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

CHICAGO
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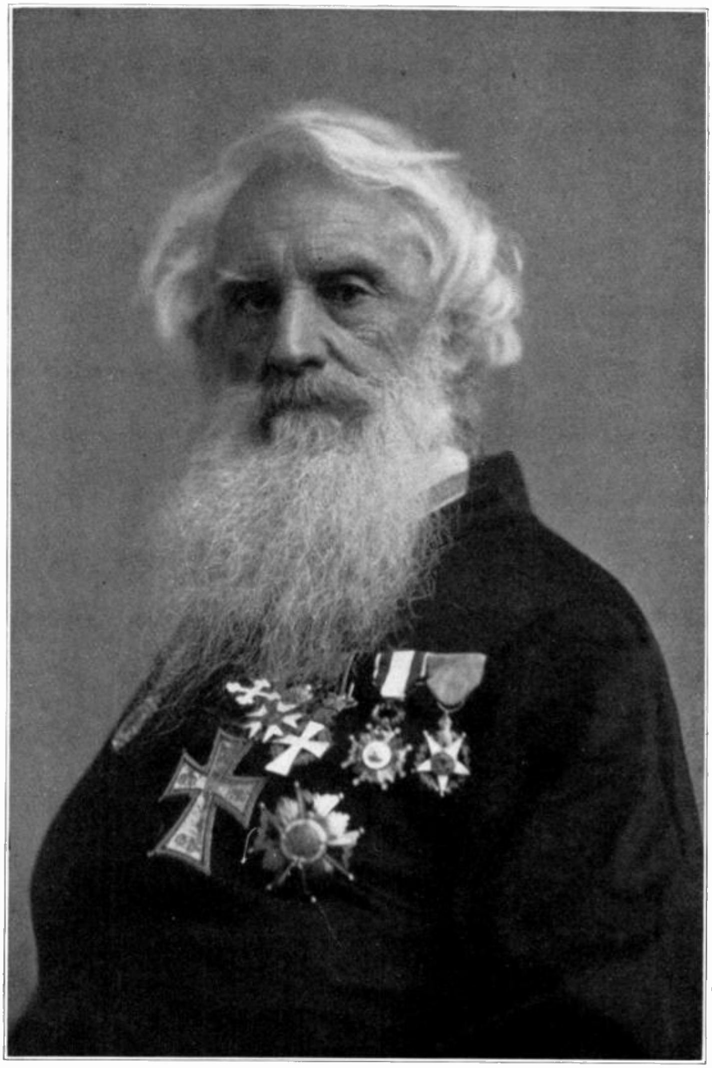

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost engineering firms and manufacturers in making these volumes thoroughly representative of the very best and latest practice in the transmission of intelligence, also for the valuable drawings, data, suggestions, criticisms, and other courtesies.

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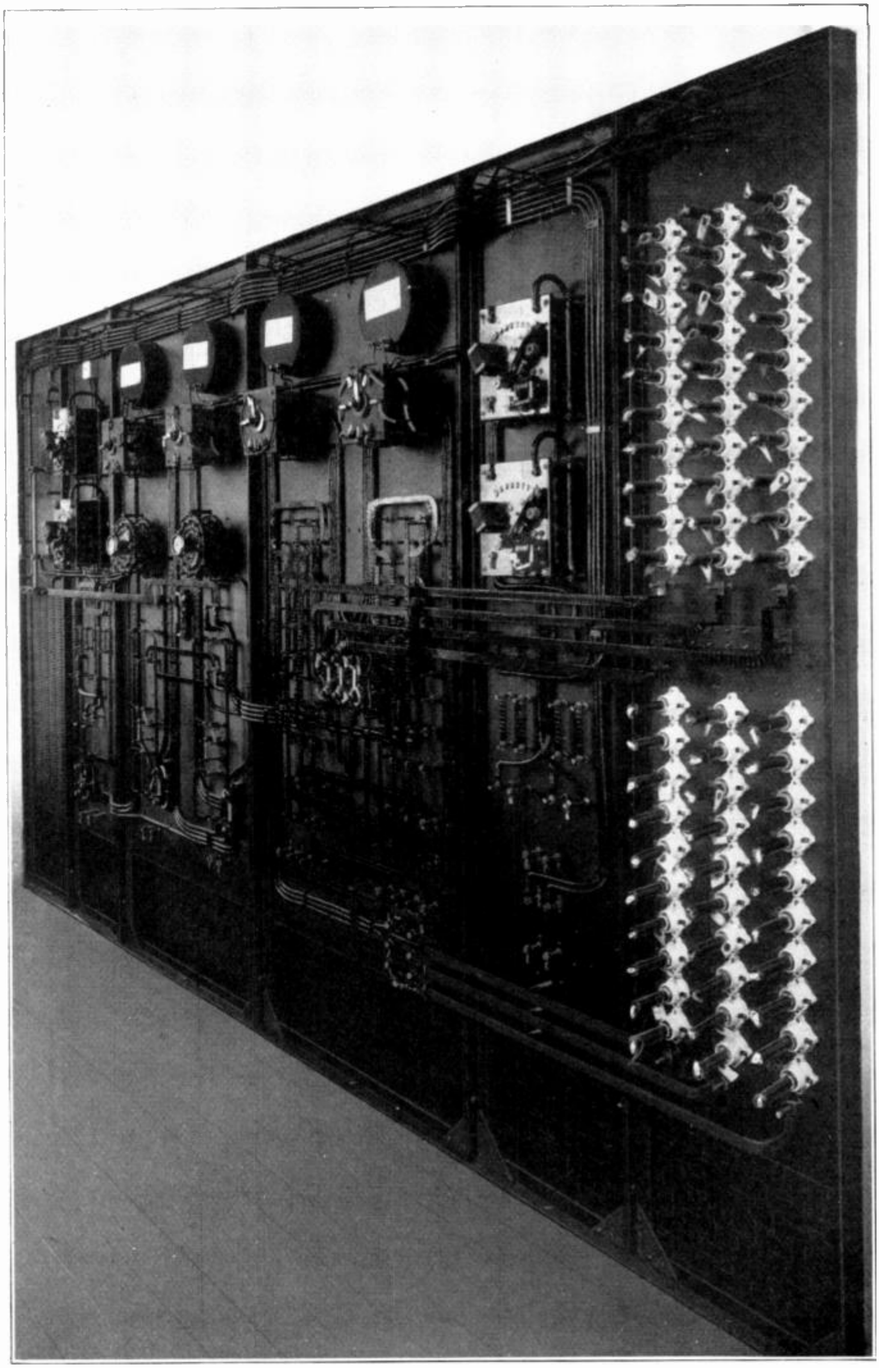

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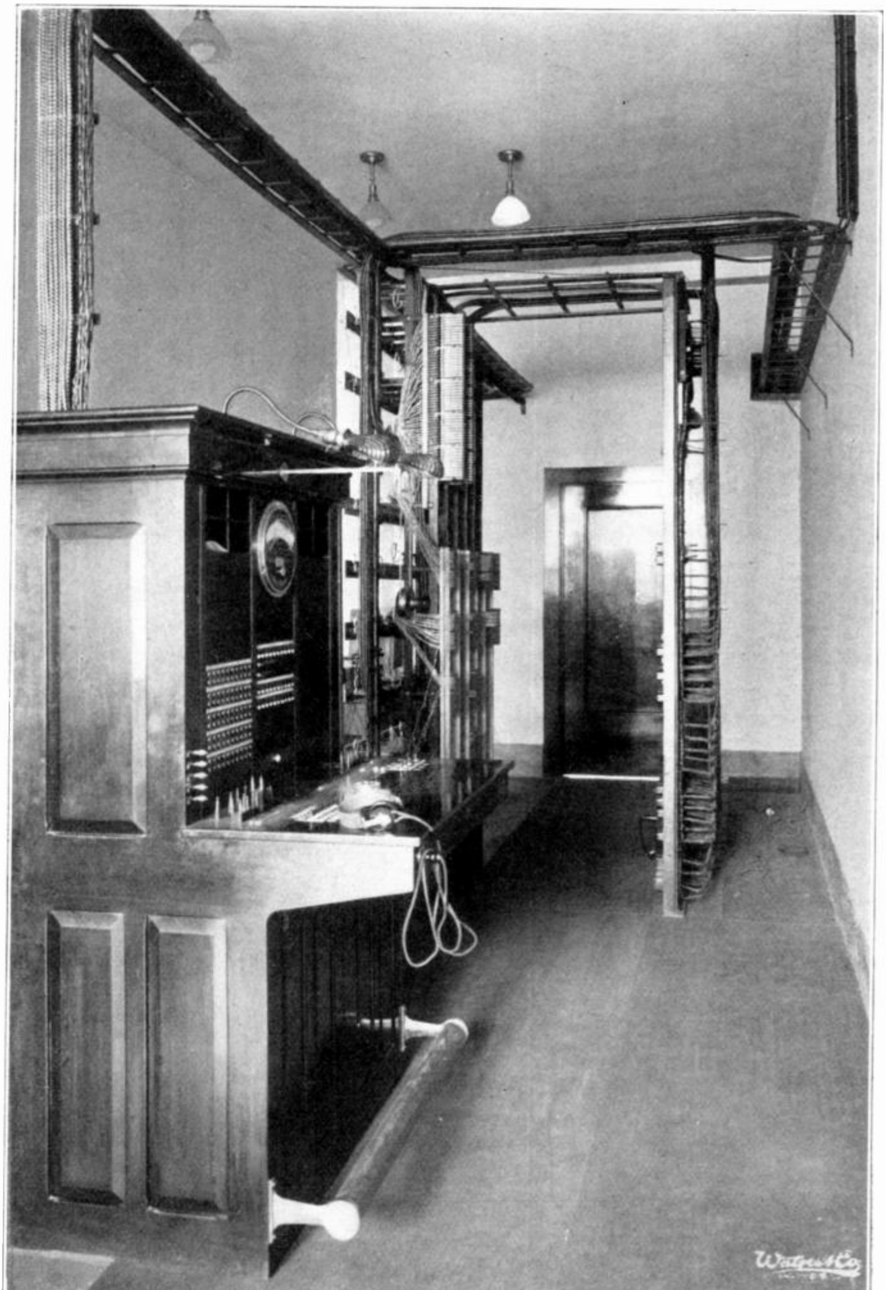

LONG-DISTANCE TEST BOARD OF SAN FRANCISCO HOME TELEPHONE COMPANY
Distributing Frame and Testing Appliances for Long-Distance Lines.

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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† For professional standing of authors, see list of Authors and Collaborators at front of volume.

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CHAPTER XLI

TYPES OF TELEPHONE LINES

Telephone lines may be underground or overhead. If the latter, they are called *aërial lines.* Wherever placed, the lines must be insulated from each other and from other things, such as the earth. If aërial, the lines either are of bare wire supported by solid insulators, or they are of wire insulated throughout its length by some covering. That covering in the present practice is principally of rubber, gutta-percha, or dry paper.

The mechanical conditions of practice require bare aërial wires to be borne by poles or other supports 100 to 200 feet apart; to be spaced 8 to 12 inches apart; to be stretched tightly enough not to be swung together by winds, and to be strong enough to bear their own weight plus wind pressure and a load of ice. These dimensions cause the total space occupied by a line of several hundred wires to be great.

The electrical conditions of practice require of exchange (city) lines that the loop resistance be not over about 500 ohms and the mutual capacity not over about .3 microfarad. These conditions are not so severe as to require large wires far apart. Open wires on poles must be larger and farther apart for mechanical reasons than they need to be for electrical reasons. Small wires close together are good enough for exchange lines if they do not have to be strung on poles as bare wires.

The solution for these requirements is the telephone cable. Many wires can be put in a small space if cabled. Cables may be supported by poles, buildings, or fences, or may be laid in the earth or in water. There is no difference between the electrical operations of cables in the earth, in the water, and in the air.

Cabled wires have the advantage that they are less likely to individual insulation and continuity troubles than are open wires. Insulation troubles, when they do happen to cable wires, usually affect more circuits than in open-wire construction; cabled wires have higher mutual capacity than open wires; these are disadvantages. Cost facts also concern the question "cabled wires *versus* open wires for exchange lines"; the solution of all the facts is favorable to cables if the number of exchange lines along a route is more than a dozen or two.

Feasibility, first cost, owning-and-using costs, self-interest, and public policy are the considerations which control the decision whether cable shall be overhead or underground. Cities steadily increase the areas in which local laws prohibit pole lines on the street. In cities having such laws at all, and having also adequate development of telephone service, the area in which it is *economical* to place wires underground usually is larger than the area in which it is legally *obligatory* to place them so. This is fortunate for all concerned.

