the variations of intensity of the radiated waves. The complete circuit, including diagrammatic representation of the Marjorana liquid microphone, or transmitter, is shown in Fig. 18. The aërial is inductively coupled with the source of oscillations. The arc is fed through the blow-out magnets, which thus serve as choke coils to prevent the high-frequency current from flowing through the direct-current dynamo, which acts as supply. The receiving portion of the system possesses no points of novelty, as it is of the simple inductively coupled type and employs any of the well-known detectors suitable for this class of work.

It is the transmitter which, as suggested above, forms the distinguishing feature of this system. Its action is based upon the fact observed by Marjorana that a steady stream of water falling from an elevated containing vessel through a small orifice may have its uniformity modified by extremely minute mechanical jars imparted

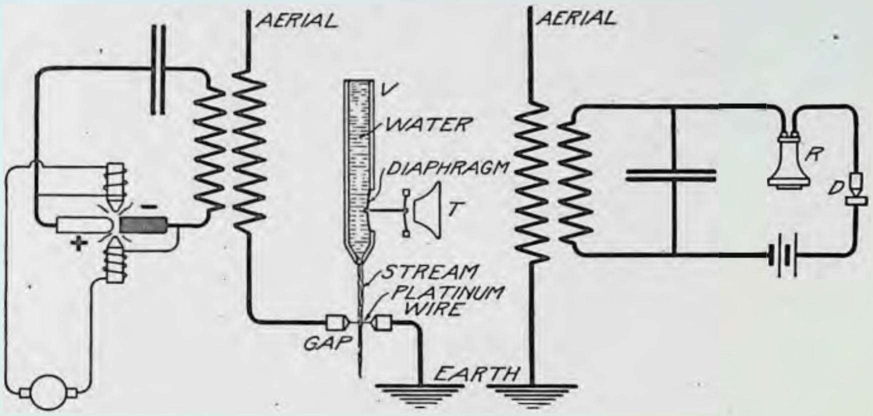


Fig. 18. Circuits of Marjorana System

to the containing vessel. The liquid transmitter is designed to take advantage of this property, and is shown partially in section in the illustration. A stationary rigid containing vessel *V* terminates at its lower end in a small hole through which the water, constantly supplied to said vessel, is allowed to flow continually in the form of a minute stream. Interposed in the path of this stream is a small gap in the aërial formed by two platinum points separated a short distance. The stream completes the connection across this gap. Means, in the form of a thin diaphragm introduced as a portion of the wall of the containing vessel, are provided to affect the diameter and contour of the stream in accordance with the vibrations of the voice. The center of this diaphragm is connected by a light rod to the center of another diaphragm which is acted upon by the voice through suitable mouthpiece. The action is as follows: The vibrations of the double diaphragm are communicated to the volume of the liquid in the form of variations of pressure manifested at the orifice and resulting in similar variations in the volume of water constituting the stream. Such modifications of the stream produce, at its juncture with the platinum electrodes of the aërial, corresponding variations in the resistance of the gap. It is of course obvious that this action produces corresponding variations in the intensity of the radiations. Numerous fluids and electrolytes have been employed by Marjorana in place of water. A form of ionized gas detector has been used in connection with this system with excellent results.

Fessenden System. In reviewing the development of radiotelephony it has been necessary to refer so often to the work of Fessenden relative to the many innovations introduced into the art by him that little remains to be said in this place in regard to the complete system which bears his name. The bibliography of radiotelephony includes many papers and articles by Fessenden of the greatest interest to the student of wireless communication. A remarkably clear and concise paper on the subject of wireless telephony, replete with much valuable data on transmission, etc., was presented by Prof. Fessenden at the 25th annual convention of the American Institute of Electrical Engineers at Atlantic City in June, 1908. Many illustrations and descriptions of the apparatus employed by him were given.

Among the many interesting facts determined by Fessenden in his very exhaustive tests dealing with the atmospheric absorption of electric waves, may be mentioned the fact that waves of a comparatively low frequency suffer less absorption than those of a much higher frequency, both being of equal power. Messages were successfully transmitted in daylight with a wave-frequency of 80,000 per second from Brant Rock, Massachusetts, to a radiotelegraphic station in the West Indies—a distance of 1,700 miles—with comparatively little absorption; while at the higher frequency of 200,000 per second communication was impossible.

The power required for radiotelephony, Fessenden states to be about five to fifteen times that required for radiotelegraphy. Fessenden has employed at various times all the well-known methods of generating a sustained train of waves but has met with greater success, particularly in radiotelephony, by the use of some form of the high-frequency alternator method, shown in Figs. 6, 7, and 12, used in connection with the heterodyne receiver illustrated in Fig. 13.

The Fessenden system has transmitted speech from Brant Rock to New York City with an expenditure of about 200 watts. Longer distances have also been covered with higher power apparatus. Fessenden's patents are controlled by the National Electric Signaling Company.

DeForest System. This system is exploited by the Radiotelephone Company and is due to Dr. Lee DeForest. It is an oscil-

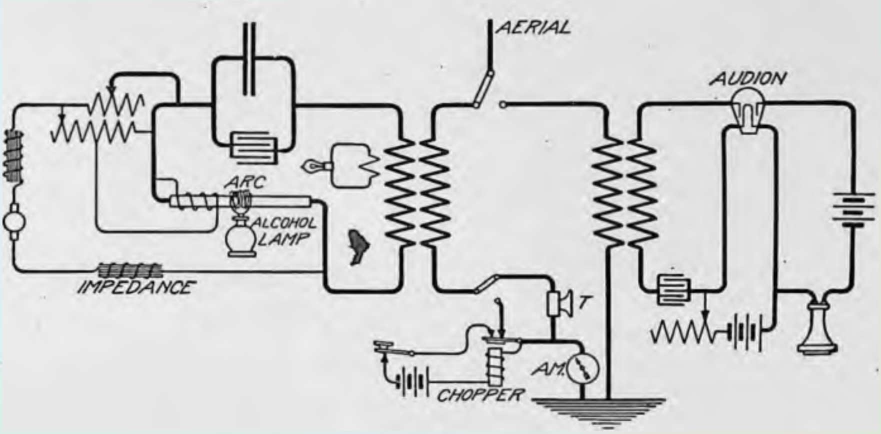


Fig. 19. Operating Circuits of the DeForest System

lating arc system presenting nothing of special novelty. Fig. 19 shows the essential features of the operating circuits, though in practice a more convenient means is provided for facilitating the change from the transmitter to receiver. The arc is of the Poulsen type, taking place between a copper positive electrode, water cooled, and a carbon negative. An electromagnetic means is provided for automatically adjusting the length of the arc by a movement of the carbon through the agency of a solenoid, which is represented in the drawing by the turns of wire around the left-hand electrode. A variable resistance is employed to effect the proper regulation of this feature. The arc is made to burn in the flame of a small alcohol lamp. The aërial is inductively coupled to the closed oscillation circuit, the latter containing two condensers connected in multiple, one of which is adjustable for tuning purposes. A small incandescent lamp, connected to a closed circuit, is placed in inductive relation with the primary of the oscillation transformer in order to give a visual indication of the proper working of the oscillation arc. The transformer used for inductive coupling with the aërial is of compact flat spiral design, the primary and secondary being placed side by side in a loose inductive couple. For telegraphic and "calling" purposes, a device for rapidly interrupting the steady flow of waves, called a "chopper," is thrown in by the movement of a switch; whereupon it becomes possible, by the operation of the Morse key, to cut up the wave-train into any desired combination of dots and

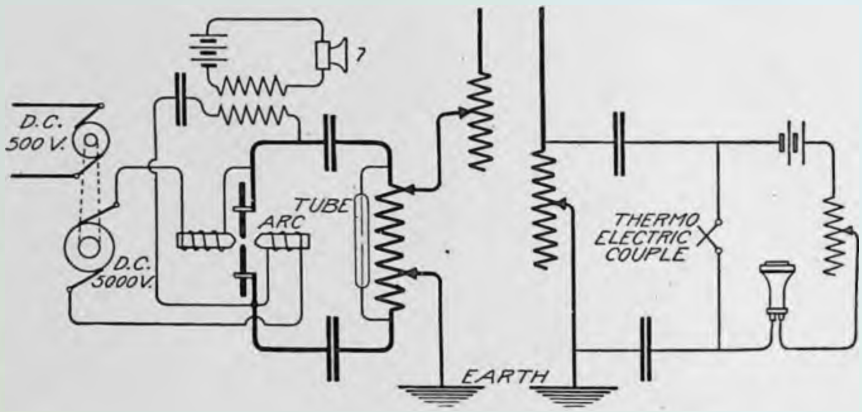


Fig. 20. Circuits of the Collins System

dashes. The telephone transmitter, which is introduced between the aërial and the ground, is out of circuit during such a performance. A hot-wire ammeter is placed in the aërial circuit to indicate when the latter is in tune. For the detector, a form of the DeForest audion receptor is used, connected in the circuit as shown.

The DeForest system has met with considerable success, and has been installed on several United States battleships. Tests have been made with the DeForest equipment by the British Admiralty, and the greatest distance over which it was possible to transmit satisfactorily was about 57 miles, a distance which has since been extended with improved apparatus. The sound from phonographic records transmitted by this system when temporarily installed at the Eiffel Tower in Paris, was said to be audible 400 miles away. This station permitted of the use of an exceedingly tall aërial, the tower being nearly 1,000 feet high.

Collins System. This system has been developed by A. F. Collins, who for several years has carried on experiments in the field of radiotelephony. The circuits employed are shown in Fig. 20, the arrangement including some unusual features though nothing in the nature of a radical departure. The oscillations are created by an arc of a higher potential than is generally used, 5,000 volts being supplied through the agency of a direct-current dynamo directly coupled to a 500-volt motor. The electrodes of the arc are both in the form of carbon disks, which are made to revolve by means of a small motor, as shown in Fig. 21. A magnetic blowout is also provided, the coils of which serve the purpose of choke-coils, thus preventing the oscillatory current from entering the generator. The aërial is of the direct-coupled type in both the transmitting and receiving stations. A visual indication of the correct working of the arc takes place in the form of a glow within an exhausted glass tube. This tube is supplied with platinum terminal wires sealed into the ends, and projecting inwardly to within a short distance from each other. This device is shunted across the inductance in the closed oscillatory circuit. The transmitter is located in a local-battery circuit and acts inductively on a shunt connected across the terminals of the arc. This shunt includes the secondary of the induction coil and a condenser. Collins has recently employed several transmitters connected in multiple and operable through a common mouthpiece. The detector employed in this system is the invention of Collins, and is in effect a sensitive thermo-electric couple composed of two dissimilar metals, the juncture of which is heated by the received oscillations. The variation of this thermal effect produces a corresponding variation in the effective resistance of the detector, and consequent vibrations of the receiver diaphragm.

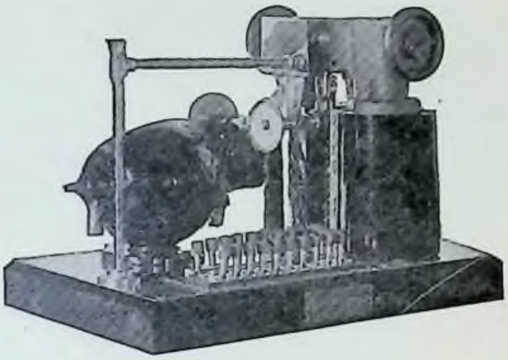


Fig. 21. Collins Revolving Electrodes

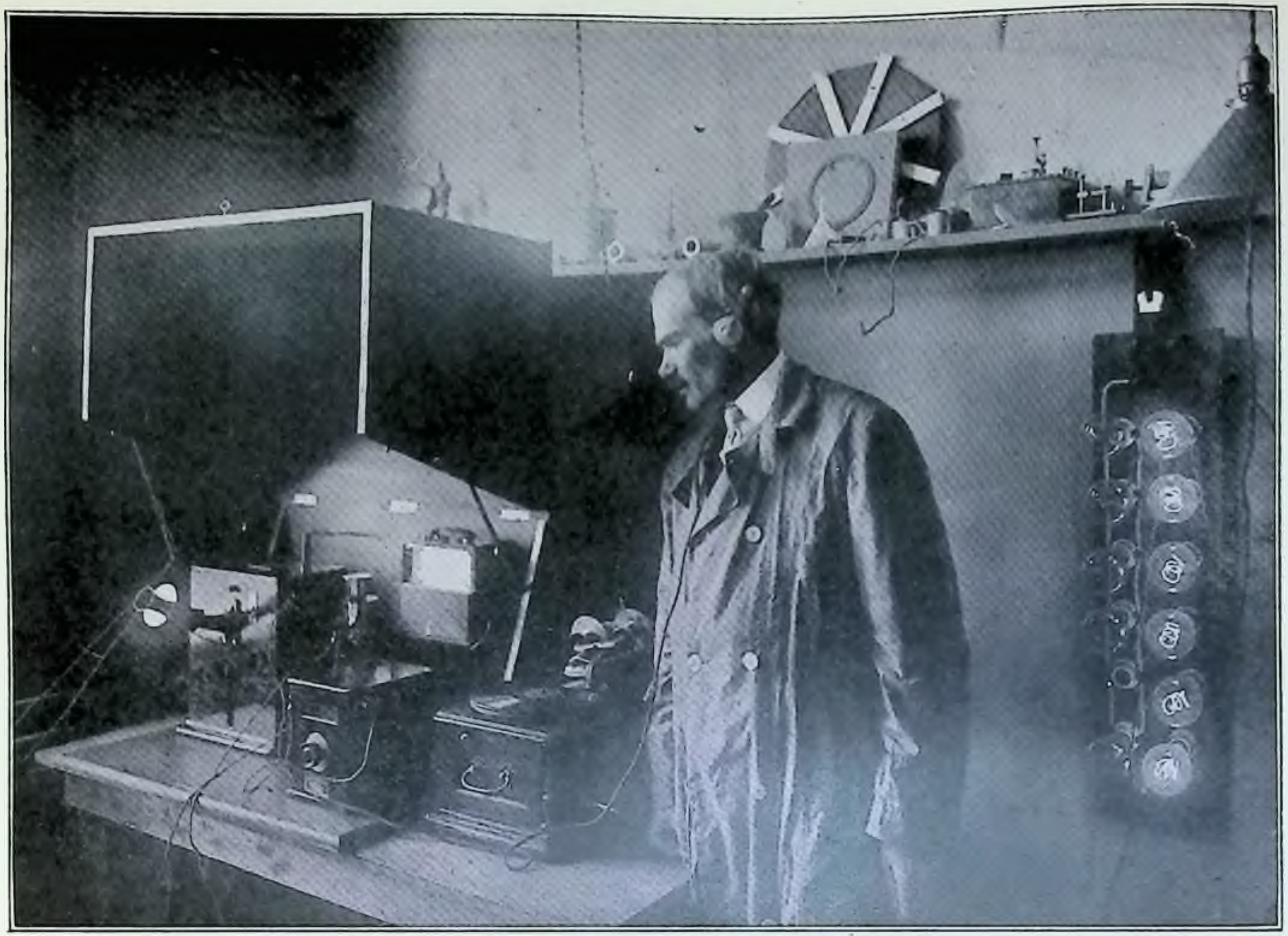
The Collins system is exploited by the Collins Wireless Telephone Company of Newark, New Jersey.

Conclusion. In conclusion attention is called to an important characteristic of radiotelephonic communication which has been observed in practice, namely, the exceptional clearness of articulation, due to an absence of wave-form distortion which is always present in wire telephony by reason of the deleterious effect of the electrostatic capacity of metallic lines and cables. This fact alone bespeaks wonderful promise for this form of telephony, particularly in view of the very limited distance over which it is at present possible to telephone when the medium is a submarine cable.

Experience has thus far shown that great advantage is to be gained by the very accurate tuning of the various circuits in connection with radiotelephony as well as with radiotelegraphy. The employment of sustained oscillations greatly facilitates the accomplishment of more perfect resonance; which, in turn, tends to eliminate interference and aids selective communication. Experience has also shown that in systems using an inductively coupled aërial, a decided gain in the clearness of articulation is noticeable when such coupling is "loose." In practice, therefore, the primary and secondary helices are often separated several inches.

In the foregoing discussion of radiotelephony it has been impossible to do more than very briefly present the subject. Many interesting questions of a theoretical nature and a description of several other systems, it has been found necessary to omit. If, however, the present short survey awakens a greater interest in space-communication, the reader may avail himself of the extensive literature dealing with the subject, and delve as deeply into the theory and problems involved as he desires.

SENDING AND RECEIVING A MESSAGE. COLLINS' SYSTEM.



DR. LEE DeFORREST AND HIS WIRELESS TELEPHONE

ELEMENTS OF ELECTRICITY AND MAGNETISM*

MAGNETISM

1. Natural and Artificial Magnets. It has been known for many centuries that some specimens of the ore known as magnetite (Fe_3O_4) have the property of attracting small bits of iron and steel. This ore probably received its name from the fact that it is abundant in the province of Magnesia in Thessaly, although the Latin writer Pliny says that the word magnet is derived from the name of the Greek shepherd Magnes, who, on the top of Mount Ida, observed the attraction of a large stone for his iron crook. Pieces of ore which exhibit this attractive property for iron or steel are known as *natural magnets.*

It was also known to the ancients that artificial magnets may be made by stroking pieces of steel with natural magnets, but it was not until the twelfth century that the discovery was made that a suspended magnet would assume a north-and-south position. Because of this property natural magnets came to be known as lodestones (leading stones), and magnets, either artificial or natural, began to be used for determining directions. The first mention of the use of a compass in Europe is in 1190. It is thought to have been introduced from China.

Artificial magnets are now made either by repeatedly stroking a bar of steel, first from the middle to one end on one of the ends, or *poles,* of a magnet, and then from the middle to the other end on the other pole, or else by passing electric currents about the bar in a manner to be described later. The form shown in Fig. 1 is called a *bar* magnet, that shown in Fig. 2 a *horseshoe* magnet.

*This paper is a modification and abridgment of the treatment of *Magnetism and Electricity* found in Millikan and Gale's *First Course in Physics* (Ginn & Co., Boston), to which the student is referred for a more complete presentation of the subject.

2. The Poles of a Magnet. If a magnet is dipped into iron filings, the filings are observed to cling in tufts near the ends, but scarcely at all near the middle (Fig. 3). These places near the ends of the magnet, in which its strength seems to be concentrated, are called the *poles* of the magnet. It has been decided to call the end of a freely suspended magnet which points to the north, the *north-seeking* or *north pole*, and it is commonly designated by the letter N. The other end is called the *south-seeking* or *south pole*, and is designated by the letter S. The direction in which the compass needle points is called the *magnetic meridian*.

Fig. 1. Bar Magnet.

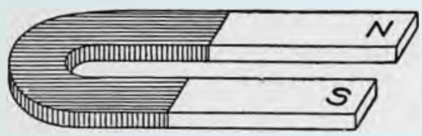


Fig. 2. Horseshoe Magnet.

3. The Laws of Magnetic Attraction and Repulsion. In the experiment with the iron filings, no particular difference was observed between the action of the two poles. That there is a difference, however, may be shown by experimenting with two magnets, either of which may be suspended (see Fig. 4). If two N poles are brought near one another, they are found to repel each other. The S poles likewise are found to repel each other. But the N pole of one magnet is found to be attracted by the S pole of another. The results of these experiments may be summarized in a general law: *Magnet poles of like kind repel each other, while poles of unlike kind attract.*

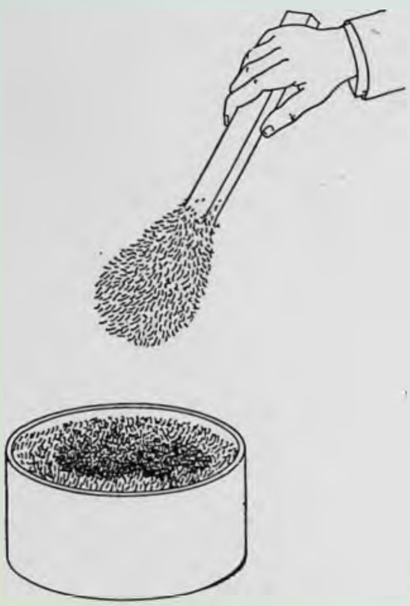


Fig. 3. Experiment Showing Existence of Magnet Poles.

The force of attraction is found, like gravitation, to vary inversely as the square of the distance between the poles; that is, separating two poles to twice their original distance reduces the force acting between them to one-fourth its original value, separating them to three times their original distance, reduces the force to one-ninth its original value, etc.

4. Magnetic Substances. Iron and steel are the only common substances which exhibit magnetic properties to a marked degree. Nickel and cobalt, however, are also attracted appreciably by strong magnets. Bismuth, antimony, and a number of other substances are actually repelled instead of attracted, but the effect is very small. Until quite recently iron and steel were the only substances whose magnetic properties were sufficiently strong to make them of any value as magnets. Within the last five years, however, it has been discovered that it is possible to make certain alloys out of non-magnetic materials such as copper, magnesium, and aluminum which are almost as strongly magnetic as iron. These are known as the *Heussler alloys*.

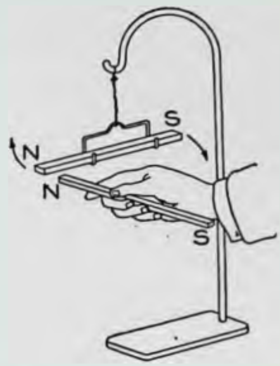


Fig. 4. Showing Variation in Action of Magnet Poles.

5. Magnetic Induction. If a small unmagnetized nail is suspended from one end of a bar magnet, it is found that a second nail may be suspended from this first nail, which itself acts like a magnet,

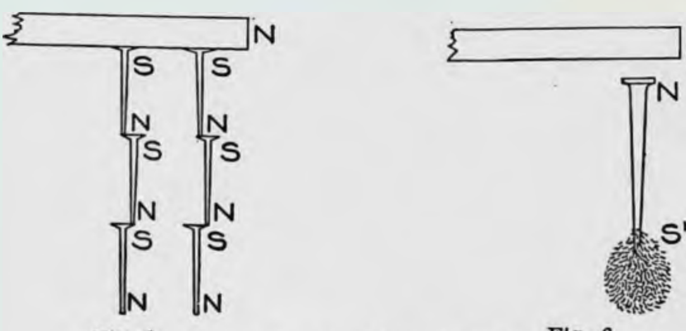


Fig. 5. Fig. 6.
Experiments Showing Magnetic Induction.

a third from the second, etc., as shown in Fig. 5. But if the bar magnet is carefully pulled away from the first nail, the others will instantly fall away from each other, thus showing that the nails were strong magnets only so long as they were in contact with the bar magnet. Any piece of soft iron may be thus magnetized *temporarily* by holding it in contact with a permanent magnet. Indeed, it is not necessary that there be actual contact, for if a nail is simply brought near to the permanent magnet it is found to become a magnet. This may be proved by presenting some iron filings to one end of a nail held near a magnet in the manner shown in Fig. 6. Even inserting a plate of glass, or of copper, or of any other material except iron between S and N will not change appreciably the number of filings which cling to the end of S'. But as soon at the permanent magnet is removed. most of the filings will fall. *Magnetism produced in this way by the mere presence of adjacent magnets, with or without contact, is called induced magnetism.* If the induced magnetism of the nail in Fig. 6 is tested with a compass needle, it is found that the *remote* induced pole S' is of the same kind as the inducing pole S, while the *near* pole N is of unlike kind. This is the general law of magnetic induction.

Magnetic induction explains the fact that a magnet attracts an unmagnetized piece of iron, for it first magnetizes it by induction, so that the near pole is unlike the inducing pole, and the remote pole like the inducing pole, and then, since the two unlike poles are closer together than the like poles, the attraction overbalances the repulsion and the iron is drawn toward the magnet. Magnetic induction also explains the formation of the tufts of iron filings shown in Fig. 3, each little filing becoming a temporary magnet such that the end which points toward the inducing pole is unlike this pole, and the end which points away from it is like this pole. The bush-like appearance is due to the repulsive action which the outside free poles exert upon each other.

6. Retentivity and Permeability. A piece of soft iron will very easily become a strong temporary magnet, but when removed from the influence of the magnet it loses practically all of its magnetism. On the other hand, a piece of steel will not be so strongly magnetized as the soft iron, but it will retain a much larger fraction of its magnetism after it is removed from the influence of the permanent magnet. This power of resisting either magnetization or demagnetization is called *retentivity*. Thus, steel has a much greater retentivity than wrought iron, and, in general, the harder the steel the greater its retentivity.

A substance which has the property of becoming strongly magnetic under the influence of a permanent magnet, whether it has a high retentivity or not, is said to possess *permeability* in large degree. Thus, iron is much more permeable than nickel. Permeability is measured by the amount of magnetization which a substance is able to receive; while retentivity is measured by the tenacity with which it holds it.

Fig. 7. Direction of Magnetic Lines of Force.

7. Magnetic Lines of Force. If we could separate the *N* and *S* poles of a small magnet so as to obtain an independent *N* pole, and were to place this *N* pole near the *N* pole of a bar magnet, it would move over to the *S* pole of the bar magnet, along some curved path similar to that shown in Fig. 7. The reason that the motion is along a curved rather than along a straight path is that the free pole is at one and the same time repelled by the *N* pole of the bar magnet and attracted by its *S* pole, and the relative strengths of these two forces are continually changing as the relative distances of the moving pole from these two poles are changed.

It is not difficult to test this conclusion experimentally. Thus, if a bar or horseshoe magnet is placed just beneath a flat dish containing water (see Fig. 8), and a cork carrying a magnetized needle placed near the *N* pole in the manner shown in the figure, the cork will actually be found to move in a curved path from *N* around to *S*. In this case the cork and the needle actually move as would an independent pole, since the upper pole of the needle is so much farther from the magnet than the lower pole that the influence of the former on the motion is very small.

Any path which an independent *N* pole would take in going from *N* to *S* is called a *line of magnetic force.* The simplest way of finding the direction of this path at any point near a magnet is to hold a compass needle at the point considered, for the needle must obviously set itself along the line in which its poles would move if independent, that is, along the line of force which passes through the given point (see *C*, Fig. 7).

Fig. 8. Direct Proof that Magnetic Lines of Force are Curved.

8. Magnetic Fields of Force. The region about a magnet in which its magnetic forces can be detected is called its *field of force.* The simplest way of gaining an idea of the way in which the lines of force are arranged in the magnetic field about any magnet is to sift iron filings upon a piece of paper placed immediately over the magnet. Each little filing becomes a temporary magnet by induction, and therefore, like the compass needle, sets itself in the direction of the line of force at the point where it is. Fig. 9 shows the shape of the *magnetic field* about a bar magnet. Fig. 10 shows the direction of the *lines of force* about a horseshoe magnet. Fig. 11 is the ideal diagram corresponding to Fig. 9 and showing the lines of force emerging from the N pole and passing around in curved lines to the S pole. This way of imagining the lines of force to be closed curves passing on the outside of the magnet from N around to S, and on the inside of the magnet from S back to N, was introduced by Faraday about 1830, and has been found of great assistance in correlating the facts of magnetism.

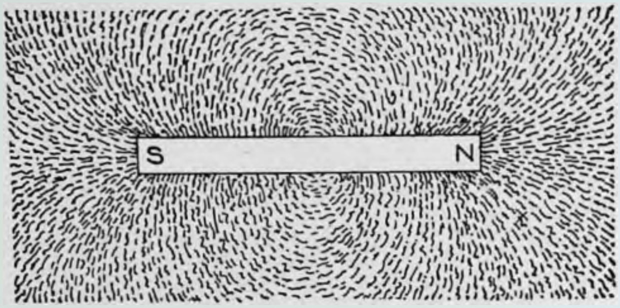


Fig. 9. Shape of Magnetic Field about a Bar Magnet.

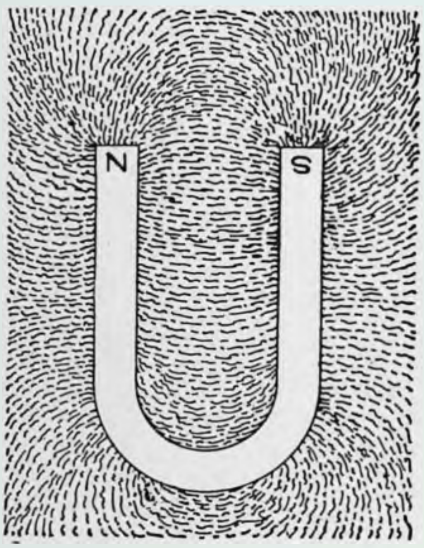
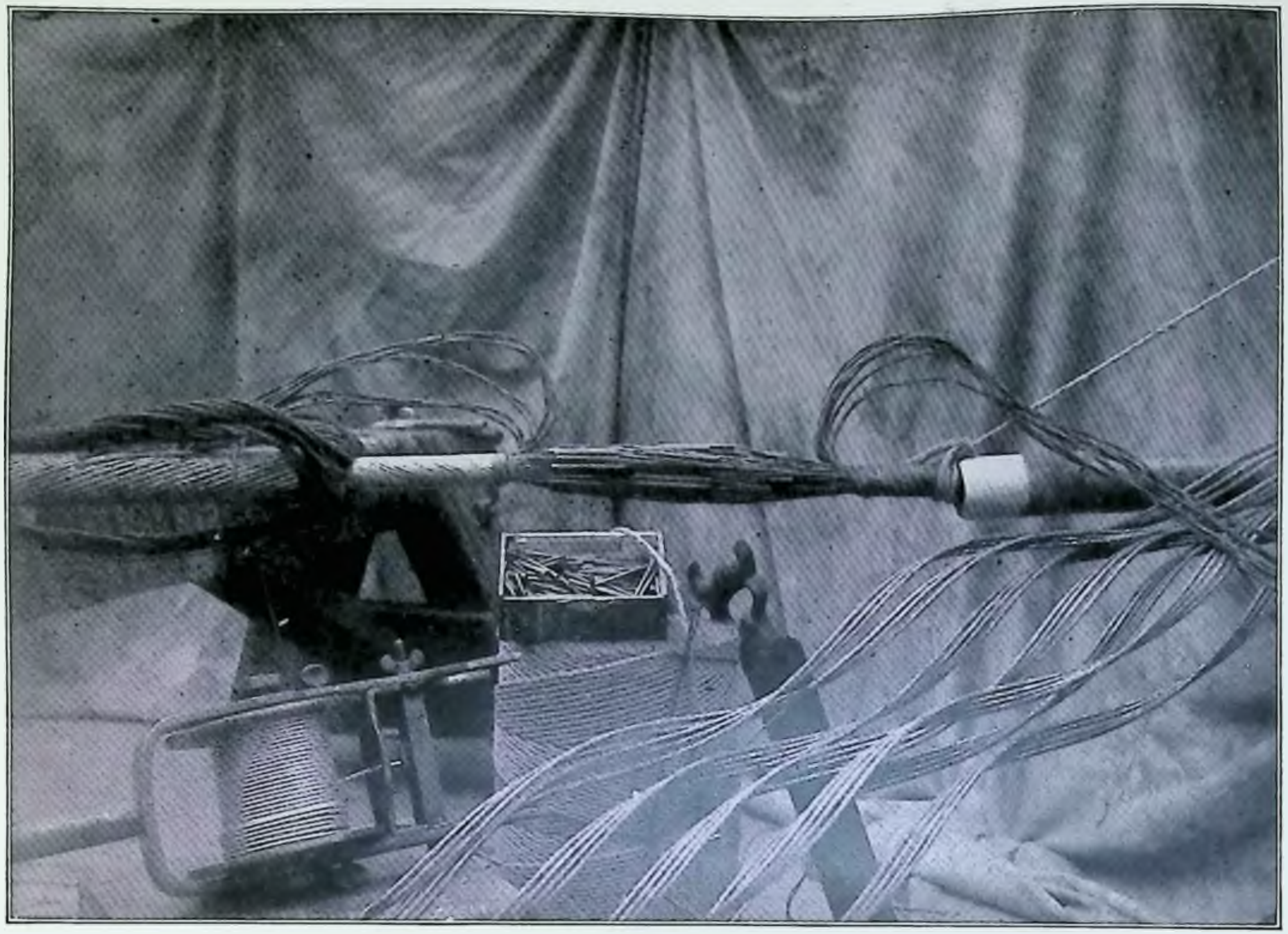


Fig. 10. Direction of Lines of Force about a Horseshoe Magnet.

9. Molecular Nature of Magnetism. If a small test-tube full of iron filings be stroked from one end to the other with a magnet, it will be found to behave toward a compass needle as if it were itself a magnet, but it will lose its magnetism as soon as the filings are shaken up. If a magnetized needle is heated red-hot, it is found to lose its



SPLICING A 50-PAIR, PAPER-INSULATED, No. 19 B. & S., GAUGE-ARMORED SUBMARINE CABLE ACROSS SAN FRANCISCO BAY magnetism completely. Again, if any magnet is jarred or hammered or twisted, the strength of its poles as measured by their ability to pick up tacks or iron filings, is found to be greatly diminished.

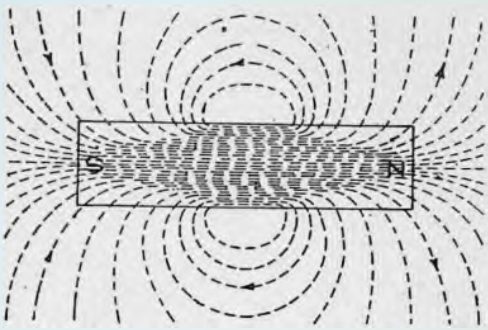


Fig. 11. Ideal Diagram of Lines of Force about a Bar Magnet.

These facts point to the conclusion that magnetism has something to do with the arrangement of the molecules, since causes which violently disturb the molecules of the magnet weaken its magnetism. Again, if a magnetized needle is broken, each part will be found to be a complete magnet. That is, two new poles will appear at the point of breaking, a new N pole on the part which has the original S pole, and a new S pole on the part which has the original N pole. The subdivision may be continued indefinitely, but always with the same result, as indicated in Fig. 12. This points to the conclusion that the molecules of a magnetized bar are themselves little magnets arranged in rows with their opposite poles in contact.

If an unmagnetized piece of hard steel is pounded vigorously while it lies between the poles of a magnet, or if it is heated to redness and then allowed to cool in this position, it will be found to have become magnetized. This points to the conclusion that the molecules of the steel are magnets even when the bar as a whole is not magnetized, and that magnetization consists in causing these molecular magnets to arrange themselves in rows, end to end.

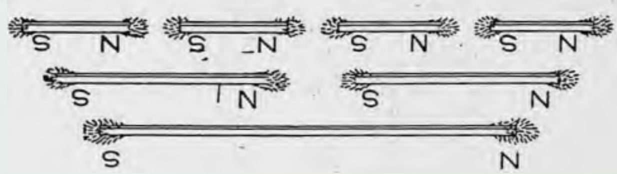


Fig. 12. A Magnet Broken into Smaller Magnets, Showing Connection between Magnetism and Molecular Arrangement.

In an unmagnetized bar of iron or steel, then, it is probable that the molecules themselves are tiny magnets which are arranged either haphazard or in little closed groups or chains, as in Fig. 13, so that, on the whole, opposite poles neutralize each other throughout the bar. But when the bar is brought near a magnet, the molecules are swung around by the outside magnetic force into some such arrangement as that shown by Fig. 14, in which the opposite poles completely neutralize one another only in the middle of the bar. According to this view, the reason that heating and jarring weaken a magnet is that disturbances of this sort tend to shake the molecules out of alignment. On the other hand heating and jarring facilitate magnetization when an unmagnetized bar is between the poles of a magnet, because they assist the magnetizing force in breaking up the molecular groups or chains and getting the molecules into alignment. Soft iron, then, has higher permeability than hard steel, merely because the molecules of the former substance do not offer so much resistance to a force tending to swing them into line as do those of the latter substance. Steel has on the other hand a much greater retentivity than soft iron, merely because its molecules are not so easily moved out of position when once they have been aligned.

Fig. 13. Theoretical Arrangement of Molecules in a Bar of Ordinary Iron or Steel.

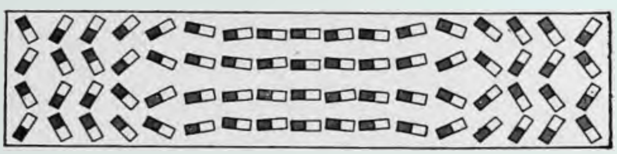


Fig. 14. Theoretical Arrangement Assumed by Molecules when Bar is Magnetized.

10. Saturated Magnets. Strong evidence for the correctness of the above view is found in the fact that a piece of iron or steel cannot be magnetized beyond a certain limit, no matter how strong the magnetizing force. This limit probably corresponds to the condition in which the axes of all the molecules are brought into parallelism, as in Fig. 14. The magnet is then said to be *saturated,* since it is as strong as it is possible to make it.

11. The Earth's Magnetism. The fact that a compass needle always points north and south, or approximately so, indicates that the earth itself is a great magnet, having an S pole near the geographical north pole and an N pole near the geographical south pole; for the magnetic pole of the earth which is near the geographical north pole must of course be unlike the pole of a suspended magnet which points toward it, and the pole of the suspended magnet which points toward the north is the one which by convention it has been decided to call the north pole. The magnetic pole of the earth which is near the north geographical pole was found in 1831 by Sir James Ross in Boothia Felix, Canada, latitude 70° 30′ N., longitude 95° W. It was located again in 1905 by Captain Amundsen at a point a little farther west. Its approximate location is 70° 5′ N., and 96° 46′ W. It is probable that it slowly shifts its position.

12. Declination. It is, of course, on account of the fact that the earth's magnetic and geographical poles do not altogether coincide, that the magnetic needle does not point exactly north, and also that the direction in which it does point changes as the needle is moved about over the earth's surface. This last fact was first discovered by Columbus on his voyage to America, and caused great alarm among his sailors. There are other local causes, however, such as large deposits of iron ore, which cause local deviations of the needle from the true north. The number of degrees by which the needle varies from the north and south line at a given point, is called the *declination* at that point.

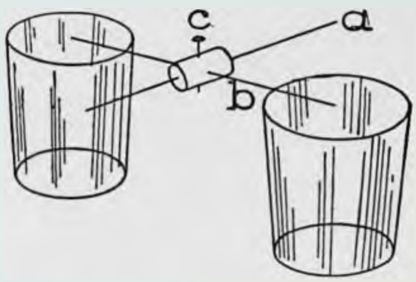


Fig. 15. Dip of the Magnetic Needle.

13. Inclination or Dip. Let an unmagnetized knitting needle a (Fig. 15) be thrust through a cork, and let a second needle b be passed through the cork at right angles to a. Let the system be adjusted by means of wax or a pin c, until it is in neutral equilibrium about b as an axis, when a is pointing east and west. Then let a be strongly magnetized by stroking one end of it from the middle out with the N pole of a strong magnet, and the other end from the middle out with the S pole of the same magnet. When now the needle is replaced on its supports and turned into a north-and-south line with its N pole toward the north, it will be found, in the north temperate zone, to dip so as to make an angle of from 60° to 75° with the horizontal. This shows that in the latitudes mentioned the earth's magnetic lines are not at all parallel to the earth's surface. The angle between these lines and the earth's surface is called the *dip*, or *inclination*, of the needle. At Washington it is 71° 5′; at Chicago, 72° 50′; at the magnetic poles it is of course 90°; and at the so-called *magnetic equator*—an irregular curved line passing through the tropics—the dip is 0°.

14. The Earth's Inductive Action. A very instructive way of showing that the earth acts like a great magnet is to hold any ordinary iron or steel rod parallel to the earth's magnetic lines, that is, about in the geographical meridian, but with the north end slanting down at an angle of say 70°, and then to strike one end a few blows with the hammer. The rod will be found to have become a magnet with its upper end an *S* pole, like the north pole of the earth, and its lower end an *N* pole. If the rod is reversed and tapped again with the hammer, its magnetism will be reversed. If held in an east-and-west position and tapped, it will become demagnetized, as is shown by the fact that both ends of it will attract either end of a compass needle.