In general terms, the solution of the facts of costs and policy usually shows that wires shall be placed underground when there are more than 500 lines in the route. Underground cables for electrical service generally may be placed directly in the earth as gas pipes are; but gas pipes are self-protecting against most attacks, such as by picks and shovels. Cables are less so. Access to cables for changes in them is necessary; they require to be changed in position and connection and to be replaced by others. Standard underground telephone-cable practice is to provide an underground system of ducts adapted to protect the cables against mechanical damage and to allow them to be placed and replaced without further opening of the earth than was first required to lay the system of ducts. Underground cables so placed cost less to maintain than do aërial cables. The value of a cable after withdrawal from a duct is greater than that of a similar aërial cable after being taken down.

The open aërial wires of exchange lines have to be larger and further apart for mechanical reasons than they do for electrical reasons. This is not true of the open aërial wires of long-distance lines. Electrical reasons, in the design of long-distance circuits, make low resistance and low mutual capacity important. Unless the inductance be increased by loading the line, cable circuits are limited in their speaking distance from one-tenth to one-fifth the speaking distance of the same wires on poles in open air.

In other words the smallest practical open wires for a given length of exchange line are larger than their *electrical* requirements demand; the smallest practical open wires for a given length of long-distance line are larger than their *mechanical* requirements demand. Also, exchange wires would fulfill electrical requirements sufficiently well if much closer together; while long-distance wires would fulfill electrical requirements much better if much further apart. Mechanical reasons only control the spacing of both kinds of wire.

When cables are laid under water, it usually is because there is no other practical way of placing them. The solution as to the best way generally has no alternatives. A given submarine cable may not be the best way of meeting the requirements; it may be the only way.

CHAPTER XLII

OPEN WIRES

Wire for open use on insulators is made of copper, bronze, steel, or iron, or of steel covered with copper. Copper for all physical reasons is best; iron and steel are cheaper; bronze is little used. Copper-clad steel, combining strength, conductivity, and freedom from corrosion with possible low cost, is likely to become more and more useful.

Iron. Iron and steel are poorer than copper in specific conductivity. Calling the specific conductivity of copper 100, that of iron is from 12 to 18 and of steel from 8 to 12, depending upon the state and purity of the metal. Iron and steel are stronger than copper. That they rust is a great fault. Galvanizing is a protection, but its value varies widely in different situations; in certain regions having dry air and no smoke, galvanized open iron wires last twenty-five years. In most cities of the temperate zone, such wires last six to eight years. In cities burning much soft coal and near smelters, such wires often last only three years. The larger the wire, the longer it will last, as there is more of it to rust away.

Galvanizing. Galvanizing is a name for the coating of iron or steel with zinc. The coating is applied, in the "hot" process, by dipping the iron or steel in molten zinc in the presence of a flux. This is a dipping process, not an electroplating process, though the name implies the latter. In the "cold" process, the iron or steel is zinc-plated by electrical means. The hot, or dipping, process is the present standard for wire.

The test for acceptable galvanizing is:

> Immerse the sample in a saturated solution of copper sulphate for one minute, then wipe it clean. Do this four times in all. If the sample appears black after the fourth wiping, the galvanizing is acceptable; if it has a copper color, wholly or in spots, the iron is exposed. Reject such galvanizing, for the coating is too thin.

Strength. The strength of iron wire is about 3.1 times its weight per mile; of steel wire about 3.7 times its weight per mile.

Mile-Ohm. The term "mile-ohm" sometimes is used to indicate the resistance of wire. It is the weight of a wire 1 mile long and having a resistance of 1 ohm. The lower the conductivity of a metal the higher is its weight per mile-ohm. For example, for soft copper the mile-ohm is about 860 pounds; for hard-drawn copper, 880 pounds; for the best iron, 4,500 pounds; for good iron, 5,400 pounds, and for steel as high as 7,000 pounds.

Copper. Copper is drawn into wire by pulling it successively through smaller and smaller holes. It hardens in being so drawn, so it is softened (annealed) by heating and cooling. If it is not annealed after the last drawings, it has much greater strength. This is hard-drawn copper. Its uses are in open wire lines, either bare or insulated. The uses of soft copper are in other circuits. Even though from the earliest times it was known of drawn copper wire that after one or two drawings the wire became so hard as not to be successfully drawn without softening, no wire was furnished to the market in such a hardened state. The earliest uses of copper wire for line purposes were failures and it was standard practice for many years to use copper only in electrical circuits where it did not have to bear its own weight. Credit for the development of the right method is due to Thomas B. Doolittle, who developed the present successful method of producing hard-drawn copper wire for use in open lines.

Copper vs. Iron. When high conductivity and long life are required, use copper. Hard-drawn copper is stronger than soft (annealed) copper. Where greater strength than this of hard-drawn copper is required and high conductivity is not of importance, use iron or steel. This case meets certain needs of long spans. Where low cost is important, corrosive causes are not great, and high conductivity is not essential, use iron or steel. This case describes the needs of many country lines (toll lines, rural lines) under 15 miles long.

Copper-Clad Steel. The advantages of copper wire, in its superior conductivity and its freedom from corrosion when exposed to the elements, and the advantage of steel wire in its superior strength long have added zest to the search for a wire combining the advantages of both. Many efforts have been made to provide a strong steel wire with a good copper coating, but until recently these efforts have been unsuccessful. In some of the earlier attempts, the copper was applied to the wire by electroplating. It was not found that the coating would cling to the steel tightly enough to preserve it perfectly, and in time rust crept between the metals and the copper would fall away. Other attempts have been in the direction of fitting a billet of steel tightly into a copper tube, then drawing the whole into wire. In this attempt also the lack of a perfect union between the two metals defeated the attempt.

Monnot Process. The Monnot process, named after the inventor, is that employed by the Duplex Metals Company of New York, and consists of uniting the steel core and copper shell while they are hot. Under proper conditions actual welding and alloying take place between the two metals. Such a billet may be drawn into wire without breaking the contact between the two metals. The steel remains centered through many drawings and the experience which is available at the time of this writing indicates that copper-clad steel wire may be considered a practical element of electrical construction.

Characteristics. Compared with hard-drawn copper wire, copper-clad steel wire has, in general terms, higher tensile strength and lower conductivity. It is obvious that in the manufacture of copper-clad wire, its resulting tensile strength will depend both upon the grade of steel chosen for the core and upon the relative amounts of copper in a wire of given diameter. The more steel in the core, the less copper there will be in the shell, and, therefore, the greater the strength, and the lower the conductivity.

The inductance of copper-clad steel wire is less than that of iron, and yet it is more than that of copper, for the same diameter of wire, for the same distance between the two sides of the circuit, and for the same permeability of iron and steel.

Uses. Copper-clad steel wire for electrical uses may be had of conductivities 30 and 40 per cent of that of solid copper wire, but with these reduced conductivities go an increase of strength. As we have shown, there are many uses of wire for lines exposed to the elements in which a reasonable conductivity only is required, coupled with a minimum tensile strength. For these purposes a copper-clad steel wire is eminently suitable, if it is made in such a way as to be as non-corrosive as copper and if it can be bought at a lower price. Copper-clad steel wire has been used with considerable success for line wire in train-dispatching work. These lines are as a rule not of extreme length, and the freedom from corrosion of copper-clad steel wire, increased conductivity over iron, and greater strength than copper have, together with its moderate cost, made it attractive for railroads.

Insulated wires twisted in pairs for connecting subscribers' premises to nearby cable terminals would be perfectly satisfactory, so far as conductivity is concerned, if they were as small as No. 22 B. & S. gauge, as the remainder of the line in the cable is of that size. But wires as small as No. 22 B. & S. gauge can not support their own weight successfully, so that the added weight of the rubber insulation and braid would break them down promptly. If these were of high-grade steel, they might support themselves successfully, if of No. 22 B. & S. gauge, but wherever exposed at terminals or elsewhere, the steel wire would rust. It is in such cases as these and in moderate length of bare-wire lines that copper-clad wire finds use if costs permit.

Insulated Open Wire. Even when carried on glass or porcelain insulators on poles, open telephone wires sometimes require to be insulated by an actual wire covering. The circumstances making this necessary usually are where foliage may touch the wires. The best practice is to insulate such conductors with rubber compound of high insulating quality and to cover this in turn with a heavy cotton braid saturated with some weatherproof compound.

Drops. In some plans of construction, wires which leave a pole line to reach a subscriber's premises are both open wires. These wires are called "drops" or "drop wires." Where two single wires make up such a drop and the span is long, it is good practice to have at least one of them insulated, so that if the two wires swing together, as is more likely than in a straight span of a pole line, they will not short-circuit the line and throw it out of service.

The better practice for drop wires, and that which is becoming customary with the wide use of cables and the limited use of open wires in city systems, is to use two insulated wires twisted into a pair for drop service. Such twin or paired wire is known as drop wire. The conductor usually is of No. 14 or No. 16 B. & S. gauge, if of hard-drawn copper, or of No. 17 gauge, if of copper-clad steel wire. No. 14 wire is used where the climate makes ice a possible burden. No. 16 is suitable in climates where ice does not form. If No. 18 copper-clad steel wire of suitable quality can be had with a tensile strength as great as that of No. 16 hard-drawn copper, it forms an acceptable substitute in regions where ice does not form.

Wall and Fence Wire. It is becoming a more general practice to terminate underground cables on the back walls of buildings and to carry twisted pairs of wires through rings along horizontal and vertical lines on those back walls. As compared with a distributing pole, the method is more sightly and as simple to maintain. The distance between the rings being short, no great tensile strength is required of the wire. It is, therefore, good practice to use No. 18 B. & S. copper wire, with a thinner insulation than is required of drop wires.

Braiding. All classes of insulated line wires for outdoor use require a braiding saturated with a weatherproof compound as a

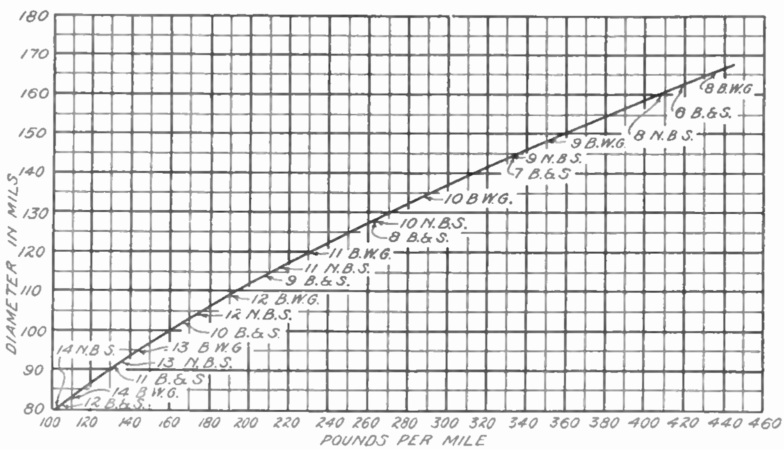


Fig. 500. Sizes and Weights of Line Wires

protection to the rubber covering, for rubber deteriorates by exposure to the air and to the sunlight, the action of sunlight being a particularly powerful deteriorating cause.

Designation of Sizes. There are three ways in which wires may be designated as to their size: by their diameter, by arbitrary gauge numbers indicating this diameter, and by their weight per unit length.

TABLE XVIII

Sizes of Copper Wire Suitable for Bare Line Construction, in Various Standard Gauges

(Arranged in Order of Size)

Number	Diameter in Mils	Weight per Mile in Pounds	Resistance per Mile of Wire in Ohms, 60° F.	Resistance per Mile of Circuit in Ohms, 60° F.
8 B. W. G.	165.	435	1.9742	3.9484
6 B. & S. G.	162.	419	2.0481	4.0962
8 N. B. S. G.	160.	409	2.0998	4.1996
9 B. W. G.	148.	350	2.4541	4.9082
7 B. & S. G.	144.3	331	2.5925	5.1850
9 N. B. S. G.	144.	331	2.5925	5.1850
10 B. W. G.	134.	287	2.9838	5.9676
8 B. & S. G.	128.5	262	3.2810	6.5620
10 N. B. S. G.	128.	262	3.2810	6.5620
11 B. W. G.	120.	230	3.7330	7.4660
11 N. B. S. G.	116.	215	3.9948	7.9896
9 B. & S. G.	114.4	208	4.1363	8.2726
12 B. W. G.	109.	190	4.5244	9.0488
12 N. B. S. G.	104.	173	4.9701	9.9402
10 B. & S. G.	101.9	166	5.1665	10.3330
13 B. W. G.	95.	144	5.9558	11.9116
13 N. B. S. G.	92.	135	6.3518	12.7036
11 B. & S G.	90.74	132	6.4891	12.9782
14 B. W. G.	83.	110	7.8038	15.6076
12 B. & S. G.	80.81	105	8.1946	16.3892
14 N. B. S. G.	80.	102	8.4005	16.8010

All three of these ways are in common practice. Wires for use in open lines are frequently designated merely by their weight in pounds per mile. As the weight and conductivity both vary as functions of the cross-section of the wire, speaking of the weight immediately suggests the conductivity. Stating the diameter of the wire in fractions of an inch or of a meter is good practice and avoids errors which are introduced by the use of the third method, that of arbitrary gauge numbers. If there were but one wire gauge in use throughout the world, these errors would not arise as often as they do. The requirements of practice having become more exact, it often is found that a wire having exactly the right cross-section to meet a given case falls between two sizes of a given wire gauge system.

Wire Gauges. For use in actual telephone lines, there are three principal wire gauges. These are the American wire gauge (also known as the Brown and Sharpe gauge, abbreviated B. & S.), the new British standard gauge (legal in Great Britain; also known as English Legal Standard and abbreviated N. B. S. and E. L. S.), and the Birmingham wire gauge (B. W. G., also known as Stubs gauge).

All of these gauges are in common use in the United States. The Brown and Sharpe gauge is only universal in this country for the smaller wires. Wires in windings of apparatus, for example, do not follow any other gauge. In line construction, the special needs of a case may make it necessary to choose sizes in other than the Brown and Sharpe gauge.

TABLE XIX

Size, Weight, Approximate Elastic Limit, Approximate Breaking Weight, and Average Resistance of Copper-Clad Wire

(40 Per Cent Conductivity)

B. & S. Gauge No.	Weight Per Mile	Approximate Elastic Limit	Approximate Breaking Weight	Av. Resistance in Ohms per Mile at 60° F.
0000	3140.	8523.	9470.	0.634
000	2490.	6660.	7400.	0.800
00	1975.	5922.	6580.	1.009
0	1570.	4707	5230.	1.272
1	1240.	4104	4560.	1.605
2	985.	3240.	3600.	2.024
3	780.	2970.	3300.	2.552
4	620.	2340.	2600	3.217
5	491.	1980.	2200.	4.060
6	390.	1530.	1700.	5.117
7	309.	1305.	1450.	6.450
8	245.	035.	1150.	8.132
9	194.	855.	950.	10.26
10	154.	684.	760.	12.93
11	122.	558.	620.	16.33
12	97.	441.	490.	20.57
13	77.	351.	390.	25.90
14	61.	288.	320.	32.70
15	49.0	225.	250.	41.20
16	38.3	180.	200.	52.05
17	30.5	149.	165.	65.45
18	24.1	117.	130.	82.68
19	19.1	90.	100.	104.2
20	15.2	72.	80.	131.1

Characteristics of Copper Wire. The diameters, weights, and resistances of copper wires of all the sizes in common use in bare-wire telephone lines appear in Table XVIII.

The curve of Fig. 500 gives the weight per mile of wire of the sizes given in Table XVIII. The curve gives at a glance an idea of the similarity between certain sizes of the different gauges.

Characteristics of Copper-Clad Wire. The mechanical and electrical characteristics of copper-clad wire, having a conductivity of about 40 per cent of that of copper wire of the same gauges, are given in Table XIX.

Characteristics of Iron Wire. The mechanical and electrical characteristics frequently specified for iron wire, of the sizes most commonly used for telephone lines, are given in Table XX.

TABLE XX

Size, Weight, Tensile Strength, and Approximate Resistance of Iron Wire Commonly Used in Telephone Lines

B. W. G. Gauge	Dia. in Mils	Length of Bundles Miles	Weight in Lb. per Mile	Min. Tensile Strength in Lbs.			Approx. Resis. in Ohms, per Mile		
				E.B.B.	B. B.	Steel	E.B.B.	B. B.	Steel
6	203.	1/3	590	1475	1652	1770	8.0	9.5	11.0
8	165.	1/2	390	975	1092	1170	12.1	14.4	16.7
9	148.	1/2	314	785	879	942	15.0	17.8	20.7
10	134.	1/2	258	645	722	774	18.2	21.7	25.2
11	120.	1/2	206	515	577	618	22.8	27.2	31.6
12	109.	1/2	170	425	476	510	27.7	32.9	38.2
14	83.	1/2	99	247	277	297	47.5	56.6	65.7

CHAPTER XLIII

CABLES

Early Types. Early telephone cables were copies of telegraph cables. For outdoor use, the wires were insulated with rubber; for indoor use they were insulated with cotton. Rubber soon was found unsatisfactory for telephone cables, principally on account of its high specific inductive capacity. Cotton insulation, as used on the wires of indoor cables, was found preferable in that respect, so such cables, covered by a lead sheath to keep the cotton dry, were used somewhat widely. The lead sheath was applied by threading the cable through successive lengths of lead pipe, and soldering together the adjacent ends of the sections of pipe. A next step in the development of the process was to pass the cabled wires through a machine to make the lead pipe directly upon them, in a continuous length. The cotton covered and cabled wires were saturated with paraffin or with some hydrocarbon compound.

Dry Paper. The search for an insulating material of still lower specific inductive capacity finally led to the adoption of the present standard, dry paper, a material much better than others because a cable insulated with it contains so much air, not only in the paper itself, but in the spaces between the wires, when the core of wires and paper is not compressed too tightly.

Manufacture. The process is roughly that of insulating the untinned copper wire by loosely wrapping paper ribbon around it, twisting two wires so insulated into a pair, laying up the requisite number of pairs into a rope, and forming a lead sheath over it.

Conductors:—Cables for exchange uses usually are formed of No. 19 or No. 22 B. & S. gauge wires. Paper ribbon $\frac{1}{2}$ to $\frac{5}{8}$ inch wide, and from .002 to .004 inch thick, is wrapped spirally on the wire. The edges of the spirals of paper overlap. Either one or two paper wrappings are applied, as required by the fancy of the engineer or the real requirements of the cable's intended use. A single wrap suffices for all needs in most cases, though repairs requiring boiling out of moisture by hot paraffin are more certainly done when two wrappings exist.

Pairs:—Two paper-wrapped wires are then twisted into a pair, the two wires having different colored papers, to enable them to be distinguished from each other in splicing and terminating. The

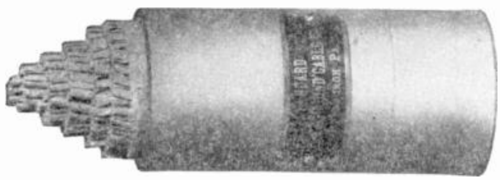


Fig. 501. Paper Cable

"lay" of the twist, *i. e.*, the length of one complete spiral, varies from 3 to 6 inches, depending on the size of wire used; the smaller the wire, the shorter the length of lay. The reason for twisting the wires of pairs in cables is the same as that for transposing the wires of an open air line, viz, in order to neutralize the effects of electro-magnetic and electrostatic induction between adjacent lines. In telephone cables, if the wires were not twisted into pairs, it would be possible for conversations which are being carried on on one line to be overheard on another line.

Core:—A number of pairs are taken as a beginning, and others are wrapped around them in a spiral layer. Over this, other layers

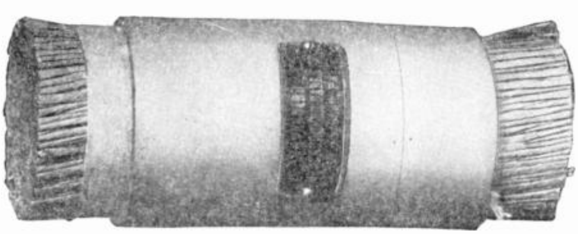


Fig. 502. Paper Cable

are wrapped, the direction of the spiral reversing from layer to layer. When all the pairs are in place, one or more layers of paper tape are wrapped over the entire cable-core to hold it in form. Some makers use a binding of cotton yarn instead of the paper tape, or with it. The wick-like nature of cotton yarn is an objectionable quality, as cotton carries moisture further from a fault than does paper tape alone.

Drying:—The cable-core now is dried, to free the paper from moisture absorbed from the air before and during the manufacture of the core. Heat is applied by putting the reeled core into an oven, and often by exhausting air from the oven. The core is then drawn directly from its reel in the oven into and through a lead press to apply the sheath. Figs. 501 and 502 show finished cables.

Forming Lead Sheath:—It is an interesting way in which the lead press acts, to mould a lead or lead-alloy sheath directly upon the cable-core. Fig. 503 is not a slavishly exact picture of a lead press in action, but is meant to help show how a lead press works. The core of the cable *6* passes into the press at the right of the figure, and emerges at the left with its sheath *1* moulded over it. Let *4* represent, in general terms, a strong containing vessel, acting as the barrel of the press. Note that everything shaded as are the areas *2* in the figure, is a part of one mass of lead, hot but not quite fluid. The piston *5* presses downward on this mass of lead, and the lead is forced out through the opening in the part *7*, through which also the cable emerges. This opening and the part *3*, taken as a unit, form the *die* of the press, and it is the die which is the unique feature of the whole matter. Obviously the mere hole in the side of the press would squeeze out lead and the cable together, by the pressure of the piston, but this would compel the sheath to compress the core. The part *3* cares for this feature. The outer surface of the part *3* moulds the *inner* surface of the sheath, just as the walls of the hole in the part *7* mould the *outer*. If it be noted that the mass of lead is always *one* mass, a part always exuding from the press in the form of a pipe, carrying

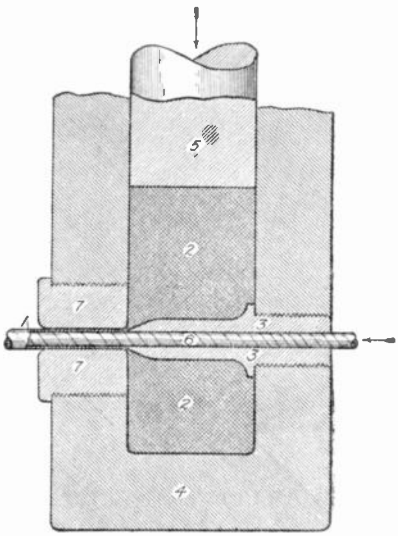


Fig. 503. Principle of Lead Press

the cable within it, the thought will be complete. If the core should be omitted, a mere lead pipe would exude. This re-suggests the fact that the lead is not molten but semi-molten only, and flows partly because softened by heat and partly because of the great pressure upon it.

Alloyed Sheath:—An alloy of 97 per cent lead with 3 per cent tin is used as sheath material in some cables. The tin originally was adopted to lessen the corrosive effect of acetic acid from wood ducts, but that hazard having disappeared through the change of methods in duct construction, the tin was retained in the belief that it gave a tougher sheath, less likely to be crushed by misuse or to be cracked from vibration and flexure. The tendency of present belief is favorable to the alloy with tin.

Capacity. In a cable formed of No. 19 B. & S. gauge wires it is possible to secure a mutual electrostatic capacity as low as .05 microfarad per mile of pair, the term *mutual capacity* meaning the ca-

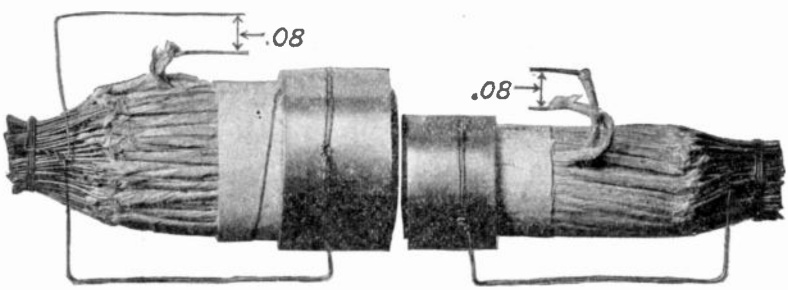


Fig. 504. Relative Sizes of Cables Having Same Numerical Capacity

pacity from one wire to another only. Capacities are also expressed in terms of the capacity of one wire with relation to its mate and all the other wires together. Measured in the latter way, the capacity is about 50 per cent greater than when measured in the former way. Capacity by the second method is sometimes known as "*regular*" capacity, although one is no more regular than the other.

Mutual and "Regular." The two methods of specifying should be contrasted. One says: "*The electrostatic capacity of the wire, measured against its mate, the remaining wires being grounded to the sheath, shall be not more than x microfarads per mile.*" This is *mutual* capacity. The other says: "*The electrostatic capacity of* *the wire, measured against the remaining wires grounded to the sheath, shall be not more than x microfarads per mile.*" This is "*regular*" capacity.

Fig. 504, which is from a photograph loaned by the Standard Underground Cable Company, shows the relative sizes of cables specified to have *the same numerical capacity* in the two methods of expression. In actual terms, the capacity of the larger cable is only .054 microfarad per mile, expressed in the preferable form, as mutual capacity. The reason for calling the mutual expression the better is that it is the amount of mutual or shunt capacity which determines the influence of capacity on voice currents. For purposes of calculation the capacity enters in that form. Therefore, it is rational to speak of and think of it in those terms.