STATIC ELECTRICITY

15. Electrification by Friction. If a piece of hard rubber or a stick of sealing wax is rubbed with flannel or cat's fur and then brought near some dry pith balls, bits of paper, or other light bodies, these bodies are found to jump toward the rod. After coming into contact with it, however, they become repelled. These experiments may be very satisfactorily performed in winter with the aid of a pith ball suspended by a fine silk thread, as shown in Fig. 16.

This sort of attraction was observed by the Greeks as early as 600 B. C., when it was found that amber which had been rubbed with silk attracted various sorts of light bodies. It was not, however, until 1600 A. D. that Dr. William Gilbert, physician to Queen Elizabeth, and sometimes called the father of the modern science of electricity and magnetism, discovered that the effect could be produced by rubbing together a great variety of other substances besides amber and silk, such, for example, as glass and silk, sealing wax and flannel, hard rubber and cat's fur, etc.

Gilbert named the effect which was produced upon these various substances by friction, *electrification,* after the Greek name for amber, *electron.* Thus, a body which, like rubbed amber, has been endowed with the property of attracting light bodies is said to have been *electrified,* or to have been given a charge of *electricity.* In this statement nothing whatever is said about the nature of electricity. We simply define an electrically charged body as one which has been put into the condition in which it acts toward light bodies like the rubbed amber or the rubbed sealing wax. To this day we do not know with certainty what the nature of electricity is, but we are fairly familiar with the laws which govern its action. It is these laws to which attention will be mainly devoted in the following sections.

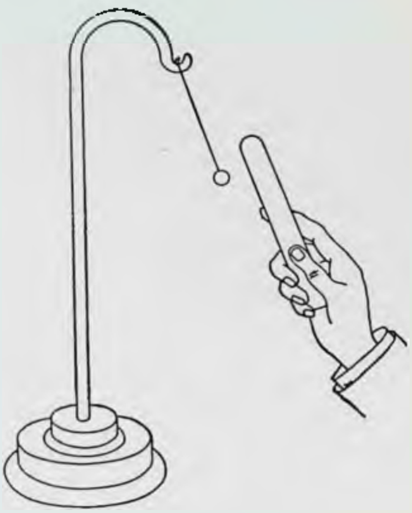


Fig. 16. Electrification by Friction.

16. Positive and Negative Electricity. If a pith ball has touched a glass rod which has been rubbed with silk and thus been put into the condition in which it is strongly repelled by this rod, it is found not to be repelled, but on the contrary to be very strongly attracted by a stick of sealing wax which has been rubbed with cat's fur or flannel. Similarly, if the pith ball has touched the sealing wax so that it is repelled by it, it is found to be strongly attracted by the glass rod. Again, two pith balls both of which have been in contact with the glass rod are found to repel one another, while pith balls one of which has been in contact with the glass rod and the other with the sealing wax attract one another.

Evidently, then, the electrifications which are imparted to glass by rubbing it with silk, and to sealing wax by rubbing it with flannel are opposite in the sense that an electrified body that is attracted by one is repelled by the other. We say, therefore, that there are two kinds of electrification, and we arbitrarily call one *positive* and the other *negative.* Thus, a *positively electrified body* is one which acts with respect to other electrified bodies like a *glass rod which has been* *rubbed with silk*, and a *negatively electrified body* is one which acts like a piece *of sealing wax which has been rubbed with flannel.* These facts and definitions may then be stated in the following general law: *Electrical charges of like sign repel each other, while charges of unlike sign attract each other.* The forces of attraction or repulsion are found, like those of gravitation and magnetism, *to decrease as the square of the distance increases.*

17. Conductors and Insulators. If a pith ball is in contact with a metal body A (Fig. 17), and if this body is connected to another metal body B by a wire, then, when B is rubbed with an electrified glass rod, A will be found immediately to repel the pith ball from itself. That is, a portion of the charge communicated to B evidently passes instantly over the wire to A. If the experiment is repeated when A and B are connected with a thread of silk, or with a rod of wood instead of metal, no effect will be observed at all upon the pith ball. If a moistened thread connects A and B, the pith ball will be affected, but not so soon as when A and B are connected with a wire.

Fig. 17. Experiment Showing the Conducting or Insulating Property of Various Materials.

These experiments make it clear that while electric charges pass with perfect readiness through a wire, they are quite unable to pass along dry silk or wool, while they pass with considerable difficulty along moist silk. We are therefore accustomed to divide substances into two classes, *conductors* and *non-conductors* or *insulators*, according to their ability to transmit electrical charges from point to point. Thus metals and solutions of salts and acids in water are all conductors of electricity, while glass, porcelain, rubber, mica, shellac, wood, silk, vaseline, turpentine, paraffin, and oils generally are insulators. No hard and fast line, however, can be drawn between conductors and non-conductors, since all so-called insulators conduct to some extent, while the so-called conductors differ greatly among themselves in the facility with which they transmit charges.

The fact of conduction brings out sharply one of the most essential distinctions between electricity and magnetism. Magnetic poles exist only in iron and steel, while electrical charges can be communicated to any body whatsoever, provided they are insulated.

These charges pass from point to point over conductors, and can be transferred by contact from one body to any other, while magnetic poles remain fixed in position, and are wholly uninfluenced by contact with other bodies, unless these bodies themselves are magnets.

18. Electrostatic Induction. If a metal ball A, Fig. 18, is strongly charged by rubbing it with a charged rod, and then brought near an insulated metal body B which is provided with pith balls or strips of paper, a, b, c, as shown, the divergence of a and c, will show that the ends of B have received electrical charges because of the presence of A, while the failure of b to diverge will show that the middle of B is uncharged. Further, the rod which charged A will be found to repel c but to attract a. When A is removed all evidences of electrification in B will disappear.

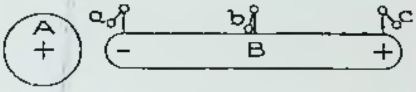


Fig. 18. Electrostatic Induction.

From experiments of this sort we conclude that when a conductor is brought near a charged body the end away from the charged body becomes electrified with the same kind of electricity as that on the charged body, while the end near the charged body receives a charge of opposite sign. *This method of producing electrification by the mere influence which an electric charge has upon a conductor placed in its neighborhood, is called electrostatic induction.* The fact that as soon as A is removed, a and c collapse, shows that this form of electrification is only a temporary phenomenon.

19. The Two-Fluid Theory of Electricity. We can describe the facts of induction conveniently by assuming that in every conductor there exists an equal number of positively and negatively charged corpuscles, which are very much smaller than atoms and which are able to move about freely among the molecules of the conductor. According to this view, when no electrified body is near the conductor B, it appears to have no charge at all, because all of the little positive charges within it counteract the effects upon outside bodies of all the little negative charges. But as soon as an electrical charge is brought near B, it drives as far away as possible the little corpuscles which carry charges of sign like its own, while it attracts the corpuscles of unlike sign. B, therefore, becomes electrified like A at its remote end, and unlike A at its near end. As soon as the inducing charge s removed, B immediately becomes neutral again because the little positive and negative corpuscles come together under the influence of their mutual attraction. This picture of the mechanism of electrification by induction is a modern modification of the so-called *two-fluid theory* of electricity, which conceived of all conductors as containing equal amounts of two weightless electrical fluids, called positive electricity and negative electricity. Although it is extremely doubtful whether this theory represents the actual conditions within a conductor, yet we are able to say with perfect positiveness that *the electrical behavior of a conductor is exactly what it would be if it did contain equal amounts of positive and negative electrical fluids*, or equal numbers of minute positive and negative corpuscles which are free to move about among the molecules of the conductor under the influence of outside electrical forces. Furthermore, since the real nature of electricity is as yet unknown, it has gradually become a universally recognized convention to speak of the positive electricity within a conductor as being repelled to the remote end, and the negative electricity as being attracted to the near end by an outside positive charge, and *vice versa*. This does not imply the acceptance of the two-fluid theory. It is merely a way of describing the fact that the remote end does acquire a charge like that of the inducing body, and the near end a charge unlike that of the inducing body.

20. The Electron Theory. A slightly different theory has recently been put forward by physicists of high standing both in England and in Germany. According to this theory a certain amount of positive electricity is supposed to constitute the nucleus of the atom of every substance. About this positive charge are grouped a number of very minute negatively charged corpuscles or electrons, the mass of each of which is approximately $\frac{1}{2000}$ of that of the hydrogen atom. The sum of the negative charges of these electrons is supposed to be just equal to the positive charge of the atom, so that in its normal condition, the whole atom is neutral and uncharged. But in the jostlings of the molecules of the conductor, electrons are continually getting loose from the atoms, moving about freely among the molecules, and re-entering other atoms which have lost their electrons. Therefore, at a given instant, there are always in every conductor a large number of free negative electrons and an exactly equal number of atoms which have lost electrons and which are therefore positively charged. Such a conductor would, as a whole, show no charge of either positive or negative electricity. But if a body charged, for example, negatively, were brought near such a body, the negatively charged electrons would stream away to the remote end, leaving behind them the positively charged atoms which are not supposed to be free to move from their positions. On the other hand, if a positively charged body is brought near the conductor, the negative electrons are attracted and the remote end is left with the immovable positive atoms.

The only advantage of this theory over that suggested in the preceding section, in which the existence of both positive and negative corpuscles is assumed, is that there is much direct experimental evidence for the existence of free negatively charged corpuscles of about $\frac{1}{2000}$ the mass of the hydrogen atom, but no direct evidence as yet for the existence of positively charged electrons.

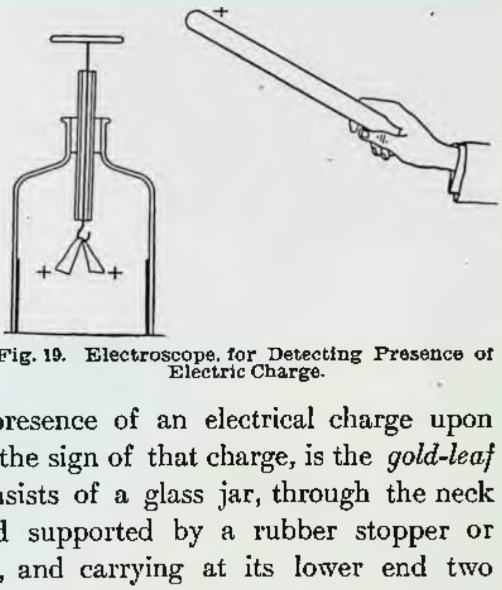


Fig. 19. Electroscope, for Detecting Presence of Electric Charge.

21. The Gold-Leaf Electroscope. One of the most sensitive and convenient instruments for detecting the presence of an electrical charge upon a body and for determining the sign of that charge, is the *gold-leaf electroscope* (Fig. 19). It consists of a glass jar, through the neck of which passes a metal rod supported by a rubber stopper or some other insulated material, and carrying at its lower end two gold leaves or strips of aluminum foil. To detect with this instrument the *presence* of an electrical charge, it is only necessary to bring near the upper end of the electroscope the body which is to be tested. If it is charged, it will repel electricity of the kind which it possesses to the leaves and draw the unlike kind to the upper end. The leaves under the influence of the like charges which they possess will stand apart or diverge. If the body is not charged the gold leaves will not be affected at all.

To determine the *sign* of an unknown charge with an electroscope, we first impart a charge of known sign to the electroscope by touching it with a piece of sealing wax, for example, which has been rubbed with cat's fur. This charges the leaves negatively and causes them to diverge. The unknown charge is then slowly brought near the upper end of the electroscope; and if the divergence of the leaves is *increased*, the sign of the unknown charge is negative, for the increased divergence means that more negative electricity has been repelled to the leaves. If the divergence is *decreased* instead of increased, the sign of the unknown charge is *positive*, for, the decreased divergence of the leaves means that a part of the negative electricity already on the leaves has been drawn to the upper end.

22. Charging by Induction. If a positively charged body C (Fig. 20) is brought near two conductors A and B in contact, we have seen that a positive charge will appear upon A and a negative charge upon B. If C were removed these charges would recombine and A and B both become neutral. But if, before C has been removed, A and B are separated, and if then C is removed, there is no opportunity for this recombination. Hence A is left permanently charged positively, and B negatively. These charges can be easily detected by bringing A and B into the neighborhood of a charged electroscope. One will cause the divergence of the leaves to increase, the other will cause it to decrease.

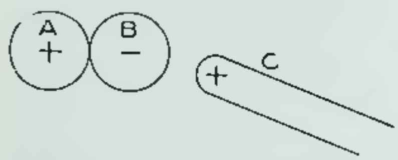


Fig. 20. Two Conductors in Contact, Charged by Induction.

Again, if a positively charged body C (Fig. 21) is brought near a conductor B, and if, while C is still in position, the finger is touched anywhere to the conductor B and then removed, then, when C is removed, B is found to be negatively charged. In this case the body of the experimenter corresponds to the conductor A of the preceding experiment, and removing the finger from B corresponds therefore to separating the two conductors A and B. In the use of this method of charging a single body by induction, it makes no difference with the sign of the charge left upon B where the finger touches the body B, whether at a or at b or at any other point, for it is always the kind of electricity which is like that on the charging body C that is repelled off to earth through the finger; while the charge which is unlike that upon C is drawn to the part of B which is next to C, and as soon as C is removed this spreads over the whole body B. Whenever, then, a single body is charged by induction in this manner, *the sign of the charge left upon it is always opposite to that of the inducing charge.*

Thus, if we wished to charge an electroscope negatively by induction from a positively charged glass rod, we should first bring the rod near the knob of the electroscope, thus causing the leaves to diverge because of the positive electricity which is repelled to them. Then while the rod was still in position near the electroscope, we should touch the knob of the latter with the finger. The leaves would at once collapse. This is because the positive electricity on the electroscope passes off to earth through the finger, while the negative is held attracted to the knob of the electroscope by the positive charge on the rod. In this condition the negative is sometimes said to be *bound* by the attraction of the positive charge on *C*. We should then remove the finger and finally the rod. The negative would then be free to pass to the leaves and cause them to diverge. The electroscope would thus be charged negatively. This is often one of the most convenient methods of charging an electroscope. It should always be used where it is desired to obtain a charge of opposite sign to that of the charging body. If it is desired to obtain a charge on the electroscope of like sign to that of the charging body we simply touch the body directly to the knob of the electroscope, and thus charge it by conduction rather than by induction.

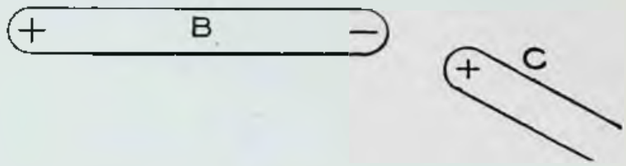


Fig. 21. Single Body Charged by Induction.

One advantage of charging by induction lies in the fact that the charging body loses none of its own charge, whereas, in charging by conduction the charging body must of course part with a portion of its charge.

23. Positive and Negative Electricities Always Appear Simultaneously and in Equal Amounts. If a strip of flannel is stuck fast to one side of a rod of sealing wax and rubbed back and forth over a a second rod of sealing wax, and if then the two bodies are brought near the knob of a charged electroscope before they are separated, it is found that they give no evidence at all of electrification. But if they are separated and brought in succession to the knob of the electroscope, they will exhibit positive and negative charges of equal strength, the flannel being positive and the bare sealing wax negative. Similarly, when a glass rod is charged positively by rubbing it with silk, the silk when tested is always found to possess a negative charge. These experiments show that in producing electrification by friction, positive and negative charges appear simultaneously and in equal amount. This confirms the view, already brought forward in connection with induction, that the process of electrification always consists in a separation of positive and negative charges which already exist in equal amounts within the bodies in which the electrification is developed. Certain it is that it is never possible to produce in any way whatever one kind of electricity without producing at the same time an equal amount of the opposite kind.

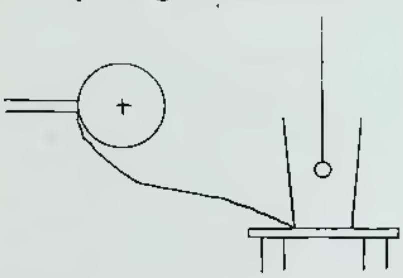


Fig. 22. Showing that an Electric Charge Lies on Outer Surface of Conductor.

24. An Electrical Charge Resides upon the Outside Surface of a Conductor. If a deep metal cup is placed upon an insulating stand and charged as strongly as possible, either from a charged rod or from an electrical machine (see Fig. 22), and a metal ball suspended by a silk thread is touched to the inside of the cup, the ball is found upon removal to show no evidence of charge when brought near the knob of the electroscope. If, on the other hand, the ball is touched to the outside of the cup, it exhibits a strong charge. Or, again, if the metal ball is first charged and then touched to the inside of the cup, it loses completely its charge, even though the cup itself may be very strongly charged. These experiments show that an electric charge resides entirely on the outside surface of a conductor. This is a result which might have been inferred from the fact that all the little electrical charges of which the total charge is made up repel each other and therefore move through the conductor until they are on the average as far apart as possible, that is, until they are all upon the surface.

25. Density of Charge Greatest where Curvature of Surface is Greatest. Since all of the parts of an electrical charge tend, because of their mutual repulsions, to get as far apart as possible, we might infer that if a charge of either sign is placed upon an oblong conductor, like that of Fig. 23 (1), it would distribute itself so that the electrification at the ends will be stronger than that in the middle. The correctness of this inference is easy to verify experimentally, for it is only necessary to attach a penny to the end of a piece of sealing wax and touch it first to the middle of a long charged conductor, and then bring it over the knob of the electroscope, then to repeat the operation when the penny is touched to the end of the conductor. The electroscope will be affected much more strongly in the latter case than in the former. If we should test in this way the distribution on a pear-shaped body, Fig. 23 (2), we should find the density of electrification considerably greater on the small end than on the large end. By density of electrification is meant the quantity of electricity on unit-area of the surface.

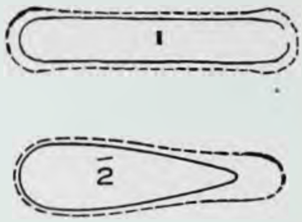


Fig. 23. Variation of Electric Charge with Curvature of Surface.

26. The Discharging Effect of Points. It might be inferred from the above that if one end of a pear-shaped body is made more and more pointed, then, when a charge is imparted to the body, the electric density on the small end will become greater and greater as the curvature of this end is made less and less. That this is in fact the case is indicated by the effect which experiment shows that points have upon electrical charges; for if a very sharp needle is attached to any insulated conductor which is provided with paper or pith-ball indicators (as shown in Fig. 18), it is found impossible to impart to the body a permanent charge; that is, if one attempts to charge it by rubbing over it a charged glass rod or other charged body, the indicators will be found to collapse as soon as the rod is removed. That this is due to an effect of the point can be proved either by removing the needle, or by covering up the point with wax, when the charge will be retained, as in the case of any insulated body. The probable explanation of the phenomenon is as follows:

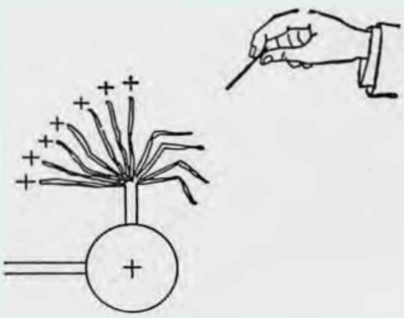


Fig. 24. Influence of Pointed Conductor upon Electric Charge.

The density of the charge becomes so intense upon the point that the molecules of air immediately adjoining the point are broken apart into positive and negative parts, and portions which are of unlike sign to the charge on the point are attracted to it, thus neutralizing the charge upon the body, while portions of like sign are repelled away.

The effect of points upon an electrical charge may be shown very strikingly by holding a very sharp needle in the hand and bringing it toward the knob of a charged electroscope. The leaves will fall together rapidly. Or, if the needle is brought near a tassel of tissue paper which is attached to an electrified conductor (see Fig. 24), the electrified streamers, which stand out in all directions because of their mutual repulsions, will at once fall together. In both of these cases the needle becomes electrified by *induction* and discharges to the knob of the electroscope, or to the tassel, electricity of opposite sign to that which it contains, thus neutralizing its charge.

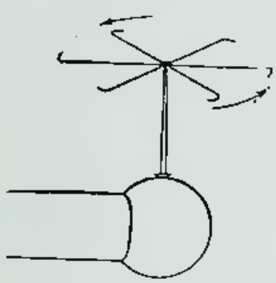


Fig. 25. Electric Whirl on Knob of Electrical Machine.

An interesting variation of the last experiment is to mount an electric whirl (see Fig. 25) upon one knob of an electrical machine. As soon as the machine is started, the whirl will rotate rapidly in the direction of the arrow. The explanation is as follows: On account of the great magnitude of the electric force near the points, the molecules of the gas just in front of them are broken into positive and negative parts. The part of sign unlike that of the charge on the points is drawn to them, while the other part is repelled. But since this repulsion is mutual, the point is pushed back with the same force with which the particles are pushed forward; hence the rotation. The repelled particles in their turn drag the air with them in their forward motion, and thus produce the *electric wind,* which may be detected easily by the hand or by a candle held in front of the point.

27. The Lightning Rod. The discharging effect of a sharp point is utilized in the lightning rod, invented by Franklin in 1752. The way in which the rod discharges the cloud and protects the building is as follows: As an electrically charged cloud approaches a building provided with a lightning rod, it induces an opposite charge in the earth and in the rod which is connected to the earth. As soon as the charge on the point becomes strong enough to break apart the molecules of the air in front of it, a stream of electrified particles, of sign opposite to that of the charge on the cloud, passes from the neighborhood of the rod to the cloud and thus neutralizes the charge of the cloud. We are accustomed to say merely that the point discharges the cloud.

28. **Electrical Potential.** There is a very instructive analogy between the use of the word *potential* in electricity and *pressure* in hydrostatics. For example, if water will flow from tank A (Fig. 26) to tank B through the connecting pipe R, we infer that the hydrostatic pressure at a must be greater than that at b, and we attribute the flow directly to this difference in pressure. In precisely the same way, if, when two bodies A and B (Fig. 27) are connected by a conducting wire r, a charge of positive electricity is found to pass from A to B, or of negative from B to A, we are accustomed to say that the electrical potential is higher at A than at B, and we assign this *difference of potential* as the cause of the flow. Thus, just as water tends to flow from points of higher hydrostatic pressure to points of lower hydrostatic pressure, so electricity is conceived of as tending to flow from points of higher electrical pressure or potential to points of lower electrical pressure or potential.

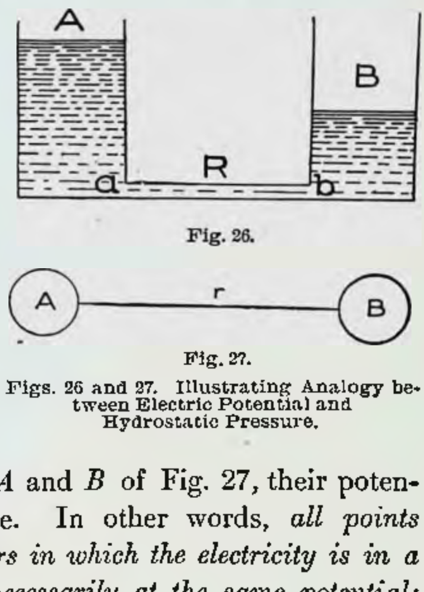


Fig. 26.

Fig. 27.

Figs. 26 and 27. Illustrating Analogy between Electric Potential and Hydrostatic Pressure.

Again, if water is not continuously supplied to one of the tanks of Fig. 26, we know that the pressures at a and b must soon become the same. Similarly, if no electricity is supplied to the bodies A and B of Fig. 27, their potentials very quickly become the same. In other words, *all points on a system of connected conductors in which the electricity is in a stationary, or static, condition are necessarily at the same potential*; for if this were not the case, then the electricity which we imagine all conductors to contain would move through the conductor until the potentials of all points were equalized. In other words, equality in the potentials of all points on a conductor in the static condition follows at once from the fact of mobility of electrical charges through or over a conductor.

But if water is continually poured into A (Fig. 26) and removed from B, the pressure at a will remain permanently above the pressure at b, and a continuous flow of water will take place through R. Similarly if A (Fig. 27) is connected with an electrical machine and B to earth, a permanent potential difference will exist between A and B and a continuous current of electricity will flow through r. Difference in potential is commonly denoted simply by the letters P. D. (potential difference).

When we speak simply of the *potential* of a body we mean the *difference of potential* which exists between the body and the earth, for the electrical condition of the earth is always taken as the zero to which the electrical conditions of all other bodies are referred. Thus a body which is positively charged is regarded as one which has a potential higher than that of the earth, while a body which is negatively charged is looked upon as one which has a potential lower than that of the earth. Fig. 28 represents the hydrostatic analogy of positively and negatively charged bodies. Since it has been decided to regard the flow of electricity as taking place from a point of higher to that of lower potential, it will be seen that when a discharge takes place between a negatively charged body and the earth we must regard the positive electricity as passing from the earth to the body, rather than the negative as passing from the body to the earth. This is, indeed, a mere convention, but it is one which it is very important to remember in connection with the study of current electricity. From the point of view of the electron theory (§ 20), it would be natural to invert this convention exactly, since this theory regards the negative electricity alone as moving through conductors. But since the opposite convention has become established, it will not be wise to attempt to change it until the electron theory has become more thoroughly established than is at present the case.

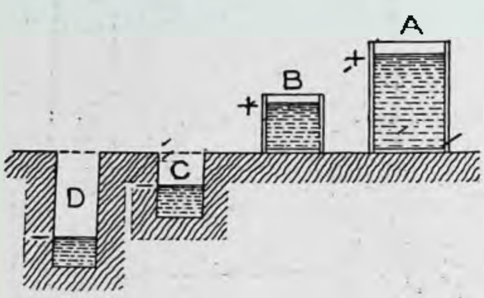


Fig. 28. Hydrostatic Analogy of Positively and Negatively Charged Bodies.

29. Some Methods of Measuring Potentials. One of the

CABLE ENTRANCE TO LARGE TELEPHONE OFFICE BUILDINGS

The Cables Enter the Basement from the Street Ducts and Pass in a Single Row through a Fireproof Floor Directly to the Distributing Frame Above.

simplest methods of comparing the potential difference which exists between any two charged bodies and the earth, is to connect the charged bodies successively to the knob of an electroscope, the conducting case of which is in electrical connection with the earth. The amount of separation of the gold leaves is then a measure of the P. D. between the earth and the charged body.

Another very convenient way of measuring approximately a very large P. D. is to measure the length of the spark which will pass between the two bodies whose P. D. is sought. This P. D. is approximately proportional to the spark length, provided the dimensions of the bodies are large in comparison with the distance between them, each centimeter of spark length representing a P. D. of about 30,000 volts.

30. Condensers. If a metal plate *A* is mounted on an insulating plate and connected with an electroscope, as in Fig. 29, and if a

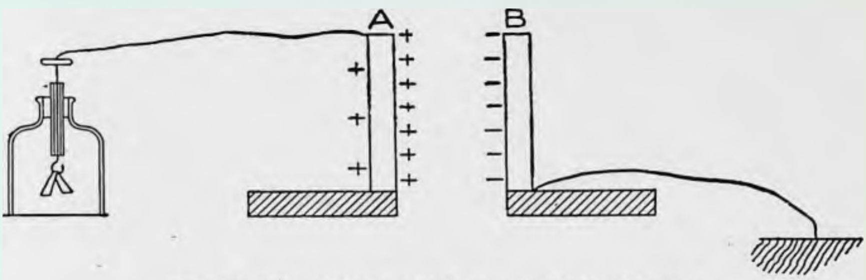


Fig. 29. Illustrating the Principle of the Condenser.

second plate *B* is similarly mounted and connected to earth, then, when a charge is placed on *A*, it will be found that the gold leaves fall together as *B* approaches *A* and diverge farther as *B* recedes from *A*. This shows that the potential of *A* is diminished by bringing *B* close to it, in spite of the fact that the quantity of electricity on *A* has remained unchanged. If we convey additional plus charges to *A*, we find that many times the original amount of electricity may be placed on *A* when *B* is close to it, before the leaves return to their original divergence, that is, before the body regains its original potential.

We say, therefore, that the *capacity* of *A* for holding electricity has been very greatly increased by bringing near it another conductor which is connected to earth. It is evident from this statement that *we measure the capacity of a body by the amount of electricity which must be put upon it in order to raise its potential to a given point.* The explanation of the increase of capacity in this case is obvious. As soon as B was brought near to A, it became charged, by induction, with electricity of sign opposite to that of A, the electricity of sign like that of A being driven off to earth through the connecting wire. The attraction between these opposite charges on A and B drew the electricity on A to the face nearest to B, and removed it from the more remote parts of A, so that it became possible to put a very much larger charge on A before the tendency of the electricity on A to pass over to the electroscope became as great as at first, that is, before the potential of A rose to its original value. Under circumstances of this sort the electricity on A is said to be *bound* by the opposite electricity on B.

An arrangement of this sort consisting of two conductors separated by a nonconductor is called a *condenser*. If the conducting points are very close together and one of them is joined to earth, the capacity of the system may be thousands of times as great as that of one of the plates alone.

31. The Leyden Jar. The most common form of condenser is a glass jar coated part way to the top inside and outside with tinfoil (Fig. 30). The inside coating is connected by a chain to the knob, while the outside coating is connected to earth. Condensers of this sort first came into use in Leyden, Holland, in 1745. Hence they are now called *Leyden jars*.

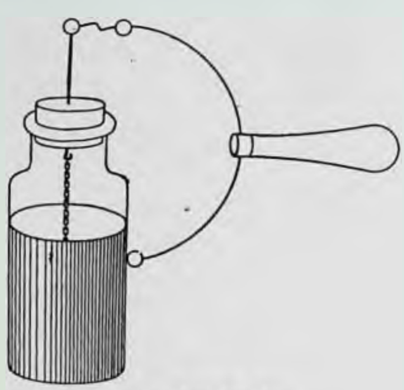


Fig. 30. Leyden Jar

Such a jar is charged by holding the knob in contact with one terminal of an electrical machine and connecting the outer coat to earth either by a wire or simply by holding it with the hand. As fast as electricity passes to the knob, it spreads to the inner coat of the jar where it attracts electricity of the opposite kind from the earth to the outer coat, repelling electricity of the same kind. If the inner and outer coatings are now connected by a discharging rod (as in Fig. 30), a very powerful spark will be produced. If a charged jar is placed on a glass plate so as to insulate the outer coat, the knob may be touched with the finger and no appreciable discharge noticed. Similarly the outer coat may be touched with the finger with the same result. But if the inner and outer coats are connected with the discharger, a powerful spark passes.

The experiment shows that it is impossible to discharge one side of the jar alone, for practically all of the charge is *bound* by the opposite charge on the other coat. Therefore, the full discharge can occur only when the inner and outer coats are connected.

32. **Electrical Screens.** We have seen that if a positively charged body *A* (Fig. 31) is brought near an uncharged conductor *B*, negative electricity is attracted to the near end of the conductor and positive electricity appears on the remote end. This appearance of the two opposite charges on the two opposite ends of the conductor evidently tends to create a field of force at any point *p*, inside the conductor, which is opposite in direction to the field due to the charge on *A*. Since the electricity within the conductor is free to move under the influence of any electrical force which is acting upon it, it is clear that the accumulation of negative electricity at one end and of positive at the other will cease only when all electrical forces inside the conductor are reduced to zero, that is, when the charges on *A* and *B*, acting jointly, neutralize one another completely at any point *p* within the conductor. It appears, therefore, that the distribution of the induced charge on the surface of a conductor in the electrical field of a charged body must always be such that there is no force whatever inside the body. This theoretical conclusion was first experimentally verified by Faraday, who coated a large box with tinfoil and went inside the box with delicate electroscopes. He found that these electroscopes showed no effects whatever, even when powerfully charged bodies were brought near the outside of the box. The experiment is often repeated in a small way by placing an electroscope under a wire cage of rather small mesh. A charged rod brought near the cage will produce no effect whatever upon the electroscope. We thus learn that electrical influences can be completely cut off from a body by surrounding it on all sides with a conductor.

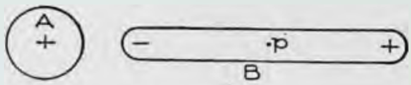


Fig. 31. Illustrating Principle of the Electrical Screen.

ELECTRICAL GENERATORS.

33. The Electrophorus. The electrophorus is a simple electrical generator which illustrates well the principle underlying the action of all electrostatic machines. All such machines generate electricity primarily by induction, not by friction. *B* (Fig. 32) is a hard rubber plate which is first charged by rubbing it with fur or flannel. *A* is a metal plate provided with an insulating handle. When the plate *A* is placed upon *B*, touched with the finger, and then removed, it is found possible to draw a spark from it, which in dry weather may be a quarter of an inch or more in length. The process may be repeated an indefinite number of times without producing any diminution in the size of the spark which may be drawn from *A*.

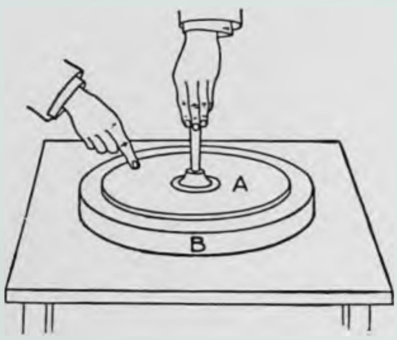


Fig. 32. The Electrophorus.

If the sign of the charge on *A* is tested by means of an electroscope, it will be found to be positive. This proves that *A* has been charged by induction, not by contact with *B*, for it is to be remembered

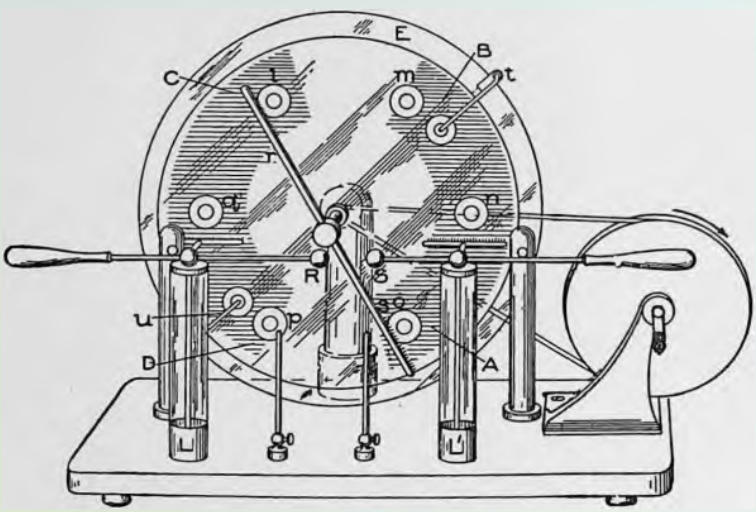


Fig. 33. Toepler-Holtz Static Machine.

that the latter is charged negatively. The reason for this is that even when *A* rests upon *B* it is in reality separated from it, at all but a very few points, by an insulating layer of air; and, since *B* is a non-conductor, its charge cannot pass off appreciably through these few points of contact. It simply repels negative electricity to the top side of the metal plate *A*, and draws positive to the lower side of this plate. The negative passes off to earth when the plate is touched with the finger. Hence, when the finger is removed and *A* lifted, is possesses a strong positive charge.

34. The Toepler-Holtz Static Machine. The ordinary static machine is nothing but a continuously acting electrophorus. Fig. 33 represents one type of such machine. Upon the back of the stationary glass plate *E* are pasted paper sectors, beneath which are strips of tinfoil *A B* and *C D*, called *inductors*. In front of *E* is a revolving glass plate carrying disks *l*, *m*, *n*, *o*, *p*, and *q*, called *carriers*. To the inductors *A B* and *C D* are fastened metal arms *t* and *u*, which bring *C* and *D* into electrical contact with the disks *l*, *m*, *n*, *o*, *p*, and *q*, when these disks pass beneath the tinsel brushes carried by *t* and *u*. A stationary metallic rod *r s* carries at its ends stationary brushes as well as sharp-pointed metallic combs. The two knobs *R* and *S* have their capacity increased by the Leyden jars *L* and *L'*.

The action of the machine is best understood from the diagram (Fig. 34). Suppose that a small + charge is originally placed on the inductor *C D*. Induction takes place in the metallic system consisting of the disks *l* and *o* and the rod *r s*, *l* becoming negatively charged, and *o* positively charged. As the plate carrying *l*, *m*, *n*, *o*, *p*, *q* rotates in the direction of the arrows, the negative charge on *l* is carried over to the position *m*, where a part of it passes over to the inductor *A B*, thus charging it negatively. When *l* reaches the position *n*, the remainder

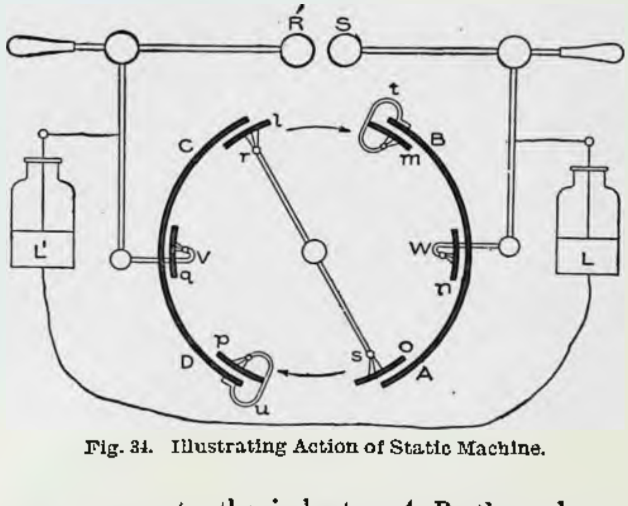


Fig. 34. Illustrating Action of Static Machine.

of its charge, being repelled by the negative which is now on *A B*, passes over into the Leyden jar *L*. When *l* reaches the position *o*, it again becomes charged by induction, this time positively, and more strongly than at first, since now the negative on *A B*, as well as the positive on *C D*, is acting inductively upon the rod *r s*. When *l* reaches the position *u*, a part of its now strong positive charge passes to *C D*, thus increasing the positive charge upon this inductor. In the position *v*, the remainder of the positive charge on *l* passes over to *L′*. This completes the cycle for *l*. Thus, as the rotation continues, *A B* and *C D* acquire stronger and stronger charges, the inductive action upon *r s* becomes more and more intense, and positive and negative charges are continuously imparted to *L* and *L′* until a discharge takes place between the knobs *R* and *S*.

There is usually sufficient charge on one of the inductors to start the machine, but in damp weather it is often found necessary to apply a charge to one of them by means of a piece of sealing wax or a glass rod before the machine will work.

ELECTRICITY IN MOTION—ELECTRICAL CURRENTS

35. The Magnetic Effect Due to a Charge in Motion. An electrical charge at rest produces no magnetic effect whatever. This can be proved by bringing a charged body near a compass needle or suspended magnet. It will attract both ends equally well by virtue of the principle of electrostatic induction. If the effect were magnetic, one end should be repelled and the other attracted. Again, if a sheet of zinc, aluminum, or copper is inserted between the deflected needle and the charge, all effect which was produced upon the needle by the charge will be cut off, for the metallic sheet will act as an electric screen (cf. § 32). But if such a metal screen is inserted between a compass needle and magnet, its insertion has no effect at all on the magnetic forces (cf. § 5).