Effect of Temperature on Capacity. Cables should have their specified capacities when the core has a temperature of 60° or 80° F., or some other known temperature. If the test is not made with the core actually at that temperature, the corrective factors given in Table XXI should be used to learn the capacity at 60° F. To apply them, merely multiply the observed capacity by the factor in the table corresponding to the observed temperature. The product is the capacity at 60° F. This table is due to the tests of H. W. Fisher.

Insulation. The insulation resistance of dry-core telephone cables should be specified as not less than 500 megohms per mile at 60° F. Each wire is measured against all the others grounded to

TABLE XXI

Corrective Factors for Capacity

Observed Temperature, Fahrenheit	Factor
30°	1.065
40	1.043
50	1.021
60	1.000
70	0.970
80	0.945
90	0.918
100	0.894
110	0.864
120	0.836
130	0.805

the sheath. If not tested at that temperature, the corrective factors given in Table XXII should be used. That is, multiply the observed insulation resistance by the factor corresponding to the observed temperature. The data of this table is also due to tests of H. W. Fisher.

It will be seen, therefore, from a study of Tables XXI and XXII that the colder the cable, the better it is, the insulation being higher and the mutual capacity lower.

Diameters and Weights. The electrostatic capacity, thickness of sheath, external diameter, and approximate weight of paper insulated cable, of the sizes most frequently employed in telephone use, are given in Table XXIII. It must be understood, however, that these figures, particularly as to diameters and weights, are subject to considerable variation.

Submarine Cables. *Paper.* Submarine cables for telephone lines, in present practice, are of limited length. Unless they differ radically in construction, submarine cables have the same general characteristics as underground cables. Present apparatus enables good speech to be limited by about 35 miles of No. 19 B. & S. gauge dry-core cable, unless loading coils are inserted. Under that length, for distances where unloaded underground cables would be practical, submarine cables are used freely.

Armor:—The usual practice, for such reasonable lengths of submarine cables, is to add to the cable, over the sheath, a protecting armor of some kind. No ducts being available in submarine work,

TABLE XXII

Corrective Factors for Insulation

Observed Temperature, Fahrenheit	Factor
60	1.00
65	1.67
70	2.45
75	3.33
80	4.66
85	6.85
90	7.66
95	9.45
100	11.65
110	19.40
120	39.00

TABLE XXIII

Aërial and Underground Telephone Cable

No. Pairs	Gauge B. & S.	Electro-static Capacity	Thickness of Sheath	Approximate External Diameter	Approxim'e Weight Per Foot
5	22	High	$\frac{1}{12}$	0.48	0.55
10	22	High	$\frac{1}{12}$	0.59	0.71
15	22	High	$\frac{1}{12}$	0.66	0.83
20	22	High	$\frac{1}{12}$	0.72	0.93
25	22	High	$\frac{1}{12}$	0.77	1.02
50	22	High	$\frac{1}{12}$	0.97	1.45
50	20	High	$\frac{3}{32}$	1.10	1.88
100	22	High	$\frac{3}{32}$	1.32	2.36
100	22	Low	$\frac{3}{32}$	1.50	2.63
100	20	High	$\frac{1}{8}$	1.57	3.60
100	20	Low	$\frac{1}{8}$	1.81	4.11
200	22	High	$\frac{1}{8}$	1.84	4.43
200	22	Low	$\frac{1}{8}$	2.11	4.99
200	20	High	$\frac{1}{8}$	2.11	5.47
200	20	Low	$\frac{1}{8}$	2.46	6.19
200	19	High	$\frac{1}{8}$	2.24	6.08
200	19	Low	$\frac{1}{8}$	2.65	6.94
300	22	High	$\frac{1}{8}$	2.21	5.71
300	22	Low	$\frac{1}{8}$	2.51	6.32
300	20	High	$\frac{1}{8}$	2.53	7.09
300	20	Low	$\frac{1}{8}$	2.96	7.94
300	19	High	$\frac{1}{8}$	2.69	7.95
300	19	Low	$\frac{1}{8}$	3.20	9.04
400	22	High	$\frac{1}{8}$	2.51	6.84
400	22	Low	$\frac{1}{8}$	2.86	7.56
400	20	High	$\frac{1}{8}$	2.89	8.56
400	20	Low	$\frac{1}{8}$	3.43	9.37
600	22	High	$\frac{1}{8}$	3.20	9.21
90	16	Low	$\frac{1}{8}$	2.88	7.20
43	13	Low	$\frac{1}{8}$	2.88	7.17
50	10	High	$\frac{1}{8}$	2.88	8.95

Note. High capacity 0.067—0.090 mutual; 0.10—0.12 grounded. Low capacity 0.054—0.067 mutual; 0.080—0.10 grounded.

the armor is necessary for protection of the cable, lest its sheath be torn or punctured. In lakes and seas, anchors may foul the cable. The waters may chafe it against rocks. In streams, drifting things may encounter it.

Two kinds of armor are used, one of steel tape, shown in Fig. 505, and the other of steel wires, shown in Fig. 506, both of these being applied spirally. In both cases a cushion or bed of tarred jute is laid over the lead cable sheath, then the armor of wires or steel tape is applied, then another tarred jute covering, finished by applying lime and sand. The cable then may be reeled and unreeled without danger of the armor injuring the sheath or core by buckling.

The wire armor is the better and has been used since the first deep-sea telegraph cables were made; it protects many miles of lead-covered cable and very many more miles of gutta-percha cable without lead sheath.

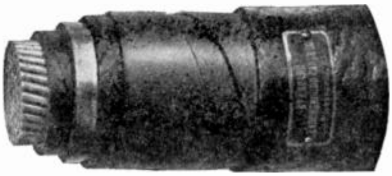


Fig. 505. Submarine Cable Steel-Tape Armor

Double sheaths of lead sometimes are used in lieu of or in conjunction with armor. The failure of one sheath, in this construction, may still allow the other to protect the cable core from the water.

Loading. For longer lengths than those just considered, loading coils are essential, as the capacity can not be kept low enough in any cable to allow it to approach the speaking quality of an open wire line. There are only two known ways of loading cables: by inserting distributed inductance and by inserting "lumped" inductance — loading coils at intervals. Only the latter way has been generally employed; however, the former has been used in several instances with submarine cables. In underground cables, these coils are located in manholes. In submarine cables, they have to be incorporated in the cable itself, a matter of no great simplicity, as the cable needs to be paid out from a ship, and such lumps as loading coils add little to the ease of the task. Such a cable, however, has been laid in Lake Constance. It is a lead-sheathed, dry-core cable, the loading coils being within the sheath.

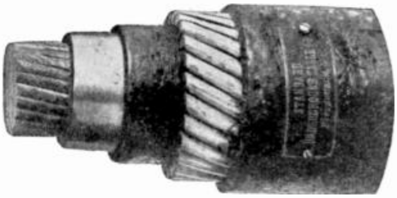


Fig. 506. Submarine Cable Steel-Wire Armor

Rubber and Gutta-Percha. For uses where capacity is negligible, such as for very short lengths, rubber-insulated wires may be formed into cables and armored with wires or tape as in Figs. 505 and

506, the lead sheath being omitted. The rubber compound on the wires serves as a sufficient protection against water.

Gutta-percha insulated submarine cables have the advantage that they also require only mechanical protection by armor, and no lead sheath. They have, however, the disadvantage that the specific inductive capacity of rubber is high. It has been asserted by competent cable engineers, however, that the contribution to human knowledge by O. Heaviside is not limited in its application, and that as inserting serial inductance in small degree offsets shunt capacity of small degree, the same general result would ensue if larger inductances were inserted to offset larger capacity.

This seems reasonable. Indeed, it would be strange if it were not so. The proof is at hand, in one of two telephone cables recently laid between England and France. An unloaded cable has been in service under those waters for years. Recently the governments of England and France agreed to lay two new cables, each government to lay one of them. France laid a duplicate of the old one. England laid a loaded gutta-percha cable, of vastly superior working qualities, and having in it the loading inductances in lumps. This cable contains two pairs of soft copper wires, each weighing 160 pounds per mile of wire (about No. 10 B. & S. gauge). Each wire is insulated with 300 pounds of gutta-percha per mile. The length of the cable is 24.2 statute miles, and the total loop resistance of each pair, unloaded, is 302.5 ohms. Twenty loading coils are inserted in each wire; the two coils of a pair of wires, at each point of loading, are wound on one circular core. Therefore, two cores carrying two coils each are inserted at each point, the points being 1.153 statute miles (one nautical mile) apart. The coils have an inductance of .1 henry and a resistance of 6 ohms each. The mutual capacity these coils oppose is (for the unloaded cable) .12 microfarad per mile. Fig. 507 shows the arrangement of mounting the coils in cable. The increase in size of the cable at the loading point is marked, but it was possible to pay out the entire length of cable without unusual risk or difficulty.

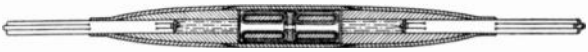


Fig. 507. Arrangement of Loading Coils in Cables

CHAPTER XLIV

POLES AND POLE FITTINGS

Pole Equipment. *Poles.* The cheapest way to support line conductors and the way that is nearly always practiced, except in communities of dense congestion, is to place them on poles. The poles are usually of wood, although in special cases structural iron poles and reinforced concrete poles have been used. Owing to the increasing scarcity of timber in the United States, it is not unlikely that the reinforced concrete pole will find greater favor in the future, as the cost of wooden ones increases and as the methods of manufacturing those of concrete are bettered and cheapened.

Cedar:—All things considered, the Michigan, or white cedar, pole is the best adapted for telephone use. While cedar is not in itself a wood of very great strength, it has several important things in its favor. Principal among these is its long life. A good cedar pole, properly cut and seasoned, may under ordinary circumstances be depended upon for a life of from sixteen years up. Another thing in its favor is its shape. Nature caused it to grow in just about the form that an engineer would have designed it for strength, *i. e.*, large at the butt and gently tapering toward the top. Of less importance, it is a light wood and, therefore, easily transported and erected, and also presents a sightly appearance, if poles may ever be said to be sightly.

Chestnut:—Another good wood is chestnut. It has a life equal to or greater than that of white cedar and is of stronger fiber. It is not so well shaped as the white cedar pole, being relatively smaller at the butt for a given length and top diameter; its greater inherent strength, however, in large measure makes up for this deficiency, and while it is somewhat less sightly than cedar and also much heavier, there is very little to choose between them. Chestnut is very largely used in the eastern states and in the south, where the cost of transportation of cedar poles is almost prohibitive.

Other Timbers:—In sections of the country where neither white cedar nor chestnut are available, cypress, pine, tamarack, and Idaho cedar are employed with varying degrees of success. Cypress under certain conditions is said to have excellent lasting qualities, but the writers' experience with it and the experiences of others has seemed to indicate that cypress is, to say the least, a treacherous wood, and will often rot away to an astonishing extent in a very few years, leaving only a small core of sound wood at the center of the pole. There are, however, well-authenticated cases of cypress poles that have shown good life, and its very low cost in some localities frequently forces it into consideration, especially where the conditions for its endurance are known to be favorable.

Idaho cedar is widely employed throughout the country particularly where very high poles are required. The fiber of the wood is good, but these poles have a very grave defect in their extreme slenderness for a given top dimension. They are perfectly smooth and straight, and there is a common joke about them to the effect that either end of them may be put in the ground equally well.

In southern and western districts pine poles are widely used with varying success. Yellow pine, on account of the amount of pitch it contains, would lead one to believe that it would have good lasting qualities, but it frequently rots very rapidly.

Cutting:—Poles should be cut from live, growing timber, while the sap is down, and should be free from knots and shakes, and reasonably sound. With cedar poles a certain amount of butt rot, *i. e.*, rot exposed at the butt section of the pole, is to be permitted, since it is not commercially possible to obtain poles free from this. With cedar and chestnut poles it is not practicable always to secure perfectly straight poles and, therefore, a reasonable amount of crookedness is to be permitted.

Sizes:—Standard sizes of poles vary in length by five-foot steps. The usual way of indicating the size of a pole irrespective of its height is by the diameter in inches at its top. Thus, a pole referred to as a "7-inch 30" would be 7 inches in diameter at the top and 30 feet long. On account of the great variations that may occur in the butt sizes of poles of equal top diameter and length, it is well that the butt sizes be specified also, since this is a feature having most bearing on the strength of the pole.

Northwestern Cedarmen's Specifications:—The latest specification of the Northwestern Cedarmen's Association, which practically governs the purchase of white cedar poles in the United States, is as follows:

STANDARD TELEGRAPH, TELEPHONE, AND ELECTRIC POLES.—Sizes, 5-inch 25 foot, and upwards. Above poles must be cut from live, growing timber, peeled, and reasonably well proportioned for their length. Tops must be reasonably sound, and when seasoned must measure as follows: 5-inch poles, 15 inches in circumference at top end; 6-inch poles, 18½ inches in circumference at top end; 7-inch poles, 22 inches in circumference at top end. If poles are green, fresh cut, or water soaked, then 5-inch poles must be 16 inches in circumference at top end, and 6-inch poles must be 19½ inches in circumference, and 7-inch poles must be 22¾ inches in circumference at top end. One way sweep allowable not exceeding 1 inch for every 5 feet; for example, in a 25-foot pole, sweep not to exceed 5 inches, and in a 40-foot pole not to exceed 8 inches. Measurement for sweep should be taken as follows: That part of the pole when in the ground (six feet) not being taken into account in arriving at sweep, tightly stretch a tape line on the side of the pole where the sweep is greatest, from a point 6 feet from butt to the upper surface at top, and having so done measure widest point from tape to surface of pole and if, for illustration, upon a 25-foot pole said widest point does not exceed 5 inches, said pole comes within the meaning of these specifications. Butt rot in the center including small ring rot outside of the center; total rot must not exceed 10 per cent of the area of the butt. Butt rot of a character which plainly seriously impairs the strength of the pole above the ground is a defect. Wind twist is not a defect unless very unsightly and exaggerated. Rough large knots if sound and trimmed smooth are not a defect.

Trimming:—The knots on all poles should be closely trimmed and the bark removed, as the presence of the bark induces rotting. It is preferable to remove the bark by stripping, but if this is not feasible it should be done by shaving, and the amount of shaving in all cases should be kept a minimum, since the strength and life of a pole is reduced by too deep shaving. The poles should be thoroughly seasoned before setting.

Treating:—The constantly increasing cost of wooden poles, due to the scarcity of timber, has led in some cases to the practice of treating the poles with a preservative. This is not generally done where cedar and chestnut are used, but in the south where the difficulty of securing a long-lived pole is very great, there is a growing tendency toward the use of these preservative processes. The most successful of these so far is the process of creosoting, which consists in the impregnation of the pole with creosote, which is a dead oil of coal-tar.

There are a number of methods by means of which this impregnation is accomplished, some of them securing a penetration of the creosote

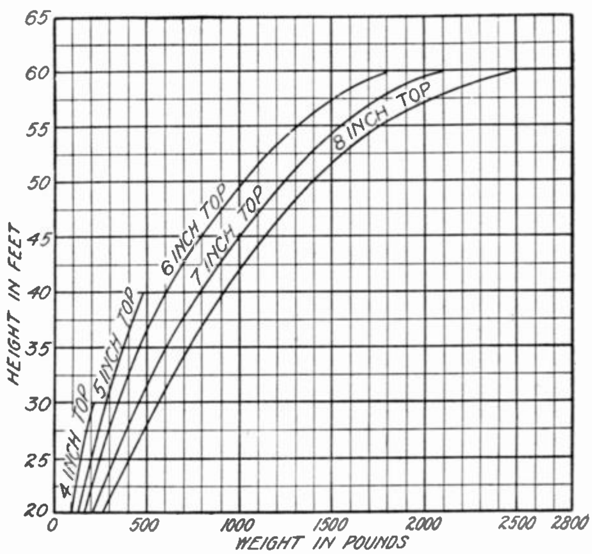


Fig. 508. Weights of Cedar Poles

for only a short distance below the surface, and others a penetration reaching almost or quite to the center of the pole. Another material used for impregnation is chloride of zinc. The reports of the United States Department of Agriculture give much valuable information and data on the subject of preservation of timber, particularly that used for telephone and telegraph poles, railway ties, etc.

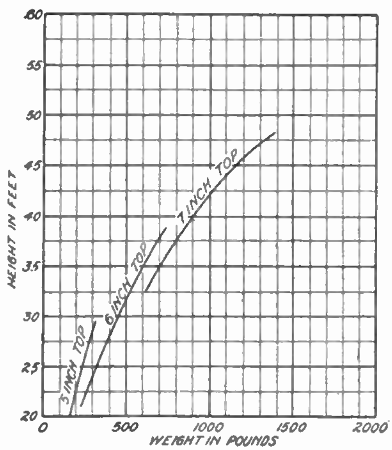


Fig. 509. Weights of Cypress Poles

In localities where timber is cheap and not of good lasting quality and where creosoting plants have been established, it is undoubtedly economical to use creosoted poles. In other localities it is found that creosoting an already expensive pole results in prohibitive cost.

It is the practice, however, of the large telephone and telegraph companies to treat the poles externally by painting them for a distance of about three feet, above and below the ground line, with two coats of *carbolineum avenarius*. The roofs and gains of the poles are also painted with the same material. In city work the poles are usually painted all over with a good oil paint.

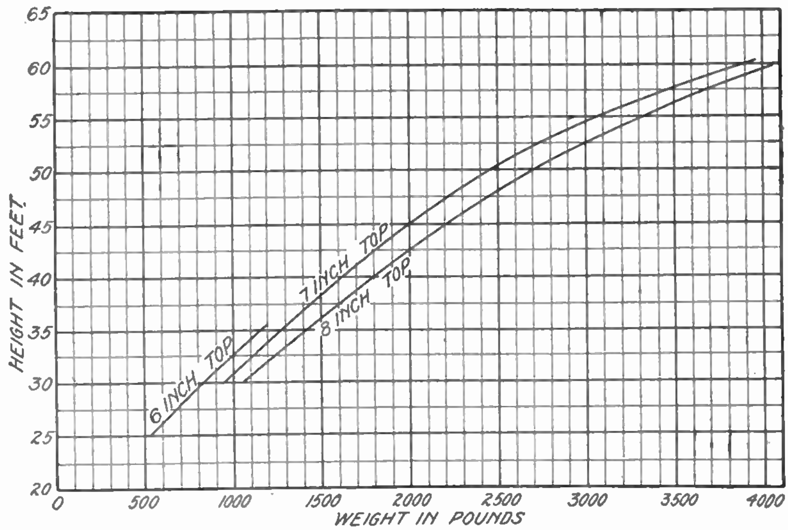


Fig. 510. Weights of Chestnut Poles

Weights:—The curves of Figs. 508, 509 and 510 give the approximate weights of different sizes and lengths of cedar, cypress, and chestnut poles.

Table XXIV gives useful information concerning the loading of cedar poles on cars. Forty-foot poles and longer are usually loaded on two cars, and the number of poles in each case as given in this table is that constituting a single or double load.

Gaining:—Where a pole is to carry more than one or two bare wires, cross-arms are provided for supporting the wires, and in order to afford a seat for these, gains or mortises are cut in the side of the pole. It is a mistake to make these gains too deep, as the pole is greatly weakened and its life is shortened thereby. It should merely be a

TABLE XXIV
Cedar Poles

On Single Cars		On Double Cars	
Size	Number in Load	Size	Number in Load
4″ 25′	175 to 225	7″ 40′	60 to 75
5″ 25′	150 to 200	7″ 45′	50 to 65
6″ 25′	100 to 125	7″ 50′	40 to 50
7″ 25′	75 to 100	7″ 55′	35 to 45
5″ 30′	100 to 125	7″ 60′	25 to 35
6″ 30′	75 to 100	7″ 65′	20 to 25
7″ 30′	60 to 80		
5″ 35′	75 to 100		
6″ 35′	60 to 80		
7″ 35′	55 to 75		

rectangular notch about ½ inch deep and of sufficent height to just accommodate the cross-arm.

Roofing:—In order that the tops of the poles may drain as rapidly as possible, and thus rid themselves of moisture which would otherwise tend to rot them, the top is usually beveled in two planes

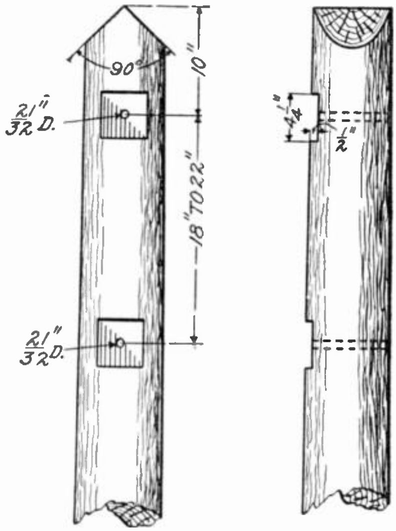


Fig. 511. Details of Roofing and Gaining

parallel to the direction of the pole line so as to form a roof. The details of the roofing and gaining of a pole are shown in Fig. 511.

The distance between the centers of the gains and, therefore, between the centers of the cross-arms, varies from 18 to 22 inches, according to the type of line.

Cross-Arms. Cross-arms for telephone work may be of two, four, six, eight, and ten pins each, and the best practice usually is to employ only ten-pin arms, even though a fewer number of wires than ten are to be strung. This provides for growth, which nearly always is greater than expected. Good cross-arms are becoming scarce. They are most commonly of white pine, yellow pine, or Washington fir. The latter is by far the most expensive in most parts of the United States on account of the transportation charge, but as a rule it is true economy to use them. The life of cross-arms varies from four to sixteen or more years, according to the kind of wood used and the climatic conditions. There are two sizes of cross-arms employed in telephone work, one known as the *telephone arm* and having a cross-section of $2\frac{3}{4}$ by $3\frac{3}{4}$ inches. The other, known as the *standard arm*, has a cross-section of $3\frac{1}{4}$ by $4\frac{1}{4}$ inches. The saving in cost of the smaller arm does not usually warrant its use.

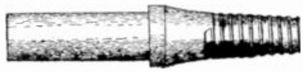


Fig. 512. Insulator Pin

Pins:—The arms are bored usually with $1\frac{1}{4}$-inch holes, into which the pins for supporting the insulators are placed. A standard pin

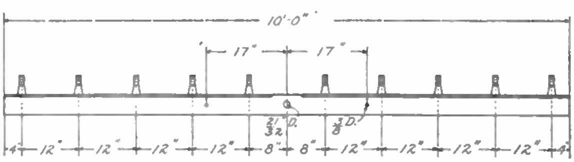


Fig. 513. Ten-Pin Cross-Arms

is shown in Fig. 512. They are made of various woods, locust, catalpa, maple, Bois d'Arc, kalkeen, or oak. A ten-pin arm equipped with pins is shown in Fig. 513, the spacing between pins being that of standard practice.

Hardware. Through Bolts.—The standard way of attaching a cross-arm to the pole is by means of a through bolt long enough to pass through the pole and the cross-arm and receive a nut on its screw-threaded end. A large, flat iron washer about $\frac{3}{16}$ inch thick and $2\frac{1}{4}$ inches square is placed under the head of the bolt and under the nut to afford a large bearing surface on the wood against

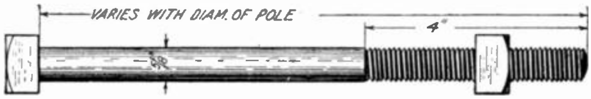


Fig. 514. Through Bolt

which the bolt may draw. The details of a standard through bolt are shown in Fig. 514.

Braces:—In order to more rigidly support the cross-arm on the pole, two braces are employed for each arm. These consist usually

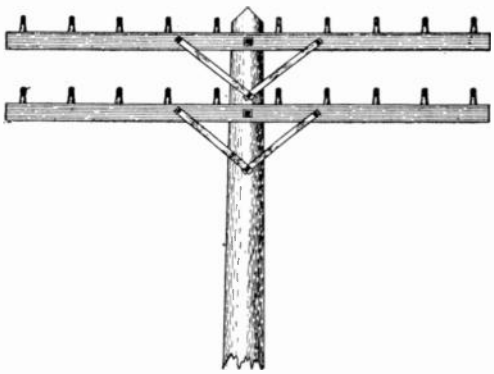


Fig. 515. Cross-Arms Attached

of rectangular strips of wrought iron about $\frac{1}{4}$ by $1\frac{1}{4}$ inches in cross-section and from 20 to 30 inches in length. The details of the method of securing a cross-arm to a pole, including the attachment

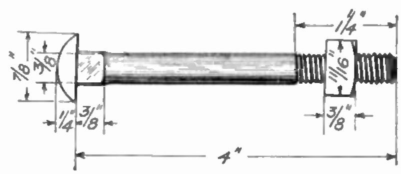


Fig. 516. Carriage Bolt

of the cross-arm braces, is shown in Fig. 515. Where the two lower ends of the braces meet at the pole they are secured by a single lag screw passing through both of them at the end of the pole, and the outer ends of the braces are secured to the cross-arm by means of carriage bolts passing through both the brace and the arm and held in place by a nut and washer.

Carriage Bolts and Lag Screws:—The form and dimensions of a

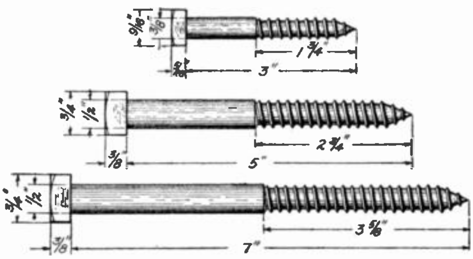


Fig. 517. Lag Screws

carriage bolt for attaching braces to cross-arms are shown in Fig. 516. Fig. 517 shows three sizes of lag screws, the 5-inch size usually being employed to secure two braces to the pole.