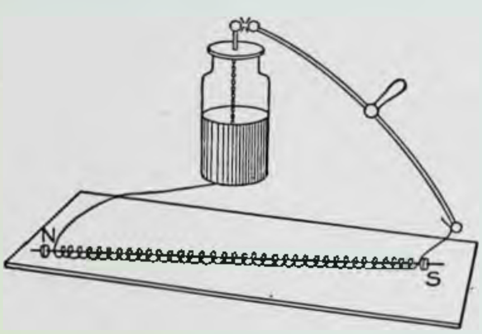


Fig. 35. Demonstrating Magnetic Effect of Electric Current.

If, however, a charged Leyden jar is discharged through a coil which surrounds an unmagnetized knitting needle in the manner shown in Fig. 35, the needle will be found after the discharge to have become distinctly magnetized. If the sign of the charge on the jar is reversed, the poles will, in general, be reversed also.

This experiment demonstrates the existence of some connection between electricity and magnetism. Just what this connection is, is not yet known with certainty; but it is known that *magnetic effects are always observable near the path of a moving electrical charge,* while no such effects can ever be observed near a charge at rest.

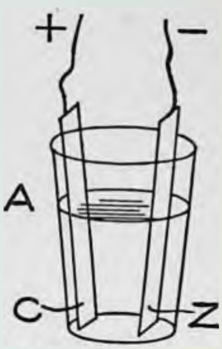


Fig. 36. Simplest Form of Galvanic Cell.

An electrical charge in motion is called an electrical current, and the presence of such current in a conductor is most commonly detected by the magnetic effect which it produces.

36. The Galvanic Cell. When a Leyden jar is discharged, but a very small quantity of electricity passes through the connecting wires, since the current lasts but a small fraction of a second. If we could keep the current flowing continuously through the wire, we should expect the magnetic effect to be more pronounced. This might be done by discharging Leyden jars in rapid succession through the wire. In 1786, however, Galvani, an Italian anatomist at the University of Bologna, accidentally discovered that there is a chemical method for producing such a continuous current. His discovery was not understood, however, until Volta, professor of physics at Como, devised an arrangement which is now known sometimes as the *voltaic,* sometimes as the *galvanic* cell.

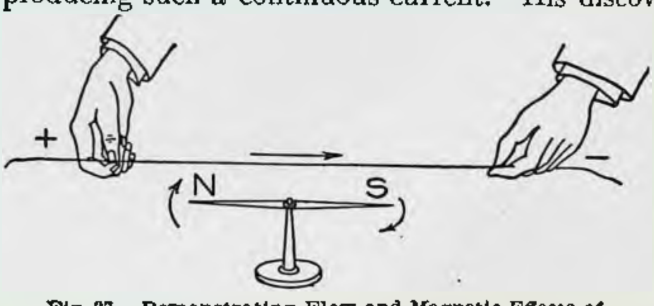


Fig. 37. Demonstrating Flow and Magnetic Effects of Current from Galvanic Cell.

Such a cell consists in its simplest form of a strip of copper and a strip of zinc immersed in dilute sulphuric acid (Fig. 36). If the wires leading from the copper and the zinc are connected for a few seconds to the end of the coil of Fig. 35, when an unmagnetized needle lies within this coil, the needle will be found to be much more strongly magnetized than it was when the Leyden jar was discharged through the coil. Or, if the wire connecting the copper and zinc is simply held above the needle in the manner shown in Fig. 37, the latter will be found to be strongly deflected. It is evident from these experiments that the wire which connects the terminals of a galvanic cell carries a current of electricity. Historically the second of these experiments, performed by the Danish physicist Oersted in 1819, preceded the discovery of the magnetizing effect of currents upon needles. It created a great deal of excitement at the time because it was the first clew which had been found to a relationship between electricity and magnetism.

It might be inferred from the above experiments that the two plates of a galvanic cell when not connected by a wire carry static positive and negative charges just as do the two coats of a Leyden jar before it is discharged through the wire. This inference can be easily verified with an electroscope.

Thus, if a metal plate *A* (Fig. 38) covered with shellac on its lower side and provided with an insulating handle, is placed upon a similar plate *B* which is in contact with the knob on an electroscope; and if the copper plate, for example, of a galvanic cell is connected to *A* and the zinc to *B*; then, when the connecting wires are removed and the plate *A* lifted away from *B*, the leaves of the electroscope will diverge and when tested will be found to be negatively charged. If the deflection observed

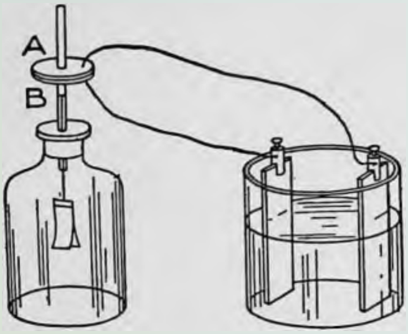


Fig. 38. Showing Existence of Static Charges on Plates of Galvanic Cell.

in the leaves of the electroscope is too small for purposes of demonstration, the conditions can be bettered by using a battery of from five to ten cells instead of the single cell. If, however, the plates *A* and *B* are sufficiently large—say, three or four inches in diameter—and if their surfaces are very flat, a single cell will be found to be sufficient. If, on the other hand, the copper plate is connected to *B* and the zinc to A in the above experiment, the electroscope will be found to be positively charged. This shows clearly that the copper plate possesses a positive electrical charge, while the zinc plate possesses a negative charge, these charges originating in the chemical action within the galvanic cell.

In this experiment the two metal plates separated by shellac constitute an electrical condenser which is charged positively on one side and negatively on the other by connecting it with the two plates of the galvanic cell, in precisely the same way in which a Leyden jar is charged by connecting its two coats one to one terminal and the other to the other terminal of a static machine. The potential of plate B is increased by moving A away from it, just as in the arrangement shown in Fig. 29 the potential of A was increased by moving B away from it. This device makes it possible to detect very small potential differences.

37. Comparison of a Galvanic Cell and Static Machine. If one of the terminals of a galvanic cell is touched directly to the knob of the gold-leaf electroscope without the use of the condenser plates A and B of Fig. 38, no divergence of the leaves can be detected; but if one knob of a static machine in operation were so touched, the leaves would be thrown apart very violently. Since we have seen that the divergence of the leaves is a measure of the potential of the body to which they are connected, we learn from this experiment that the chemical actions going on in a galvanic cell are able to produce between its terminals but very small potential differences in comparison with that produced by the static machine between its terminals. As a matter of fact, the potential difference between the terminals of the cell is but one volt (cf. § 40), while that between the terminals of an electrical machine may be several hundred thousand volts.

On the other hand, if the knobs of the static machine are connected to the ends of the wire shown in Fig. 37, and the machine operated, the current will not be large enough to produce any appreciable effect upon the needle. Since, under these same circumstances the galvanic cell produced a very large effect upon the needle, we learn that although the cell develops a much smaller P. D. than does the static machine, it nevertheless sends through the wire a very much larger amount of electricity per second. This means merely that the chemical actions which are going on within the cell are able to recharge the plates when they become discharged through the electric wire, far more rapidly than is the static machine able to recharge its terminals after they have once been discharged.

38. Shape of the Magnetic Field about a Current. If we place the wire which connects the plates of a galvanic cell in a vertical position (see Fig. 39), and explore with a compass needle the shape of the magnetic field about the current, we find that the magnetic lines are concentric circles lying in a plane perpendicular to the wire and having the wire as their common center. If we reverse the direction of the current, we find that the direction in which the compass needle points reverses also. If the current is very strong (say 40 amperes), this shape of the field can be shown by scattering iron filings on a plate through which the current passes, in the manner shown in Fig. 39. The relation between the direction in which the current flows and the direction in which the positive end of the needle points (this is, by definition, the direction of the magnetic field) is given in the following convenient rule: *If the right hand grasps the wire as in Fig. 40, so that the thumb points in the direction in which the positive electricity is moving, that is, in the direction from the copper toward the zinc, then the magnetic lines encircle the wire in the same direction as do the fingers of the hand.* Another way of stating this rule is as follows: *The relation between the direction of the current in a wire and the direction of the magnetic lines about it, is the same as the relation between the direction of the forward motion of a right-handed screw and the direction of rotation when it is being driven in.* In this form the rule is known as the *right-hand screw rule.*

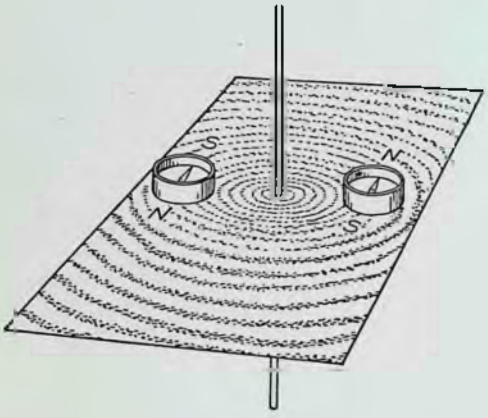


Fig. 39. Exploring Magnetic Field around a Conductor by means of Compass and Iron Filings.

39. The Measurement of Electrical Currents. Electrical currents are, in general, measured by the strength of the magnetic effect which they are able to produce under specific conditions. Thus, if the wire carrying a current is wound into circular form as in Fig. 41, the right-hand screw rule shows us that the shape of the magnetic field at the center of the coil is similar to that shown in the figure. If, then, the coil is placed in a north-and-south plane and a compass needle is placed at the center, the passage of the current through the coil tends to deflect the needle so as to make it point east and west. The amount of deflection under these conditions is taken as the measure of current strength. The unit of current is called the ampere and is in fact approximately the same as the current which, flowing through a circular coil of three turns and 10 cm. radius, set in a north-and-south plane, will produce a deflection of 45 degrees at Washington in a small compass needle placed in its center (as in Fig. 41). Nearly all current-measuring instruments, commonly called *ammeters*, consist essentially either of a small magnet suspended at the center of a fixed coil as in Fig. 41, or of a movable coil suspended between the poles of a fixed magnet. The passage of the current through the coil produces a deflection, in the first case, of the magnetic needle with reference to the fixed coil, and in the second case, of the coil with reference to the fixed magnet. If the instrument has been suitably calibrated, the amount of the deflection gives at once the strength of the current in amperes.

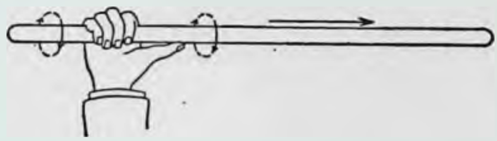


Fig. 40. Illustrating Right-Hand Screw Rule for Determining Direction of Magnetic Field.

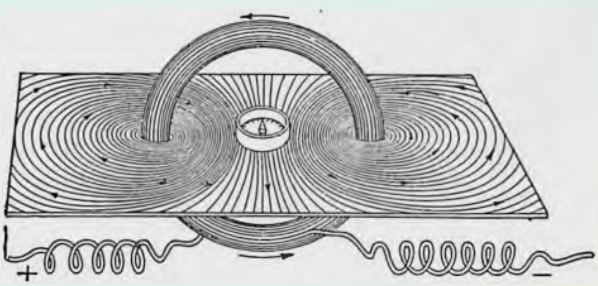


Fig. 41. Arrangement of Circular Conductor and Compass for Measuring Current Strength.

40. **Electromotive Force and its Measurements.** The potential difference which a galvanic cell or any other generator of electricity is able to maintain between its terminals when these terminals are not connected by a wire, *i. e.*, the total electrical pressure which the

generator is capable of exerting, is commonly called its *electromotive force,* usually abbreviated to E. M. F. *The E. M. F. of an electrical generator may then be defined as its capacity for producing electrical pressure, or P. D.* This P. D. might be measured, as in §§ 29 and 36, by the deflection produced in an electroscope, or other similar instrument, when one terminal was connected to the case of the electroscope and the other terminal to the knob. Potential differences are in fact measured in this way in all so-called electrostatic voltmeters, which are now coming more and more into use.

The more common type of potential difference measurers, so-called *voltmeters,* consists, however, of an instrument made like an ammeter, save that the coil of wire is made of an enormous number of turns of extremely fine wire, so that it carries a very small current. The amount of current which it does carry, however, and therefore the amount of deflection of its needle is taken as proportional to the difference in electrical pressure existing between its ends when these are touched to the two points whose P.D. is sought. The principle underlying this type of voltmeter will be better understood from a consideration of the following water analogy. If the stop-cock *K* (Fig. 42) in the pipe connecting the water tanks *C* and *D* is closed, and if the water wheel *A* is set in motion by applying a weight *W*, the wheel will turn until it creates such a difference in the water levels between *C* and *D* that the back pressure against the left face of the wheel stops it and brings the weight *W* to rest. In precisely the same way, the chemical action within the galvanic cell whose terminals are not joined (Fig. 43) develops positive and negative charges upon these terminals, that is, creates a P. D. between them, until the back electrical pressure through the cell due to this P. D. is sufficient to put a stop to further chemical action.

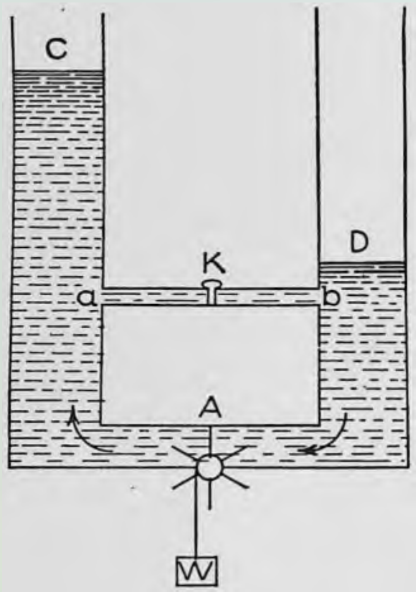


Fig. 42. Hydrostatic Analogy of Potential Difference.

Now, if the water reservoirs (Fig. 42) are put in communication by opening the stop-cock *K*, the difference in level between *C* and *D* will begin to fall, and the wheel will begin to build it up again. But if the carrying capacity of the pipe *a b* is small in comparison with the capacity of the wheel to remove water from *D* and to supply it to *C*, then the difference of level which permanently exists between *C* and *D* when *K* is open will not be appreciably smaller than when it is closed. In this case the current which flows through *A B* may obviously be taken as a measure of the difference in pressure which the pump is able to maintain between *C* and *D* when *K* is closed.

In precisely the same way, if the terminals *C* and *D* of the cell (Fig. 43) are connected by attaching to them the terminals *a* and *b* of any conductor, they at once begin to discharge through this conductor, and their P. D. therefore begins to fall. But if the chemical action in the cell is able to recharge *C* and *D* very rapidly in comparison with the ability of the wire to discharge them, then the P.D. between *C* and *D* will not be appreciably lowered by the presence of the connecting conductor. In this case the current which flows through the conducting coil, and therefore the deflection of the needle at its center, may be taken as a measure of the electrical pressure developed by the cell, that is, of the P. D. between its unconnected terminals.

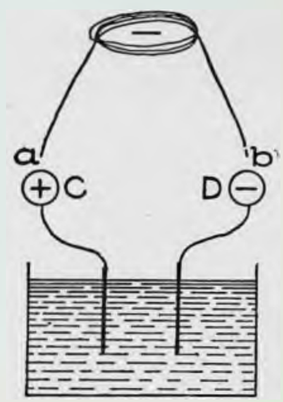


Fig. 43. Illustrating Principle of Common Voltmeter.

The common voltmeter is, then, exactly like an ammeter, save that its coil offers so high a resistance to the passage of electricity through it that it does not assist appreciably in discharging, that is, in reducing the P.D. between the points to which it is connected.

The unit of P. D. may be taken for practical purposes as the electrical pressure produced by a simple galvanic cell consisting of zinc and copper immersed in dilute sulphuric acid. It is named a *volt* in honor of Volta.

41. The Electromotive Forces of Galvanic Cells. When a voltmeter of any sort is connected to the terminals of a galvanic cell, it is found that the deflection produced is altogether independent of the shape or size of the plates or their distance apart. But if the nature of the plates is changed, the deflection changes. Thus, while copper and zinc in dilute sulphuric acid have an E. M. F. of one volt, carbon and zinc show an E. M. F. of at least 1.5 volts, while carbon and copper will show an E. M. F. of very much less than a volt. Similarly, by changing the nature of the liquid in which the plates are immersed, we can produce changes in the deflection of the voltmeter. We learn therefore that *the E. M. F. of a galvanic cell depends simply upon the materials of which the cell is composed and not at all upon the shape, size, or distance apart of the plates.*

42. Electrical Resistance. If the terminals of a galvanic cell are connected first to, say, ten feet of No. 30 copper wire, and then to ten feet of No. 30 German-silver wire, it is found that a compass needle placed at a given distance from the copper wire will show a much larger deflection than when placed the same distance from the German-silver wire. A cell, therefore, which is capable of developing a certain fixed electrical pressure is able to force very much more current through a given wire of copper than through an exactly similar wire of German-silver. We say, therefore, that German-silver offers a higher *resistance* to the passage of electricity than does copper. Similarly, every particular substance has its own characteristic power of transmitting electrical currents. Silver is the best conductor of any known substances. The resistances of different substances are commonly referred to silver as a standard, and the ratio between the resistance of a given wire of any substance and the resistance of an exactly similar silver wire is called the *specific resistance* of that substance. The specific resistances of some of the commoner metals are given below:

Fig. 44. Exact Size of No. 7 Copper Wire.

Silver	1.00	Soft iron	7.40	German silver	20.4
Copper	1.13	Nickel	7.87	Hard steel	21.0
Aluminum	2.00	Platinum	9.00	Mercury	62.7

The unit of resistance is the resistance at 0° of a column of mercury 106.3 cm. long and 1 sq. mm. in cross-section. It is called an *ohm*, in honor of the great German physicist, Georg Ohm (1789-1854). A length of 9.35 feet of No. 30 copper wire, or 6.2 inches of No. 30 German-silver wire, has a resistance of about one ohm.

Copper wire of the size shown in Fig. 44 has a resistance of about 2.62 ohms per mile.

The resistances of all of the metals increase with rise in temperature. The resistances of liquid conductors on the other hand usually decrease with rise in temperature. Carbon and a few other solids show a similar behavior: the filament in an incandescent lamp has only about half the resistance when hot that it has when cold. The resistances of wires of the same material are found to be directly proportional to their lengths, and inversely proportional to their cross-sections.

43. Ohm's Law. In 1827 Ohm announced the discovery that *the currents furnished by different galvanic cells, or combinations of cells, are always directly proportional to the E. M. F.'s existing in the circuits in which the currents flow, and inversely proportional to the total resistances of these circuits*; *i.e.*, if C represents the current in amperes, E the E. M. F. in volts, and R the resistance of the circuit in ohms, then Ohm's law as applied to the complete circuit is:

$$C = \frac{E}{R};\ i.e.,\ \text{Current} = \frac{\text{Electromotive force}}{\text{Resistance}}. \qquad (1)$$

As applied to any portion of an electrical circuit, Ohm's law is:

$$C = \frac{PD}{r};\ i.e.,\ \text{Current} = \frac{\text{Potential difference}}{\text{Resistance}}, \qquad (2)$$

where $P.D.$ represents the difference of potential in volts between any two points in the circuit, and r the resistance in ohms of the conductor connecting these two points. This is one of the most important laws in physics.

Both of the above statements of Ohm's law are included in the equation:

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}. \qquad (3)$$

44. Internal Resistance of a Galvanic Cell. If the zinc and copper plates of a simple galvanic cell are connected to an ammeter, and the distance between the plates then increased, the deflection of the needle is found to decrease, or if the amount of immersion is decreased the current also will decrease. But since the E. M. F. of a cell was shown in § 41 to be wholly independent of the area of the plates immersed or of the distance between them, it will be seen from Ohm's law that the change in the current in these cases must be due to some change in the total resistance of the circuit. Since the wire which constitutes the outside portion of the circuit has remained the same, we must conclude that *the liquid within the cell, as well as the external wire, offers resistance to the passage of the current.* This internal resistance of the liquid is directly proportional to the distance between the plates, and inversely proportional to the area of the immersed portion of the plates. If, then, we represent the external resistance of the circuit of a galvanic cell by R_e and the internal by R_i, then Ohm's law as applied to the entire circuit takes the form:

$$C = \frac{E}{R_e + R_i}. \qquad (4)$$

Thus, if a simple cell has an internal resistance of 2 ohms and an E. M. F. of 1 volt, the current which will flow through the circuit when its terminals are connected by 9.3 ft. of No. 30 copper wire (1 ohm) is $\frac{1}{1+2} = .33$ ampere. This is about the current which is usually obtained from an ordinary Daniell cell (see § 49).

PRIMARY CELLS

45. The Action of a Simple Cell. If the simple cell already mentioned—namely, zinc and copper strips in dilute sulphuric acid—is carefully observed, it will be seen that, so long as the plates are not connected by a conductor, fine bubbles of gas are slowly formed at the zinc plate, but none at the copper plate. As soon, however, as the two strips are put into electrical connection, bubbles instantly appear in great numbers about the copper plate and at the same time a current manifests itself in the connecting wire (Fig. 45). The bubbles are of hydrogen. Their original appearance on the zinc plate may be prevented either by using a plate of chemically pure zinc, or by amalgamating impure zinc, that is, by coating it over with a thin film of mercury. But the bubbles on the copper cannot be thus disposed of. They are an invariable accompaniment of the current in the circuit. If the cur-

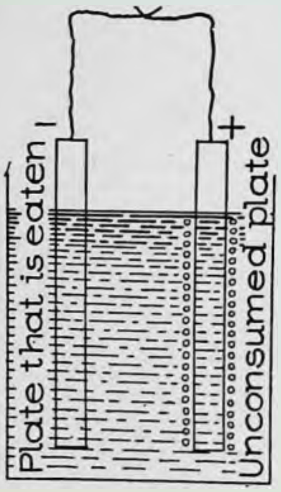


Fig. 45. Action of a Simple Cell.

CABLE ENTRANCE, MAIN OFFICE, CUBAN HOME TELEPHONE COMPANY, HAVANA, CUBA rent is allowed to run for a considerable time, it will be found that the zinc wastes away, even though it has been amalgamated, but the copper plate does not undergo any change.

An electrical current in a simple cell is, then, accompanied by the eating up of the zinc plate by the liquid, and by the evolution of hydrogen bubbles at the copper plate. In every type of galvanic cell, actions similar to these two are always found. That is, *one of the plates is always eaten up, and on the other some element is deposited.* The plate which is eaten is always the one which is found to be negatively charged, while the other is always found to be positively charged; so that in all galvanic cells, when the terminals are connected through a wire, the positive electricity flows through this wire from the uneaten plate to the eaten plate. It will be remembered that the direction in which the *positive* electricity flows is taken for convenience as the direction of the current (see §§ 19 and 28).

46. Theory of the Action of a Simple Cell. A simple cell may be made of any two dissimilar metals immersed in a solution of any acid or salt. For simplicity, let us examine the action of a cell composed of plates of zinc and copper immersed in a dilute solution of hydrochloric acid. The chemical formula for hydrochloric acid is HCl. This means that each molecule of the acid consists of one atom of hydrogen combined with one atom of chlorine. In accordance with the theory now in vogue among physicists and chemists, when hydrochloric acid is mixed with water so as to form a dilute solution, the HCl molecules split up into two electrically charged parts, called *ions*, the hydrogen ion carrying a positive charge and the chlorine ion an equal negative charge (Fig. 46). This phenomenon is known as *dissociation*. The solution as a whole is neutral; *i. e.*, it is uncharged, because it contains just as many positive as negative ions.

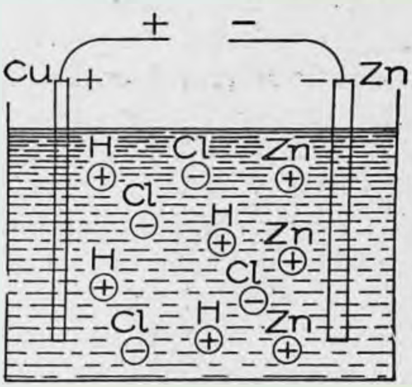


Fig. 46. Illustrating Dissociation of Ions and Theory of Action of a Simple Cell.

When a zinc plate is placed in such a solution, the acid attacks it and pulls zinc atoms into solution. Now, whenever a metal dissolves in an acid, its atoms, for some unknown reason, go into solution bearing little positive charges. *The corresponding negative charges must be left on the zinc plate* in precisely the same way in which a negative charge is left on silk when positive electrification is produced on a glass rod by rubbing it with the silk. It is in this way, then, that we attempt to account for the negative charge which we find upon the zinc plate in the experiment described in § 36.

The passage of positively charged zinc ions into solution gives a positive charge to the solution about the zinc plate, so that the hydrogen ions tend to be repelled toward the copper plate. When these repelled hydrogen ions reach the copper plate some of them give up their charges to it and then collect as bubbles of hydrogen gas. It is in this way that we account for the positive charge which we find on the copper plate in the experiment described in § 36.

If the zinc and copper plates are not connected by an outside conductor, this passage of positively charged zinc ions into solution continues but a very short time, for the zinc soon becomes so strongly charged negatively that it pulls back on the plus zinc ions with as much force as the acid is pulling them into solution. In precisely the same way the copper plate soon ceases to take up any more positive electricity from the hydrogen ions, since it soon acquires a large enough plus charge to repel them from itself with a force equal to that with which they are being driven out of solution by the positively charged zinc ions. It is in this way that we account for the fact that on open circuit no chemical action goes on in the simple galvanic cell, the zinc and copper plates simply becoming charged to a definite difference of potential which is called the E. M. F. of the cell.

When, however, the copper and zinc plates are connected by a wire, a current at once flows from the copper to the zinc, and the plates thus begin to lose their charges. This allows the acid to pull more zinc into solution at the zinc plate, and allows more hydrogen to go out of solution at the copper plate. These processes, therefore, go on continuously so long as the plates are connected. Hence a continuous current flows through the connecting wire until the zinc is all eaten up or the hydrogen ions have all been driven out of the solution, *i.e.*, until either the plate or the acid has become exhausted.

47. Polarization. If the simple cell which has been described is connected to an ammeter and the deflection observed for a few minutes, it is found to produce a current of continually decreasing strength; but if the hydrogen is removed from the copper plate by taking out the plate and drying it, the deflection returns to its first value. This phenomenon is called *polarization.*

The presence of the hydrogen on the positive plate causes a diminution in the strength of the current for twc reasons: First, since hydrogen is a non-conductor, by collecting on the plate it diminishes the effective area of the plate and therefore increases the internal resistance of the cell; second, by collecting upon the copper plate it lowers the E. M. F. of the cell, because it virtually substitutes a hydrogen plate for the copper plate, and we have already seen (in § 41) that a change in any of the materials of which a cell is composed changes its E. M. F.

The different forms of galvanic cells in common use differ chiefly in different devices employed either for disposing of the hydrogen bubbles or for preventing their formation. The most common types of such cells are described in the following sections.

48. The Bichromate Cell. The bichromate cell (Fig. 47) consists of a plate of zinc immersed in sulphuric acid between two plates of carbon, carbon being used instead of copper because it gives a greater E. M. F. In the sulphuric acid is dissolved some bichromate of potassium or sodium, the function of which is to unite chemically with the hydrogen as fast as it is formed at the positive plate, thus preventing its accumulation upon this plate.* Such a cell has the high E. M. F. of 2.1 volts. Its internal resistance is low, from .2 to .5 ohm, since the plates are generally large and close together. It will be seen, therefore, that when the external resistance is very small it is capable of furnishing a current of from 5 to 10 amperes. Since, however, the chromic acid formed by the union of the sulphuric

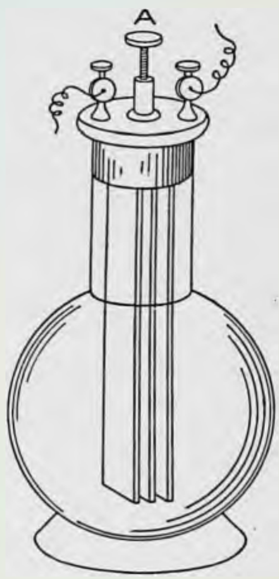


Fig. 47. Bichromate Cell.

* To set up a bichromate cell, dissolve 12 parts, by weight, of sodium bichromate in 180 parts of boiling water. After cooling, add 25 parts of commercial sulphuric acid.

acid with the bichromate attacks the zinc even when the circuit is open, it is necessary to lift the zinc from the liquid by the rod A, when the cell is not in use. Such cells are useful where large currents are needed for a short time. The great disadvantages are that the fluid deteriorates rapidly, and that the zinc cannot be left in the liquid.

49. The Daniell Cell. The Daniell cell consists of a zinc plate immersed in zinc sulphate, and a copper plate immersed in copper sulphate, the two liquids being kept apart either by means of a porous earthen cup, as in the type shown in Fig. 48, or else by gravity, as in the type shown in Fig. 49. This last type, commonly called the *gravity,* or *crowfoot* type, is used almost exclusively on telegraph lines. The copper sulphate, being the heavier of the two liquids, remains at the bottom about the copper plate, while the zinc sulphate remains at the top about the zinc plate.

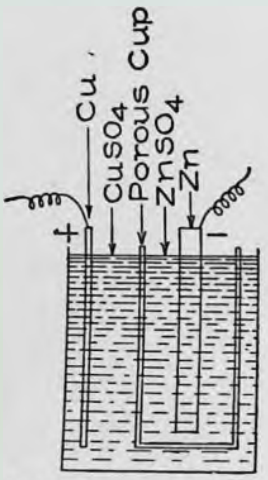


Fig. 48a. Typical Section of Daniell Cell.

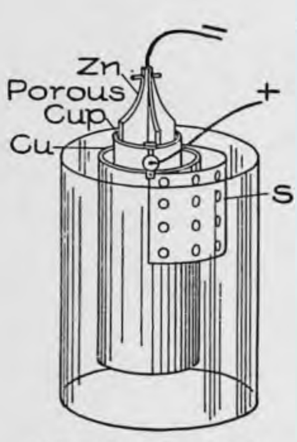


Fig. 48b. Daniell Cell (Commercial Type)

In this cell polarization is almost entirely avoided, for the reason that no opportunity is given for the formation of hydrogen bubbles. For, just as the hydrochloric acid solution described in § 46 consists of positive hydrogen ions and negative chlorine ions in water, so the zinc sulphate ($ZnSO_4$) solution consists of positive zinc ions and negative SO_4 ions. Now the zinc of the zinc plate goes into solution in the zinc sulphate in precisely the same way that it goes into solution in the hydrochloric acid of the simple cell described in § 46. This gives a positive charge to the solution about the zinc plate, and causes a movement of the positive ions between the two plates from the zinc towards the copper, and of negative ions in the opposite direction, both the Zn and the SO_4 ions being able to pass through the porous cup. Since the positive ions about the copper plate consist of atoms of copper, it will be seen that the material which is driven out of solution at the copper plate, instead of being hydrogen, as in the simple cell, is metallic copper. Since, then, the element which is deposited on the copper plate is the same as that of which it already consists, it is clear that neither the E. M. F. nor the resistance of the cell can be changed because of this deposit; *i.e.*, the cause of the polarization of the simple cell has been removed.

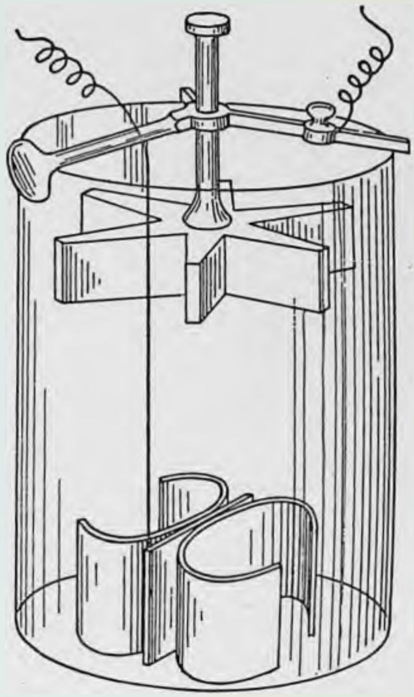


Fig. 49. Daniell Cell in which Zinc and Copper Plates are Kept Separate by Gravity.

The great advantage of the Daniell cell lies in the relatively high degree of constancy in its E. M. F. (1.08 volts). It has a comparatively high internal resistance (one to six ohms) and is therefore incapable of producing very large currents, about one ampere at most. It will furnish a very constant current, however, for a great length of time; in fact, until all of the copper is driven out of the copper sulphate solution. In order to keep a constant supply of the copper ions in the solution, copper sulphate crystals are kept in the compartment *S* of the cell of Fig. 48, or in the bottom of the gravity cell. These dissolve as fast as the solution loses its strength through the deposition of copper on the copper plate.

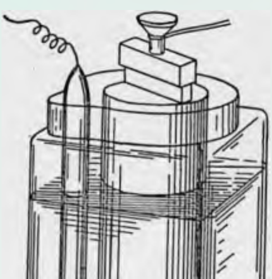


Fig. 50. Leclanché Cell.

The Daniell is a so-called *closed-circuit* cell, *i.e.*, its circuit should be left closed (through a resistance of thirty or forty ohms) whenever the cell is not in use. If it is left on open circuit, the copper sulphate diffuses through the porous cup, and a brownish muddy deposit of copper or copper oxide is formed upon the zinc. Pure copper is also deposited in the pores of the porous cup. Both of these actions damage the cell. When the circuit is closed, however, since the electrical forces always keep the copper ions moving toward the copper plate, these damaging effects are to a large extent avoided.

50. The Leclanché Cell. The Leclanché cell (Fig. 50) consists of a zinc rod in a solution of ammonium chloride (150 g. to a liter of water), and a carbon plate placed inside of a porous cup which is packed full of manganese dioxide and powdered graphite or carbon. As in the simple cell, the zinc dissolves in the liquid, and hydrogen is liberated at the carbon, or positive, plate. Here it is slowly attacked by the manganese dioxide. This chemical action is, however, not quick enough to prevent rapid polarization when large currents are taken from the cell. The cell slowly recovers when allowed to stand for a while on open circuit. The E. M. F. of a Leclanché cell is about 1.5 volts, and its initial internal resistance is somewhat less than an ohm. It therefore furnishes a momentary current of from one to three amperes.

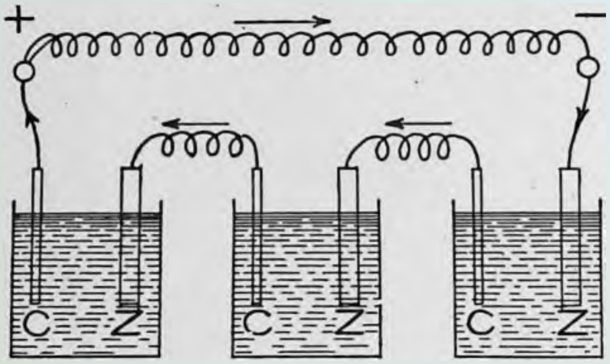


Fig. 51. Cells Connected in Series.

The immense advantage of this type of cell lies in the fact that the zinc is not at all eaten by the ammonium chloride when the circuit is open, and that, therefore, unlike the Daniell or bichromate cells, it can be left for an indefinite time on open circuit without deterioration. Leclanché cells are used almost exclusively where momentary currents only are needed, as, for example, on door-bell circuits. The cell requires no attention for years at a time, other than the occasional addition of water to replace loss by evaporation, and the occasional addition of ammonium chloride (NH_4Cl) to keep positive NH_4 and negative Cl ions in the solution.

51. The Dry Cell. The dry cell is only a modified form of the

Leclanché cell. It is not really *dry*, since the zinc and carbon plates are imbedded in moist paste which consists usually of one part of crystals of ammonium chloride, three parts of plaster of Paris, one part of zinc oxide, one part of zinc chloride, and two parts of water. The plaster of Paris is used to give the paste rigidity. As in the Leclanché cell, it is the action of the ammonium chloride upon the zinc which produces the current.

52. Combinations of Cells. There are two ways in which cells may be combined: First, in series; and second, in parallel. When they are connected in series the zinc of one cell is joined to the copper of the second, the zinc of the second to the copper of the third, etc., the copper of the first and the zinc of the last being joined to the ends of the external resistance (see Fig. 51). The E. M. F. of such a combination is the sum of the E. M. F.'s of the single cells. The internal resistance of the combination is also the sum of the internal resistances of the single cells. Hence, if the external resistances are very small, the current furnished by the combination will not be larger than that furnished by a single cell, since the total resistance of the circuit has been increased in the same ratio as the total E. M. F. But if the external resistance is large, the current produced by the combination will be very much greater than that produced by a single cell. Just how much greater can always be determined by applying Ohm's law, for if there are n cells in series, and E is the E. M. F. of each cell, the total E. M. F. of the circuit is $n E$. Hence if R_e is the external resistance and R_i the internal resistance of a single cell, then Ohm's law gives

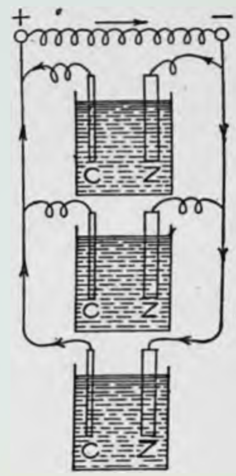


Fig. 52. Cells Connected in Parallel.

$$C = \frac{nE}{R_e + nR_i}.$$

If the n cells are connected in parallel, that is, if all the coppers are connected together and all the zincs, as in Fig. 52, the E. M. F. of the combination is only the E. M. F. of a single cell, while the internal resistance is $1/n$ of that of a single cell, since connecting the cells in this way is simply equivalent to multiplying the area of the plates n

times. The current furnished by such a combination will be given by the formula:

$$C = \frac{E}{R_e + \frac{R_i}{n}}.$$

If, therefore, R_e is negligibly small, as in the case of a heavy copper wire, the current flowing through it will be n times as great as that which could be made to flow through it by a single cell. These considerations show that the rules which should govern the combination of cells are as follows:

When the external resistance is large in comparison with the internal resistance of a single cell, the cells should be connected in series.

When the external resistance is small in comparison with the internal resistance of a single cell, the cells should be connected in parallel.

CHEMICAL EFFECTS OF THE ELECTRIC CURRENT

53. Electrolysis. If two platinum electrodes are dipped into a solution of dilute sulphuric acid, and the terminals of a battery producing an E. M. F. of 2 volts or more is applied to these *electrodes*, oxygen gas is found to be given off at the electrode at which the current enters the solution, called the *anode*, while hydrogen is given off at the electrode at which the current leaves the solution, called the *cathode*. The modern theory of this phenomenon is as follows: Sulphuric acid (H_2SO_4), when it dissolves in water, breaks up into positively charged hydrogen ions and negatively charged SO_4 ions. As soon as an electrical field is established in the solution by connecting the electrodes to the positive and negative terminals of a battery, the hydrogen ions begin to migrate toward the cathode, and there, after giving up their charges, unite to form molecules of hydrogen gas. On the other hand, the negative SO_4 ions migrate to the positive electrode (that is, the anode), where they give up their charges to it, and then act upon the water, H_2O, thus forming H_2SO_4 and liberating oxygen.

If the volumes of hydrogen and of oxygen are measured, the hydrogen is found to occupy in every case just twice the volume occupied by the oxygen. This is, indeed, one of the reasons for believing that water consists of two atoms of hydrogen and one of oxygen.