Pole Steps:—The standard iron pole step is shown in Fig. 518 and is made of $\frac{5}{8}$-inch stock. It is attached to the pole by drilling a $\frac{1}{2}$-inch hole in the pole to a depth of from 2 to 3 inches for cedar and about 4 inches for harder woods, and then the step is driven into the pole to such a depth that the distance from the pole to the outside edge of the step is approximately $5\frac{1}{2}$ inches. Ordinarily the

Fig. 518. Pole Step

lower five steps on a pole are made of triangular pieces of wood secured to the pole by one 60d and one 20d nail. The purpose of employing the wooden steps at the bottom is to avoid the injury which the projecting iron steps might cause to passing persons or teams.

Hardware Requirements:—The cross-arm braces, bolts, steps, and other pieces of hardware employed in pole line work are commonly referred to as pole hardware. In general the material should of course be free from flaws, cracks, and other imperfections.

In the case of bolts, rods, braces, steps, and like fittings, the wrought iron or mild steel, of which they are necessarily made, should have the properties which conform to the standard specifications adopted by the bridge builders, as set forth in the handbook on constructional iron, issued by the Carnegie Steel Company in 1893. Where malle-

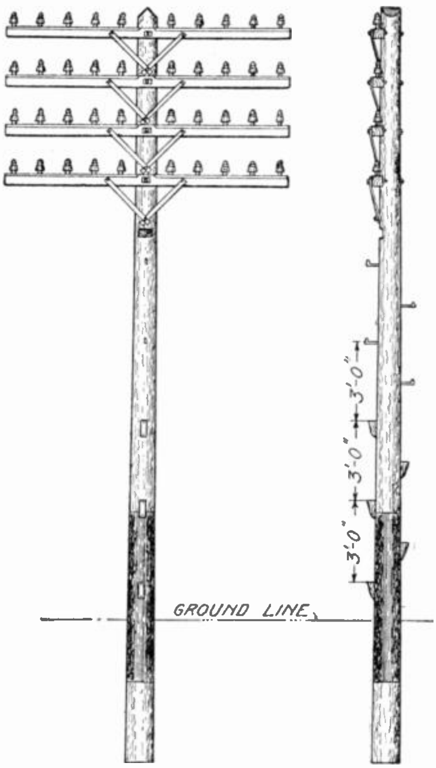


Fig. 519. Equipped Pole

able castings are used, as in clamps, they should be reasonably straight, smooth, and true to pattern and free from imperfections. They should also be capable of being bent to a reasonable degree without breaking. All bolts and rods should be capable of standing a 90-degree bend on a radius equal to the diameter of the bolt without fracture of the steel on the outside of the bend. The breaking strength of all bolts and drive screws should be at least equal to the following:

Size of Bolt	Breaking Strength
$\frac{3}{8}$ inches	3400 pounds
$\frac{1}{2}$ inches	6300 pounds
$\frac{5}{8}$ inches	10000 pounds

The holding power of the nuts on such bolts should not fall below the figures just given.

Galvanizing:—Hardware, including bolts—threads and nuts—should be thoroughly galvanized. A coating of zinc should be evenly and uniformly applied and should be capable of withstanding the standard four-immersion test in a saturated solution of sulphate of copper.

Equipped Pole. The number of cross-arms on a pole depends, of course, on the number of open wires to be carried, it being understood that in standard practice ten wires is the maximum that any arm may carry. The growing tendency to use cable is causing the gradual disappearance of very heavy bare wire pole leads, and poles of enormous height carrying ten, fifteen, and even twenty-five cross-arms are no longer seen. Few lines are now to be found with more than six cross-arms, and these only in heavy cross-country lines.

A pole completely equipped with four cross-arms is shown in Fig. 519. The steps shown on the sides of this pole would ordinarily be employed only in city work, and not on toll lines except at test poles.

Pole Setting. The distance to which poles should be set in the ground depends on the height of the pole, character of the soil, and

TABLE XXV

Pole Setting Data

LENGTH OF POLE	DEPTH IN SOIL	DEPTH IN ROCK
20 feet	4 feet	3 feet
25 feet	5 feet	3 feet
30 feet	5½ feet	3½ feet
35 feet	6 feet	4 feet
40 feet	6 feet	4½ feet
45 feet	6½ feet	4½ feet
50 feet	7 feet	4½ feet
55 feet	7 feet	4½ feet
60 feet	7½ feet	5 feet
65 feet	7½ feet	5 feet
70 feet	8 feet	5½ feet

the strain to which the pole is to be subjected. In general, Table XXV represents good practice.

Where a pole is set on a sloping bank, the depth as given in Table XXV should measure from the lowest side of the opening of the hole.

With this preliminary discussion of poles and pole fittings we may divide the discussion of pole lines into three principal headings: Toll Lines, Rural Lines, and City or Exchange Lines.

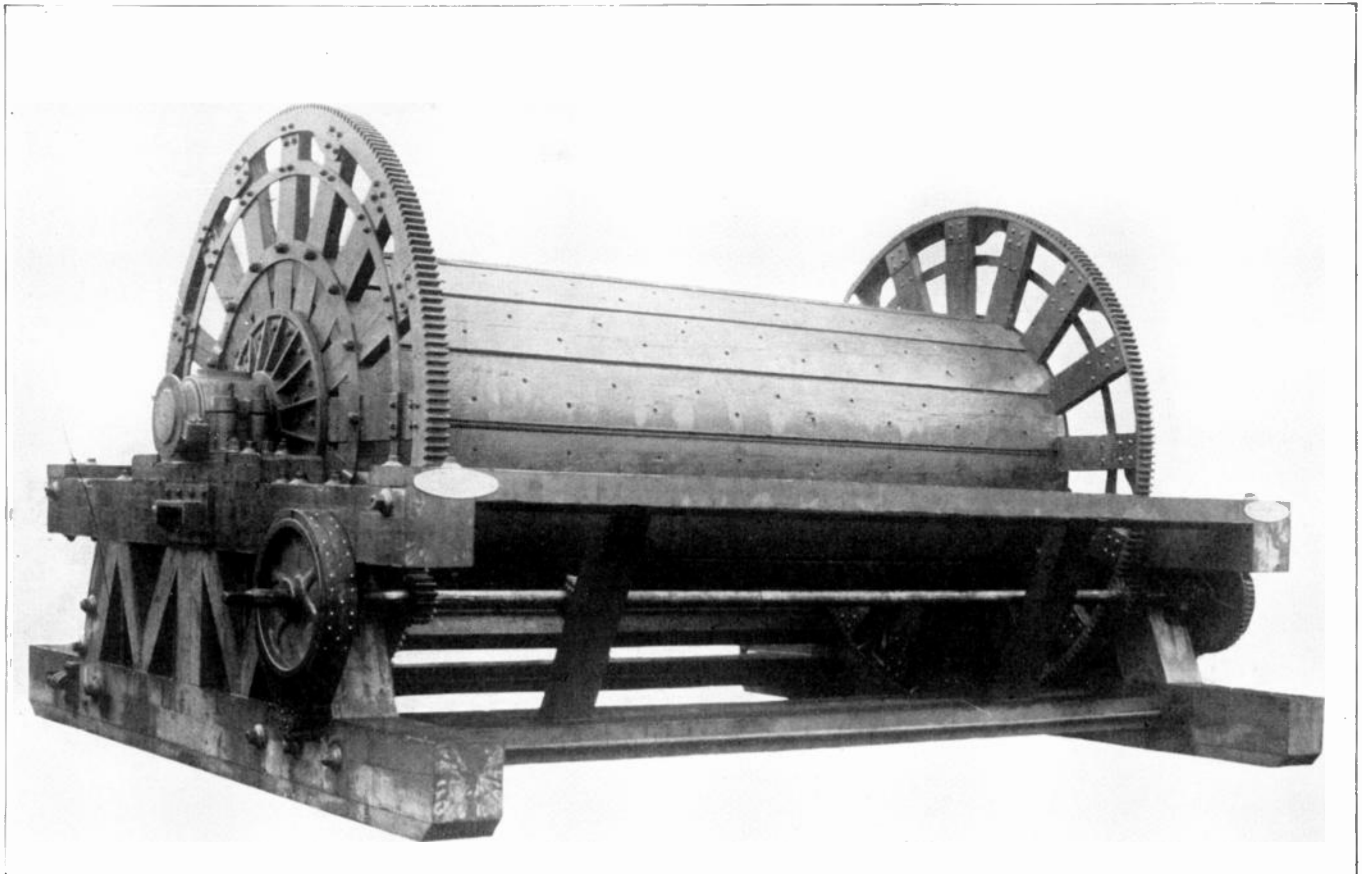
Toll Lines. The term toll lines is rather loosely applied to lines extending across country between cities or towns and carrying the wires which serve as interurban trunks. A governing factor in the construction of such a line is the number of wires that it will ultimately carry, since this determines the number of cross-arms and, in large measure, the height and the strength of the pole.

Sizes of Poles. The usual well-constructed toll line of the present day is built *close to the ground,* that is, it is built on poles as short as will allow the use of the required number of cross-arms and at the same time give the required clearness under the wires. A great many toll lines are built of 25-foot poles, with the use of longer poles as required by the contour of the country and the necessity at crossings. Such a line would be called a 25-foot line. Where more wires must be carried, 30- or 35-foot poles are employed, the line being graded with taller poles as required. The following discussion will apply equally well to a 25-, 30-, or 35- foot pole line.

The diameter of a pole enters as a factor not only in its strength but in its lasting quality. For the highest grade of construction nothing smaller than 7-inch tops should be used, but on less important toll lines 6-inch and even 5-inch tops are sometimes used.

Route. The general route of the toll line preferably follows the highways, but frequently the route may be made much shorter or difficult construction may be avoided by locating on private property. Wherever this is done permanent rights of way should be obtained from the property owners for all poles, guys, and braces, and other fittings, including the wires that are on the private property. All rights of way so obtained should be in writing and should include permanent tree-trimming privileges.

Locating Poles. In laying out the line, a stake should be driven firmly in the ground to locate each pole, guy stub, or anchor. It is a good plan to number these stakes in order that full data as to the



SPECIAL CABLE REEL

Built and Used by San Francisco Home Telephone Company for Laying Submarine Cable across San Francisco Bay, December 1909. Distance between Heads, 16 Feet; Winding Depth, 2 Feet; Shaft Diameter, 11 Inches. Capacity Over 25,000 Feet of 3.3-Inch Cable Weighing 7.5 Pounds per Foot.

kind of stub or anchor may be kept in the field book of the survey. It is not the usual practice to employ surveying instruments in laying out the line, the survey being made by sighting between stakes. On the other hand, in laying out long lines, a transit may sometimes be used to advantage, although there is danger of wasting time with it if the man using it attempts to do too fine work.

The line should be laid out as straight as possible and where long curves occur they should, as far as possible, be reduced to straight sections joining each other at corners. Except for the very heaviest type of construction, forty poles to the mile is a good average, and this means that the poles on straight sections will be about 132 feet apart. On curves and corners the distance between poles should be shortened. Wherever the angle between any two spans is 30 degrees or over, the distance between the poles of those spans should be reduced to about 75 feet. For smaller angles the distance between poles may be proportionately greater. Wherever possible right-angle turns should be made on two poles, that is, the line wires should make two 45-degree bends instead of one 90-degree bend. The span adjacent to such corner in each case should be reduced to about 75 feet. It is also well at the terminal of the line to reduce the last span to 75 feet.

Frequently, owing to the contour of the ground, longer spans must be employed. Sometimes as the line approaches a ravine the choice must be made between running the line down into the ravine or spanning it with a single span. If the depression may be cleared with a span of about 200 feet, this is to be preferred to the use of very high poles in the bottom of a depression or to very abrupt changes in the level of the line that would occur by setting poles of ordinary height in the bottom of the depression. Spans of very much greater length than 200 feet may be employed where absolutely necessary, but such spans should always be made the subject of special study. Wherever the pole line changes from one side of the road to the other, the crossing should be made at an angle of about 45 degrees.

On railroad rights-of-way no poles should be set less than a distance of 12 feet from the outer edge of the nearest rail, and in any event the minimum distance must always be subject to the terms of the agreement under which the right-of-way is secured. In passing through towns or cities the poles should be located as generally as possible at corners of intersecting streets or alleys, so as to facilitate the employment of side guys, if necessary, and also to facilitate the branching off of wires to other pole lines if the necessity for such exists.

Grading. The length of the poles is, as stated, determined by the character of the line being built, the shortest poles being determined by the number of cross-arms that are to be carried. Longer poles are used where, on account of the profile of the country, it is necessary to do so in order to avoid abrupt changes in the level of the wires.