54. Electroplating. If the solution, instead of being sulphuric acid, had been one of copper sulphate, $CuSO_4$, the results would have been precisely the same in every respect, except that, since the hydrogen ions in the solution are now replaced by copper ions, the substance deposited on the cathode is pure copper instead of hydrogen. This is the principle involved in electroplating of all kinds. In commercial work, the positive plate, that is, the plate at which the current enters the bath, is always made from the same metal as that which is to be deposited from the solution; for in this case the SO_4 or other negative ions dissolve this plate as fast as the metal ions are deposited upon

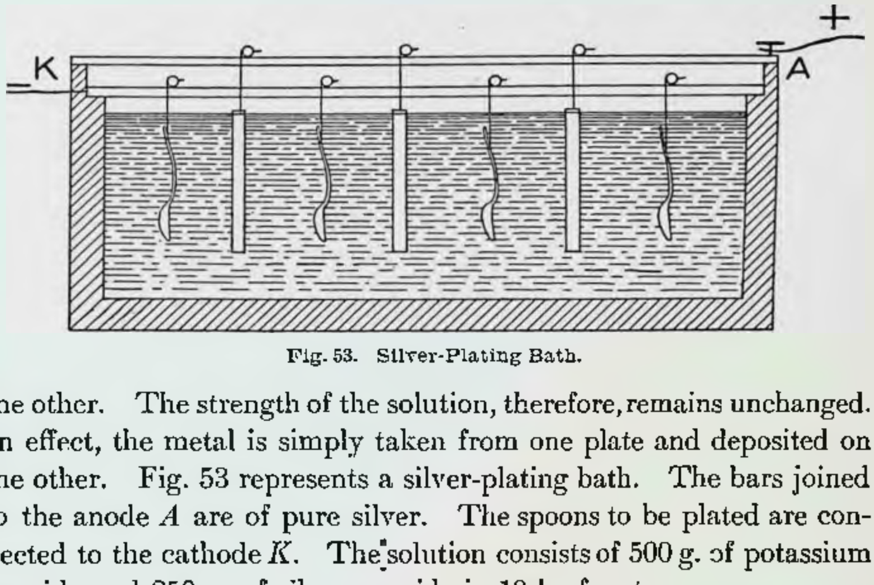


Fig. 53. Silver-Plating Bath.

the other. The strength of the solution, therefore, remains unchanged. In effect, the metal is simply taken from one plate and deposited on the other. Fig. 53 represents a silver-plating bath. The bars joined to the anode *A* are of pure silver. The spoons to be plated are connected to the cathode *K*. The solution consists of 500 g. of potassium cyanide and 250 g. of silver cyanide in 10 l. of water.

55. Chemical Method of Measuring Current. In 1834, Faraday found that a given current of electricity flowing for a given time always deposits the same amount of a given element from a solution, whatever be the nature of the solution which contains the element. For example, one ampere always deposits in an hour 4.025 g. of silver, whether the solution is of silver nitrate, silver cyanide, or any other silver compound. Similarly, an ampere will deposit in an hour 1.181 g. of copper, 1.203 g. of zinc. etc. This fact is made use of in calibrating fine ammeters, since it is possible to compute with great accuracy the strength of a current which will deposit a given weight of metal in a known time. In fact, the Electrical Congress held in Chicago in 1893 defined the ampere as *the amount of current which will deposit* .001188 *g. of silver per second.*

56. The Storage Battery. If two lead plates are immersed in sulphuric acid and the current sent through the cell, the anode or plate at which the current enters the solution will be found in the course of a few minutes to turn dark brown. This brown coat is a compound of lead with the oxygen which, in the case of the platinum electrodes, was evolved as a gas. The other lead plate is not affected by the hydrogen, which is, in this case, as in that

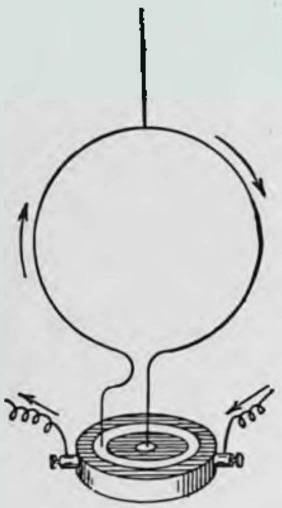


Fig. 54.

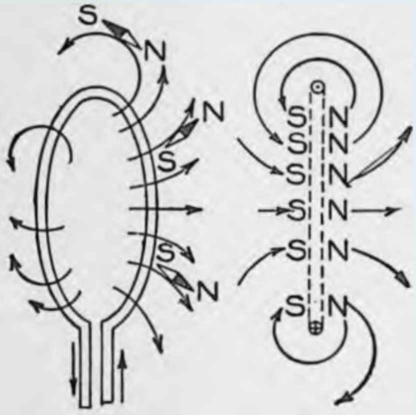


Fig. 55.

Illustrating the Magnetic Properties of a Loop.

of the platinum, evolved as a gas. Since, then, the passage of the current through this cell has left one plate unchanged, while it has changed the surface of the other plate to a new substance, namely, lead peroxide, PbO_2, it might be expected that if the charging battery were removed, and these two dissimilar plates connected with a wire, a current will flow through the wire, for the arrangement is now essentially a simple galvanic cell, which in its essentials consists simply of two dissimilar plates immersed in an electrolyte (a conducting liquid other than a molten metal). In this case the plate having the lead peroxide upon it corresponds to the copper of an ordinary cell, and the unchanged lead plate to the zinc. The arrangement will furnish a current until the lead peroxide is all used up. The only important difference between a commerical storage cell and the two lead plates just considered, is that the former is provided in the process of manufacture with a very much thicker coat of the *active material* (lead peroxide on the positive plate, and a porous, spongy lead on the negative) than can be formed by a single charging such as we considered. In one type of storage cell this active material is actually formed by the repeated charging and discharging of plates which are originally ordinary sheets of lead. With each new charging a slightly thicker layer of the lead peroxide is formed. In the more common type of commercial cell the active material is pressed into interstices of the plate in the form of a paste. It will be seen from this discussion that a storage battery is not, properly speaking, a device for storing electricity. It is rather a device in which the electrical current produces chemical changes, and these new chemicals, so long as they last, are capable of generating a new electrical current.

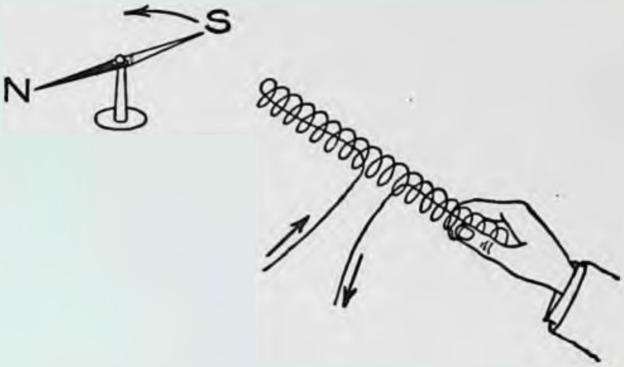


Fig. 56. Illustrating the Magnetic Properties of a Helix.

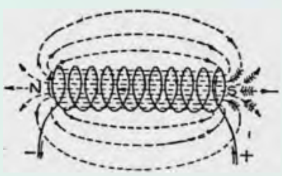


Fig. 57. Magnetic Field Surrounding a Helix.

ELECTROMAGNETISM

57. Magnetic Properties of a Loop. We have seen in § 38 that an electrical current is surrounded by a magnetic field the direction of which is given by the right-hand rule. We have seen also that a loop or coil of wire through which a current flows produces a magnetic field of the shape shown in Fig. 41. Now, if such a loop is suspended in the manner shown in Fig. 54 while a current is passed through it, it is found slowly to set itself in an east-and-west plane, and so that the face of the loop from which the magnetic lines emerge (see right-hand rule, § 38 and also Fig. 55) is toward the north. In other words, the loop will be found to behave with respect to the earth or to any other magnet precisely as though it were a flat magnetic disc whose boundary is the wire, the face which turns toward the north, that is, that from which the magnetic lines emerge, being an N pole and the other an S pole.

58. Magnetic Properties of a Helix. If a wire carrying a current be wound in the form of a helix and held near a suspended magnet as in Fig. 56, the coil will be found to act in every respect like a magnet, with an N pole at one end and an S pole at the other.

This result might have been predicted from the fact that a single loop is equivalent to a flat-disc magnet. For when a series of such discs is placed side by side, as in the helix, the result must be the same as placing a series of disc magnets in a row, the N pole of one

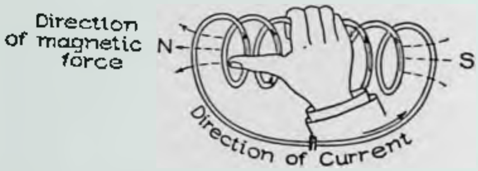


Fig. 58. Right-Hand Rule for Determining Direction of Magnetic Field of a Helix.

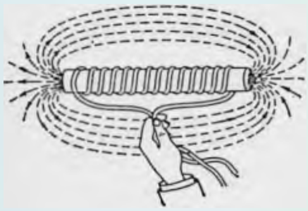


Fig. 59. A Simple Eletromagnet and Its Field.

being directly in contact with the S pole of the next, etc. These poles would therefore all neutralize each other except at the two ends. We therefore get a magnetic field of the shape shown in Fig. 57, the direction of the arrows representing as usual the direction in which an N pole tends to move.

59. Rules for North and South Poles of a Helix. The right-hand rule, as given in § 38, is sufficient in every case to determine which is the N and which the S pole of a helix, *i.e.*, from which end the lines of magnetic force emerge from the helix and at which end they enter it. But it is found convenient, in the consideration of coils, to restate the right-hand rule in a slightly different way, thus:

If the coil is grasped in the right hand in such a way that the fingers point in the direction in which the current is flowing in the wires, the thumb will point in the direction of the north pole of the helix (see Fig. 58).

Similarly, if the sign of the poles is known, but the direction of the current unknown, the latter may be determined as follows:

If the right hand is placed against the coil with the thumb pointing in the direction of the lines of force (i.e., toward the north pole of the

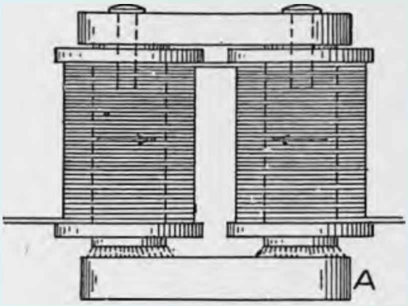


Fig. 60. Horseshoe Electromagnet, with Armature.

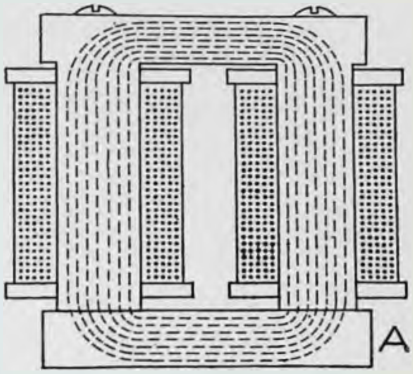


Fig. 61. Showing Lines of Force in Horseshoe Electromagnet.

helix), the fingers will pass around the coil in the direction in which the current is flowing.

60. The Electromagnet. If a core of soft iron be inserted in the helix (Fig. 59), the poles will be found to be enormously stronger than before. This is because the core is magnetized by induction from the field of the helix in precisely the same way in which it would be magnetized by induction if placed in the field of a permanent magnet. The new field strength about the coil is now the sum of the fields due to the core and that due to the coil.

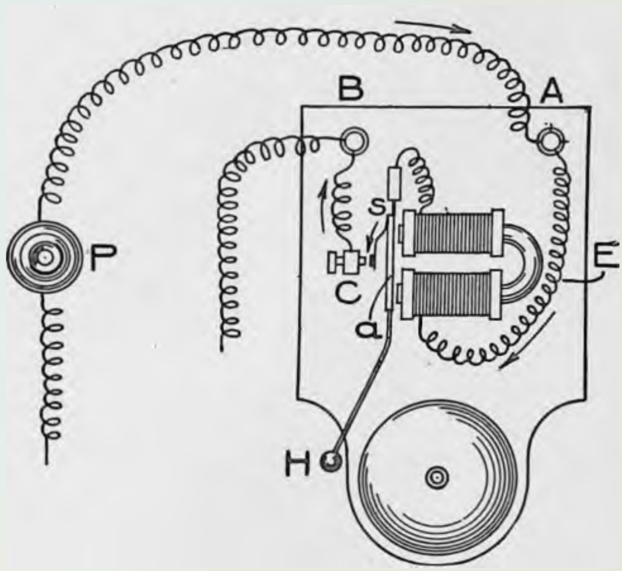


Fig. 62. Simple Electric Bell, and Connections.

If the current is broken, the core will at once lose the greater part of its magnetism. If the current is reversed, the polarity of the core will be reversed. Such a coil with a soft-iron core is called an *electromagnet.*

The strength of an electromagnet can be very greatly increased by giving it such form that the magnetic lines can remain in iron throughout their entire length instead of emerging into air, as they do in Fig. 59. For this reason electromagnets are usually built in the horseshoe form and provided with an armature A (Fig. 60)

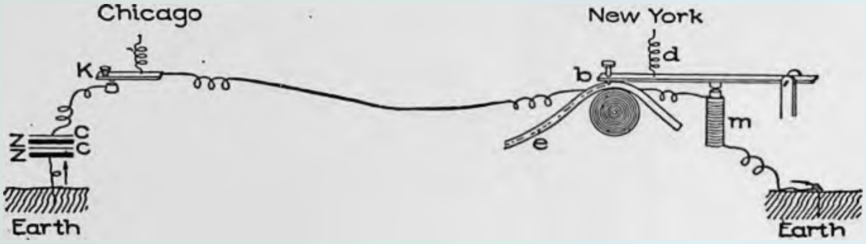


Fig. 63. Illustrating the Principle of the Electric Telegraph.

through which a complete iron path for the lines of force is established, as shown in Fig. 61. The strength of such a magnet depends chiefly upon the number of *ampere-turns* which encircle it, the expression *ampere-turns* denoting the product of the number of turns of wire about the magnet by the number of amperes flowing in each turn. Thus a current of $\frac{1}{100}$ ampere flowing 1,000 times around a core will make an electromagnet of precisely the same strength as a current of 1 ampere flowing 10 times about the core.

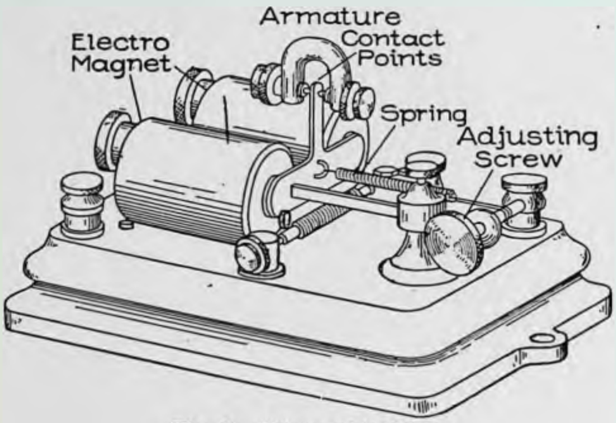


Fig. 64. Telegraphic Relay.

61. The Electric Bell. The electric bell (Fig. 62) is one of the simplest applications of the electromagnet. When the button P is pressed, the electric circuit of the battery is closed and a current flows in at A, through the magnet, over the closed contact C, and out again at B. But no sooner is this current established than the electromagnet E pulls over the armature a, and in so doing breaks the contact at C. This stops the current and demagnetizes the magnet E. The armature is then thrown back against C by the elasticity of the spring *s* which supports it. No sooner is the contact made at *C* than the current again begins to flow and the former operation is repeated. Thus the circuit is automatically made and broken at *C* and the hammer *H* is in consequence set into rapid vibration against the rim of the bell.

62. The Telegraph. The electric telegraph is another simple application of the electromagnet. The principle is illustrated in Fig. 63. As soon as the key *K* at Chicago, for example, is closed, the current flows over the line to, we will say, New York. There it passes through the electromagnet *m*, and thence back to Chicago through the earth. The armature *b* is held down by the electromagnet *m* as long as the key *K* is kept closed. As soon as the circuit is broken at *K*, the armature is pulled up by the spring *d*. By means of a clockwork device the tape *e* is drawn along at a uniform rate beneath the pencil or pen carried by the armature *b*. A very short time of closing of *K* produces a dot upon the tape, a longer time a dash. As the Morse, or telegraphic, alphabet consists of certain combinations of dots and dashes, any desired message may be sent from Chicago and recorded in New York.

AMERICAN MORSE CODE

A	. —	J	— . — .	S	. . .	2	. . — . .
B	— . . .	K	— . —	T	—	3	. . . — .
C	. . .	L	——	U	. . —	4	. . . . —
D	— . .	M	— —	V	. . . —	5	— — —
E	.	N	— .	W	. — —	6	. . . . . .
F	. — .	O	. .	X	. — . .	7	— — . .
G	— — .	P	. . . . .	Y	. . . .	8	— . . . .
H	. . . .	Q	. . — .	Z	. . . .	9	— . . —
I	. .	R	. . .	1	. — — .	0	——

In modern practice the message is not ordinarily recorded on a tape, for operators have learned to read messages by ear, a very short interval between two clicks being interpreted as a dot, a longer interval as a dash.

The first commercial telegraph line was built by S. F. B. Morse between Baltimore and Washington. It was opened on May 24, 1844, with the now famous message: "What hath God wrought?"

63. The Relay and Sounder. On account of the great resistance of long lines, the current which passes through the electromagnet is so weak that the armature of this magnet must be made very light in order to respond to the action of the current. The clicks of such an armature are not sufficiently loud to be read easily by an operator. Hence at each station there is introduced a local circuit which contains a local battery, and a second and heavier electromagnet which is called a *sounder*. The electromagnet on the main line is then called the *relay* (see Figs. 64, 65, and 66). The sounder has a very heavy armature (*A*, Fig. 65), which is so arranged that it clicks both when it is drawn down by its electromagnet against the stop *S* and when it is pushed up again by its spring, on breaking the current, against the stop *t*. The interval which elapses between those two clicks indicates to the operator whether a dot or dash is sent. The current in the main line simply serves to close and open the circuit in the local battery which operates the sounder (see Fig. 66). The electromagnets of the relay and the sounder differ in that the former consists of many thousand turns of fine wire, usually having a resistance of about 150 ohms, while the latter consists of a few hundred

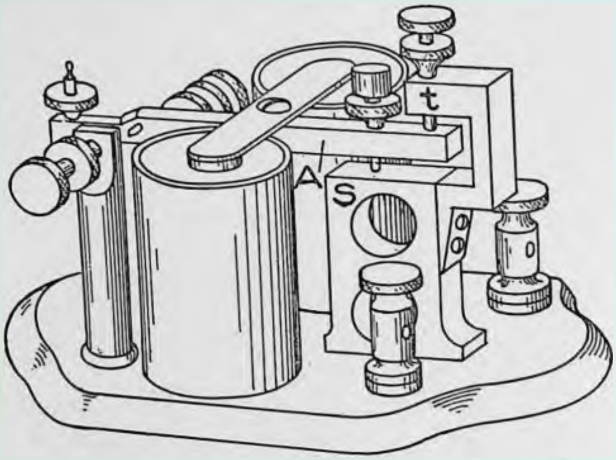


Fig. 65. Telegraphic Sounder.

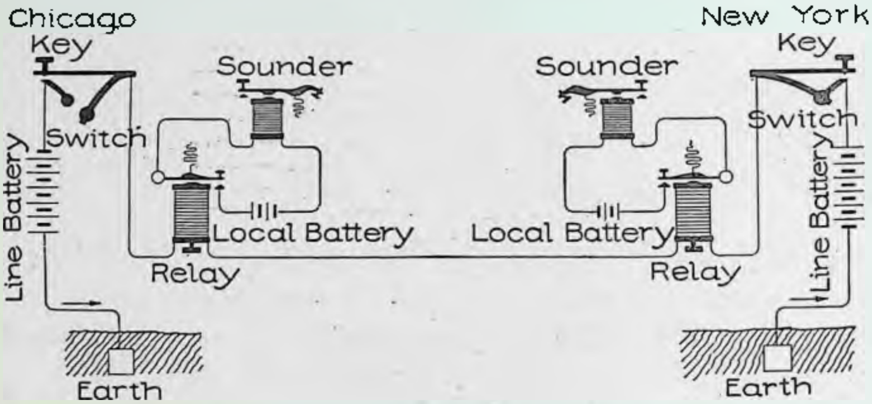


Fig. 66. Diagram of Arrangement of Parts in a Telegraphic System between Chicago and New York.

IRON DISTRIBUTING POLE
Twin-City Telephone Co., Minneapolis, Minn.

turns of coarse wire having ordinarily a resistance of about 4 ohms.

64. Plan of a Telegraph System. The actual arrangement of the various parts of a telegraphic system is shown in Fig. 66. When an operator at Chicago wishes to send a message to New York, he first opens the switch which is connected to his key, and which is always kept closed except when he is sending a message. He then begins to operate his key, thus controlling the clicks of both his own sounder and that at New York. When the Chicago switch is closed and the one at New York open, the New York operator is able to send a message back over the same line. In practice a message is not usually sent as far as from Chicago to New York over a single line, save in the case of trans-oceanic cables. Instead, it is automatically transferred at, say, Cleveland, to a second line which carries it on to Buffalo, where it is again transferred to a third line which carries it on to New York. The transfer is made in precisely the same way as the transfer from the main circuit to the sounder circuit. If, for example, the sounder circuit at Cleveland is lengthened so as to extend to Buffalo, and if the sounder itself is replaced by a relay (called in this case a *repeater*), and the local battery by a main battery, then the sounder circuit has been transformed into a repeater circuit, and all the conditions are met for an automatic transfer of the message at Cleveland to the Cleveland-Buffalo line. There is, of course, no time lost in this automatic transfer.

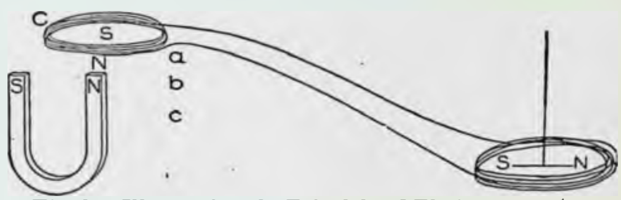


Fig. 67. Illustrating the Principle of Electromagnetic Induction.

INDUCED CURRENTS

65. Induction of Currents by Magnets. If a coil of wire C is connected to any sensitive current detector, as in Fig. 67, and then thrust over the pole of a magnet from the position a to the position c, a momentary current is observed to flow through the circuit. If the coil is held stationary over the magnet, the needle will come to rest in its natural position. If the coil is removed suddenly from the pole, the needle will move in the direction opposite to that of its first deflection, which shows that a reverse current is now being generated in the coil.

These experiments show that *a current of electricity may be induced in a conductor by causing the latter to move through a magnetic field.* This discovery, one of the most important in the history of science, was announced by Faraday in 1831. From it have sprung directly most of the modern industrial developments of electricity.

When we test the direction in which the current is induced in the coil C (Fig. 67) by applying the right-hand rule to the direction of deflection of the needle, we find that while the coil C was moving from a down to c the induced current flowing through it was in such a direction as to make its lower face an N pole and its upper face an S pole. Now if we split up this motion into two parts, namely, that from a to b and that from b to c, we see that while the coil is being moved from a to b the repulsion of the N pole of the magnet for the N pole of the coil is greater than the attraction of the N pole of the magnet for the S pole of the coil, so that the motion must be made *against an opposing force.* Similarly, while the coil is going from b to c, the S pole of the coil is nearer the N pole of the magnet than is the N pole of the coil, and consequently the attraction of the N pole of the magnet for this S pole of the coil is greater than the repulsion of the two N poles. Hence the motion from B to C also must be made against an opposing force. When the coil was moving from c to a, the current was in the reverse direction, hence the poles of the coil were reversed, so that *at every point the motion had to be made against an opposing force.*

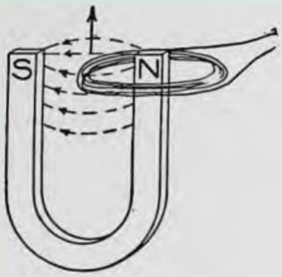


Fig. 68. Showing that a Conductor must Cut Lines of Magnetic Force in order to Induce an E. M. F.

From these experiments and others of a similar kind, it has been discovered that *whenever a current is induced in a conductor by the relative motion of the conductor and the magnetic field, the direction of the induced current is always such as to set up a magnetic field which opposes the motion.* This is known as *Lenz's law.* It is a law which might have been predicted beforehand from the principle of the conservation of energy, for, since an electrical current possesses energy, the principle of conservation of energy tells us that no such current can possibly be created without the expenditure of work of some sort. In this case there is no place for the energy to come from except from the mechanical work done in pushing the coil against some resisting force.

If, instead of moving the coil up and down over the pole, we had held it in the position shown in Fig. 68, and moved it back and forth so that its motion was *parallel* to the line *N S*, no induced current would have been observed. By experiments of this sort it is found that an *E. M. F. is induced in a coil only when the motion takes place in such a way as to change the total number of magnetic lines of force which are enclosed in the coil.* Or, to state this rule in a more general form: *An E. M. F. is induced in any element of a conductor when and only when that element is moving in such a way as to cut magnetic lines of force.*

It will be noticed that the first statement of the rule is included in the second, for whenever the number of lines of force which pass through a coil changes, some lines of force must cut across the coil from the inside to the outside, or *vice versâ.*

In the preceding statement we have used the expression *induced E. M. F.* instead of *induced current* for the reason that whether or not a continuous current flows in a conductor in which an E. M. F. (*i. e.*, a pressure tending to produce a current) exists, depends simply on whether or not the conductor is a portion of a closed electrical circuit. In our experiment the portion of the wire in which the E. M. F. was being generated by its passage across the lines of force running from *N* to *S* was a part of such a closed circuit, and hence a current resulted. If we had moved a straight conductor like that shown in Fig. 69, the E. M. F. would have been induced precisely as before; but since the circuit would then have been open, the only effect of this E. M. F. would have been to establish a P. D. between the ends of the wire, *i. e.*, to cause a positive charge to appear at one of its ends and a negative charge at the other, in precisely the same way that the E. M. F. of a battery causes positive and negative charges to appear on the terminals of the battery when it is on open circuit.

66. Strength of the Induced E. M. F. The strength of an induced E. M. F. is found to depend simply upon *the number of lines of force cut per second by the conductor*, or, in the case of a coil, upon the *rate of change* in the number of lines of force which pass through the coil. The strength of the current which flows is then given by Ohm's law; *i. e.*, it is equal to the induced E. M. F. divided by the resistance of the circuit. The number of lines of force which the conductor cuts per second may always be determined if we know the velocity of the conductor and the strength of the magnetic field through which it moves.*

In a conductor which is cutting lines at the rate of 100,000,000 lines per second, there is an induced electromotive force of exactly one volt.

67. The Dynamo Rule. Since the experiment illustrated in Fig. 67 shows that reversing the direction in which a conductor is

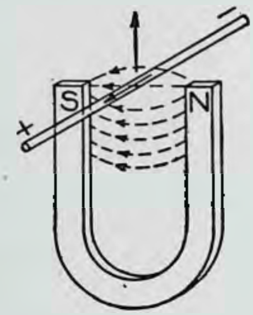


Fig. 69. Showing Relation between Directions of Motion of Conductor, Magnetic Lines, and Induced Current.

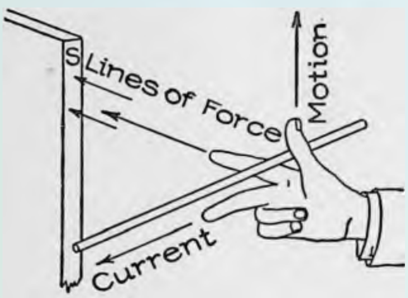


Fig. 70. Illustrating the "Dynamo Rule."

cutting lines of force also reverses the direction of the induced electromotive force, it is clear that a fixed relation must exist between these two directions and the direction of the magnetic lines. What this relation is may be obtained easily from Lenz's law. When the conductor was moving upward (Fig. 68), the current flowed in such a direction as to oppose the motion, that is, so as to make the lower face of the coil an S pole. This means that in the portion of the conductor between N and S where the E. M. F. was being generated,

*A magnetic pole of unit strength is by definition a pole which when placed at a distance of one centimeter from an exactly similar pole repels it with a force of one dyne (about one thousandth of a gram, or $\frac{1}{28000}$ of an ounce). A magnetic field of unit strength is, by definition, a field in which a unit-pole is acted upon by a force of one dyne. Hence, if a unit-pole is found in a given field to be acted upon by a force of one thousand dynes, we say that the field strength is one thousand units. Now, it is customary to represent a magnetic field by drawing as many lines per square centimeter taken at right angles to the direction of the field as the field has units of strength. Thus, a field of unit strength is said to contain one line per square centimeter, a field of a thousand units strength a thousand lines per square centimeter, etc. The magnetic fields used in powerful dynamos will have sometimes as high as 20,000 lines per square centimeter.

its direction was from back to front, that is, toward the reader (see arrow, Fig. 69). We therefore set up the following rule, which is found to apply in every case:

If the forefinger of the right hand points in the direction of the magnetic lines (see Fig. 70), and the thumb in the direction in which the conductor is cutting these lines, then the middle finger, held at right angles to both thumb and forefinger, will point in the direction of the induced current.

This rule is known as the *dynamo rule.*

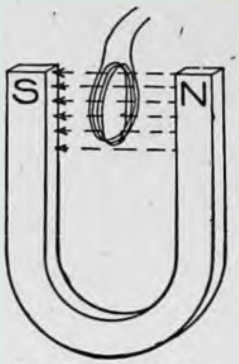


Fig. 71. Illustrating the Principle of the Dynamo.

68. The Principle of the Dynamo. A dynamo is essentially nothing but a coil of wire rotating continuously between the poles of a magnet. Thus, suppose that starting with the coil in the position shown in Fig. 71, it be rotated through 180 degrees from left to right as one looks down upon it. During the first half of the revolution the wires on the right side of the loop are cutting the lines of force while moving toward the reader, while the lines on the left side are cutting the same lines while moving away from the reader. Hence, by applying the dynamo rule, we find that a current is being generated which flows down on the right side of the coil and up on the left side. It will be seen that both currents flow around the coil in the same direction. The induced current is strongest when the coil is in the position shown in Fig. 72, because there the lines of force are being cut most rapidly. Just as the coil is being moved into or out of the position shown in Fig. 71, it is moving *parallel* to the lines of force and hence no current is induced, since no lines of force are being cut. As the coil is now moved through the last 180 degrees of a complete revolution, both sides are cutting the same lines of force as before, but they are cutting them while moving in an opposite direction from that in which they were first moving, hence the current generated during this last half is opposite in direction to that of the first half. If the coil is continuously rotated in the field, therefore, an alternating current is set up in

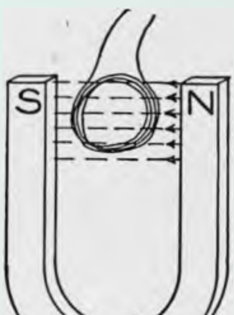


Fig. 72. Position of Revolving Coil when Current is Strongest.

it, which reverses direction every time the coil passes through the position shown in Fig. 71. This is the essential principle of the alternating-current dynamo. The direct-current dynamo differs from the alternating-current dynamo, only in that a so-called *commutator* is used for the purpose of changing the direction of the current in the external circuit every time the coil passes through the position shown in Fig. 71, so that the current always flows in the same direction through this external portion of the circuit in spite of the fact that in the rotating coil it changes direction every half-revolution.

69. The Principle of the Electric Motor. If a vertical wire *a b* is made to pass between the poles of a magnet in the manner shown in Fig. 73, and the current from an outside source—for example, a Leclanché cell—sent through it from *a* to *b*, the wire *a b* will be found to move through the mercury, into which its lower end dips, in the direction indicated by the arrow *f*, namely, at right angles to the direction of the lines of magnetic force. If the direction of the current in *a b* is reversed the direction of the motion of the wire will be found to be reversed also. This experiment shows that *a wire carrying a current in a magnetic field tends to move in a direction at right angles both to the direction of the field and to the direction of the current.* The experiment illustrates the essential principle of the electric motor. The relation between the direction of the magnetic lines, the direction of the current, and the direction of the force, is often remembered by means of the following rule, known as the *motor rule.* It differs from the dynamo rule, only in that it is applied to the fingers of the *left hand* instead of to those of the right.

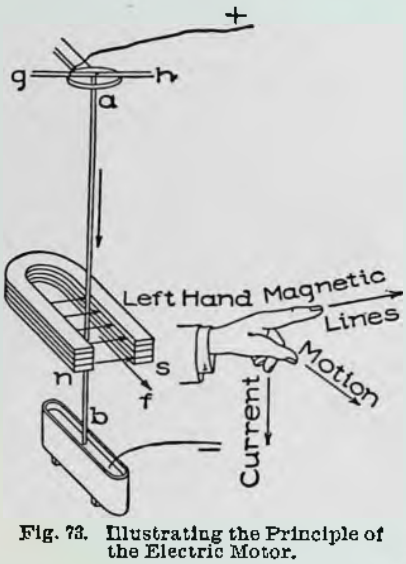


Fig. 73. Illustrating the Principle of the Electric Motor.

Let the forefinger of the left hand point in the direction of the magnetic lines of force and the middle finger in the direction of the current sent through the wire; the thumb will then point in the direction of the mechanical force acting to move the wire (see Fig. 73).

In practice the motor does not differ in construction at all from the dynamo. Thus, if a current is sent into the right side of the coil shown in Fig. 72, and out of the left side, the wires on the left side of the coil will be seen, by an application of the motor rule, to be urged toward the reader, while the wires on the right side are urged away from the reader. Hence the coil begins to rotate. After it has rotated through the position shown in Fig. 71, if the direction in which the current flows through it were not changed, it would be urged to rotate back to the position of Fig. 71; but in the actual motor, at the instant at which the coil passes through the position shown in Fig. 71, the commutator reverses the direction of the current as it enters the coil. Hence the coil is always impelled to rotate in the same direction.

70. The Principle of the Induction Coil and Transformer. If a coil of wire p is wound about an iron core, as in Fig. 74, and connected to the circuit of a battery, and if another coil of wire is wrapped about the same core, and its terminals connected to any current detector as shown in the figure, it is found that when the key K is closed, the deflection of the detector indicates that a temporary current has been induced in one direction through the coil s, but when it is opened an equal but opposite deflection will indicate an equal induced current in the opposite direction.

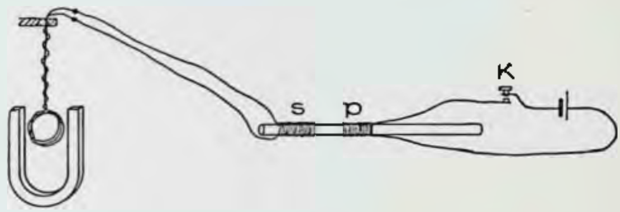


Fig. 74. Illustrating the Principle of the Induction Coil and Transformer.

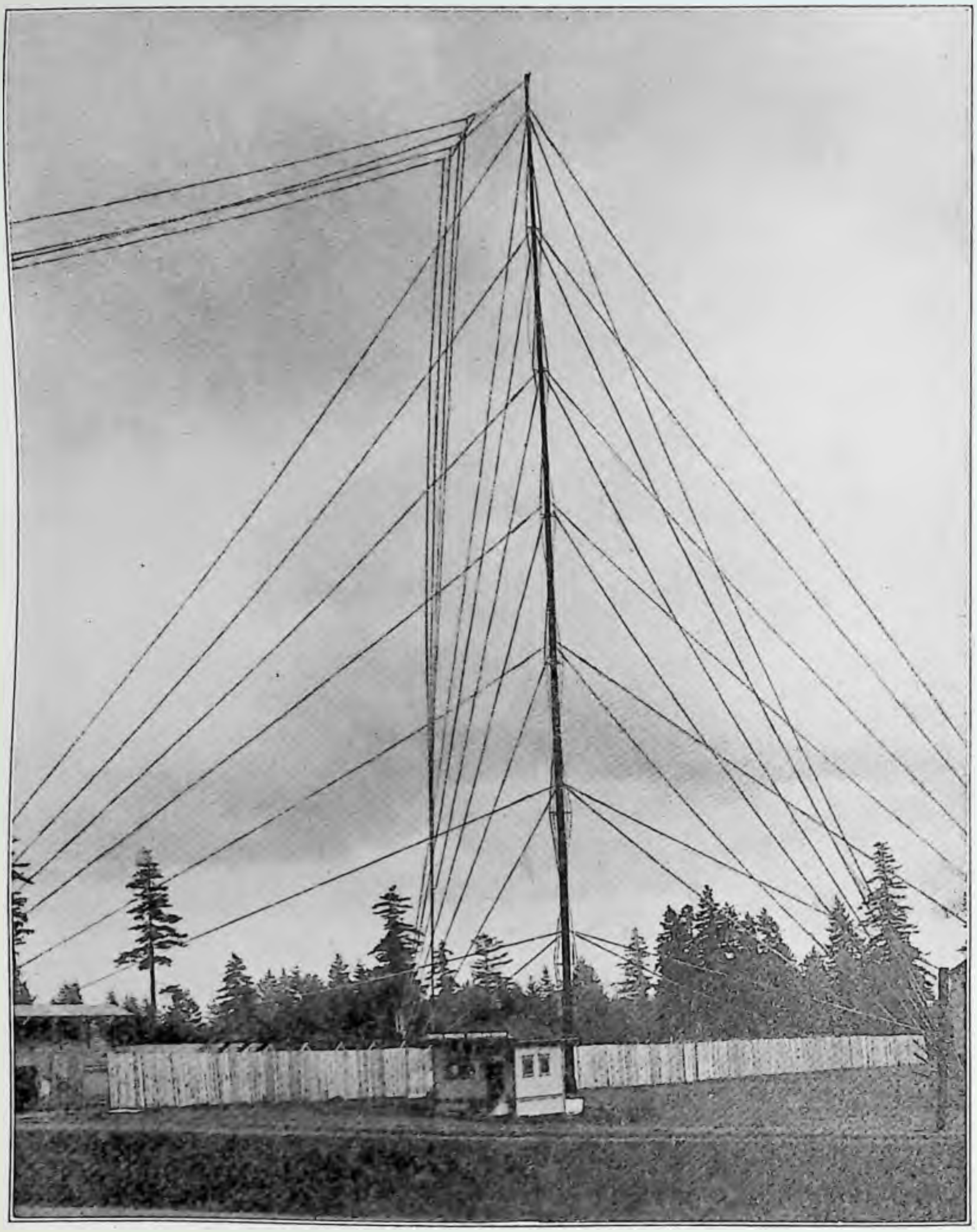
The experiment illustrates the principle of the induction coil and the transformer. The coil p, which is connected to the source of the current, is called the *primary* coil, and the coil s, in which the currents are induced, is called the *secondary* coil. Causing lines of force to spring into existence inside of s—in other words, magnetizing the space inside of s (that is, the core about which the coils are wound) —has caused an induced current to flow in s; and demagnetizing the space inside of s has also induced a current in s in accordance with the general principle stated in § 65 that any change in the number of magnetic lines of force which thread through a coil induces a current in the coil. We may think of the lines which suddenly appear within the iron core upon magnetization as springing from without across the loops into the core, and as springing back again upon demagnetization, thus cutting the loops while moving in opposite directions in the two cases.