The number of poles, longer than the standard of the line, will depend on the character of the country through which the line passes. In general it may be stated that an effort should be made to accomplish the required grading by the use of as few poles as possible that are over 5 feet longer than the standard pole of the line. The use of many long poles is not only expensive but such poles are not so strong or durable.

For sharp depressions that are too wide for a single span and that would ordinarily require the use of extra high poles, the poles should be placed close enough together to make the change in level on any pole as small as possible. In such cases, in order to facilitate the grading, poles as short as 20 feet in length in a 25-foot line, or 25 feet in length in a 30-foot line may be used on the highest ground adjoining depressions.

At highway crossings the poles should be of such length that no wire or attachment will be less than 18 feet above the crown of the highway. Of course, local ordinances or laws may require a greater height. At railway crossings the height of the wires or pole attachments above the rail should not be less than 28 feet.

To clear obstacles, poles of such length or such method of construction should be used as will give a clearance of at least 18 inches from the obstacles when all of the arms are full of wires. In avoiding trees or other obstacles, side arms may be used and their use is to be preferred to the use of very high poles. The side-arm construction will be illustrated later in connection with city pole line work.

Distributing Poles. In distributing poles from wagons or cars, the heaviest poles should be placed at corners or bends in the line and at the terminals of long spans. The straightest and best looking poles should be employed through the cities and towns, and particularly in front of good residences.

Equipping Poles. In general, it is better to attach the cross-arms and braces to the poles before the poles are set. The cross-arms are fitted with the standard pins and with the braces attached at one end before they are distributed. The pins are held in place on the arms by driving a wire nail through the arm and shank of the pin after the pin is driven home in the arm. After the cross-arm is attached in position on the pole by the through bolt, it is squared with the pole and then the free ends of the braces are overlapped on the pole and attached by a 5-inch lag screw, as already pointed out, thus maintaining the square position of the arm on the pole.

In countries where lightning storms are common, it is a good plan to equip about every tenth pole with a lightning rod, which may be made of No. 10 B. W. G. galvanized iron wire. This wire may be wrapped two or three times around the extreme butt end of the pole before the pole is set, and extended up the pole, being attached every two feet by a $1\frac{1}{2}$-inch galvanized-iron wire staple.

Setting Poles. In setting the poles it is important that all of the holes should be sufficiently large to allow the butt of the pole to enter without scraping in so much dirt from the side of the hole as to partially fill it up. Sufficient space should be left all around for adequate tamping. Also, in order to prevent the dirt from being filled in faster than it can be properly tamped, it is well to employ two tampers for each shoveler. The soil should be piled up above the surface and packed around the pole approximately 12 inches above the surface of the ground.

On straight lines the poles should always be set so that the cross-arms will be at right angles to the direction of the line, and the arms on adjacent poles should face in opposite directions. The reason for this is to prevent the strain on the cross-arm on all the poles being away from the pole rather than against it, in case such a condition should arise as to cause a heavy pull of all the wires in one direction. For the same reason the arms of the last few poles at the end of a straight lead should be placed on the side of the pole toward the end of the lead so as to make them all pull against their respective poles.

Guying and Bracing. It is not sufficient to rely only on the strength of the poles or on the firmness of their setting in the ground to maintain the rigidity of the line, particularly when the line is subjected to the stress of violent storms. In order to give the line greater stability, therefore, guys or braces are used. Guys may be defined as *tension members in the form of wires or ropes extending from a point near the upper end of the pole to some stationary object, such as an anchor, tree, or another pole.* Braces may be defined as *compression members, usually of wood, extending at an angle from a point high up on the pole to a solid foundation in the ground.* Guys act to resist the forces which tend to pull the pole out of its proper alignment by the tension of the guy wire or rope. Braces act to resist such forces by the compression in the brace member.

Guys may be classed as *side guys* when they are placed at right angles to the direction of the line to prevent the line from going over sidewise; as *head guys* when they are placed in the direction of the

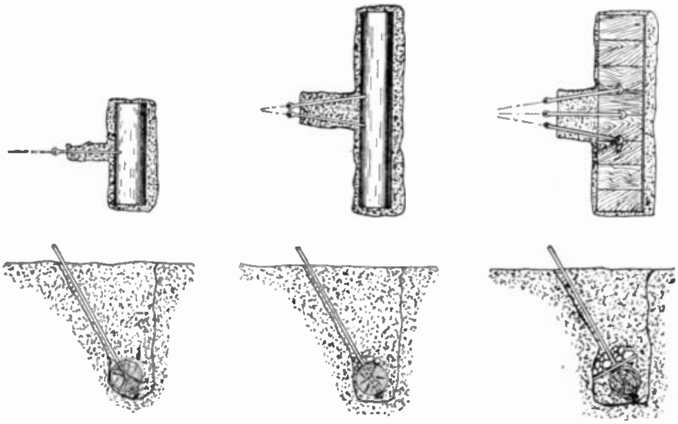


Fig. 520. Log Anchors

line to prevent the line from going down endwise; and as *corner guys* when they serve to resist the pull of the line wires on corner poles, due to the bend in the direction of the line.

For bare-wire line construction guys may be of No. 6 B. W. G. solid wire for lighter construction, and of stranded steel for heavier construction. For ordinary 25- and 30-foot pole lines, $\frac{5}{16}$-inch galvanized strand is an excellent material, since it possesses the adequate strength and is more easily handled than the larger sizes of solid wire. Where necessary, two or more strands of this may be used in order to resist excessive pulls.

The subject of anchors is an important one. For heavy work the practice is to bury anchor logs deep in the ground, wrought-iron anchor rods extending from these logs to a point above the surface of the ground in the direction in which the guy wire will run. In Fig.

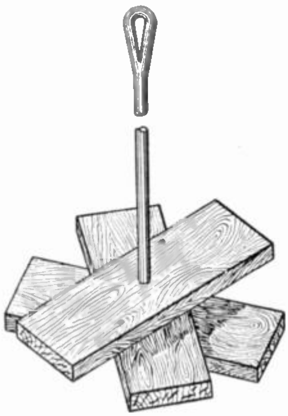


Fig. 521. Plank Anchor

Fig. 522. Matthews' Anchor

520 are shown the details of a number of anchors made in this way. The anchor log itself is usually made of a section cut from a pole.

Fig. 523. Setting Matthews' Anchor

Railway ties also make good anchor logs. For lighter construction an anchor may be made of 2-inch planks nailed together, as shown in Fig. 521.

Except for very heavy construction some of the many forms of patent anchors may be used with good results and economy. A

Fig. 524. Solid Iron Wire Guy

familiar type of these is the Matthews' anchor, which is of such form as to bore itself into the ground when turned. Such an anchor is shown in Fig. 522, and the method of setting it in Fig. 523. Other forms of patented anchors require a hole to be drilled by an earth auger, after which the anchor is put in place and the tension which is put upon it sets the body of the anchor crosswise of the hole in such a way as to resist its being pulled out. Still another type, known as the D. and T. anchor (drive and twist) is put into the ground by driving it with a sledge, and it is then set or expanded by twisting on the rod.

Fig. 525. Stranded Wire Guy

The efficacy of any of these patented forms of anchors depends largely on the character of the soil in which they are used. They are not effective in sand, and indeed it is hard to get an anchor that is.

The method of attaching solid iron guy wire to a pole is shown in Fig. 524. There are two distinct methods of attaching a stranded guy wire to the pole. One is to pass the guy strand twice around the pole and then fan out the separate strands and wrap each about the main body of the guy strand, as shown in Fig. 525. Another is to employ guy clamps, as shown in Fig. 526, and this is the plan in general to be preferred.

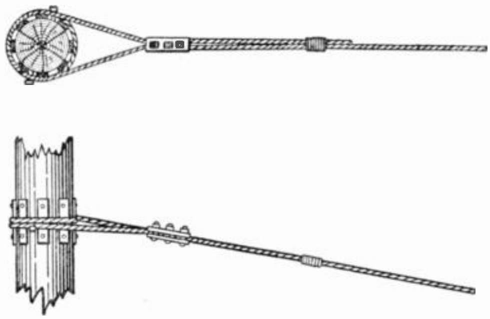
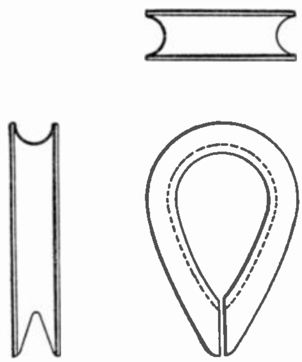


Fig. 526. Stranded Wire Guy

Attaching the guy wire or rope to the eye of the anchor rod is usually done with the aid of a thimble, the form of which is shown in Fig. 527. This may be done either with or without guy clamps, Fig. 528 showing such a connection made with the use of guy clamps.



527. Guy Thimble

One method of attaching a guy to a tree is shown in Fig. 529. In rocky country it is often convenient to anchor a guy in rock and the manner of doing this is made clear in Fig. 530.

Sometimes, as where a guy must necessarily cross a road or sidewalk, insufficient clearance would be afforded under the guy wire if the guy were run directly to an anchor. In such cases guy stubs are used. These are in effect poles set in the ground, and to the top of these the guy wire is fastened. The guy stub may be made sufficiently rigid to need no guying itself but

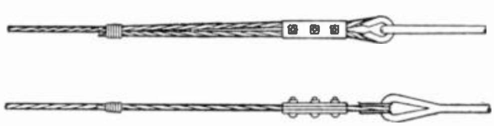


Fig. 528. Attaching Guy Wire to Anchor

nevertheless it is preferable to guy it to an anchor exactly as if it were a pole. Such a construction is shown in Fig. 531. If it is not feasible to anchor the guy stub because of lack of space in which to place the anchor or guy thereto, the guy stub may be made extra heavy and set very deep in the ground, the setting being reinforced by concrete or by heavy planks placed sidewise across the hole. The reinforcement at the top of the hole should, of course, be toward the pole to which the guy runs and those at the bottom of the hole on the side of the stub opposite the pole.

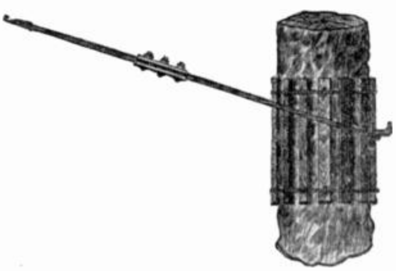


Fig. 529. Attaching Guy to Tree

In locating guy anchors the horizontal distance from the butt of the pole to the anchor should be as great as possible up to a distance equal to the length of the pole.

The length of the anchor rod is usually about 8 feet, and in any event, sufficient to allow the eye of the anchor rod to project 6 or 8 inches above the ground. Practice differs as to the galvanizing of anchor rods, some advocating that it be done and others claiming that it is useless.

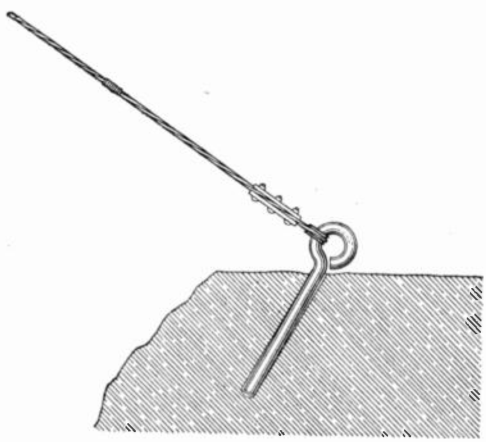


Fig. 530. Rock Anchor

On a line containing one cross-arm only, the guys should be attached to the pole at a point just below the arm, but with two or more cross-arms, the guy should be attached about midway between the bottom and the top arms.

At the end of pole leads the last pole should be guyed to an anchor beyond the last pole and in the direction of the last span, and head guys should be run from a point near the top of each of the last few poles to a point near the base of the next pole toward the end of the line.