71. Direction of the Induced Current. Lenz's law, which, it will be remembered, followed from the principle of conservation of energy, enables us to predict at once the direction of the induced currents in the above experiments; and an observation of the deflections of the galvanometer enables us to verify the correctness of the predictions. Consider first the case in which the primary circuit is made and the core thus magnetized. According to Lenz's law, the current induced in the secondary circuit must be in such a direction as to *oppose* the change which is being produced by the primary current, *i. e.* in such a direction as *to tend to magnetize the core oppositely to the direction in which it is being magnetized by the primary.* This means, of course, that the induced current in the secondary must encircle the core in a direction opposite to the direction in which the primary current encircles it. We learn, therefore, that *on making the current in the primary, the current induced in the secondary is opposite in direction to that in the primary.*

When the current in the primary is *broken*, the magnetic field created by the primary tends to die out. Hence, by Lenz's law, the current induced in the secondary must be in such a direction as to tend to oppose this process of demagnetization, *i.e.*, in such a direction as to magnetize the core in the same direction in which it is magnetized by the decaying current in the primary. Therefore, *at break, the current induced in the secondary is in the same direction as that which is dying out in the primary.*

72. E. M. F. of the Secondary. If half of the turns of the secondary s (Fig. 74) are unwrapped, the deflection when K is opened or closed, will be found to be just half as great as before. Since the resistance of the circuit has not been changed, we learn from this that the *E. M. F. of the secondary is proportional to the number of turns of wire upon it.* This result followed also from the statement made in § 66 that the electromotive force induced in any circuit is equal to the rate of cutting of lines of force by that circuit. For all of the lines which pass through the core cut all of the coils on s. If, therefore, there are twice as many coils in one case as in another, twice as many lines of force cut the circuit, and hence the E. M. F. is twice as great. If, then, we wish to develop a very high E. M. F. in the secondary, we have only to make it of a very large number of turns of fine wire. The wire must not, however, be wrapped so far away from the core as to include the lines of force which are returning through the air (see Fig. 59), for, when this happens, the coils are threaded in both directions by the same lines, and hence have no current induced in them.

73. E. M. F. at Make and Break. If the secondary coil *s* is replaced by a spool or paper cylinder upon which are wound 5,000 or 10,000 turns of No. 36 copper wire, and if the ends of the coil are attached to metal handles and held in the moistened hands, then, when the key *K* is closed, no shock whatever will be felt; but a very marked one will be observable when the key is opened. The experiment can easily be tried with an inexpensive medical coil. It shows that the E. M. F. developed at the *break* of the circuit is enormously greater than that at the *make*. The explanation is found in the fact that the E. M. F. developed in a coil depends upon the *rate* at which the number of lines of force passing through it is made to change (see § 66). When the circuit of the primary was *made*, the current required an appreciable time, perhaps a tenth of a second, to rise to its full value, just as a current of water, started through a hose, requires an appreciable time to rise to its full height, on account of the inertia of the water. An electrical current possesses a property similar to inertia. Hence the magnetic field about the primary also rises equally gradually to its full strength, and therefore its lines pass into the coil comparatively slowly. At break, however, by separating the contact point very quickly, we can make the current in the primary fall to zero in an exceedingly short time, perhaps not more than .00001 of a second; *i.e.*, we can make all of its lines pass out of the coil in this time. Hence the rate at which lines thread through, or cut, the secondary is perhaps 10,000 times as great at break as at make, and therefore the E. M. F. is also something like 10,000 times as great. It should be remembered, however, that in a closed secondary the make current lasts as much longer than the break current as its E. M. F. is smaller; hence the total energy of the two is the same, as was indeed indicated by the equal deflections in § 65.



SEATTLE STATION OF UNITED WIRELESS ON UNIVERSITY OF WASHINGTON CAMPUS
[Showing the Mast 210 Feet High, Which Carries the 1,000 Feet of Antenna Wires.]

THE ELECTRIC CURRENT.

Electromotive Force. When a difference of electrical potential exists between two points, there is said to exist an *electromotive force*, or tendency to cause a current to flow from one point to the other. In the voltaic cell one plate is at a different potential from the other, which gives rise to an electromotive force between them. Also in the induction coil, an electromotive force is created in the secondary circuit caused by the action of the primary. This electromotive force is analogous to the *pressure*, caused by a difference in level of two bodies of water connected by a pipe. The pressure tends to force the water through the pipe, and the electromotive force tends to cause an electric current to flow.

The terms potential difference and electromotive force are commonly used with the same meaning, but strictly speaking the potential difference gives rise to the electromotive force. Electromotive force is commonly designated by the letters *E. M. F.* or simply *E*. It is also referred to as *pressure* or *voltage*.

Current. A current of electricity flows when two points, at a difference of potential, are connected by a wire, or when the circuit is otherwise completed. Similarly water flows from a high level to a lower one, when a path is provided. In either case the flow can take place only when the path exists. Hence to produce a current it is necessary to have an electromotive force and a closed circuit. The current continues to flow only as long as the electromotive force and closed circuit exist.

The strength of a current in a conductor is defined as the quantity of electricity which passes any point in the circuit in a unit of time.

Current is sometimes designated by the letter *C*, but the letter *I* will be used for current throughout this and following sections. The latter symbol was recommended by the International Electrical Congress held at Chicago in 1893, and has since been universally adopted.

Resistance. Resistance is that property of matter in virtue of which bodies oppose or resist the free flow of electricity. Water passes with difficulty through a small pipe of great length or through a pipe filled with stones or sand, but very readily through a large clear pipe of short length. Likewise a small wire of considerable length and made of poor conducting material offers great resistance to the passage of electricity, but a good conductor of short length and large cross section offers very little resistance.

Resistance is designated by the letter R.

Volt, Ampere and Ohm. The *volt* is the practical unit of electromotive force.

The *ampere* is the practical unit of current.

The *ohm* is the practical unit of resistance. The *microhm* is one millionth of an ohm and the *megohm* is one million ohms.

The standard values of the above units were very accurately determined by the International Electrical Congress in 1893, and are as follows:

The International ohm, or true ohm, as nearly as known, is the resistance of a uniform column of mercury 106.3 centimeters long and 14.4521 grams in mass, at the temperature of melting ice.

The ampere is the strength of current which, when passed through a solution of silver nitrate, under suitable conditions, deposits silver at the rate of .001118 gram per second. Current strength may be very accurately determined by electrolysis, and it is used therefore in determining the standard unit.

The volt is equal to the E. M. F. which, when applied to a conductor having a resistance of one ohm, will produce in it a current of one ampere. One volt equals $\frac{1000}{1434}$ of the E. M. F. of a Clark standard cell at 15° Centigrade.

RESISTANCE.

All substances resist the passage of electricity, but the resistance offered by some is very much greater than that offered by others. Metals have by far the least resistance and of these, silver possesses the least of any. In other words, silver is the best conductor. If the temperature remains the same, the resistance of a conductor is not affected by the current passing through it. A current of ten, twenty or any number of amperes may pass through a circuit, but its resistance will be unchanged with constant temperature. Resistance is affected by the temperature and also by the degree of hardness. Annealing decreases the resistance of a metal.

Conductance is the inverse of resistance; that is, if a conductor has a resistance of R ohms, its conductance is equal to $\frac{1}{R}$.

Resistance Proportional to Length. The resistance of a conductor is directly proportional to its length. Hence, if the length of a conductor is doubled, the resistance is doubled, or if the length is divided, say into three equal parts, then the resistance of each part is one third the total resistance.

Example. — The resistance of 1283 feet of a certain wire is 6.9 ohms. What is the resistance of 142 feet of the same wire?

Solution. — As the resistance is directly proportional to the length we have the proportion,

$$\text{required resistance} : 6.9 :: 142 : 1283$$

or,
$$\frac{\text{required resistance}}{6.9} = \frac{142}{1283}$$

Hence,
$$\text{required resistance} = 6.9 \times \frac{142}{1283}$$
$$= .76 \text{ ohm (approx.)}$$

Ans. .76 ohm.

Example. — The resistance of a wire having a length of 521 feet is .11 ohm. What length of the same wire will have a resistance of .18 ohm?

Solution. — As the resistance is proportional to length, we have the proportion,

$$\text{required length} : 521 :: .18 : .11$$

or,
$$\frac{\text{required length}}{521} = \frac{.18}{.11}$$

Hence,
$$\text{required length} = 521 \times \frac{.18}{.11}$$
$$= 852 \text{ feet (approx.)}$$

Ans. 852 feet.

Resistance Inversely Proportional to Cross-Section. The resistance of a conductor is inversely proportional to its cross-sectional area. Hence the greater the cross-section of a wire the less is its resistance. Therefore, if two wires have the same length, but one has a cross-section three times that of the other, the resistance of the former is one-third that of the latter.

Example.—The ratio of the cross-sectional area of one wire to that of another of the same length and material is $\frac{257}{101}$. The resistance of the former is 16.3 ohms. What is the resistance of the latter?

Solution.—As the resistances are inversely proportional to the cross-sections, the smaller wire has the greater resistance, and we have the proportion:

$$\text{required resist.} : 16.3 :: 257 : 101$$

or,
$$\frac{\text{required resist.}}{16.3} = \frac{257}{101}$$

Hence,
$$\text{required resist.} = 16.3 \times \frac{257}{101}$$
$$= 41.5 \text{ ohms (approx.)}$$

Ans. 41.5 ohms.

Example.—If the resistance of a wire of a certain length and having a cross-sectional area of .0083 square inch is 1.7 ohms, what would be its resistance if the area of its cross-section were .092 square inch?

Solution.—Since increasing the cross-sectional area of a wire decreases its resistance, we have the proportion,

$$\text{required resist.} : 1.7 :: .0083 : .092$$

or,
$$\frac{\text{required resist.}}{1.7} = \frac{.0083}{.092}$$

Hence,
$$\text{required resist.} = 1.7 \times \frac{.0083}{.092}$$
$$= .15 \text{ ohm (approx.)}$$

Ans. .15 ohm.

As the area of a circle is proportional to the square of its diameter, it follows that the resistances of round conductors are inversely proportional to the squares of their diameters.

Example.—The resistance of a certain wire having a diam.

eter of .1 inch is 12.6 ohms. What would be its resistance if the diameter were increased to .32 inch?

Solution. — The resistances being inversely proportional to the squares of the diameters, we have,

$$\text{required resist.} : 12.6 :: .1^2 : .32^2$$

or,
$$\frac{\text{required resist.}}{12.6} = \frac{.1^2}{.32^2}$$

Hence,
$$\text{required resist.} = 12.6 \times \frac{.1^2}{.32^2}$$
$$= \frac{12.6 \times .01}{.1024}$$
$$= 1.23 \text{ ohms (approx.)}$$

Ans. 1.23 ohms.

Specific Resistance. The specific resistance of a substance is the resistance of a portion of that substance of unit length and unit cross-section at a standard temperature. The units commonly used are the centimeter or the inch, and the temperature that of melting ice. The specific resistance may therefore be said to be the resistance (usually stated in microhms) of a centimeter cube or of an inch cube at the temperature of melting ice. If the specific resistances of two substances are known then their relative resistance is given by the ratio of the specific resistances.

Conductivity is the reciprocal of specific resistance.

Example. — A certain copper wire at the temperature of melting ice has a resistance of 29.7 ohms. Its specific resistance (resistance of 1 centimeter cube in microhms) is 1.594, and that of platinum is 9.032. What would be the resistance of a platinum wire of the same size and length of the copper wire, and at the same temperature?

Solution. — The resistance would be in direct ratio of the specific resistances, and we have the proportion:

$$\text{required resist.} : 29.7 :: 9.032 : 1.594$$

Hence,
$$\text{required resist.} = 29.7 \times \frac{9.032}{1.594}$$
$$= 168. \text{ ohms (approx.)}$$

Ans. 168. ohms.

Calculation of Resistance. From the preceding pages it is evident that resistance varies directly as the length, inversely as the cross-sectional area, and depends upon the specific resistance of the material. This may be expressed conveniently by the formula,

$$R = s\frac{L}{A}$$

in which R is the resistance, L the length of the conductor, A the area of its cross section, and s the specific resistance of the material.

Example.— A telegraph relay is wound with 1,800 feet of wire .010 inch in diameter, and has a resistance of 150 ohms. What will be its resistance if wound with 400 feet of wire .022 inch in diameter?

Solution.— If the wires were of equal length, we should have the proportion,

Required resistance : 150 : : $(.010)^2 : (.022)^2$

or, Required resistance $= 150 \times \frac{(.010)^2}{(.022)^2} = 30.99+$ ohms.

For a wire 400 feet long, we have, therefore, by direct proportion,

Required resistance $= \frac{400}{1,800} \times 30.99 = 6.88+$.

Ans. 6.88+ ohms.

If a circuit is made up of several different materials joined in series with each other, the resistance of the circuit is equal to the sum of the resistances of its several parts. In calculating the resistance of such a circuit, the resistance of each part should first be calculated, and the sum of these resistances will be the total resistance of the circuit.

The table on page 9 gives the resistance of chemically pure substances at 0° Centigrade or 32° Fahrenheit in International ohms. The first column of numbers gives the relative resistances when that of annealed silver is taken as unity. For example, mercury has 62.73 times the resistance of annealed silver. The second and third columns give the resistances of a foot of wire .001 inch in diameter, and of a meter of wire 1 millimeter in diameter, respectively. The fourth and fifth columns give respectively the resistance in microhms of a cubic inch and cubic centimeter, that is, the specific resistances.

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Table Showing Relative Resistance of Chemically Pure Substances at Thirty-two Degrees Fahrenheit in International Ohms.

Metal	Relative Resistance.	Resistance of a wire 1 foot long, .001 inch in diameter.	Resistance of a wire 1 meter long, 1 millimeter in diameter.	Resistance in Microhms.	
				Cubic Inch.	Cubic Centimeter.
Silver, annealed.	1.000	9.023	.01911	.5904	1.500
Copper, annealed.	1.063	9.585	.02028	.6274	1.594
Silver, hard drawn.	1.086	9.802	.02074	.6415	1.629
Copper, hard drawn.	1.086	9.803	.02075	.6415	1.629
Gold, annealed.	1.369	12.35	.02613	.8079	2.052
Gold, hard drawn.	1.393	12.56	.02661	.8224	2.088
Aluminum, annealed	1.935	17.48	.03700	1.144	2.904
Zinc, pressed.	3.741	33.76	.07143	2.209	5.610
Platinum, annealed.	6.022	54.34	.1150	3.555	9.032
Iron, annealed.	6.460	58.29	.1234	3.814	9.689
Lead, pressed.	13.05	117.7	.2491	7.706	19.58
German silver.	13.92	125.5	.2659	8.217	20.87
Platinum-silver alloy ($\frac{1}{3}$ platinum, $\frac{2}{3}$ silver.)	16.21	146.3	.3097	9.576	24.32
Mercury.	62.73	570.7	1.208	37.05	94.06

It should be noted that the resistances in the above table are for chemically pure substances, and also at 32° Fahrenheit. A very small portion of foreign matter mixed with a metal greatly increases its resistance. An alloy of two or more metals always has a higher specific resistance than that of any of its constituents. For example, the conductivity of silver mixed with 1.2 per cent in volume of gold, will be 59 when that of pure silver is taken as 100. Annealing reduces the resistance of metals.

The following examples are given to illustrate the use of the table above in connection with the formula at the top of page 8, and to show the application of preceding laws.

Example.—From the specific resistance of annealed aluminum as given in the next to the last column of the table, calculate the resistance given in the second column of figures for that substance.

Solution.—The resistance in microhms of a cubic inch of annealed aluminum at 32° F. is 1.144, which is equal to .000001144 ohms. The resistance of a wire 1 foot long and .001

inch in diameter is required. In the formula on page 8, we have $s = .000001144$, $L = 1$ foot $= 12$ inches and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .001^2}{4} = .0000007854 \text{ sq. in.}$$

Substituting these values in the formula,

$$R = s\frac{L}{A}$$

we have,

$$R = .000001144 \times \frac{12}{.0000007854}$$

$= 17.48$ ohms. Ans. 17.48 ohms.

Example.—The resistance in microhms of a cubic centimeter of annealed platinum at 32° F. is 9.032. What is the resistance of a wire of the same substance one meter long and one millimeter in diameter at the same temperature?

Solution.—In the formula for resistance we have the quantities $s = 9.032$ microhms $= .000009032$ ohms; $L = 1$ meter $=$ 100 centimeters; and

$$A = \frac{\pi d^2}{4} = \frac{3.1416 \times .1^2}{4} = .007854 \text{ sq. cm.}$$

the diameter being equal to 1 millimeter = .1 cm.

Substituting these values we have,

$$R = .000009032 \times \frac{100}{.007854}$$

$= .1150$ ohms. Ans. .115 ohms.

Example.—From the table the resistance of 1 ft. of pure annealed silver wire .001 inch in diameter at 32° F. is 9.023 ohms. What is the resistance of a mile of wire of the same substance .1 inch in diameter at that temperature?

Solution.—As the resistance of wires is directly proportional to their length and inversely proportional to the squares of their diameters, the required resistance is found by multiplying the resistance per foot by 5,280 and the product by the inverse squares of the diameters.

$$\text{Therefore } R = 9.023 \times 5280 \times \left\{ \frac{.001}{.1} \right\}^2$$

$= 4.76$ ohms (approx.)

Ans. 4.76 ohms.

Example.—A mile and one-half of an annealed wire of pure iron has a resistance of 46.1 ohms. What would be the resistance of hard drawn wire of pure copper of the same length and diameter, assuming each to be at the temperature of melting ice?

Solution.—The only factor involved by this example is the relative resistance of the two metals. From the table, page 9, annealed iron has 6.460 and hard-drawn copper 1.086 times the resistance of annealed silver. Hence the resistance of the copper is to that of the iron as 1.086 is to 6.460, and the required resistance is

$$R = 46.1 \times \frac{1.086}{6.460} = 7.75 \text{ ohms (approx.)}$$

Ans. 7.75 ohms.

Example.—If the resistance of a wire 7,423 feet long is 18.7 ohms, what would be its resistance if its length were reduced to 6,253 feet and its cross-section made one half again as large?

Solution.—As resistance is directly proportional to the length, and inversely proportional to the area of the cross-section, the required resistance is

$$R = 18.7 \times \frac{6253}{7423} \times \frac{2}{3} = 10.5 \text{ ohms (approx.)}$$

Ans. 10.5 ohms.

Resistance Affected by Heating. The resistance of metals depends upon the temperature, and the resistance is increased by heating. The heating of some substances, among which is carbon, causes a decrease in their resistance. The resistance of the filament of an incandescent lamp when lighted is only about half as great as when cold. All *metals*, however, have their resistance increased by a rise in temperature. The percentage increase in resistance with rise of temperature varies with the different metals, and varies slightly for the same metal at different temperatures. The increase is practically uniform for most metals throughout a considerable range of temperature. The resistance of copper increases about .4 per cent. per degree Centigrade, or about .22 per cent. per degree Fahrenheit. The percentage increase in resistance for alloys is much less than for the simple metals. Standard resistance coils are therefore made of alloys, as it is desirable that their resistance should be as nearly constant as possible.

The change in resistance of one ohm per degree rise in temperature for a substance is called the *temperature coefficient* for that substance. The following table gives the temperature coefficients for a few substances.

TEMPERATURE COEFFICIENTS.

MATERIAL.	RISE IN R. OF 1 OHM WHEN HEATED: 1° F.	1° C.
Platinoid	.00012	.00022
Platinum-silver	.00014	.00025
German silver	.00022	.00040
Platinum	.0019	.0035
Silver	.0021	.0038
Copper, aluminum	.0022	.0040
Iron	.0026	.0046

If the resistance of a conductor at a certain temperature is known, the resistance the conductor will have at a higher temperature may be found by multiplying the temperature coefficient for the substance, by the number of degrees increase and by the resistance at the lower temperature, and adding to this result the resistance at the lower temperature. The product of the temperature coefficient by the number of degrees increase gives the increase in resistance of one ohm through that number of degrees, and multiplying this by the number of ohms gives the increase in resistance for the conductor. The result obtained is practically correct for moderate ranges of temperature.

The above method of calculating the resistance of conductors at increased temperatures is conveniently expressed by the following formula:

$$R_2 = R_1 \ (1 + a\ t)$$

where R_2 is the resistance at the higher temperature, R_1 that at the lower temperature, a the temperature coefficient for the substance and t the number of degrees change.

From the preceeding formula it follows that if the resistance at the higher temperature is known, that at the lower temperature will be given by the formula:

$$R_1 = \frac{R_2}{1 + at}$$

In calculating resistances at different temperatures, the temperature coefficient based on the Fahrenheit scale should be used if the number of degrees change is given in degrees Fahrenheit, and that based on the Centigrade scale if given in degrees Centigrade.

Example.— The resistance of a coil of German silver wire at 12° C. is 1304 ohms. What would be its resistance at a temperature of 60° C.?

Solution.— From the statement of the example $R_1 = 1304$, $t = 60 - 12 = 48$, and from the table page 12, $a = .0004$. Substituting these values in the first of the preceding formulas we have,

$$\begin{aligned} R_2 &= 1304\ (1 + .0004 \times 48) \\ &= 1304 \times 1.0192 \\ &= 1329 \text{ ohms (approx.)} \end{aligned}$$

Ans. 1329 ohms.

Example. — If the resistance of a copper conductor at 95° F. is 48.2 ohms, what would be the resistance of the same conductor at 40° F.?

Solution. — In this case $R_2 = 48.2$, $t = 95 - 40 = 55$, and from the table $a = .0022$. Substituting these values in the formula at the foot of page 12, we have,

$$\begin{aligned} R_1 &= \frac{48.2}{1 + .0022 \times 55} = \frac{48.2}{1.121} \\ &= 43. \text{ ohms (approx.)} \end{aligned}$$

Ans. 43 ohms.

The first table on page 14 gives the resistance of the most common sizes of copper wire according to the American or Brown and Sharpe (B. & S.) gauge. The resistance given is for pure copper wire at a temperature of 75° F. or 24° C.

The first column gives the number of the wire, the second the diameter in thousandths of an inch or mils, and the third the diameter in millimeters. The fourth column gives the equivalent number of wires each one mil or one thousandth of an inch in diameter. This is called the size of the wire in circular mils and is equal to the square of the diameter in mils. The fifth column gives the ohms per thousand feet and the resistance per mile is found by multiplying these values by 5.28. Ordinary commercial copper has a conductivity of about 95 to 97 per cent. of that of pure copper. The resistance of commercial wire is therefore about 3 to 5 per cent. greater than the values given in the table. The resistance for any metal other than copper may be found by multiplying the resistance given in the table by the ratio of the specific resistance of the given metal to the specific resistance of copper.

American Wire Gauge (B. & S.)

No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.	No.	Diameter in		Circular Mils.	Ohms per 1000 Ft.
	Mils.	Millim.				Mils.	Millim.		
0000	460.00	11.684	211600.0	.051	19	35.89	.912	1288.0	8.617
000	409.64	10.405	167805.0	.064	20	31.96	.812	1021.5	10.566
00	364.80	9.266	133079.4	.081	21	28.46	.723	810.1	13.323
0	324.95	8.254	105592.5	.102	22	25.35	.644	642.7	16.799
1	289.30	7.348	83694.2	.129	23	22.57	.573	509.5	21.185
2	257.63	6.544	66373.0	.163	24	20.10	.511	404.0	26.713
3	229.42	5.827	52634.0	.205	25	17.90	.455	320.4	33.684
4	204.31	5.189	41742.0	.259	26	15.94	.405	254.0	42.477
5	181.94	4.621	33102.0	.326	27	14.19	.361	201.5	53.563
6	162.02	4.115	26250.5	.411	28	12.64	.321	159.8	67.542
7	144.28	3.665	20816.0	.519	29	11.26	.286	126.7	85.170
8	128.49	3.264	16509.0	.654	30	10.03	.255	100.5	107.391
9	114.43	2.907	13094.0	.824	31	8.93	.227	79.7	135.402
10	101.89	2.588	10381.0	1.040	32	7.95	.202	63.2	170.765
11	90.74	2.305	8234.0	1.311	33	7.08	.180	50.1	215.312
12	80.81	2.053	6529.9	1.653	34	6.30	.160	39.7	271.583
13	71.96	1.828	5178.4	2.084	35	5.61	.143	31.5	342.443
14	64.08	1.628	4106.8	2.628	36	5.00	.127	25.0	431.712
15	57.07	1.450	3256.7	3.314	37	4.45	.113	19.8	544.287
16	50.82	1.291	2582.9	4.179	38	3.96	.101	15.7	686.511
17	45.26	1.150	2048.2	5.269	39	3.53	.090	12.5	865.046
18	40.30	1.024	1624.1	6.645	40	3.14	.080	9.9	1091.865

The following table gives the size of the English or Birmingham wire gauge. The B. & S. is however much more frequently used in this country. The Brown and Sharpe gauge is a little smaller than the Birmingham for corresponding numbers.

Stubs' or Birmingham Wire Gauge (B. W. G.)

No.	Diameter in		No.	Diameter in		No.	Diameter in	
	Mils.	Millim.		Mils.	Millim.		Mils.	Millim.
0000	454	11.53	8	165	4.19	18	49	1.24
00	380	9.65	10	134	3.40	20	35	0.89
1	300	7.62	12	109	2.77	24	22	0.55
4	238	6.04	14	83	2.11	30	12	0.31
6	203	5.16	16	65	1.65	36	4	0.10

EXAMPLES FOR PRACTICE.

1. What is the resistance of an annealed silver wire 90 feet long and .2 inch in diameter at 32° F.? Ans. .02+ ohm.

2. What is the resistance of 300 meters of annealed iron wire 4 millimeters in diameter when at a temperature of 0° C.?
Ans. 2.31+ ohms.

3. What is the resistance of 2 miles of No. 27 (B. & S.) pure copper wire at 75° F.? Ans. 565.+ ohms.

4. The resistance of a piece of copper wire at 32°F. is 3 ohms. What is its resistance at 49°F.? Ans. 3.11+ ohms.

5. The resistance of a copper wire at 52°F. is 7 ohms. What is its resistance at 32°F.? Ans. 6.70+ ohms.

6. What is the resistance of 496 ft. of No. 10 (B. & S.) pure copper wire at 45°F.? Ans. .483+ ohms.

On pages 16 and 17 is given a table disclosing among other data the resistance of various primary cells. The resistance of a circuit of which a battery forms a part, is made up of the external resistance, or the resistance of outside wires and connections, and the internal resistance, or the resistance of the battery itself. The table referred to gives in the first column the name of the cell. In the second and third column appears the name of the anode and kathode respectively. These terms are commonly used with reference to electrolysis but may also be applied to primary cells. The current passes from the anode to the kathode through the cell, and therefore with reference to the cell itself, the anode may be considered the positive element and the kathode the negative element. In regard to the outside circuit however, the current passes of course, from the kathode to the anode, and hence with reference to the outside circuit the kathode is positive and the anode negative; ordinarily the external circuit is considered. As the anode of almost all primary cells is zinc it may readily be remembered that the current passes from the other element *to* the zinc through the *external* circuit. The fourth and fifth columns of the table give the excitant and depolarizer respectively. The sixth column gives the E. M. F. of each cell when it is supplying no current, and the last column gives the internal resistance in ohms.

TABLE IN RELATION TO PRIMARY CELLS, ELECTROMOTIVE FORCE, RESISTANCE, ETC.

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARIZER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Volta (Wollaston, etc.)	Zinc	Copper	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Smee	Zinc	Platinized Silver	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	0.5
Law	Zinc	Carbon	Solution of Sulphuric Acid (H_2SO_4)	None	1 to 0.5	
Poggendorff (Grenet)	Zinc	Graphite (Carbon)	Solution of Sulphuric Acid (H_2SO_4)	Potassium Dichromate ($K_2Cr_2O_7$)	2.1	
Poggendorff (Grenet) two fluid	Zinc	Graphite (Carbon)	Saturated Solution of Potassium Dichromate and Sulphuric Acid	None Separate	1.93	.001 to .08
Grove	Zinc	Platinum	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid (HNO_3)	1.96	0.1 to 0.12
Bunsen	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Nitric Acid	1.8 to 1.98	0.08 to 0.11
				Chromic Acid	1.8	0.1 to 0.12
Leclanche	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Manganese Dioxide (MnO_2)	1.4 to 1.6	1.13 to 1.15
Lalande Lalande—Chaperon	Zinc	Graphite (Carbon)	Caustic Potash or Potassium Hydrate (KOH)	Cupric Oxide	0.8 to 0.98	1.3
Upward	Zinc	Graphite (Carbon)	Zinc Chloride ($ZnCl_2$)	Chlorine (Cl)	2.0	
Fitch	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl)	Sodium & Potassium Chlorates ($NaClO_3$ + $KClO_3$)	1.1	
Papst	Iron	Graphite (Carbon)	Ferric Chloride (Fe_2Cl_6)	(Fe_2Cl_6)	0.4	
Obach (dry)	Zinc	Graphite (Carbon)	Ammonium Chloride (NH_4Cl) in Calcium Sulphate ($CaSO_4$)	Manganese Dioxide (MnO_2)	1.46	
Daniell (Meidinger Minotto, etc.)	Zinc	Copper	Zinc Sulphate ($ZnSO_4$)	Copper Sulphate ($CuSO_4$)	1.079	2 to 5
De la Rue	Zinc	Silver	Ammonium Chloride	Silver Chloride (AgCl)	1.03 to 1.42	0.4 to 0.6
Marie Davy	Zinc	Graphite (Carbon)	Sulphuric Acid dilute (H_2SO_4)	Paste of Sulphate of Mercury (Hg_2SO_4)	1.52	0.75 to 1
Clark (Standard)	Zinc	Mercury	Zinc Sulphate ($ZnSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.434*	0.3 to 0.5
Weston	Cadmium	Mercury	Cadmium Sulphate ($CdSO_4$)	Mercurous Sulphate (Hg_2SO_4)	1.025	

NAME OF CELL.	ANODE.	KATHODE.	EXCITANT.	DEPOLARIZER.	E. M. F. IN VOLTS.	INTERNAL RESISTANCE IN OHMS.
Von Helmholtz	Zinc	Mercury	Zinc Chloride ($Zn\,Cl_2$)	Mercurous Chloride ($Hg_2\,Cl_2$)	1.0	
Chromic Acid single fluid	Zinc	Graphite (Carbon)	Sulphuric and Chromic Acids, dilute mixed	None Separate	2.3	.016 to .08
Fuller	Zinc	Graphite (Carbon)	Sulphuric Acid ($H_2\,SO_4$)	Potassium Dichromate ($K_2\,Cr_2\,O_7$)	2.0	0.5 to 0.7
Gaiffe	Zinc	Silver	Zinc Chloride ($Zn\,Cl_2$)	Silver Chloride ($Ag\,Cl$)	1.02	0.5 to 0.6
Maiche	Zinc scraps in bath of Mercury	Platinized Carbon	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	None Separate	1.25	1 to 2
Niaudet	Zinc	Graphite (Carbon)	Common Salt Solution *i. e.* Sodium Chloride ($NaCl$)	Chloride of Calcium (Lime) ($Ca\,Cl_2$)	1.0 to 1.6	5 to 6
Schanschieff	Zinc	Graphite (Carbon)	Mercurial Solution	None Separate	1.56	0.05 to 0.75
Skrivanoff	Zinc	Silver	Caustic Potash or Potassium Hydrate (KOH)	Chloride of Silver ($Ag\,Cl$)	1.5	1.5

* At 15 degrees Centigrade or 59 degrees Fahrenheit.

Resistances in last column measured in cells standing 6″ × 4″

OHM'S LAW.

One of the most important and most used laws of electricity is that first formulated by Dr. G. S. Ohm, and known as Ohm's law. This law is as follows:

The current is directly proportional to the electromotive force and inversely proportional to the resistance.

That is, if the electromotive force applied to a circuit is increased, the current will be increased in the same proportion, and if the resistance of a circuit is increased then the current will be decreased proportionally. Likewise a decrease in the electromotive force causes a proportional decrease in current and a decrease in resistance causes a proportional increase in current. The current depends only upon the electromotive force and resistance and in the manner expressed by the above simple law. The law may be expressed algebraically as follows:

$$\text{current } \textit{varies as } \frac{\text{electromotive force}}{\text{resistance}}$$

The units of these quantities, the ampere, volt and ohm, have been so chosen that an electromotive force of 1 volt applied to a resistance of 1 ohm, causes 1 ampere of current to flow. Ohm's law may therefore be expressed by the following equation:

$$I = \frac{E}{R}$$

where I is the current in amperes, E the electromotive force in volts and R the resistance in ohms.

It is therefore evident, that if the electromotive force and resistance are known the current may be found, or if any two of the three quantities are known the third may be found. If the current and resistance are known the electromotive force may be found from the formula:

$$E = R\,I$$

and if the current and electromotive force are known, the resistance may be found from the formula:

$$R = \frac{E}{I}$$

Simple Applications. The following examples are given to illustrate the simplest applications of Ohm's law.

Example.—If the E.M.F. applied to a circuit is 4 volts and its resistance is 2 ohms, what current will flow?

Solution.—By the formula for current,

$$I = \frac{E}{R} = \frac{4}{2} = 2 \text{ amperes.}$$

Ans. 2 amperes.

Example.—What voltage is necessary to cause a current of 23 amperes to flow through a resistance of 820 ohms?

Solution.—By the formula for E.M.F.,

$$E = RI = 820 \times 23 = 18{,}860 \text{ volts.}$$

Ans. 18,860 volts.

Example.—The E.M.F. applied to a circuit is 110 volts, and it is desired to obtain a current of .6 ampere. What should be the resistance of the circuit?

Solution.—By the formula for resistance,

$$R = \frac{E}{I} = \frac{110}{.6} = 183. + \text{ ohms.}$$

Ans. 183 ohms.

Series Circuits. A circuit made up of several parts all joined in series with each other, is called a series circuit and the resistance of the entire circuit is of course the sum of the separate resistances. In calculating the current in such a circuit the total resistance must first be obtained, and the current may then be found by dividing the applied or total E.M.F. by the total resistance. This is expressed by the formula,

$$I = \frac{E}{R_1 + R_2 + R_3 + \text{etc.}}$$

Example. — Three resistance coils are connected in series with each other and have a resistance of 8, 4 and 17 ohms respectively. What current will flow if the E.M.F. of the circuit is 54 volts?

Solution. — By the preceding formula,

$$I = \frac{E}{R_1 + R_2 + R_3} = \frac{54}{8 + 4 + 17} = \frac{54}{29} = 1.8+ \text{ amperes.}$$

Ans. 1.8+ amperes.

Example. — Six arc lamps, each having a resistance of 5 ohms, are connected in series with each other and the resistance of the connecting wires and other apparatus is 3.7 ohms. What must be the pressure of the circuit to give a desired current of 9.6 amperes?

Solution. — The total resistance of the circuit is $R = (6 \times 5) + 3.7 = 33.7$ ohms and the current is to be $I = 9.6$ amperes, Hence by the formula for E.M.F.,

$$E = R\,I = 33.7 \times 9.6 = 323.+ \text{ volts.}$$

Ans. 323.+ volts.

Example. — The current passing in a certain circuit was 12 amperes and the E.M.F. was 743 volts. The circuit was made up of 4 sections all connected in series, and the resistance of three sections was 16, 9 and 26 ohms respectively. What was the resistance of the fourth section?

Solution. — Let x = the resistance of the fourth section, then $R = 16 + 9 + 26 + x = 51 + x$, $I = 12$, and $E = 743$. By the formula for resistance,

$$R = \frac{E}{I} \text{ or, } \quad 51 + x = \frac{743}{12} = 61.9 \text{ ohms (approx.)}$$

If $51 + x = 61.9$ we have, by transposing 51 to the other side of the equation,

$$x = 61.9 - 51 = 10.9 \text{ ohms.}$$

Ans. 10.9 ohms.

Example. — A current of 54 amperes flowed through a circuit when the E.M.F. was 220 volts. What resistance should be added in series with the circuit to reduce the current to 19 amperes?

Solution. — The resistance in the first case was,

$$R = \frac{220}{54} = 4.07 \text{ ohms (approx.)}$$

The resistance in the second must be,

$$R = \frac{220}{19} = 11.58 \text{ ohms (approx.)}$$

The required resistance to insert in the circuit is the difference of these two resistances, or $11.58 - 4.07 = 7.51$ ohms.

Ans. 7.51 ohms.

Fall of Potential in a Circuit. Fig. 1 illustrates a series circuit in which the resistances A, B, C, D and E are connected in series with each other and with the source of electricity. If the E. M. F. is known, the current may be found by dividing the E. M. F. by the sum of all the resistances. Ohm's law may, however, be applied to any part of a circuit separately, as well as to the complete circuit. Suppose the resistances of A, B, C, D and E are 4, 3, 6, 3 and 4 ohms respectively, and assume that the source has no resistance. Suppose the current flowing to be 12 amperes. The E. M. F. necessary to force a current of 12 amperes through the resistance A of 4 ohms is, by applying Ohm's law, equal to $E = RI = 4 \times 12 = 48$ volts. Hence between the points a and b outside of the resistance A, there must be a difference of potential of 48 volts to force the current through this resistance. Also to force the same current through B, the voltage necessary is $3 \times 12 = 36$. Similarly, for each part C, D and E, there are required 72, 36 and 48 volts respectively.

As 48 volts are necessary for part A and 36 volts for part B, it is evident that to force the current through both parts a difference of potential of $48 + 36 = 84$ volts is required; that is, the voltage between the points *a* and *c* must be 84 volts. For the three parts *A*, *B* and *C*, 48 + 36 + 72 = 156 volts are necessary, and for the entire circuit, 240 volts must be applied to give the current of 12 amperes. From the above it is evident that there is a gradual fall of potential throughout the circuit, and if the voltage between any two points of the circuit be measured, the E. M. F. obtained would depend upon the resistance included between these two points. For example, the voltage between points *b* and *d* would be found to be 72 + 36 = 108 volts, or between *d* and *e* 36, volts, etc. From the preceding it is apparent that the fall of potential in a part of a circuit is equal to the current multiplied by the resistance of that part.

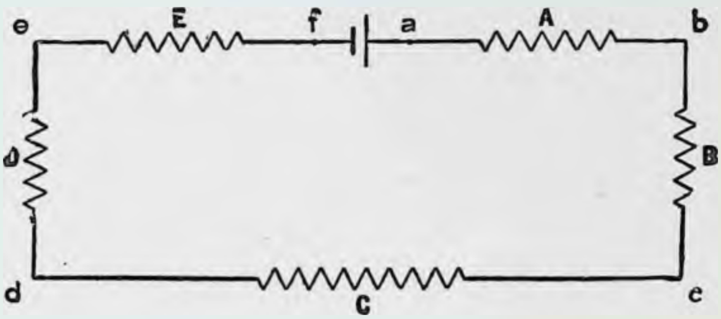


Fig. 1.

This gradual fall of potential, or *drop* as it is commonly called, throughout a circuit, enters into the calculations for the size of conductors or mains supplying current to distant points. The resistances of the conductors cause a certain drop in transmitting the current, depending upon their size and length, and it is therefore necessary that the voltage of machines at the supply station shall be great enough to give the voltage necessary at the receiving stations as well as the additional voltage lost in the conducting mains.

For example, in Fig. 1 the voltage necessary between the points *e* and *b* is 144 volts, but to give this voltage the source must supply in addition the voltage lost in parts *A* and *E*, which equals 96 volts.

Example.—The voltage required by 17 arc lamps connected in series is 782 volts and the current is 6.6 amperes. The resist ance of the connecting wires is 7 ohms. What must be the E. M. F. applied to the circuit?

Solution.—The drop in the connecting wires is $E = R\,I = 7 \times 6.6 = 46.2$ volts. The E. M. F. necessary is therefore $782 + 46.2 = 828.2$ volts. Ans. 828.2 volts.

Example.—The source of E. M. F. supplies 114 volts to a circuit made up of incandescent lamps and conducting wires. The lamps require a voltage of 110 at their terminals, and take a current of 12 amperes. What should be the resistance of the conducting wires in order that the lamps will receive the necessary voltage?

Solution.—The allowable drop in the conducting wires is $114 - 110 = 4$ volts. The current to pass through the wires is 12 amperes. Hence the resistance must be

$$R = \frac{E}{I} = \frac{4}{12} = .33 + \text{ohms.}$$

Ans. .33 + ohms.

Divided Circuits. When a circuit divides into two or more parts, it is called a *divided* circuit and each part will transmit a portion of the current.

Such a circuit is illustrated in Fig. 2, the two branches being represented by *b* and *c*. The current passes from the positive pole of the battery through *a* and then divides; part of the current passing through *b* and part through *c*. The current then unites and passes through *d* to the negative pole of the battery. The part *c* may be considered as the main part of the circuit and *b* as a by-pass about it. A branch which serves as a by-pass to another circuit is called a *shunt* circuit, and the two branches are said to be connected in *parallel*.

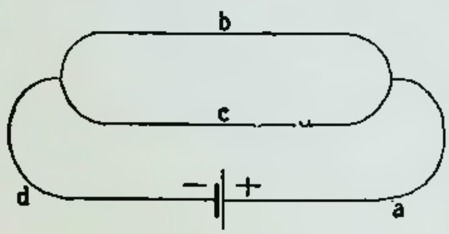


Fig. 2.

In considering the passage of a current through a circuit of this sort, it may be necessary to determine how much current will pass through one branch and how much through the other. Evidently this will depend upon the relative resistance of the two branches, and more current will pass through the branch offering the lesser resistance than through the branch having the higher resistance. If the two parts have equal resistances, then one half of the total current will pass through each branch. If one branch has twice the resistance of the other, then only one-half as much of the total current will pass through that branch as through the other; that is, $\frac{1}{3}$ of the total current will pass through the first branch and the remaining $\frac{2}{3}$ will pass through the second.

The relative strength of current in the two branches will be inversely proportional to their resistances, or directly proportional to their conductances.

Suppose the resistance of one branch of a divided circuit is r_1 (see Fig. 3), and that of the other is r_2. Then by the preceding law,

$$\text{current in } r_1 : \text{current in } r_2 :: r_2 : r_1$$

Also,

$$\text{current in } r_1 : \text{total current} :: r_2 : r_1 + r_2$$

and

$$\text{current in } r_2 : \text{total current} :: r_1 : r_1 + r_2$$

Let I represent the total current, i_1 the current through the resistance r_1 and i_2 the current through the resistance r_2. Then the two preceding proportions are expressed by the following formulas:

$$i_1 = \frac{I r_2}{r_1 + r_2} \quad \text{and} \quad i_2 = \frac{I r_1}{r_1 + r_2}$$

Example.—The total current passing in a circuit is 24 amperes. The circuit divides into two branches having resistances of 5 and 7 ohms respectively. What is the current in each branch?

Solution.—In this case $I = 24$, $r_1 = 5$ and $r_2 = 7$. Substituting these values in the above formulas we have,

$$i_1 = \frac{I r_2}{r_1 + r_2} = \frac{24 \times 7}{5 + 7} = 14 \text{ amperes.}$$

and

$$i_2 = \frac{I r_1}{r_1 + r_2} = \frac{24 \times 5}{5 + 7} = 10 \text{ amperes.}$$

Ans. { In 5 ohm branch, 14 amperes.
In 7 ohm branch, 10 amperes.

Joint Resistance of Divided Circuits. As a divided circuit offers two paths to the current, it follows that the joint resistance of the two branches will be less than the resistance of either branch alone. The ability of a circuit to conduct electricity is represented by its conductance, which is the reciprocal of resistance; and the conductance of a divided circuit is equal to the sum of the conductances of its parts.

For example, in Fig. 3, the conductance of the upper branch equals $\frac{1}{r_1}$ and that of the lower branch equals $\frac{1}{r_2}$. If R represents the joint resistance of the two parts then the joint conductance equals:

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} = \frac{r_1 + r_2}{r_1 r_2}$$

Having thus obtained the joint conductance, the joint resistance is found by taking the reciprocal of the conductance, that is,

$$R = \frac{r_1 r_2}{r_1 + r_2}$$

This formula may be stated as follows:

The joint resistance of a divided circuit is equal to the product of the two separate resistances divided by their sum.

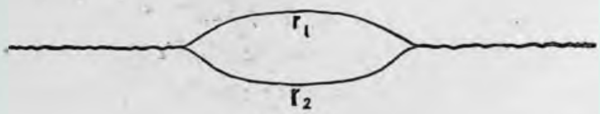


Fig. 3.

For example, suppose the resistance of each branch to be 2 ohms. The conductance of the circuit will be,

$$\frac{1}{R} = \frac{1}{2} + \frac{1}{2} = 1, \text{ and hence } R = 1 \text{ ohm.}$$

Also by the preceding formula,

$$R = \frac{2 \times 2}{2 + 2} = 1 \text{ ohm.}$$

The resistance of a divided circuit in which each branch has a resistance of 2 ohms is therefore 1 ohm.

Example.—The resistances of two separate conductors are 3

WIRE CHIEF'S DESK FOR AUTOMATIC EQUIPMENT

and 7 ohms respectively. What would be their joint resistance if connected in parallel?

Solution.—In this case $r_1 = 3$ and $r_2 = 7$, hence by the formula,

$$R = \frac{3 \times 7}{3 + 7} = 2.1 \text{ ohms.} \qquad \text{Ans. } 2.1 \text{ ohms.}$$

Suppose, as illustrated in Fig. 4, the conductors having resistances equal to r_1, r_2 and r_3 respectively, are connected in

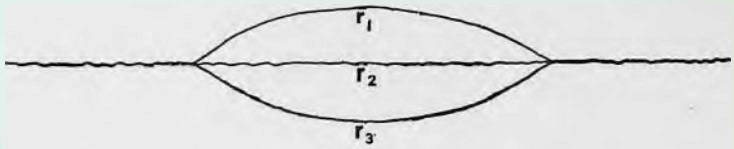


Fig. 4.

parallel. The joint total conductance will then be equal to,

$$\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} = \frac{r_2\,r_3 + r_1\,r_3 + r_1\,r_2}{r_1\,r_2\,r_3}$$

and as the joint resistance is the reciprocal of the joint conductance, the joint resistance R of the three branches is expressed by the formula,

$$R = \frac{r_1\,r_2\,r_3}{r_2\,r_3 + r_1\,r_3 + r_1\,r_2}$$

Example.—What is the joint resistance when connected in parallel, of three wires whose respective resistances are 41, 52 and 29 ohms respectively?

Solution.—In this case $r_1 = 41$, $r_2 = 52$ and $r_3 = 29$. Hence, by the preceding formula,

$$R = \frac{41 \times 52 \times 29}{52 \times 29 + 41 \times 29 + 41 \times 52} = 12.8 + \text{ohms.}$$

Ans. 12.8 + ohms.

In general, for any number of conductors connected in parallel, the joint resistance is found by taking the reciprocal of the sum of the reciprocals of the separate resistances.

Example.—A circuit is made up of five wires connected in parallel, and their separate resistances are respectively 12, 21, 28, 8 and 42 ohms. What is the joint resistance?

Solution.—The sum of the conductances is:

$$\frac{1}{12}+\frac{1}{21}+\frac{1}{28}+\frac{1}{8}+\frac{1}{42}=\frac{53}{168}$$

Hence the joint resistance equals:

$$R=\frac{168}{53}=3.1+\text{ ohms.}$$ Ans. 3.1 + ohms.

If the resistance of each branch is known and also the potential difference between the points of union, then the current in each branch may be found by applying Ohm's law to each branch separately. For example, if this potential difference were 96 volts, and the separate resistances of the 4 branches were 8, 24, 3 and 48 ohms respectively, then the current in the respective branches would be 12, 4, 32 and 2 amperes respectively.

If the current in each branch is known and also the potential difference between the points of union, then the resistance of each branch may likewise be found from Ohm's law.

The following examples are given to illustrate the application of the preceding principles.

EXAMPLES FOR PRACTICE.

1. Two conductors having resistances of 71 and 19 ohms respectively are connected in parallel, and the total current passing in the circuit is 37 amperes. What current passes in the conductor whose resistance is 71 ohms? Ans. 7.8 + amperes.

2. What is the joint resistance of two wires connected in parallel if their separate resistances are 2 and 8 ohms respectively? Ans. 1.6 ohms.

3. What is the joint resistance of three wires when connected in parallel, whose separate resistances are 5, 7 and 9 ohms respectively? Ans. 2.2 + ohms.

4. Three wires, the respective resistances of which are 8, 10 and 20 ohms, are joined in parallel. What is their joint resistance? Ans. 3.6 + ohms.

5. Four wires are joined in parallel, and their separate resistances are 2, 4, 6 and 9 ohms respectively. What is the joint resistance of the conductor thus formed? Ans. .97 + ohm.

Battery Circuits. Fig. 5 illustrates a simple circuit having a single cell C connected in series with a resistance. This is the customary manner of representing a cell, the short, heavy line representing the zinc and the long light line representing the copper or carbon plate. In determining the amount of current which will flow in such a circuit, the total resistance of the circuit must be considered. This is made up of the external resistance R and the internal resistance r, or the resistance of the cell itself. If E represents the total E.M.F. of the cell, then the current I which will flow is expressed by the formula,

$$I = \frac{E}{R + r}$$

It has been shown that whenever a current passes through any resistance, there is always a certain *drop* or fall of potential. The total E.M.F. above referred to, expresses the total potential difference between the plates of the cell and is the E.M.F. of the cell on *open* circuit. When the current flows, however, there is a fall of potential or loss of voltage within the cell itself, and hence the E.M.F. of the cell on closed circuit is less than on open circuit. That is, if the voltage be measured when the cell is supplying current, it will be found to be less than when the voltage is measured on open circuit, or when the cell is supplying no current. The voltage on closed circuit is that available for the external circuit, and is therefore called the *external* or *available* voltage or E.M.F.

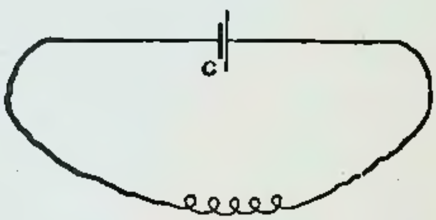


Fig. 5.

The external E.M.F. depends of course upon the strength of current the cell is supplying, and may be calculated as follows:

If the current passing is I and the resistance of the cell is r, then from Ohm's law the voltage lost in the cell equals $r\,I$. If E represents the total E.M.F. of the cell and E_1 the external E.M.F., then,

$$E_1 = E - r\,I$$

The E. M. F. of a cell is understood to be the total E. M. F. unless otherwise stated.

When two or more cells are interconnected they are said to form a *battery*.

Fig. 6 illustrates three cells connected in series with each other and with the external circuit. That is, the positive terminal of one cell is connected to the negative of the next, and the positive of that cell to the negative of the adjacent, etc. By this method of connecting, the E. M. F. of each cell is added to that of the others, so that the total E. M. F. of the circuit is three times that of a single cell. If one of the cells were connected so that its E. M. F. opposed that of the other two, it would offset the E. M. F. of one of the cells and the resultant E. M. F. would be that of a single cell. The connecting of cells in series as in

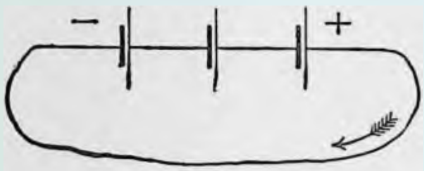


Fig. 6.

Fig. 6 not only increases the E. M. F. of the circuit but also increases the internal resistance, the resistance of each cell being added to that of the others. If E equals the E. M. F. of each cell, r the internal resistance of each and R the external resistance, then the current that will flow is expressed by the formula,

$$I = \frac{3\,E}{R + 3\,r}$$

or for n cells connected in series the formula for current is,

$$I = \frac{n\,E}{R + n\,r}$$

Fig. 7 illustrates two cells connected in parallel, and supplying current to an external circuit. Here the two positive terminals are connected with each other and also the two negative. The E. M. F. supplied to the circuit is equal to that of a single cell only. In

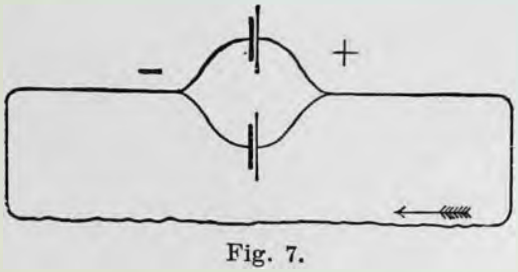


Fig. 7.

fact connecting cells in parallel, is equivalent to enlarging the plates, and the only effect is to decrease the internal resistance It is evident that coupling two cells in parallel affords two paths for the current and so decreases the resistance of the two cells to one-half that of a single cell. The formula expressing the current that would flow in the external circuit with two cells in parallel is therefore,

$$I = \frac{E}{R + \frac{r}{2}}$$

or for n cells connected in parallel, the formula for current is,

$$I = \frac{E}{R + \frac{r}{n}}$$

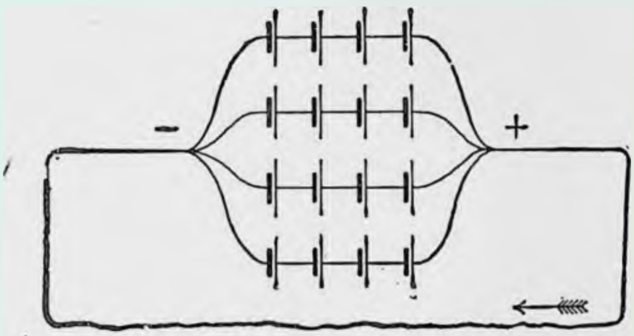


Fig. 8.

Fig. 8 represents a combination of the series and parallel method of connecting and represents four files of cells joined in parallel and each file having four cells connected in series. The E. M. F. of each file and consequently of the circuit is $4\,E$. The resistance of each file is $4\,r$ and that of all the files $\frac{4\,r}{4}$. Hence. the formula for current is,

$$I = \frac{4\,E}{R + \frac{4r}{4}}$$

If there were n files connected in parallel and m cells were connected in series in each file, the formula expressing the current in the external circuit would be,

$$I = \frac{m\,E}{R + \frac{m\,r}{n}}$$

where E is the E. M. F. of each cell, R the external resistance, and r the internal resistance of each cell.

The most advantageous method of connecting cells depends upon the results desired, the resistance of the cell and the external resistance. Suppose it is desired to pass a current through an external resistance of 2 ohms, and that Daniell's cells are to be used each having an E. M. F. of 1 volt and an internal resistance of 3 ohms.

With one cell only in circuit, the current will be,

$$\frac{E}{R + r} = \frac{1}{2 + 3} = .2 \text{ ampere,}$$

and with 5 cells all in series the current will be,

$$\frac{5\,E}{R + 5\,r} = \frac{5}{2 + 15} = .3 \text{ ampere (approx).}$$

Therefore with 5 cells in series the current is only .1 ampere greater than with a single cell, and with 100 cells in series the current is only,

$$\frac{100\,E}{R + 100\,r} = \frac{100}{2 + 300} = .33 \text{ ampere.}$$

Hence with a comparatively low external resistance, there is but little gain in current strength by the addition of cells in series. This is due to the fact that, although the E. M. F. is increased 1 volt by each cell, the resistance is increased by 3 ohms.

Now suppose 5 Daniell cells to be connected in parallel with the external circuit of 2 ohms. The E. M. F. of the circuit will then be that of a single cell and the current will be,

$$\frac{E}{R + \frac{r}{5}} = \frac{1}{2 + \frac{3}{5}} = .4 \text{ ampere (nearly),}$$

and with 100 cells connected in parallel the current will be,

$$\frac{E}{R + \frac{r}{100}} = \frac{1}{2 + \frac{3}{100}} = .5 \text{ ampere (nearly).}$$

A larger current is therefore obtained in this case by connecting the cells in parallel than by connecting them in series.

With a large external resistance on the other hand, a larger current is obtained by connecting the cells in series. For example, suppose the external resistance to be 500 ohms. One cell will then give a current of .00198 + ampere, and 5 cells in series will give about .0097 ampere, whereas 100 cells will give .125 ampere. With 5 cells connected in parallel the current will be .00199 + ampere, and with 100 cells the current will amount to approximately .002 ampere. With an external resistance of 500 ohms, there is practically no advantage in connecting the cells in parallel. The only effect of the latter method is to decrease the internal resistance which is almost negligible in comparison with the external resistance.

It may be shown mathematically that for a given external resistance and a given number of cells, the largest current is obtained when the internal resistance is *equal* to the external resistance. In order to obtain this result the values of m and n in the formula on page 30, should be so chosen that $\frac{m\,r}{n}$ equals R. This arrangement, although giving the largest current strength, is not the most economical. With the internal resistance equal to the external resistance there is just as much energy used up in the battery itself as is expended usefully in the external circuit.

In order to obtain the most economical arrangement, the internal resistance should be made as small as possible, that is, all the cells should be connected in parallel. The loss of power in the battery is then the smallest amount possible.

In order to obtain the quickest action of the current the cells should be connected in series. When the external circuit possesses considerable self-induction, as is the case when electromagnets are connected in the circuit, the action of the current is retarded.

This retardation may be decreased by having a high internal resistance, which is obtained by connecting the cells in series.

Example.—Sixteen cells, each having an internal resistance of .1 ohm are to be connected with a circuit whose resistance is .4 ohm. How should the cells be connected to obtain the greatest current?

Solution.—Here the external resistance R, equals .4 ohm and the resistance r of each cell equals .1 ohm. For maximum current,

$$\frac{m\,r}{n} = R, \text{ or } \frac{.1\,m}{n} = .4$$

Therefore, $$m = 4\,n$$

and as $m\,n = 16$, the only values of m and n which will be true for both of these equations are $m = 8$ and $n = 2$. Hence there must be 2 files of cells, with 8 cells in series in each file.

Ans. 2 files, 8 cells in each.

Example.—The external resistance in a circuit is 4 ohms. The cells used each have an E. M. F. of 1.2 volts and an internal resistance of 3.8 ohms. If 20 cells were used, which method of connecting would supply the larger current, — 5 files with 4 cells in series, or 4 files with 5 cells in series?

1st Solution.—Applying the formula on page 30, we have $R = 4$, $E = 1.2$, $r = 3.8$ and with 5 files and 4 in series, $m = 4$ and $n = 5$. Hence, the current is,

$$\frac{m\,E}{R + \frac{m\,r}{n}} = \frac{4 \times 1.2}{4 + \frac{4 \times 3.8}{5}} = .681 + \text{ampere.}$$

With 4 files and 5 cells in series, $m = 5$ and $n = 4$. Hence the current is,

$$\frac{5 \times 1.2}{4 + \frac{5 \times 3.8}{4}} = .685 + \text{ampere.}$$

The larger current is therefore supplied by having 4 files with 5 cells in series. Ans. 4 files, with 5 cells in series.

2nd Solution.—The maximum current is supplied when the internal resistance equals the external resistance or when

$$\frac{m\,r}{n} = R.$$

With 5 files and 4 cells in series,

$$\frac{m\,r}{n} = \frac{4 \times 3.8}{5} = 3.04 \text{ ohms},$$

and with 4 files and 5 cells in series,

$$\frac{m\,r}{n} = \frac{5 \times 3.8}{4} = 4.75 \text{ ohms}.$$

The latter value is nearer to 4 ohms, which is the external resistance, than is 3.04, hence the larger current will be supplied with 4 files and 5 cells in series. Ans. 4 files, with 5 cells in series.

Example.—It is desired to pass a current of .025 ampere through an external resistance of 921 ohms. The cells are to be connected in series and each has an E. M. F. of .8 volt and an internal resistance of 1.3 ohms. What number of cells must be used?

Solution.—From page 28, the general formula for cells in series is,

$$I = \frac{n E}{R + n\,r}$$

and in this case $I = .025$, $E = .8$, $R = 921$ and $r = 1.3$. Substituting these values gives,

$$.025 = \frac{n\,.8}{921 + n\,1.3}$$

Multiplying by $921 + 1.3\,n$ gives

$$23.025 + .0325\,n = .8\,n$$

Transposing $.0325\,n$ gives

$$.8\,n - .0325\,n = 23.025$$

or $$.7675\,n = 23.025$$

hence, $$n = 30$$

Ans. 30 cells.

EXAMPLES FOR PRACTICE.

1. Ten cells in series have an E. M. F. of 1 volt each and an internal resistance of .2 ohm. The external resistance is 3 ohms. What is the current? Ans. 2 amperes.

2. Six cells, each of which has an E. M. F. of 1.2 volts and a resistance of 2 ohms, are connected in parallel. With an external resistance of 10 ohms, what is the current? Ans. .116 + ampere.

3. What is the current supplied by the same cells if joined in series and the external resistance is 20 ohms?

Ans. .225 ampere.

4. A single cell whose E. M. F. on open circuit is 1.41 volts and whose internal resistance is .5 ohm is supplying a current of .3 ampere. What is the available E. M. F. of the cell?

Ans. 1.26 volts.

5. What would be the available E. M. F. with 8 of the cells referred to in example 4, when connected in series and supplying the same current? Ans. 10.08 volts.

6. Eight Daniell cells (E. M. F. = 1.05, resistance = 2.5 ohms each) are joined in series. Three wires *A*, *B* and *C* of 9, 36 and 72 ohms resistance respectively are arranged to be connected to the poles of the battery. Find the current when each wire is inserted separately, and when all three wires are connected in parallel.

Ans. Through *A*, .29 ampere nearly; through *B*, .15 ampere; through *C*, .091 + ampere; and through all three, .31 + ampere.

7. A battery of 28 Bunsen cells (E. M. F. = 1.8, resistance = .1 ohm each) are to supply current to a circuit having an external resistance of 30 ohms. Find the current (*a*) when all the cells are joined in series, (*b*) when all the cells are in parallel, (*c*) when there are 2 files each having 14 cells in series, (*d*) when there are 7 files each having 4 cells in series.

Ans. (*a*) 1.53 +; (*b*) .06 nearly; (*c*) .82 +; (*d*) .23 + ampere.

QUANTITY, ENERGY AND POWER.

Quantity. The strength of a current is determined by the amount of electricity which passes any cross section of the conductor in a second; that is, current strength expresses the *rate* at which electricity is conducted. The *quantity* of electricity conveyed evidently depends upon the current strength and the time the current continues.

The Coulomb. The coulomb is the unit of quantity and is equal to the amount of electricity which passes any cross-section of the conductor in one second when the current strength is one ampere. If a current of one ampere flows for two seconds, the quantity of electricity delivered is two coulombs, and if two amperes flow for one second the quantity is also two coulombs. With a current of four amperes flowing for three seconds, the quantity delivered is 12 coulombs. The quantity of electricity in coulombs is therefore equal to the current strength in amperes multiplied by the time in seconds, or

$$Q = I \times t$$

where Q is the quantity in coulombs, I the current in amperes and t the time in seconds.

The coulomb is also called the *ampere-second*. The quantity of electricity delivered in one hour when the current is one ampere is called one *ampere-hour*. The ampere-hour is equal to 3,600 coulombs, as it is equal to one ampere for 3,600 seconds.

From the formula $Q = It$, it follows that

$$I = \frac{Q}{t} \text{ and } t = \frac{Q}{I}$$

Example.—A current of 18 amperes flows through a circuit for $2\frac{1}{4}$ hours. What quantity of electricity is delivered?

Solution.—Reducing $2\frac{1}{4}$ hours to seconds gives 8,100 seconds, and $8,100 \times 18 = 145,800$. Ans. 145,800 coulombs.

Example.—What is the strength of current when $1\frac{1}{2}$ ampere-hours pass in a circuit in 89 seconds?

Solution.—One and one-half ampere-hours equal 5,400 coulombs and as current strength is expressed by quantity divided by time, the current is $5,400 \div 89 = 60.+$ amperes.

Ans. 60. + amperes.

EXAMPLES FOR PRACTICE.

1. How many coulombs are delivered in 9 minutes, when the current is $17\frac{1}{2}$ amperes? Ans. 9,450 coulombs.

2. What is the current when 480 coulombs are delivered per minute? Ans. 8 amperes.

3. In what time will 72,000 coulombs be delivered when the current is 80 amperes? Ans. 15 minutes.

4. How many ampere-hours pass in a circuit in $2\frac{3}{4}$ hours when the current is 22 amperes? Ans. 60.5 ampere-hours.

Energy. Whenever a current flows, a certain amount of energy is expended, and this may be transformed into heat, or mechanical work, or may produce chemical changes. The unit of mechanical energy is the amount of work performed in raising a mass of one pound through a distance of one foot, and is called the foot-pound. The work done in raising any mass through any height, is found by multiplying the number of pounds in that mass by the number of feet through which it is lifted. Electrical work may be determined in a corresponding manner by the amount of electricity transferred through a difference of potential.

The Joule. The joule is the unit of electrical energy, and is the work performed in transferring one coulomb through a difference of potential of one volt. That is, the unit of electrical energy is equal to the work performed in transferring a unit quantity of electricity through a unit difference of potential. It is evident that if 2 coulombs pass in a circuit and the difference of potential is one volt, the energy expended is 2 joules. Likewise if 1 coulomb passes and the potential difference is 2 volts, then the energy expended is also 2 joules. Therefore, to find the number of joules expended in a circuit, multiply the quantity of electricity by the potential difference through which it is transferred. This is expressed by the formula,

$$W = Q\,E, \text{ or } W = I\,E\,t,$$

where W is the work in joules, Q the quantity in coulombs, E the potential difference in volts, I the current in amperes and t the time in seconds.

By Ohm's law $E = R\,I$ and by substituting this value of E in the equation for energy, we obtain the formula,

$$W = I^2\,R\,t,$$

which may be used when the current, resistance, and time are known, R being the resistance in ohms.

Example.—With a potential difference of 97 volts and a current of 14 amperes, what energy is expended in 20 minutes?

Solution.—Work is expressed by the product of the quantity and potential difference. The time in seconds equals $20 \times 60 = 1200$, and the work $W = 14 \times 1200 \times 97 = 1{,}629{,}600$ joules.

Ans. 1,629,600 joules.

Example.—The resistance of a circuit is .9 ohm, and the current is 25 amperes. What energy is expended in half an hour?

Solution.—Substituting these values of resistance, current and time in the formula $W = I^2 R t$, we have, $W = 25^2 \times .9 \times 30 \times 60 = 1{,}012{,}500$ joules. Ans. 1,012,500 joules.

Power. Power is the *rate* of doing work, and expresses the amount of work done in a certain time. The horse-power is the unit of mechanical energy, and is equal to 33,000 foot-pounds per minute or 550 foot-pounds per second. A certain amount of work may be done in one hour or two hours, and in stating the work done to be so many foot-pounds or so many joules, the rate at which the work is done is not expressed. Power on the other hand, includes the rate of working.

It is evident that if it is known that a certain amount of work is done in a certain time, the rate at which the work is done, or the power, may be obtained by dividing the work by the time, giving the work done per unit of time.

The Watt. The electrical unit of power is the watt, and is equal to one joule per second, that is, when one joule of work is expended in one second, the power is one watt. If the number of joules expended in a certain time is known, then the power in watts is obtained by dividing the number of joules by the time in seconds. The formulas for the work done in joules as given on the preceding pages are,

$$W = I E t, \text{ and } W = I^2 R t.$$

By dividing each of these by the time t, we obtain the corresponding formulas for power as follows:

$P = I E$, and $P = I^2 R$, where P is the power in watts, I the current in amperes, E the potential difference in volts, and R the resistance in ohms.

The power is obtained therefore, by multiplying the current by the voltage, or by multiplying the square of the current by the resistance.

The watt is sometimes called the *volt-ampere*.

For large units the *kilowatt* is used, and this is equal to 1,000 watts. The common abbreviation for kilowatt is K. W. The *kilowatt-hour* is a unit of energy, and is the energy expended in one hour when the power is one kilowatt.

EXAMPLES FOR PRACTICE.

1. A current of 40 amperes is supplied to a circuit and the voltage is 110. What is the power in watts? Ans. 4400 watts.

2. What is the power in kilowatts supplied to a number of incandescent lamps when the current is 84 amperes and the voltage of the circuit 97? Ans. 8.1+ kilowatts.

3. A circuit has a resistance of 50 ohms and the current is 12 amperes. What power is expended in the circuit?

Ans. 7.2 K. W.

4. The voltage of an incandescent lamp circuit is 220 volts, and the resistance 2 ohms. What power is expended in the circuit? Ans. 24.2 K. W.

NOTE. — First find current by Ohm's law.

Equivalence of Electrical Energy in Heat Units. Whenever there is any resistance to the flow of a current there is always a certain amount of electrical energy transformed into heat. The current in passing through such resistance expends a certain amount of energy in overcoming the resistance, and this energy is dissipated as heat. The entire electrical energy of a circuit may be transformed into heat, as in a lamp circuit, or only part of the energy may appear as heat, the remainder being transformed into mechanical or chemical work. The energy which appears as heat raises the temperature of the circuit to an amount depending upon its radiating surface, and the temperature of the surrounding medium.

When the resistance of a circuit and the current are known, the electrical energy expended may be calculated by finding the product of the square of the current, the resistance, and the time, as by the formula at the foot of page 36. All this energy is transformed into heat. Other work may be done by the current, as would be the case if an electric motor were connected to the circuit, but this requires additional energy to that which is dissipated as heat. The formula referred to gives only the energy lost as heat, which is the total energy when no other work is done.

This formula, which gives the energy in joules, is in accordance with Joule's law, which is as follows :

The number of heat units developed in a conductor is proportional to its resistance, to the square of the current, and to the time the current lasts.

As we have seen, the unit of electrical energy is the joule. The common unit of heat is the calorie, which is the amount of heat necessary to raise the temperature of 1 gram of water through 1 degree Centigrade. By careful investigations it has been found that the joule is equivalent to .24 of a calorie ; that is, one joule of electrical energy when transformed into heat is equal to .24 calorie. Electrical energy may therefore be expressed in heat units by multiplying the number of joules by .24 ; that is,

$$U = I^2 \times R \times t \times .24$$

where U is the heat in calories.

As one joule is equivalent to .24 calorie, it follows that one calorie is equivalent to 4.2 joules approximately.

EXAMPLES FOR PRACTICE.

1. How many calories will be developed by a current of 30 amperes flowing through a resistance of 12 ohms for 10 seconds?

Ans. 25,920 calories.

2. What amount of heat will a current of 20 amperes develop if it flows through a resistance of 80 ohms for 2 seconds?

Ans. 15,360 calories.

Equivalent of Electrical Energy in Mechanical Units. The common unit of mechanical energy is the foot-pound, and from experiment it has been found that one joule is equivalent to .7373 foot-pound; that is, the same amount of heat will be developed by one joule as by .7373 foot-pound of work.

As one horse-power is equal to 550 foot-pounds per second, it follows that this rate of working is equivalent to

$$\frac{550}{.7373} = 746 \text{ joules per second (approx.).}$$

Hence one horse-power is equivalent to 746 watts. Therefore to find the equivalent of mechanical power in electrical power multiply the horse-power by 746, and to find the equivalent of electrical power in mechanical power divide the number of watts by 746.

EXAMPLES FOR PRACTICE.

1. A power of 287 watts is equivalent to how many horse-power? Ans. .38 + H. P.

2. The voltage applied to a circuit is 500 and the current is 196 amperes. What is the equivalent horse-power of the circuit? Ans. 131 + H. P.

3. What is the equivalent of 43 H. P. in kilowatts? Ans. 32 + K. W.

4. How many horse-power approximately are equivalent to one kilowatt? Ans. $1\frac{1}{3}$ H. P.

THE SUPPLY OF ELECTRICAL ENERGY.

Electrical energy is now made use of on such a large scale for lighting, power, heating, etc., that it is generated or produced by machines of great capacity. The dynamo is used for this purpose and machines having a capacity of several thousand kilowatts are now common.

Central Stations. Large central stations or power houses are built at convenient places and here are collected the generating, controlling and measuring apparatus. Usually steam engines or turbines are used to drive the dynamos, and from the latter, large copper mains conduct the current to the switchboard located within the station. Here are assembled all the regulating devices, instruments, and switches for the control of the system. From the switchboard conducting mains run out to various distant points, where the energy is to be used, to the receiving apparatus, such as electric motors, lamps, heating devices, etc. A complete system is therefore made up of three sub-divisions — the generating plant, the conducting mains, and the receiving apparatus.

Isolated Plants. Besides large central stations which occupy one or more entire buildings and which are usually built and designed especially for such purpose, there are the comparatively small and simple plants called isolated power plants. They are purely local systems and supply energy to a single building, or to buildings in the immediate vicinity. The generating apparatus in this case is usually located in the basement of the building.

TERMINAL ROOM, SHOWING WIRE CHIEF'S EQUIPMENT
Bedford Office, New York Telephone Co.

Large hotels and office buildings are frequently provided with individual generating plants.

Losses in Energy. In operating an electrical machine there is always some loss in energy, that is, the machine does not give out an amount of energy equivalent to the amount it receives. Besides ordinary mechanical losses there is in addition the electrical loss, which always occurs when a current flows through any resistance. This loss as previously explained, is equal to the square of the current multiplied by the resistance.

The ratio of the amount of energy which a machine gives out, to the amount which it receives is called the **commercial efficiency** of the machine. For example, if the commercial efficiency of a dynamo is stated to be 80%, then 20% of the energy given to the dynamo is lost, partly in overcoming friction and partly in electrical losses.

Where electricity is transmitted some distance by means of conducting mains, there takes place a loss in the line due to heating, which is frequently as much as 10%. Also at the receiving station, if the electrical energy is converted into mechanical by means of an electric motor, there will be a further loss.

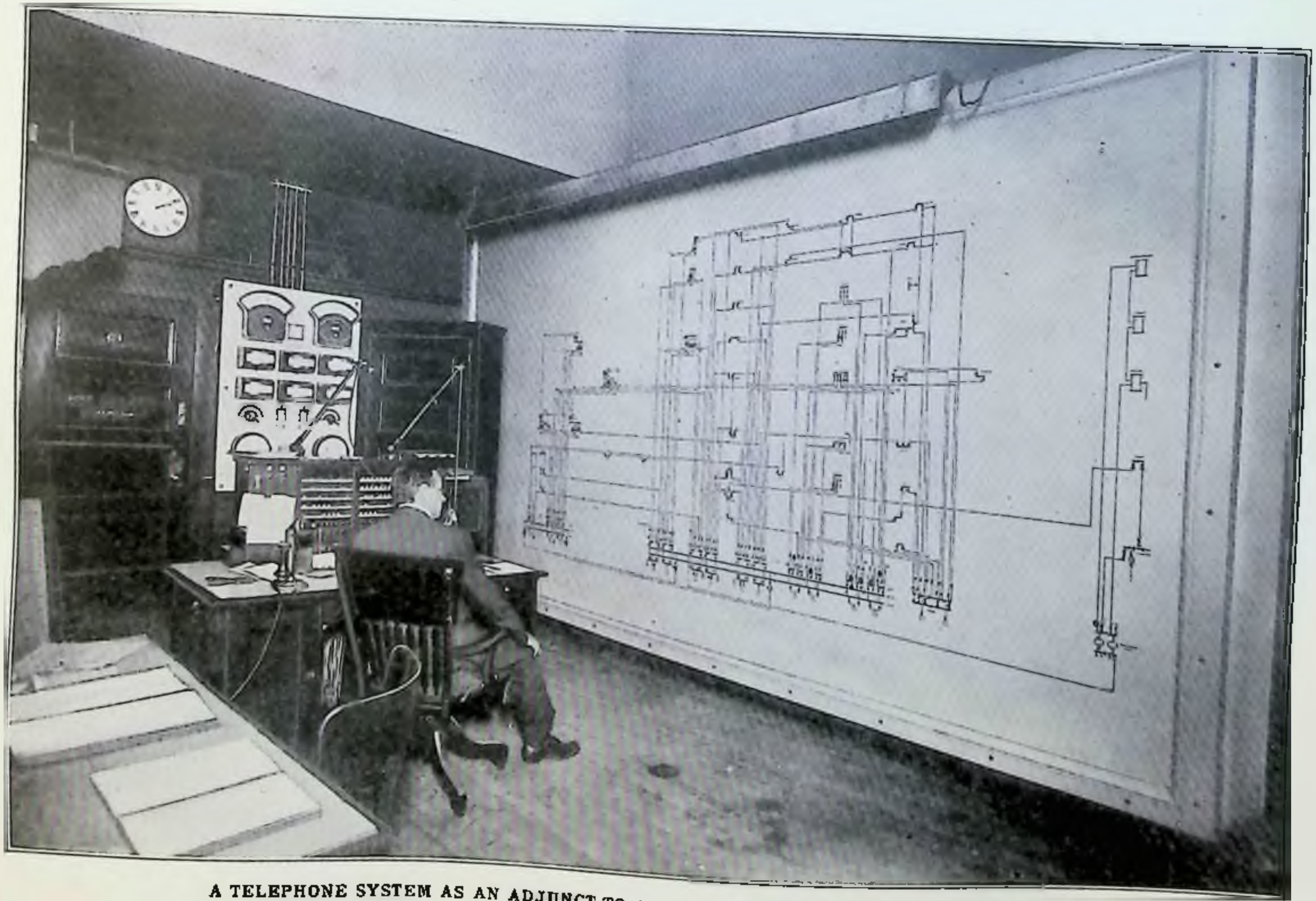
Illustrative Example. For example, suppose it is desired to ascertain the losses in a system which comprises a generator, conducting mains and an electric motor. Suppose the efficiency of the generator is 92% and that 1000 horse-power are imparted to it by the driving engine. The output of the dynamo will be $.92 \times 1000$, or 920 horse-power, and this is equivalent to 920×746, or 686,320 watts. The energy lost in the dynamo will be 80×746, or 59,680 watts. We will assume the voltage of the dynamo and the circuit to be 1000, and as the power in watts is equal to the product of the voltage and current, the current must be $686,320 \div 1000$, or 686 amperes approximately.

Now suppose the resistance of the conducting mains is equal to .11 ohms. Knowing the current in the mains and the resistance, the loss therein is obtained by applying the formula $I^2 R$ giving $686^2 \times .11$, or 51,765 watts. The energy available at the receiving end of the line will therefore be 686,320 — 51,765, or 634,555 watts.

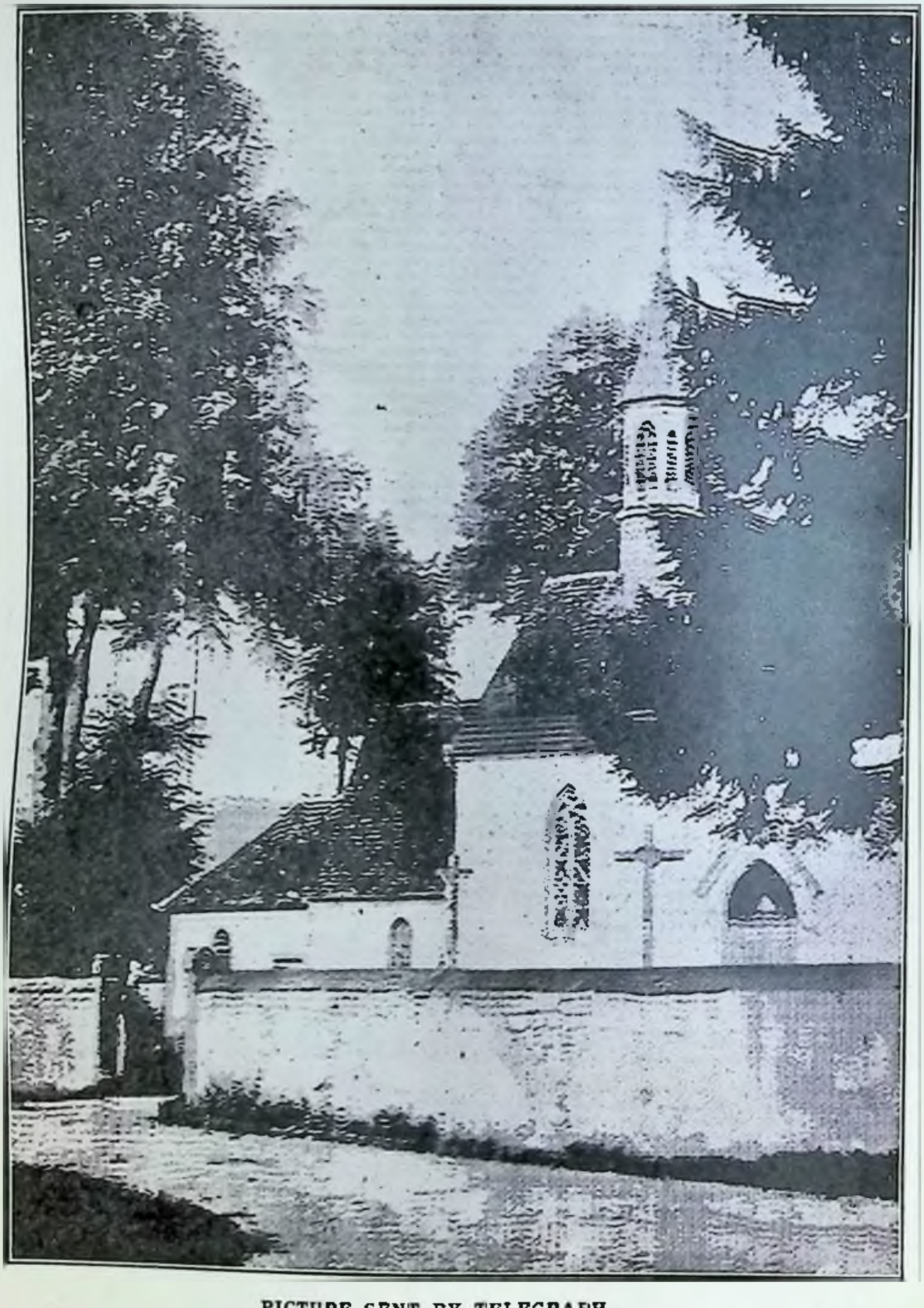
The remaining loss to be considered is that in the electric motor. Assuming the efficiency of the motor to be 90%, the power lost therein will be .10 × 634,555, or 63,455 watts. The output of the motor is therefore equivalent to 634,555 — 63,455, or 571,100 watts. This in mechanical units is equal to 571,100 ÷ 746, or 765 horse-power approximately.

Hence from an input of 1,000 horse-power at the generating station, the work the motor is capable of performing at the receiving station is 765 horse-power. The efficiency of the entire system under the assumed conditions is therefore 765 ÷ 1,000, or 76.5%.

Among the great variety of generating machines, systems of distribution and auxiliary devices, each has its particular advantage for special conditions, and the selection of the type of machine and system of distribution depends almost entirely upon the special circumstances. For example, a low voltage system is best adapted for isolated plants, whereas for the transmission of power long distances very high voltages are used. The various types of machines, systems, etc., with their special advantages and disadvantages, will be fully considered in the following Instruction Papers.



A TELEPHONE SYSTEM AS AN ADJUNCT TO AN ELECTRIC LIGHT AND POWER SYSTEM
Note the Diagram of Power Feeder System to Large City.



PICTURE SENT BY TELEGRAPH

This View was Transmitted by Means of the Belin Telestereograph. Notice the Wavy Effect Produced by Telegraphic Reproduction.

THE TELAUTOGRAPH.*

Electrical transmission of handwriting has engaged a certain amount of attention ever since telegraphic transmission of printed characters was successfully carried out.

As early as 1886, Cowper and Robertson brought the writing telegraph[1] into a fairly operative form. This instrument was adapted to operate several receivers in series in "reporting" service, where the regular news ticker service was unobtainable or too expensive. The system was put to some use, chiefly in Pittsburg and vicinity.

The writing was received on a paper tape, advanced at constant speed by clockwork. No pen-lifting device was provided and the words were connected together by a mark of the pen, making figure work poor. As the characters were formed by the combination of the pen motion and the tape motion, a certain amount of practice and skill was required to produce a legible message.

The electrical features were as follows : two independent variable currents were obtained from the transmitter; these passed over lines to the receiver where they traversed two electromagnets set at right angles to each other, and so influenced their effect upon a common armature as to cause the receiver-pen rod to reproduce the motion of the transmitter pencil.

It will be noted that this principle is nearly identical with that of Grühn's Telechirograph,[2] recently described in the technical press, the main differences being that the telechirograph writes upon a larger field and uses a beam of light, and photographic record instead of a pen with ink record.

Following the writing telegraph, Professor Elisha Gray constructed, at his Chicago laboratory, an instrument which wrote upon stationary paper, and which he called a telautograph. It

1. Wm. Maver, Jr., *American Telegraphy.*

2. *Scientific American*, August, 1903.

*Prepared by James Dixon, E.E., and read by him before the American Institute of Electrical Engineers. October 28th. 1904. Reprinted by special permission.

required four line wires and operated as follows: by means of cords and drums the motions of the transmitting stylus were resolved into two component rotary motions which were used to operate two mechanical interrupters in the primary circuits of two induction coils. The relations of the parts were such that a motion of the transmitting stylus amounting to one-fortieth of an inch caused a complete make-and-break at one or both of the interrupters.

The line currents were the impulses produced in the secondary circuits of the induction coils. These impulses passed over lines to two electromechanical escapements in the receiver. By means of cords and drums, their motions were combined and caused to act upon the receiver pen. By the use of relays and condensers and a local battery at each receiver, the paper was advanced when necessary and the pen lifted from and lowered to the paper. The mechanical difficulties met with in perfecting this instrument were very great, and in the apparatus exhibited at the World's Fair in Chicago in 1893 the escapement mechanism was brought to a perfection thought impossible of attainment only a short time before. The writing showed a saw-tooth or step-by-step character due to the action of the escapements. The instrument was abandoned on account of the number of line wires required, limited speed, numerous fine adjustments, and cost and difficulty of manufacture.

In 1893, while still working at the escapement device, Professor Gray patented a variable-current instrument,[1] using two line wires, which worked, in a general way, like the present telautograph. The motions of the transmitter pencil were resolved into two components which were used to vary two line currents, the variable resistances being carbon rods dipping into tubes of mercury. The receiver contained two D'Arsonval movements, to the moving elements of which the pen-arms were attached. Professor Gray never developed this instrument much beyond the laboratory stage, probably on account of his firm belief in the escapement type.

Foster Ritchie, at that time an assistant to Professor Gray, gave considerable attention to this patent and perfected an instru-

1. U. S. Patent 494,962, April 4, 1893.

ment based on it. He obtained a patent for improvements[1] and has produced an instrument that operates in a fairly satisfactory manner[2] under certain favorable conditions.

The telautograph has been brought to its present state chiefly through experimental work done by, or under the personal direction of, Mr. George S. Tiffany, to whom several patents[3] for improvements have been granted. Mr. Tiffany's instrument operates upon the variable-current principle and includes a number of interesting features, among them what may be called a straight-line D'Arsonval movement, which is used to operate the receiver.

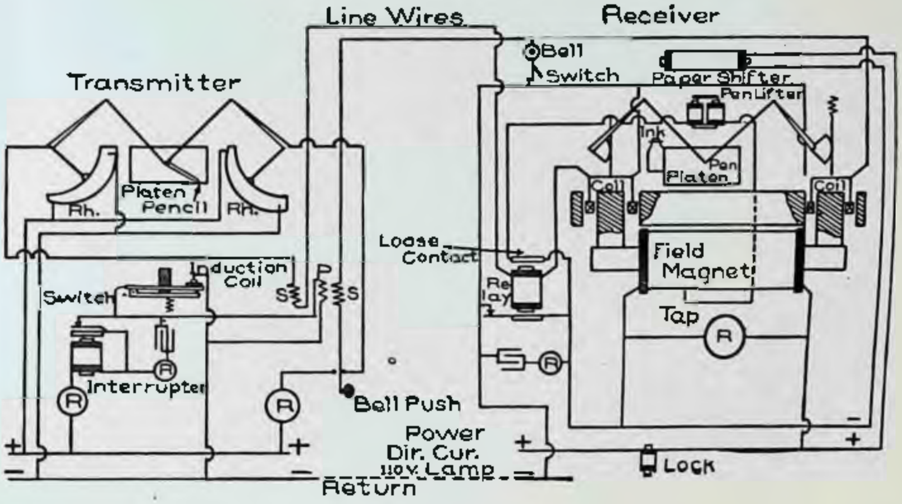


Fig. 1.

The operation may be briefly described thus: at the transmitter a pencil is attached by rods to two lever-arms which carry contact-rollers at their ends. These rollers bear against the surfaces of two current-carrying rheostats, connected to a constant-pressure source of direct current. The writing currents pass from the rheostats to the rollers and from them to the line wires. When the pencil is moved, as in writing, the positions of the rollers upon the rheostats are changed, and currents of varying strength go out upon the line wires. At the receiver these currents pass through two vertically movable coils, suspended by springs in magnetic

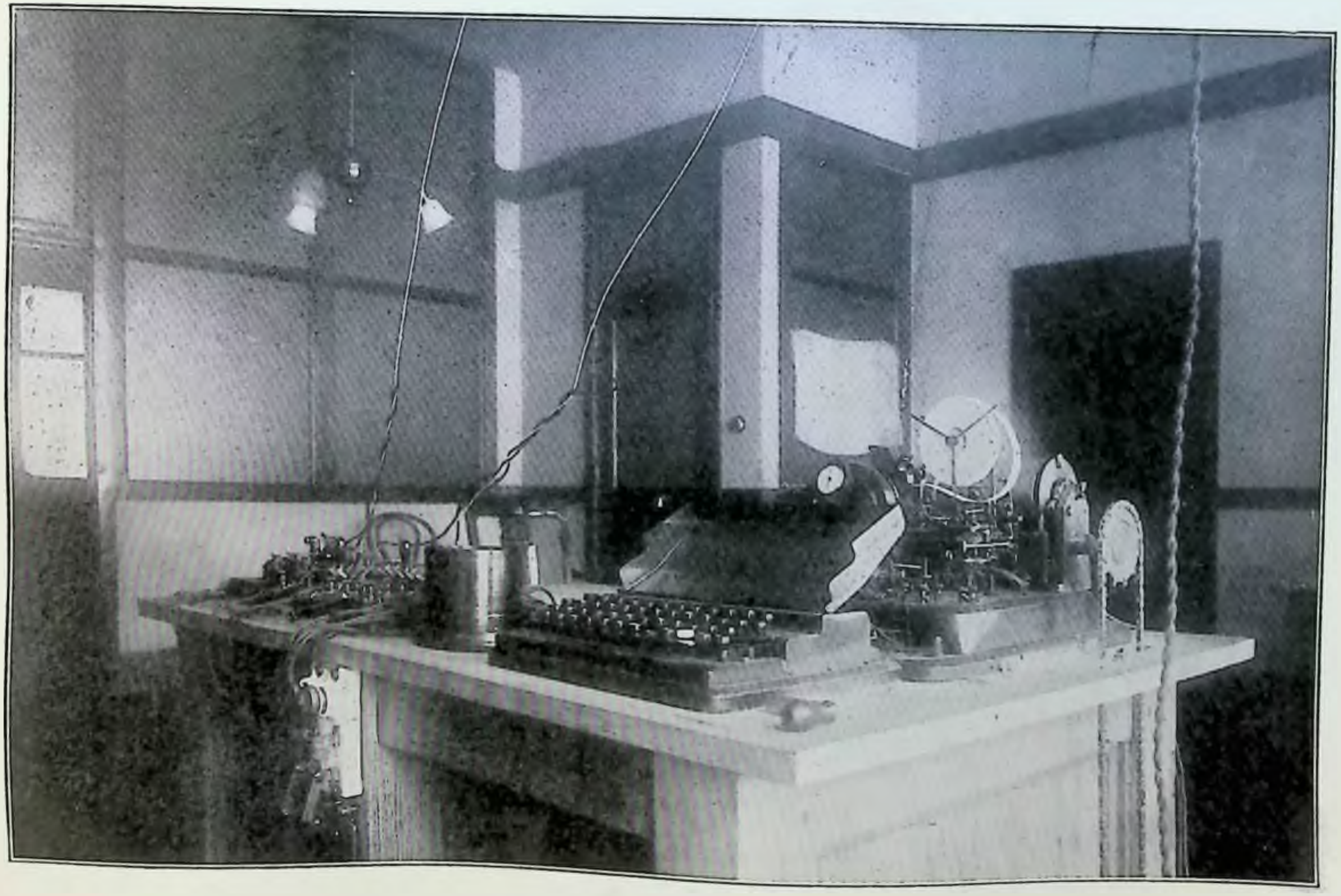
1. U. S. Pat. 656,828, Aug. 28, 1900.
2. *Elec. World and Engineer*, Dec. 8, 1900, Vol. XXXVI., No. 23.
3. U. S. Patents 668,889 to 668,895 inclusive, Feb. 26, 1901.

fields, and the coils move up or down according to the strengths of the line currents. The motions of the coils are communicated to levers similar to those at the transmitter, and on these levers is mounted the receiver pen, which, by the motions of the coils, is caused to duplicate the motions of the sending pencil. Fig. 1 shows the circuits of the instrument.

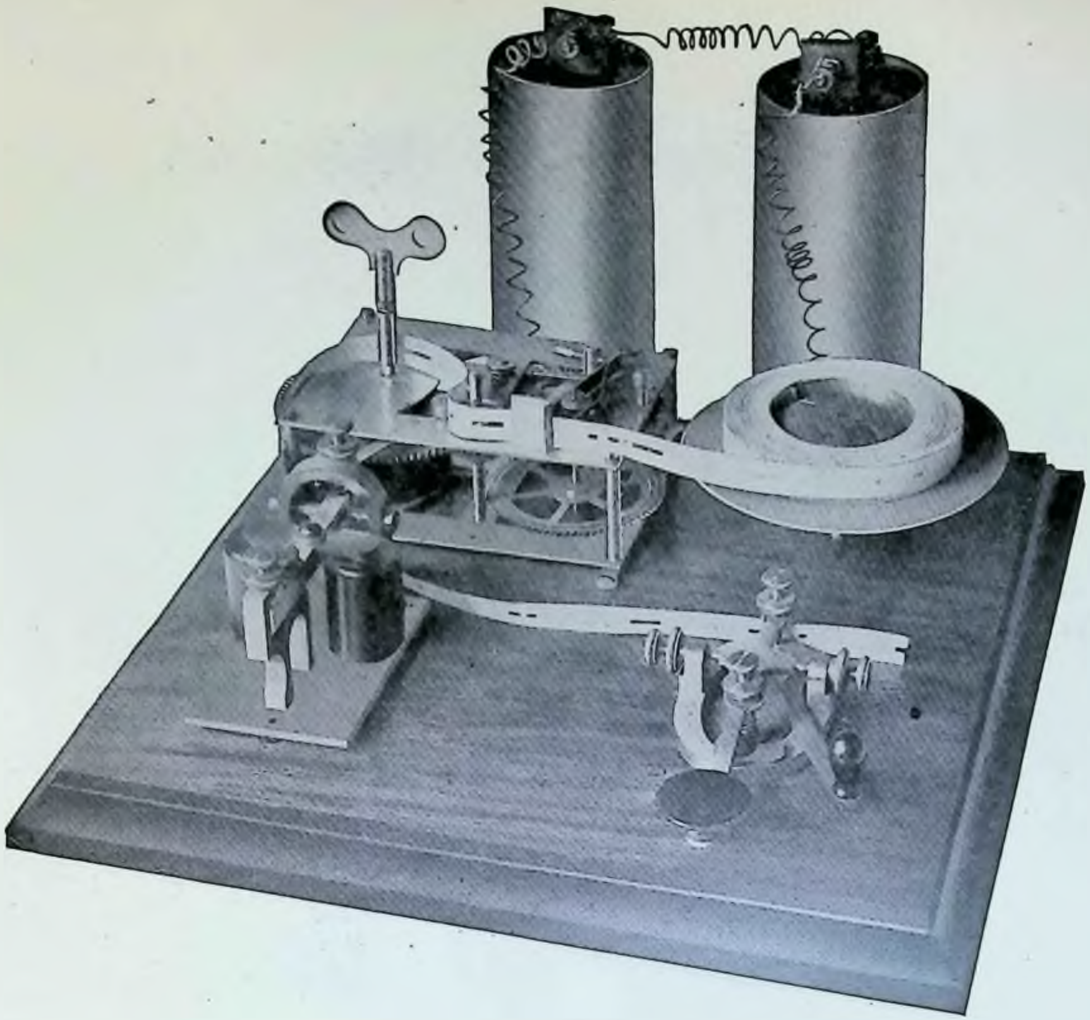
Many of the principles and devices in the instruments are of considerable interest. The method by which the variable currents are obtained is the laboratory arrangement for securing a variable pressure from a direct-current, constant-pressure circuit; that is, the line circuit (of constant resistance) is connected as a shunt around that part of the rheostat between the moving roller and the ground or return. Motion of the roller varies the amount of resistance in series with the line and also the amount in parallel with it and fine gradations are easily obtained, giving smooth motion of the receiver pen. In this way a variable pressure is impressed on the line circuit, giving a variable current. In all the other variable-current instruments, a constant pressure was impressed on the line and a resistance in series with the line varied to give the desired variations in current. One result of the shunting method is a better form of rheostat, more easy of construction and handling, in which, also, the heating is better distributed.

The rheostats are wound upon castings of I cross-section, with the turns of wire lying close together on the inner or contact-face. After winding, the insulation on this face is saturated with glue, which is allowed to harden and is then scraped off, taking the insulation with it, and giving a surface where contact is possible on every turn of the wire. This gives a rheostat of a large number of small steps, of good mechanical construction, and of low cost.

The receiver operates with what may be called a straight-line d'Arsonval movement. The moving element or coil is wound upon a copper shell for damping effect. The magnetic circuit is so arranged that one pole surrounds the other, forming an annular air-gap of short length and large cross-section in which the direction of the flux is radial. The field is electromagnetic and is highly excited, to secure uniformity. The coil, suspended in the annular space, moves up or down with little friction, as it touches the



THE TELAUTOPRINT
At the Left is Located the Controlling Device and at the Right is the Electrically-Operated Printing Bar.



Automatic Telegraph Transmitter

By means of the clockwork and perforated tape, this instrument reproduces the messages as accurately as an expert operator. The student can thus learn to read as well as to send. This instrument is supplied with the Electric Telegraph Course to students of the American School of Correspondence. A nominal deposit is required, which is refunded upon return of the instrument in good condition.

sides of the space or the core very lightly if at all. The principle is the well-known one that a current-carrying coil, in a magnetic field, tends to place itself with respect to the field so that the flux enclosed by the coil shall be a maximum.

The current for operating is taken from the ordinary lighting mains, preferably at about 115 volts. Satisfactory operation has resulted with pressures from 80 up to 250. At 115 volts, receiver and transmitter each require about one ampere while in operation. Fairly steady pressure is necessary as the receiver, being in effect a voltmeter, is rather sensitive to sudden changes, the effect being slight distortion of the message.

A master-switch at the transmitter is provided to do all necessary switching of line and power circuits, to make needed changes in connections and to cut off current when not writing. A relay in one of the lines closes the power circuit of the receiver whenever the transmitter at the distant station is switched on, and serves to prevent waste of current when not in operation.

Attached to the master-switch is a mechanical device which shifts the transmitter paper the space of one line of ordinary writing for each stroke of the switch. The relay mentioned controls the electrical receiver paper shifter and, as each stroke of the switch causes a stroke of the relay, the receiver paper is shifted an amount equal to that at the transmitter. The writing space is about two inches long and five inches wide, allowing for three or four lines of writing. When filled by messages, a few strokes of the switch serve to bring fresh paper into position at both receiver and transmitter.

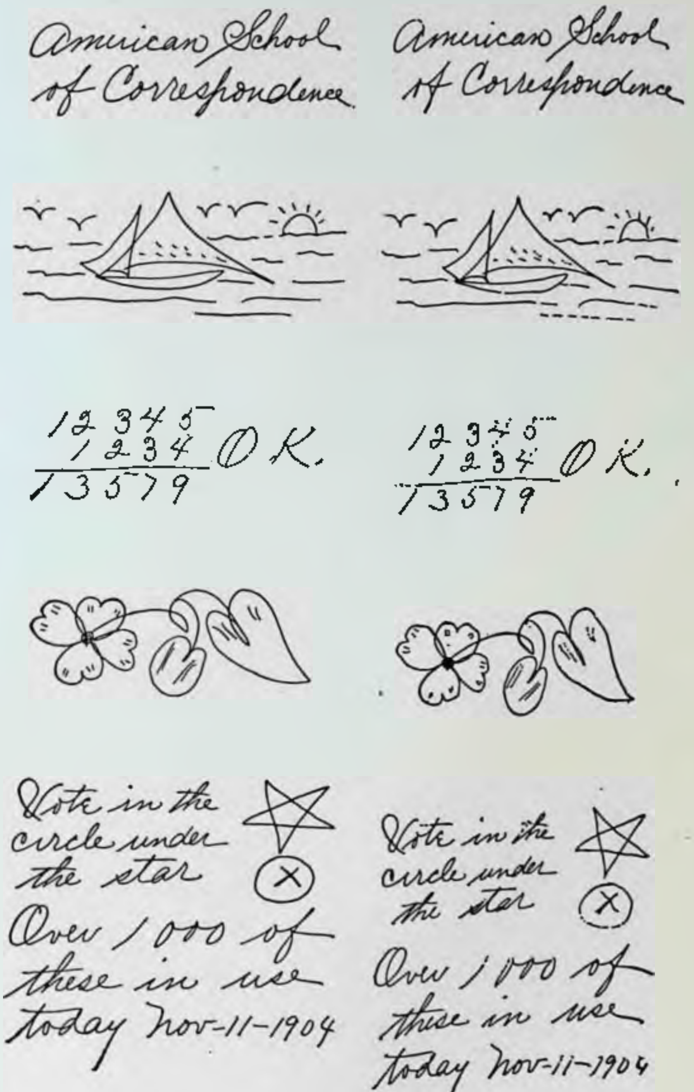
To prevent switching on of the transmitter while its home receiver is receiving a message from the distant station, an electromagnet lock is connected in the receiver power circuit, controlled by the relay, which locks the home transmitter in the "off" position until the distant transmitter is switched off. If both transmitters were switched on at once, neither station would receive any message; the lock is provided to render this condition impossible.

The ink supply is most important, and is arranged for as follows: at the left of the receiver platen is a bottle with a hole in the front near the bottom. When filled with ink and tightly corked the ink does not run out of this hole because of the pressure of the atmosphere. The ink is accessible for the pen at the hole and the surface of ink exposed to evaporation is small.

The pen is made of a piece of German silver bent double, after the manner of a ruling pen, and makes a uniform line in any direction over the paper. It takes up its supply by capillary attraction, from the hole in the front of the bottle. When the receiver is switched off, retractile springs draw the pen-arms to stops so arranged as to bring the pen exactly in front of the hole in the bottle, and when the pen-lifter armature is released the pen is caused to insert its tip in the opening. Thus a fresh filling of ink is obtained each time the paper is shifted. When not in use the pen rests in the ink, always ready to write.

For the prevention of mechanical shocks to the necessarily light moving system of the receiver, it has been necessary to supply means to prevent the switching on or off of the transmitter, and by that action of the receiver, when the transmitter pencil is "out in the field"; that is, at a position other than that corresponding to the opening in the receiver ink-bottle; as in that case the receiver pen would instantly jump to a similar position. This position is called the "unison point," a term having its origin in the days of the "self-propellor" escapement telautograph. By placing a catch, released only by pressure of the pencil-point upon it, at the transmitter unison point, the desired result is accomplished and the transmitter master-switch can not be switched either "off" or "on" unless the pencil be placed at the unison point and held there until the stroke of the switch is completed. In this case, as everywhere, the apparatus is made strong enough to stand any possible shocks, although every precaution is taken to prevent their occurrence. Aside from the shock to the moving system these jumps might shake the ink supply out of the pen and prevent the recording of the message.

The pen-lifter is a magnet placed back of the receiver writing platen, and carrying upon its armature a rod adapted to engage with the pen-arm rods and raise the pen clear of the paper when the magnet is energized. This magnet is controlled from the transmitter as follows: beneath the transmitter platen is a spring-contact, opened by pressure of the pencil upon the paper, and closed by a spring when the pencil is raised. An induction coil having an interrupter in its primary circuit is so connected to this spring-contact that when the pencil is raised the primary winding is short-circuited. The induction coil has two independent sec-



SAMPLE OF WRITING
Made especially for the American School of Correspondence over a distance of about 20 miles. At the left is shown the original, at the right the reproduction.

ondary windings through which the two variable line currents pass before leaving the transmitter. The effect of the induction coil and its interrupted primary current is to induce, in the two line currents, superimposed vibrations or "ripples" when the pencil is pressed down on the paper and the spring-contact is open. When the contact is closed, by its spring, and the primary winding is cut out, no vibrations are produced in the line currents. In one of the line wires, at the receiver, is placed a relay upon whose sheet-iron diaphragm armature is mounted a loose contact, consisting of two platinum-silver contacts in series, sealed in a glass tube, to prevent oxidation. A local circuit contains the winding of the pen-lifter magnet and this loose contact.

When the vibrations are present in the line current, due to the pressure of the pencil upon the paper and consequent opening of short circuit of the primary of the induction coil, the diaphragm of the relay is shaken, the loose contact opened, and the pen-lifter de-energized, its armature being drawn back by a spring and the pen being allowed to rest against the paper. When there are no vibrations in the line currents due to the raising of the pencil from the paper, the relay diaphragm is at rest, the pen-lifter is energized, and the pen is lifted clear of the paper.

The superimposed vibrations used for operating the pen-lifter have another minor effect. The suspended coils, and through them the entire moving system of the receiver, are kept in a state of very slight mechanical vibration while the pen is on the paper. This aids the flow of ink from the pen-point, assists the pen in passing over any roughness or irregularity in the surface of the paper, and materially reduces friction in the joints and pivots of the moving system, and results in better writing. In some of the later instruments, the two relays, that for pen-lifting and that for paper-shifting and power-switching, are combined in a single piece of apparatus.

For signaling, a push-button is placed upon the transmitter and a call-bell or buzzer is mounted on the receiver. This circuit is disconnected by the master-switch while a message is being written. Spring reels are attached when needed to roll up the received messages for preservation and future reference.

The ordinary arrangements for operation are as follows: the instruments may be operated singly, upon a private line having an instrument at each end, or on an exchange system where a switchboard provides for connection. Working in this way, satisfactory writing has been obtained with a resistance in each line wire of 1,600 ohms and an operating pressure of 110 volts. Multiple operation can be carried out to a limited extent, three receivers being at present the maximum number that can be operated at once, in multiple, using 110 volts. This allows of placing a supervisory machine upon a line.

When no response to messages beyond a bell signal is required, and the same message is to be sent to a number of stations, a series

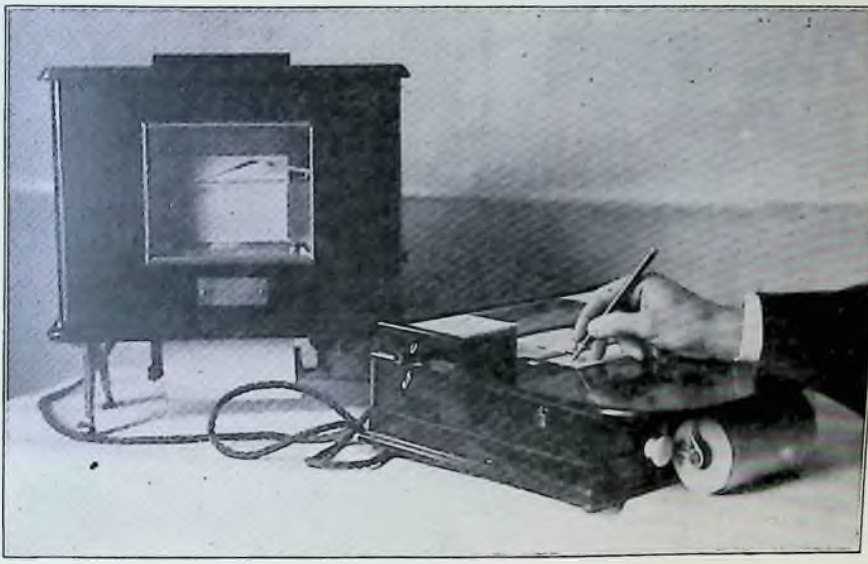


Fig. 2.

arrangement of receivers is used. With a transmitting pressure of 110 volts a maximum of seven receivers can be operated from a single pair of transmitting rheostats and rollers. This number may be increased by increasing the pressure or by adding additional rheostats and rollers, operated by the same pencil. Using both these methods a maximum of 50 or more receivers may be operated at once.

Instances in actual commercial use of the arrangements of instruments mentioned are: private lines; the transmission of mail and other orders from office to factory or yards; investigation of checks over lines between paying tellers and bookkeepers in banking concerns, and transmission of messages, usually in cipher, between brokerage firms and cable or telegraph offices. A few moments' thought will bring to mind many places where a telautograph private line could be used to save time and trouble, especially where accurate transmission of figures is essential.

Multiple operation may be resorted to when a third station upon a line desires a record, accessible at any time, of what is being sent, as, for instance, when one of the officers of a bank desires to know what passes between his bookkeepers and paying tellers. On such a line the third station receives all messages and can write to either or both of the other stations, should the necessity arise.

Series operation may be used when several stations are to receive the same message and no response except a bell signal is required, as in sending orders in a hotel or club from dining room to kitchen, pantry and wine room; in "reporting" or news service, or for bulletin work, such as the announcement of arrival and departure of trains to a number of stations in a large railway station or freight depot. Fig. 2 shows the standard commercial instrument.

One of the most important uses for series systems has been found in the U. S. Coast Defense Service, in sending ballistic data, such as range and azimuth of target, or character of projectile, from position-finding stations to the gunners. This is called "fire-control communication" and is installed in the forts by the U. S. Signal Corps. In a paper presented by Col. Samuel Reber on "Electricity in the Signal Corps,"[1] will be found a description of the position-finding systems. The desired characteristics of a system of communication for sending this data to the guns are stated as follows:

> "The system that will successfully solve this problem must be simple in construction, mecnanically strong so as not to be affected by the blast, as the receivers are placed close to the guns, rapid in operation, and give a character of record that can be read without liability of error."

Since that paper was prepared, it has been decided that the receivers must be mounted directly on the gun-carriage and can have no shelter other than that afforded by their own cases. Add to these requirements the facts that the instruments must be cared for by post electricians, and operated by enlisted artillerymen; that messages must be visible at night; and the operation must be

1. TRANSACTIONS, A. I. E. E., Vol. XIX., pp. 723 and 724.

independent of rain, salt mists, cold, heat, or tropical insects, and it is apparent that no easy problem is presented.

A special type of telautograph has been designed for this service and has been adopted by the U. S. Signal Corps[1] for fire-control communication.

In this "service telautograph," the pen-lifter controlling

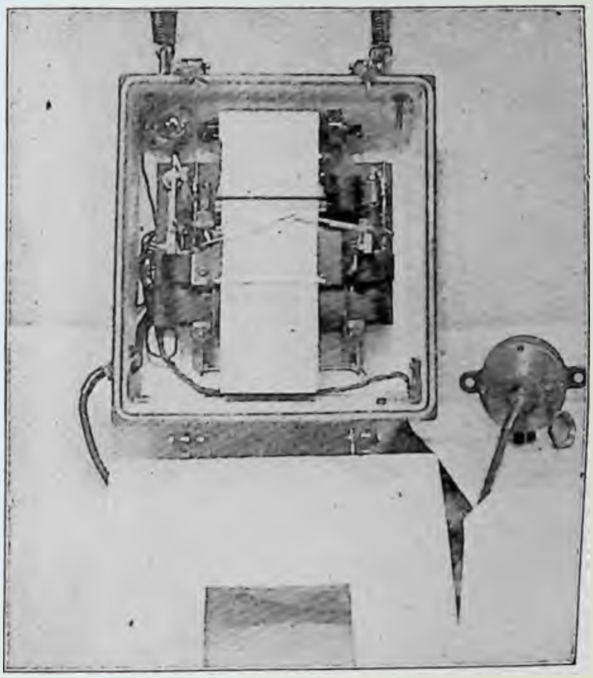


Fig. 3.

relay is eliminated and the receiver pen-lifters are operated over a third line wire by the transmitter platen switch directly.

Each gun receiver is enclosed in a water-tight brass case, suspended by springs from the gun carriage directly in front of the gunner. The parts are as far as possible made "brutally strong," and the construction is as simple as possible.

The desired rapidity of operation is inherent to the telautograph, and accuracy of record is ensured by careful writing and by the use of a "home" receiver, mounted at the transmitter where the operator can see it plainly, which is connected in series with

1. TRANSACTIONS, A. I. E. E., Vol. XIX., p. 678.

the gun receivers and records the messages as actually sent over the line.

Freezing of ink is prevented by the addition of alcohol; and rain, mists, and insects, as well as the effects of the blast, are shut out by the metal case. A heavy glass window is placed in the case so that messages can be read without opening the case.

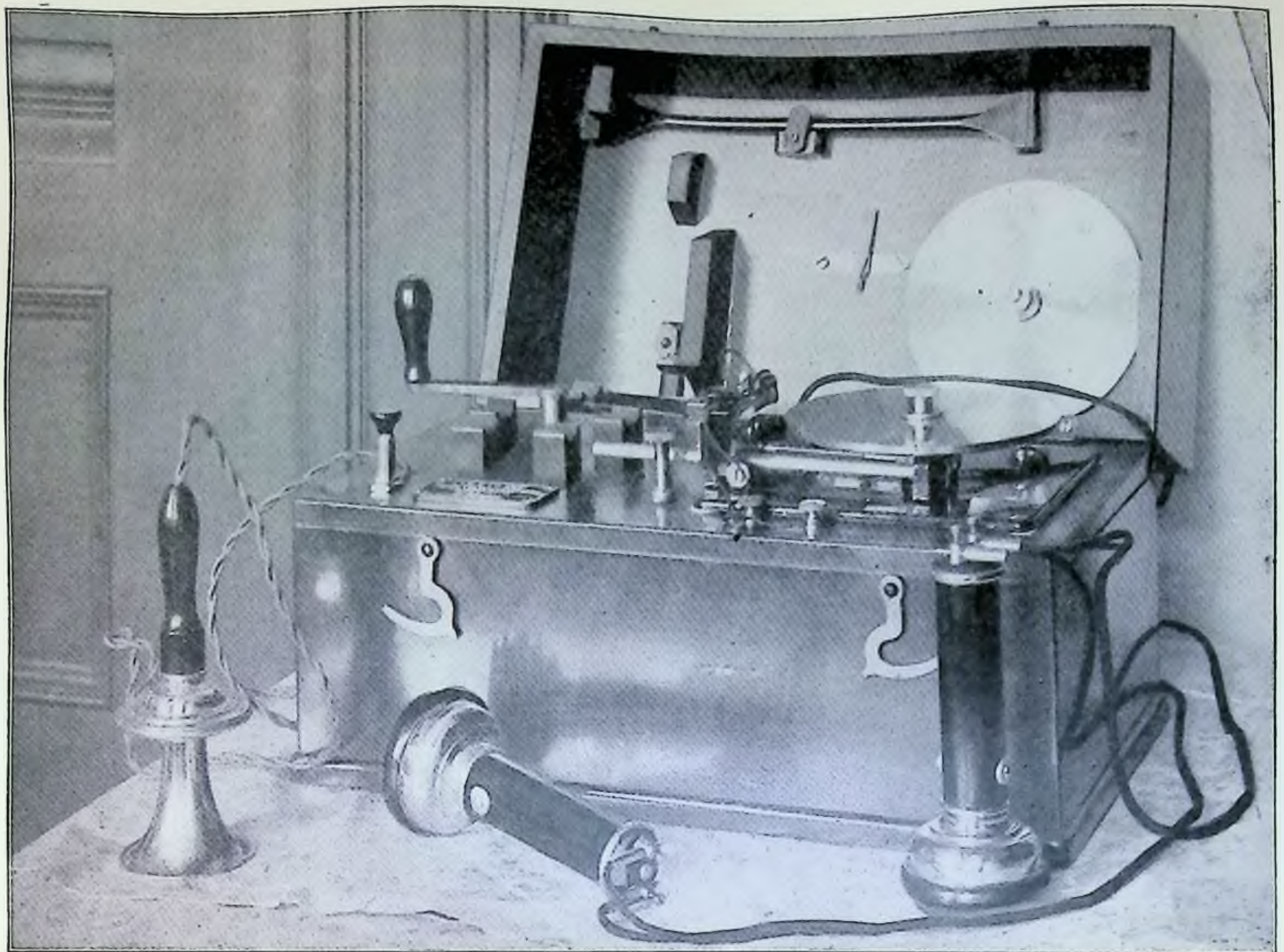
A small incandescent lamp inside the case lights automatically when the receiver is writing and may be lighted by pressing a button at other times, thus providing for visibility at night. Fig. 3 shows the army type of receiver mounting.

On warships there is a somewhat similar service to be rendered and the performance of this should fall to the army type of telautograph.

Commercial service has given opportunity for the installation of a considerable number of private line telautographs in actual use, and at least three of each of the other typical installations are in operation at the present time.

Much of the improvement in details of construction and reliability in operation has resulted from experience gained in efforts to perfect the service of these commercial plants. The experience leading up to the special army type of telautograph has extended over a period of about five years and in the present instrument all the requirements, unusually severe as they are, have been successfully fulfilled.

OPERATING ROOM, LEIPZIG, GERMANY



TELEGRAPHONE OF DISC TYPE, WITH CASE

THE TELEGRAPHONE

The telegraphone is an electro-mechanical device which records the human voice, music, or other sounds on a thin steel disc or on a fine steel wire, and then reproduces these as perfectly as a telephone—a result that is impossible with the phonograph or graphophone.

The invention of this new instrument is due to the researches of Vladimir Poulsen of Copenhagen, Denmark, who, while experimenting with a telephone about 1900, discovered a new principle in electromagnetism which seemed to offer a complete solution of the difficult problem of reproducing sound.

This principle is the *localization of magnetism*; and its action, as well as the apparatus employed, will be readily understood by referring to Fig. 1, in which E is an electromagnet of small dimensions

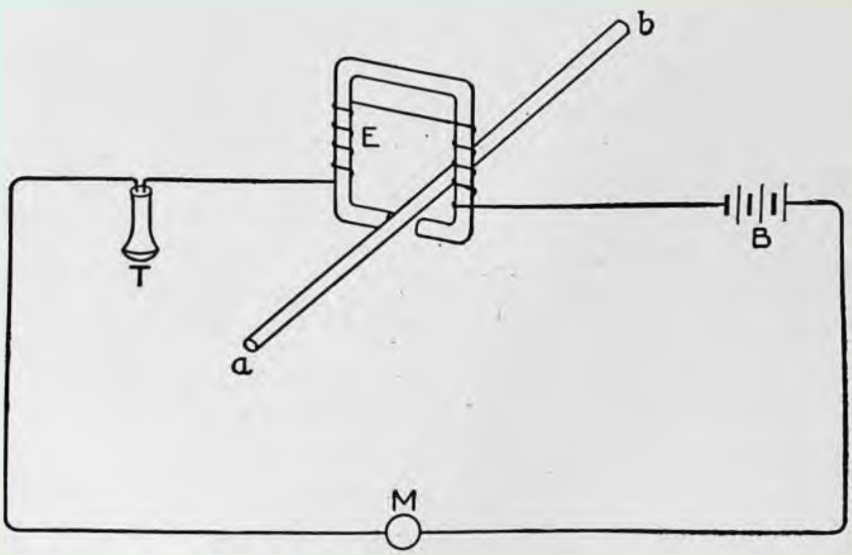


Fig. 1. Illustrating the Principle of the Telegraphone.

inserted in a telephone circuit including a battery B, telephone transmitter M, and receiver T. The poles of the electromagnet are separated by a space large enough to permit the steel wire a b to pass.

Steel piano-wire is employed, having a diameter of $\frac{1}{50}$ to $\frac{1}{100}$ inch; and this is drawn forward between the poles of the magnet so that the successive portions of the wire advance at the rate of 7 or 8 feet per second. The early type of apparatus resembled an ordinary phonograph in which the wire *a b* replaced the wax cylinder, and the magnet between the poles, the stylus.

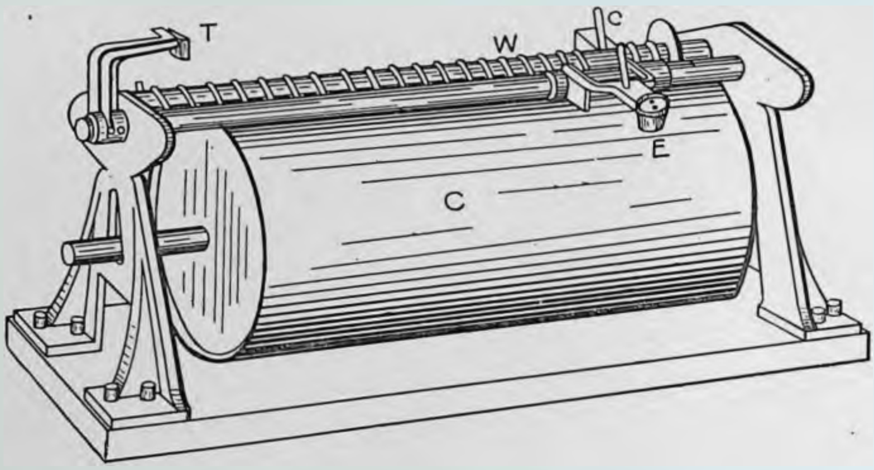


Fig. 2. Early Model of Telegraphone, Wire Type.

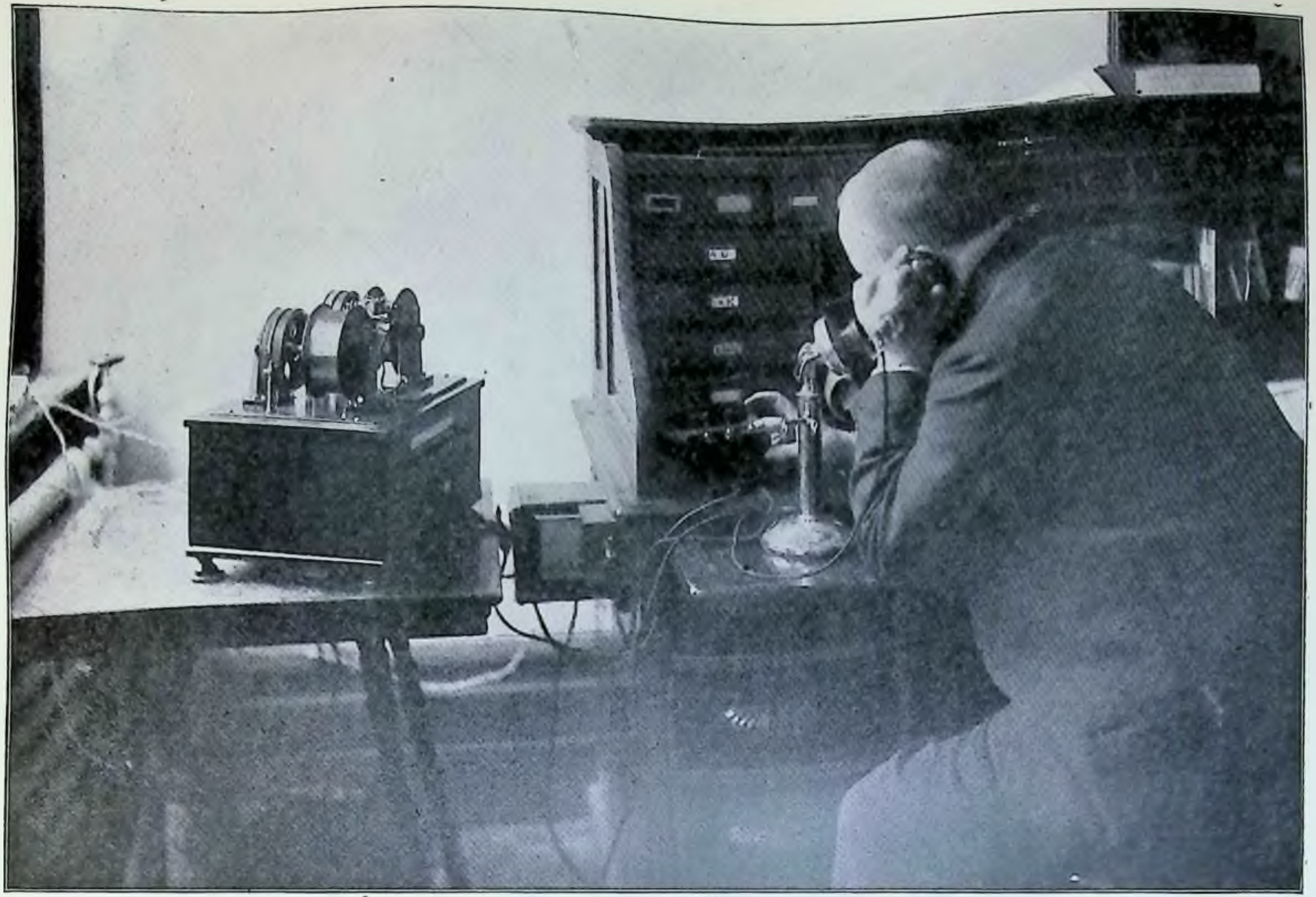
The sound is recorded by speaking into a transmitter either near at hand or located at any distance over which the telephone is capable of working. The electric impulses thus set up in the circuit cause the current in the coils surrounding the core of the electromagnet to vary in strength; and consequently the magnetic flux between the poles undergoes a series of variations corresponding to the original sound waves.

Fig. 3. Section of Electromagnet and Wire.

These magnetic forces act in turn upon the steel wire as it travels in front of the poles, and magnetize it transversely. Each part of the steel wire retains its magnetization, the strength of which depends upon the force developed at a given instant. The magnetic record upon the wire corresponds, therefore, exactly to the original sound waves.

After the record has been made, it can be reproduced at any time. To do this, it is only necessary to connect the receiver to the terminals of the electromagnet, and to cause the wire to pass again between the poles of the electromagnet in the same direction and at approximately the same speed as before. As the magnetic strength

TYPIST TAKING DICTATION FROM TELEGRAPHONE



TELEGRAPHONE USED IN COMBINATION WITH TELEPHONE

Connection with the telegraphone is made or broken by means of a push-button, as indicated, the instrument accurately recording all impulses passing over the telephone wire in either direction.

varies from point to point, the movement of the wire between the poles causes a variation in the magnetic flux and sets up a series of undulating currents in the circuit, the wave-form being precisely

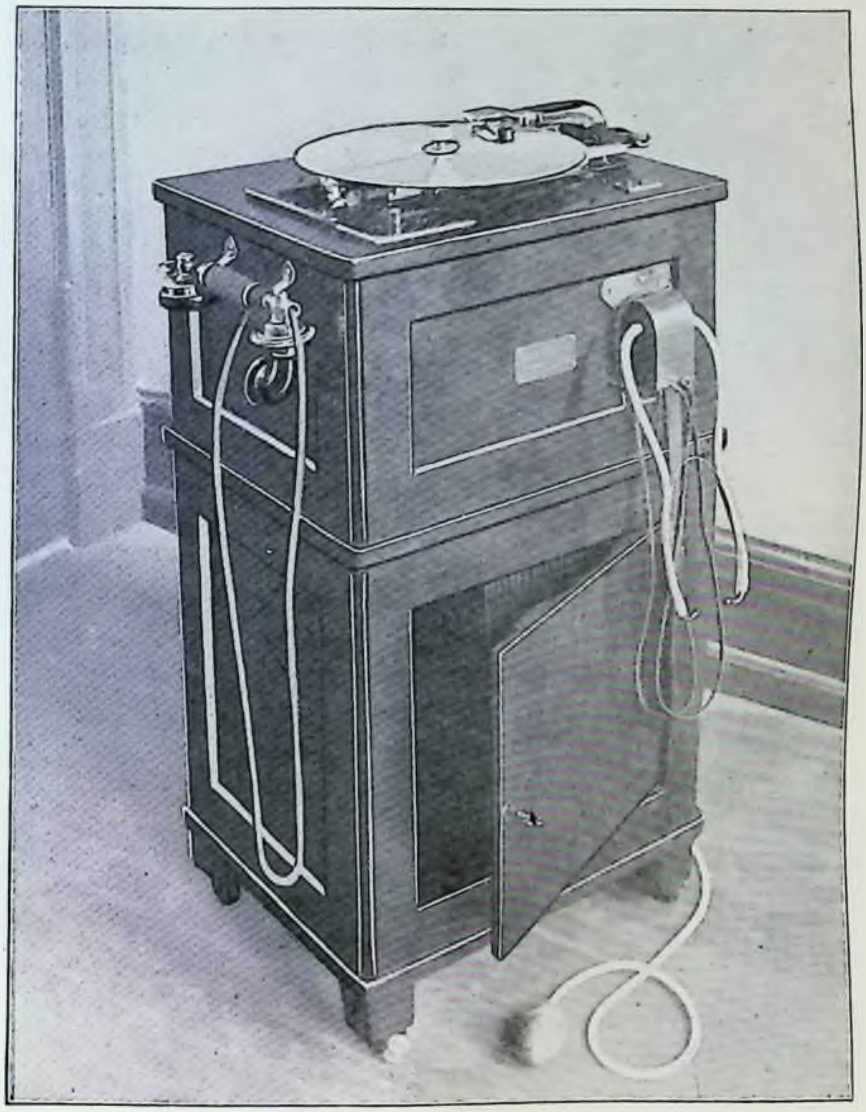


Fig. 4. Disc Type of Telegraphone, with Cabinet.

the same as in the first instance, and the sound reproduced in the telephone receiver exactly like the original.

The magnetic inscription will remain intact for many months if desired; or it may be effaced in an instant by passing a stronger magnet over the disc or the wire, whereupon the inequalities of the remanent magnetism are, as it were, planed off. This process may be accomplished while the disc or wire is being used for another record, and it causes no inconvenience or delay.

Wire and Disc Types of Machines. The first type of telegraphone completed for commercial use was exhibited in the Danish section at the Paris Exposition of 1900. In the model illustrated in Fig. 2, a steel wire .01 inch in diameter was wound spirally with 380 turns around a cylinder 15 inches in length and 5 inches in diameter. Fig. 3 represents a small electromagnet, full size, the axes of the two coils forming an acute angle so as to embrace the wire *f* at right angles to its length.

In Fig. 2, it will be observed, the electromagnet E is supported by a small carriage c which, at the end of its normal travel, will be arrested by a stop T; at this moment a screw W engages it and brings it back to its starting point. The normal duration of the travel of the carriage is 50 seconds; the electromagnet and the cylinder are set in motion by means of a 0.6 horse-power motor.

The range of this type was so limited that the inventor devised a modified form using a disc instead of the spirally wound wire. This is shown complete in Fig. 4. The principles of this telegraphone, however, remain unchanged, for in this instrument, as well as in those which preceded and have since followed it, each molecule of the steel surface is locally magnetized to an extent corresponding with the current variations set up by the voice in the speaking circuit.

In its mode of operation this instrument resembled the ordinary gramophone in appearance. The reproduction lacks the full loudness of the latter; but, on the other hand, the articulation is perfectly distinct, and entirely free from the nasal and scratching sounds emitted by the ordinary phonograph—which result is explained by the fact that there are no accessory vibrations set up by the friction of a stylus upon the wax as in the last-named instrument.

The steel disc which receives the message is about 5 inches in diameter, and is secured to a rotating plate by a milled nut. As the disc rotates, the magnet and coil, which are held in a carrier, are gradually moved toward the center of the disc, by a micrometer screw, the speed of rotation being increased as the magnet approaches the center of the disc, so that the latter rotates beneath the magnet with a constant linear velocity of about 1.5 feet per second. In place of the pair of magnets with two coils, which characterized the earlier machines, a straight magnet brought to a sharp point is employed; this can be lifted out and renewed, the coil being imbedded in an insulating composition and held in a small ebonite cylinder. The record can easily be erased by passing a bar magnet over the disc.

Still another type of instrument has been designed, in which a steel piano-wire is used. In this type, which is illustrated in Fig. 5,

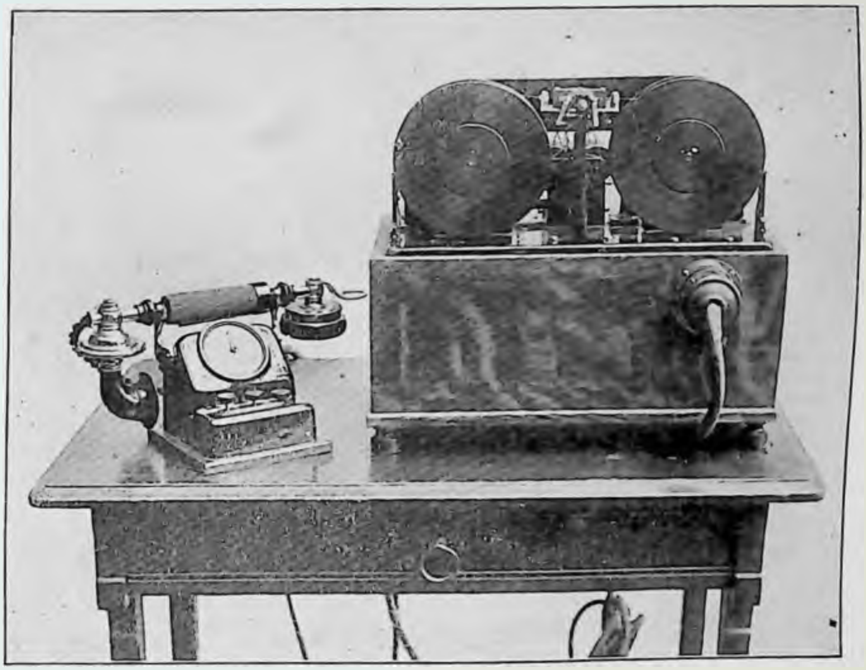


Fig. 5. Wire Type of Telegraphone. Indicator at left.

the wire is wound off one reel onto another between two magnet-poles, by means of an electric motor contained in the base of the instrument. The speed is about 10 feet per second, and enough wire is carried on the reels to make a record 7,000 words in length. Should only a part of the record be used at a time, the location of the used portion is noted by an indicator finger which rotates at a speed equal to that of the reels.

In this instrument three pairs of magnets and coils are employed, these being similar to the straight magnets used in the disc machine. Two of the pairs of magnets are placed horizontally, one on each side of the wire, which serve for erasing records and demagnetizing the wire, while the sounds are recorded by the middle pair of magnets. As the wire is reeled off, the magnet carrier travels forth and back, holding and guiding it on and off the reels.

By means of a push-button switch on the indicator, the motor can be reversed and one of the pairs of erasing magnets energized; if the wire is passing from right to left, the right-hand pair of magnets receives the current, and any previous record that may have been imposed on the wire is completely removed. A new record can then be made, and this can be heard by removing the transmitter and using in its stead the telephone receiver.

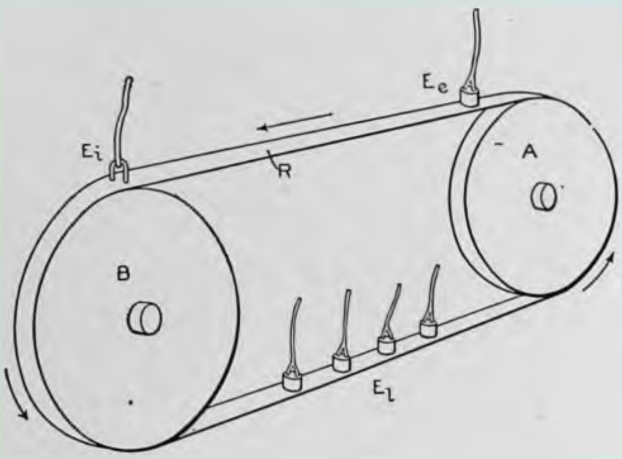


Fig. 6. Arrangement for Multiplex Transmission of Telegraphonic Messages.

The wire can be run back to any point, so that the instrument can be made to repeat any part of the record. The second pair of magnets serve the purpose of enabling the wire to record a message while it is being reeled off from right to left, or *vice versâ*; and the erasing magnets on the right or left are connected up—when the transmitter and the receiver are not in use—according to the position of the reversing switch for the motor. It is a singular fact that, although the turns of wire are packed closely together on the reels, no demagnetizing effect is to be observed, nor is the record in any way impaired. The new wire instrument leaves nothing to be desired, for the articulation is perfect.

Applications. The telegraphone has some very interesting applications. A most striking one is the simultaneous transmission by telephone of a speech, lecture, music, news of the day, etc., to any number of subscribers, up to as many as a thousand if desired. The arrangement for this purpose is shown in Fig. 6, where *A* and *B* are two parallel horizontal pulleys in alignment, over which runs an endless steel ribbon *R*; *Ei* and *Ee* are two electromagnets oppositely disposed in symmetrical positions. The first of these magnets inscribes and the latter effaces the recorded sounds. Between the two are interposed any number of electromagnets E_1 connected with independent telephone circuits.

Another practical application of the telegraphone is found in its combination with the telephone. In this case it will record verbal communications even when the subscriber is absent, which can be repeated when he arrives. The apparatus employed for this purpose comprises a spring motor mechanism for rotating the revolving parts. An inverted U-shaped frame (Fig. 7) made of tubing, has its ends connected by an arm e' mounted to turn on a sprindle c. The upper end of the U has a bearing at the middle of the frame, by means of a short stud, which passes through the U and enters the frame b. The rotary motion is imparted to the U by the motor mechanism. A fixed ring 48, carrying two annular electrical contacts 49 on its upper surface, is arranged immediately below the arm e'; and the arm is provided with a spring pin adapted to be forced into connection with both of the electrical contacts for the purpose of electrically connecting them together.

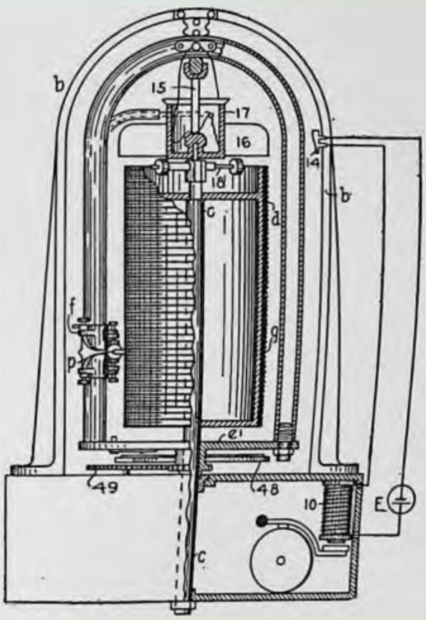


Fig. 7. Telephone Message Recorder.

On the surface of the cylinder d is wound the steel wire g. On one of the arms of the U is placed a sleeve f arranged to slide freely up and down on the U-frame; this sleeve has pivoted to it a magnet-holder, and this in turn is provided with a tail-piece, which is normally pressed upon by a spring tending to force the poles of the magnet out of contact with the wire g. When the U rotates, it carries the drum 17 with it; but, owing to the action of the brake 18 and the rings 16, there will be a certain amount of lagging on the part of the drum which will be permitted by the twisting of the wires 15. The brake is released by the electromagnet 10 in circuit with the battery *E* and a cut-out 14 attached to the frame *b*.

The operation of this apparatus in circuit with a telephone is as follows: Let it be assumed that speech or signals are being transmitted electrically over the circuit containing the magnet; that the sleeve is at the lower end of the U; and that the machine is started by closing the circuit of the magnet 10. Under these conditions, the U will immediately begin to rotate around the cylinder. When the speed is great enough, centrifugal force, acting on the weight *p*, will cause the core of the magnet to be thrown into contact with the wire *g*, when the sleeve will be caused to slide upward upon the U, because of the spiral winding of the wire on the cylinder. At the same time

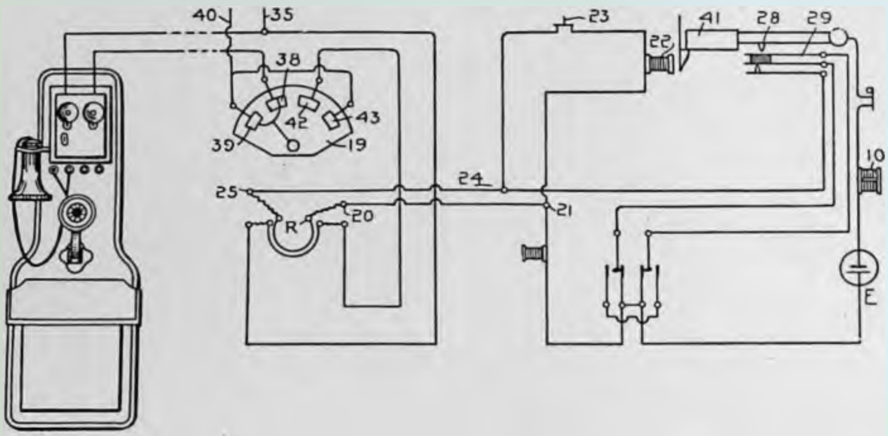


Fig. 8. Connections of the Telegraphone in a Telephone Circuit.

the undulations of current in the circuit of the magnet will vary the magnetic intensity of the latter, thus imparting to it a record.

The message may continue until the sleeve reaches the elevation of the cut-out, when the finger on the sleeve strikes the cut-out and swings it to one side, thus opening the circuit of the magnet 10.

To reproduce the message which has thus been recorded, it is only necessary to put a telephone receiver into circuit with the magnet, instead of the telephone transmitter, and start the machine again, when the sleeve will travel upon the U, and the poles of the magnet will traverse the wire *g*.

The connections of a telegraphone with a telephone are shown in Fig. 8. A switch 19 is provided, having four terminals 38, 39, 42, and 43. These terminals can be connected with each other in three different ways by means of a switch. In the position shown in the diagram, the two terminals 38 and 39 are connected together. This position establishes the circuit for the ordinary use of the telephone. The two conductors 35 and 40 constitute the outgoing and incoming lines.

If the switch lever is so adjusted as to connect the two terminals 38 and 42, the instrument can then be used as an ordinary telegraphone, and the transmitting telephone can then be used independently of it. This will be easily understood by following the course of the current when the terminals 38 and 42 are connected. When the subscriber lifts his receiver from the hook, a current will pass through the secondary of the induction coil *R*; the electromagnet 22 is thus excited, and the armature attracted, whereupon a weight 41 is released and falls. By this movement a connection is made between the contact block 28 and spring 29 whereby the local circuit of the battery *E* is closed through the electromagnet 10 and attracts an armature so that the spring motor is set in operation and the U (Fig. 7) rotated.

The sleeve, which has been resting upon the pin, begins to rise, and the connection between the contacts 49 (Fig. 7) is broken. The contact 23 consequently exists only for an instant, so that the circuit formed by 20, 21, 22, 23, 24, and 25 is open during the operation of the spring motor and mechanism.

Now, during the rise of the sleeve and while the electromagnet is in contact with the steel wire *g*, as previously described, the subscriber can speak into his transmitter, and the spirally-wound wire will accordingly be magnetized. The words thus recorded can now be transmitted over the line by using the third connection, that is, by throwing the switch 19 on the terminals 42 and 43.

As an illustration, if the message "The subscriber is not at home, but will return at 4 o'clock" is recorded on the steel wire, the subscriber at the opposite end of the line will hear this message through his receiver, and knows that in order to speak with the subscriber he must call up again at 4 o'clock. The advantages of such an arrangement are of course perfectly obvious.

Of equal value with the application above described, is the use of the telegraphone in recording telephonic conversations or contracts; and these can be made over commercial lines of any length by simply pressing a button, the operation in no way interfering with the use of the telephone. In this way the chief weakness of the telephone as a means of communication—in that it keeps no record—has been eliminated. Applications of this principle to telephonic train dispatching, so that the order of the dispatcher would be recorded at stations along the road, would be invaluable in checking errors and preventing catastrophes. Another feature that is likely to widen immensely the field of telephony, is the possibility of utilizing the telegraphone principle in a telephone repeater when trans-oceanic and trans-continental telephony shall have been realized.

The recording of Morse telegraphic signals has been easily and successfully accomplished; and the recording of signals peculiar to high-speed telegraph systems, such as the Delany, is not only possible but thoroughly practicable. Also, wireless signals and conversations can be recorded quite as easily as ordinary speech transmitted over a wire.

Next to its application in combination with the telephone, the most extensive use of the telegraphone will be for recording dictation. An instrument has been constructed which makes it possible for a person to dictate continuously for 30 minutes; and the typist is enabled afterward to hear and write the dictation without the slightest difficulty.

Compared with the commercial phonogragh now in use for this purpose, the telegraphone excels in that the person who is dictating and the typist who is writing can be isolated from the machine at telephonic distances; moreover, the record material can be used over and over again, as against repeatedly shaving the cylinders; and finally, the dictation may be long continued without having to stop to change cylinders.

The above are some of the obvious uses to which the telegraphone readily adapts itself. There are, however, many others, and when these have been fulfilled, this instrument will mean almost as much to the business man and to the world at large as does the telephone itself.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH.

PART I.

1.- Give examples of the different kinds of messages.

2. Wherein does the construction of the relay differ from that of the sounder? Why?

3. How many copies are made of train orders? Why?

4. How does the count of a government message differ from that of an ordinary message? Of a cable message?

5. How could signals be transmitted without a key?

6. (a) What is Code telegraphy? (b) Give a brief example.

7. In copying a message why is the destination placed on a line by itself?

8. (a) Give three points of difference between commercial and railway telegraphy. (b) What is the important feature of a railway operator's work?

9. In the switchboard, what is the only means of electrical connection between the bars and discs?

10. Name the apparatus used in a one-wire office.

11. What are the parts of the sounder?

12. (a) What are the six different classes in which the signals of the Morse code can be arranged? (b) Give examples.

13. What part of the relay does the work of a key for the local circuit?

14. (a) In the Auto-Alphabet instrument what determines the movement of the local points? (b) What care must be taken with regard to them?

15. (a) What are the elements of the Morse code? (b) Which is the time unit?

16. (a) How would you transform the local circuit into a learner's outfit?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC TELEGRAPH

PART II.

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1. What test can be applied to make sure that the armature of an electromagnet does not touch the core?

2. What is the essential feature of the Phonoplex? How are the signals produced?

3. What are the principal uses of the dynamo in telegraphy?

4. What two forms of apparatus are combined to form the quadruplex?

5. (*a*) What is static electricity? (*b*) How are the effects of the discharge on the duplex relay overcome?

6. If the transmitters are open in the Stearns duplex, admitting a small proportion of each battery to line, how can the effect on the relay be overcome?

7. What is the only means of electrical connection in the switchboard between the rows of discs and the strips?

8. How is the home relay in the Stearns duplex made unresponsive to the home battery?

9. What is the function of the transmitter in the quadruplex as compared with that of the pole changer?

10. What is the rule for determining the polarities in a core around which a current is passing?

11. What would be the resistance of six four-ohm sounders in series? In multiple?

12. What is a rheostat and what part does it play in the duplex?

13. How could a test of the short and long end of the quad battery be made without a meter?

14 What is meant by a differential relay?

15. In a polar duplex when like and equal poles are to the main line, how are the relays operated?

16. What feature of every form of magnet is illustrated by the action of the magnetic needle?

17. From which relay is the static eliminated in balancing the quadruplex?

18. Wherein does the movement of the armature of a polar differ from that of a common relay?

19. To set up an electric current in a closed conductor in a magnetic field what is necessary?

20. After the grounding at each terminal what is the next step in the balancing of a polar duplex? How is the ohmic balance obtained? How the static?

21. How is the dynamo made to suit the current supply to lines of different lengths?

22. Of what method of winding is the extra magnet in the Weiny-Phillips relay an illustration?

23. What is the common side of a quad? What is the function of the repeating sounder therein?

24. What are the advantages of the closed- over the open-circuit system?

25. What is the rule for the adjustment of the pole changer in either form?

26. What is the common aim in the construction of every form of automatic single line repeater?

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEGRAPHY

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1. What is meant by *conduction systems* and *induction systems* of wireless telegraphy?

2. Draw a diagram showing how a river may be used in place of telegraph lines.

3. What is meant by *radiotelegraphy?*

4. What is meant by the ether? By radiant energy?

5. What is meant by an oscillatory discharge, and what kind of waves are produced by oscillatory discharges?

6. What is meant by resonance? Sympathetic vibration?

7. What is meant by two circuits being "in tune"? What two characteristics of a circuit determine its frequency?

8. What is the characteristic of a closed oscillatory circuit? An open one? Draw two types.

9. Which are the longer ether waves—light or Hertzian waves? What is their velocity?

10. What is meant by the Righi oscillator? By the Branley coherer?

11. What effect do electric waves have upon powders and metal filings?

12. Explain what is meant by *inductive receiving antennae.* Draw a diagram.

13. What is an oscillation transformer? Should the open oscillatory circuit of the antennae and the closed oscillatory circuit be "in tune"? Why?

14. What is meant by selective signaling?

15. Name two different pieces of apparatus which may be used to charge the aërial.

16. Why cannot an ordinary Morse telegraph key be used for long-distance work in radiotelegraphy?

17. Draw a diagram of the Thomson method of creating oscillations from a direct current.

18. Draw out three methods of constructing aërials. Why is it necessary to elevate an antennae?

19. Describe a coherer.

20. What is a cymometer?

21. How many telegraphic codes are there in general use today? Name them, and tell where, and for what class of business they are commonly used.

22. Describe briefly the Marconi "X stopper" and tell what form of detector has met with success in the Marconi system.

23. Describe briefly the Fessenden system.

24. Describe the characteristics of the Telefunken system.

25. What is meant by a continuous train of undamped oscillations?

26. Name and describe briefly three systems of radiotelegraphy.

27. In what field of operation has radiotelegraphy been the most useful?

REVIEW QUESTIONS

ON THE SUBJECT OF

WIRELESS TELEPHONY

---

1. What is a Bell radiophone?

2. What is the effect of light on selenium? What is the photophone?

3. Describe the method of causing a direct-current arc to emit musical and other sounds.

4. What is the principal difficulty encountered in applying Hertzian waves to the problem of wireless telephony?

5. Why could not a common telephone transmitter be efficiently used as an interrupter for an induction coil in the production of high-frequency oscillations?

6. What is meant by intermittent wave trains?

7. Describe the method of superimposing a telephone current upon a constantly operating source of oscillations of high intermittency.

8. Name two different methods of creating sustained oscillations.

9. Draw a diagram of the Fessenden method of transmitting radiotelephonically by use of the high-frequency alternator.

10. Name the two most common methods of producing sustained oscillations.

11. Draw three different ways of connecting a telephone carbon transmitter to the oscillatory circuits in order to vary the energy of the radiation therefrom in accordance with the voice current.

12. What detectors may be used for radiotelephony? May a coherer be used?

13. Describe the action of the Fessenden "heterodyne" receiver.

14. Tell why two-way transmission in radiotelephony is not as simple of accomplishment as in ordinary wire telephony.

15. Name seven different radiotelephonic systems.

16. Describe the Telefunken system.

17. Describe briefly the Ruhmer system.

18. Describe the characteristics of the Poulsen system.

19. How does the Marjorana system differ from others?

20. What method of producing sustained oscillations does Fessenden employ?

21. Describe the DeForest system briefly.

22. What detector does DeForest use?

23. Give the general features of the Collins system.

24. Why is the clearness of articulation better in radiotelephony than in wire telephony over long lines and cables?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELEMENTS OF ELECTRICITY AND MAGNETISM

1. Explain, from the standpoint of induced magnetization, the process by which a magnet attracts a piece of soft iron.

2. What are the differences in the magnetic behavior of soft iron and hard steel?

3. What is meant by a magnetic line of force?

4. What reasons have we for thinking that magnetization is a molecular phenomenon?

5. State how you would test the sign of an unknown charge of electricity by means of the gold-leaf electroscope.

6. Describe the process of charging an electroscope by induction.

7. In charging an electroscope by induction, why must the finger be removed before the removal of the charged body?

8. If you hold a brass rod in your hand and rub it with silk, the rod will show no sign of electrification; but if you hold the brass rod with a piece of sheet rubber and then rub it with silk, you will find it electrified. Explain.

9. Why is a pith ball attracted to an electrified rod and then repelled from it?

10. What differences can you mention between magnetism and electricity?

11. Explain the principle of the condenser.

12. Explain the principle of the lightning rod.

13. Why is the capacity of a conductor greater when another conductor connected to the earth is near it than when it stands alone?

14. Why cannot a Leyden jar be appreciably charged if the outer coat is insulated?

15. If the potential difference between the terminals of a cell on open circuit is to be measured by means of an instrument consisting of a coil and magnet, why must the coil have a very high resistance?

16. How much current will flow between two points whose P. D. is two volts, if they are connected by a wire having a resistance of ten ohms?

17. If a voltmeter placed across the terminals of an incandescent lamp shows a P. D. of 110 volts, while an ammeter connected in series with the lamp indicates a current of .5 ampere, what is the resistance of the incandescent filament?

18. If a certain Daniell cell has an internal resistance of 2 ohms and an E. M. F. of 1.08 volts, what current will it send through an ammeter whose resistance is negligible? What current will it send through a copper wire of 2 ohms resistance? Through a German silver wire of 100 ohms resistance?

19. A Daniell cell indicates a certain current when connected to a galvanometer of negligible resistance. When a piece of No. 20 German-silver wire is inserted in the circuit, it is found to require a length of 5 ft. to reduce the current to one-half its former value. Find the resistance of the cell in ohms, No. 20 German-silver wire having a resistance of 190.2 ohms per 1,000 ft.

20. Why is a Daniell cell better than a bichromate cell for telegraphic purposes?

21. Why is a Leclanché cell better than a Daniell cell for ringing door-bells?

22. If the internal resistance of a Daniell cell of the gravity type is 4 ohms, and its E. M. F. 1.08 volts, how much current will 40 cells in series send through a telegraph line having a resistance of 500 ohms? What current will one such cell send through the same circuit? What current will 40 cells joined in parallel send through the same circuit?

23. What current will the 40 cells in parallel send through an ammeter which has a resistance of .1 ohm? What current would the 40 cells in series send through the same ammeter? What current would a single cell send through the same ammeter?

REVIEW QUESTIONS

ON THE SUBJECT OF

THE ELECTRIC CURRENT.

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1. (*a*) Explain what is meant by electromotive force. (*b*) What is its unit of measurement, and by what value is it represented?

2. (*a*) What is necessary to cause an electric current to flow? (*b*) What is meant by the strength of a current? (*c*) What is its unit of measurement, and by what value is it represented?

3. What is the unit of resistance and by what value is it represented?

4. Upon what three general factors does resistance depend?

5. What length of copper wire 2 millimeters in diameter will have the same resistance as 12 yards, 1 millimeter in diameter?

Ans. 48 yards.

6. State Ohm's law.

7. Two wires, whose resistances are respectively 28 and 24 ohms, are placed in parallel in a circuit so that the current divides, part passing through each. What resistance is offered by them to the current? Ans. 12.92 + ohms.

8. Fifty Grove's cells (E. M. F. = 1.8 volts) are in series. and united by a wire of 15 ohms resistance. If the internal resistance of each cell is .3 ohm, what is the current? Ans. 3 amperes.

9. (*a*) What is the unit of quantity of electricity? (*b*) Define the ampere-hour.

10. What is the power in watts when 4000 joules of work are done in 50 minutes? Ans. 1.33 + watts

11. How many horse-power are equivalent to 83 kilowatts?

Ans. 111 + horse-power

12. What is a shunt circuit?

13. A current of 18 amperes flows in a circuit whose resistance is 116 ohms. What is the voltage?

14. The resistance of 312 feet of a certain wire is 2.08 ohms. What would be the resistance of 240 feet of the same wire?

15. A total current of 56 amperes passes through a divided circuit having the resistance of its branches equal to 28 and 4 ohms respectively. What is the current in each branch?

Ans. In the 28-ohm branch, 7 amperes.
In the 4-ohm branch, 49 amperes.

16. What is the value of the current when 4 ampere-hours are delivered in a circuit in 20 minutes?

17. (*a*) Define the joule. (*b*) Define the watt.

18. A 220-volt circuit supplies a current of 18 amperes. What is the power in kilowatts?

19. If the resistance of a certain wire is 2.3 ohms per 1000 feet, how many feet of the wire will be required to make up a resistance of 17.8 ohms?

20. What is the resistance of a wire having a diameter of .2 inch if the resistance of the same length of similar wire having a diameter of .04 inch is 64.2 ohms?

21. Define specific resistance.

22. The resistance of a circuit is 1.8 ohms and the voltage is 110. What is the current?

23. A circuit contains a voltaic cell generating an electromotive force of 1 volt. Its electrodes are connected by three wires in parallel of 2, 3, and 4 ohms resistance respectively. The resistance of the cell is $\frac{1}{13}$ ohm. What is the current?

Ans. 1 ampere.

24. Eight cells each having an E. M. F. of .9 volt and an internal resistance of .6 ohm are connected in parallel, and the external resistance is 3.4 ohms. Find the current.

Ans. .26 ampere (approx.).

25. What quantity of electricity will be conveyed by a current of 40 amperes in half an hour?

26. The resistance of a circuit is 10 ohms, and the current is 33 amperes. What is the power in watts?

27. How many watts are equivalent to 14 horse-power?
Ans. 10,444 watts.

28. Five conductors having resistances respectively equal to 14, 3, 20, 31 and 8 ohms are joined in series, and the E. M. F. applied to the circuit is 50 volts. What is the current?
Ans. .65 amperes.

29. (*a*) Define conductance. (*b*) Define conductivity.

30. What is the resistance of 10 feet of annealed gold wire .001 inch in diameter at 32° F., if the resistance of an inch cube of the substance at 32° F. is .8079 microhm?

31. A copper wire has a resistance of 13.5 ohms at 43° F. What is its resistance at 57° F?

32. What must be the resistance of a 220-volt circuit if the current is to be 70 amperes?

33. The E. M. F. applied to a circuit is 582, and the current is 8 amperes. A number of lamps connected in the circuit require a total drop of 522 volts. Find the resistance of the remaining portion of the circuit.

34. A circuit is made up of six wires connected in parallel and having resistances of 72, 60, 21, 36, 40 and 210 ohms respectively. Find their joint resistance.

35. When a cell, which has an internal resistance of 1.39 ohms and an E. M. F. on open circuit of 1.32 volts, is supplying a current of .29 ampere, what is its available E. M. F.?
Ans. .92 volts (approx.).

36. With a current of 20 amperes how much time will be required to deliver 4,000 coulombs.

37. The voltage of a circuit is 103 and the current is .5 ampere. What energy is expended in a minute and a half?
Ans. 4635 joules.

38. The resistance of a coil of platinoid wire at 98° C. is 3014 ohms. What resistance would the coil have at 18° C.?
Ans. 2962 ohms (approx.).

39. What is the resistance of 28 feet of No. 6 (B. & S.) pure copper wire at 90° F.?

40. If a resistance of 116 ohms be inserted in a circuit, and it is desired to maintain a constant current of 9.6 amperes, how much must the voltage of the circuit be increased?
Ans. 1113 + volts.

GENERAL INDEX

GENERAL INDEX

In this index the *Volume number* appears in Roman numerals—thus, I, II, III, IV, etc.; and the *Page number* in Arabic numerals—thus, 1, 2, 3, 4, etc. For example, Volume IV, Page 327, is written IV, 327.

In addition to this "General Index," the reader is referred to the more exhaustive analytical index to be found in each volume.

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