Pole braces, or push braces, as they are called, may be used in cases where a guy is objectionable or impossible. Where used, the pole to be braced should be set deeper in the ground than usual. The butt of the brace should be set about 3½ feet in the ground and should be supported on a heavy plank or flat rock laid in the bottom of the hole. The upper end of the brace is beveled at an angle to fit snugly against the pole; but in no case should the pole itself be cut away. The brace is attached to the pole by a standard through

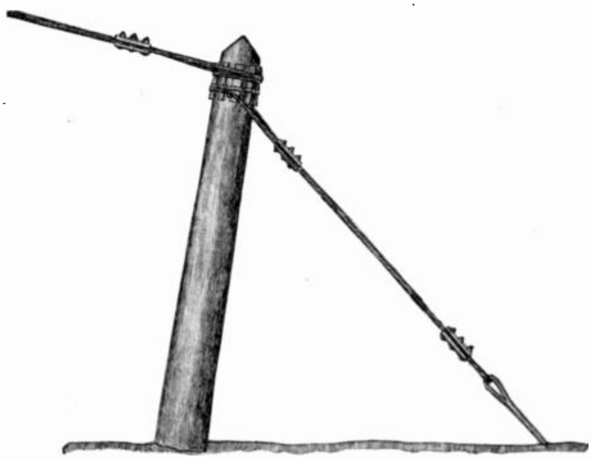


Fig. 531. Guy Stub

bolt of the type used in attaching cross-arms. Before drawing up the bolt the end of the brace and the part of the pole against which it is to rest should be given a coat of *carbolineum avenarius*. A standard method of pole bracing, as employed by some of the Bell companies, is shown in Fig. 532. In this the butt of the brace is bolted to an anchor log instead of resting directly against it, and the brace is thus enabled to resist pulling as well as pushing stresses. When so made they are called "pull-and-push" braces.

Tree Trimming. The question of tree trimming is a troublesome one. The rights of property owners have to be considered and too much cannot be said against the way in which these rights have been ignored and against the ruthless destruction of shade trees that often has been practiced by the employes of telephone companies. On the other hand, a certain amount of tree trimming is necessary and it should be done in the way least objectionable. All trees close to the line should be trimmed so as to clear the wires by a distance of about 2 feet in all directions. Dead trees, which would injure the line by falling, should be cut down.

Stringing Wire. The insulator used for bare wire lines is nearly always of glass. The standard line insulator, shown in Fig. 533,

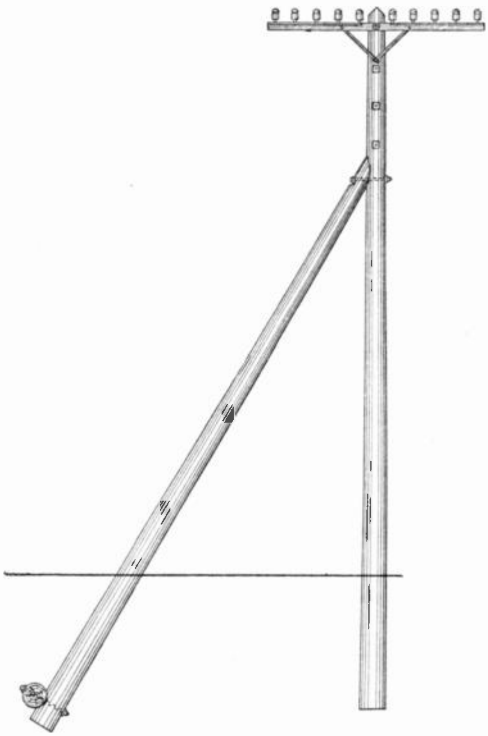


Fig. 532. Pole Brace

is provided with an internal screw thread to fit the thread on the wooden pins. The groove is for the tie wire by means of which the line wire is attached to the insulator. A factor in the design of insulators is the path for surface leakage from the wire to the pin and cross-arm. In dry weather the pins and cross-arms are themselves fairly good insulators, but in wet weather they become better conductors. The moisture which collects on the insulator also forms a path for leakage and the "petticoat" or downwardly hanging flange on the glass is to protect the pin and the inner surface of the glass from moisture as far as possible and to afford a long path over the surface of the glass from the wire to the pin.

Transpositions:—In making certain forms of transpositions in the line wires and also at test points, it is required to dead-end two wires on the same insulator. Insulators with two grooves are used for this purpose and are called *transposition insulators.* Fig. 534 shows one form of these, two grooves being formed in the same glass. A better form is that of Fig. 535 in which the two grooves are in sep-

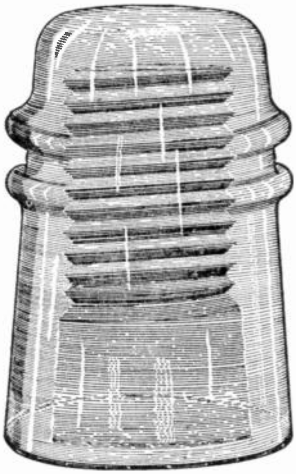


Fig. 533. Standard Insulator

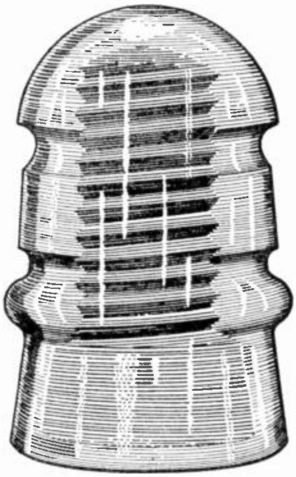


Fig. 534. Transposition Insulator

arate glasses. On account of the petticoat of the upper glass, better insulation is maintained between the two wires, and another advantage in this form is that the opposite stresses of the two wires are taken by the pin rather than by the structure of the glass, and as a result there is less breakage.

Tying:—The methods of tying the wire to the insulator differ for iron and copper wire. In neither case does the line wire pass around the insulator; rather it runs alongside of it and is held in the groove of the insulator by the tie wire which passes around the insulator. The form of tie largely employed for iron wire is shown in Fig. 536; that for copper wire in Fig. 537. It is to be noted that the copper-wire tie is now being largely employed for iron wire as well as for copper. In each case the tie wire is of the same gauge and metal as the line wire which it ties, but in each case it should be soft annealed instead of hard drawn. For standard insulators the copper tie wire should be about 19 inches long and the iron tie wire about 12 inches long.

Fig. 535. Transposition Insulator

Joints:—The standard method of joining iron wire, known as the *Western Union joint*, is shown in Fig. 538. In this the ends of the two wires to be joined are laid side by side, in a pair of *special* pliers. The wires are then twisted by means of the pliers to make five complete turns, forming what is known as the neck of the splice. After this operation the splice is completed by wrapping each end tightly around the straight section of the other wire four or five turns. Tests of various splices show that the end turns have very little virtue in them, most of the holding power being due to the turns in the neck, and that a joint with five properly made turns in the neck will be as strong as the wire it is made of, and will yield but slightly at first or until it is set, after which there is practically no yield up to the breaking point.

Copper wire is usually joined by means of the McIntyre sleeve, which consists essentially in two parallel tubes of copper about 4 inches long secured together throughout their length, the internal diameter of the tubes being such as to just accommodate the size of wires to be spliced. To make the joint by means of this connector, the two wires are run through the parallel tubes in opposite directions and then each end of the sleeve is grasped in a special clamp and the sleeve twisted through three complete turns. The McIntyre sleeves before making a connection and a completed joint are shown in Fig. 539.

Sag:—In stringing line wires it is desirable that all wires in a span have a uniform sag. Obviously, the amount of sag will depend

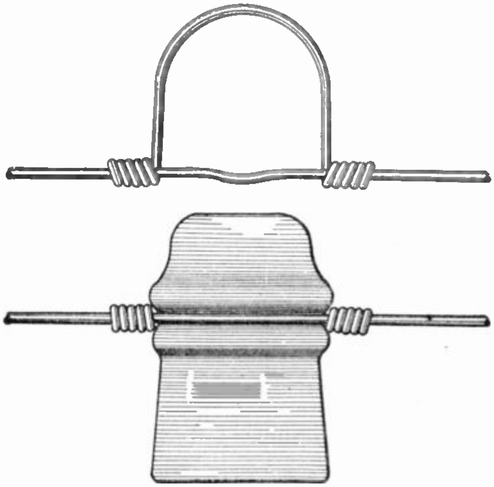


Fig. 536. Iron Wire Tie

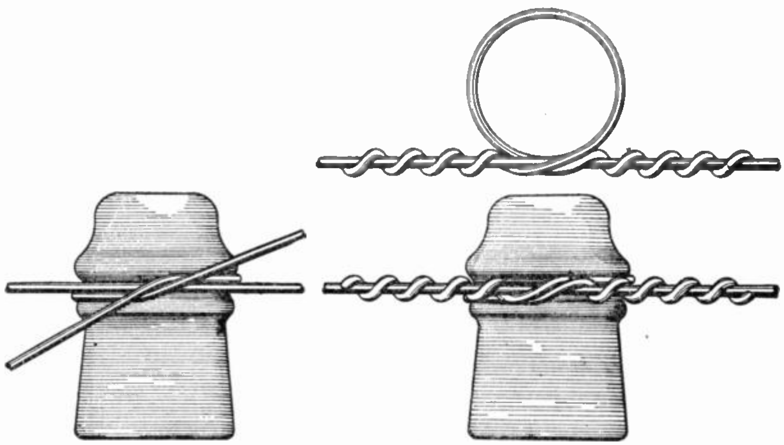


Fig. 537. Copper Wire Tie

Fig. 538. Western Union Joint

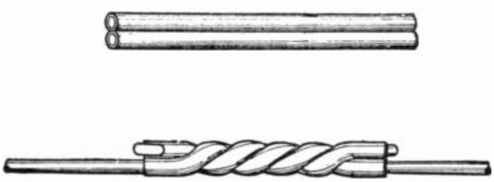


Fig. 539. McIntyre Joint

TABLE XXVI

Sag at Time of Erecting

Temp. Degrees F.	Length of Span					
	75′	100′	115′	130′	150′	200′
	Sag in Inches					
10	1½	3	3½	4½	6	10½
30	2	3	4	5½	7	12
60	2½	4½	5½	7	9	15½
80	3	5½	7	8½	11½	19
100	4½	7	9	11	14	22½

on the length of span and, for a given degree of initial tightness, on the temperature. Since the wires are shorter in winter than in summer, wires that are pulled too tight in the summer time may become so tight as to break during the winter. Table XXVI shows good practice with respect to the sag to be allowed for different lengths of span erected at different temperatures.

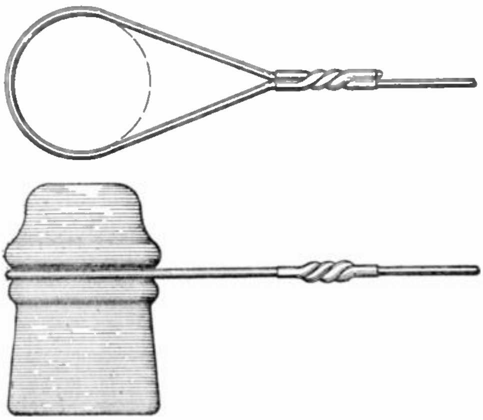


Fig. 540. Dead-Ending with Sleeve Joint

Dead-Ending:—At the ends of lines, at test points, and sometimes at transposition points it is necessary to dead-end the line wire. The method of dead-ending copper line wire is indicated in Fig. 540. In this a McIntyre sleeve of one-half the usual length is employed. The iron wire dead end is shown in Fig. 541, and is made without a sleeve, the wire being given two complete wraps around the insulator and then twisted around itself, as shown.

Test Points:—To facilitate testing on through lines, it is common to establish test points at which the line wire is cut and dead-ended and connected by some form of connecting clamp, which the

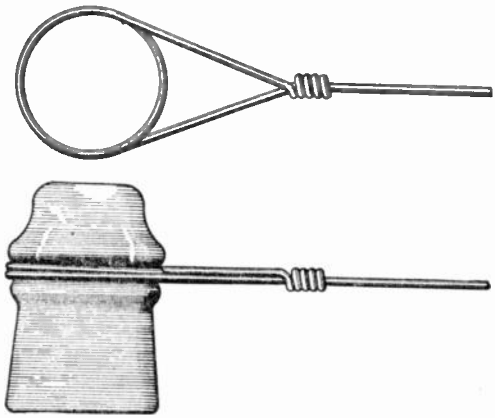


Fig. 541. Dead-Ending Without Sleeve Joint

tester may readily open in making his tests. A form of this construction is shown in Fig. 542.

Scheme of Transposition. The necessity for transposing upon circuit wires has already been dealt with. The scheme of transposition differs for the various cross-arms as well as for the different pairs on any one cross-arm. The reason for this is to provide for

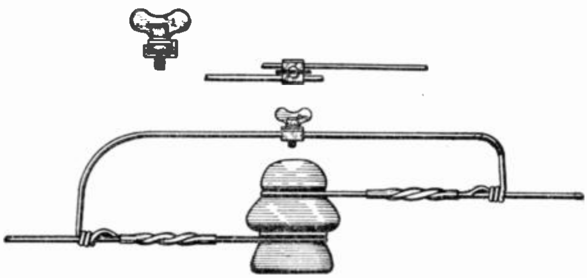


Fig. 542. Test Connection

inductive neutrality between the wires above and below each other as well as those alongside of each other.

The poles on which transpositions occur are known as *transposition poles*, and they are located at about 1,300-foot intervals. The length of a transposition section for the present standard scheme employed by the Bell companies is 8 miles and includes 32 transposition poles. The scheme for one such section is shown in Fig. 543, this being repeated in each section.

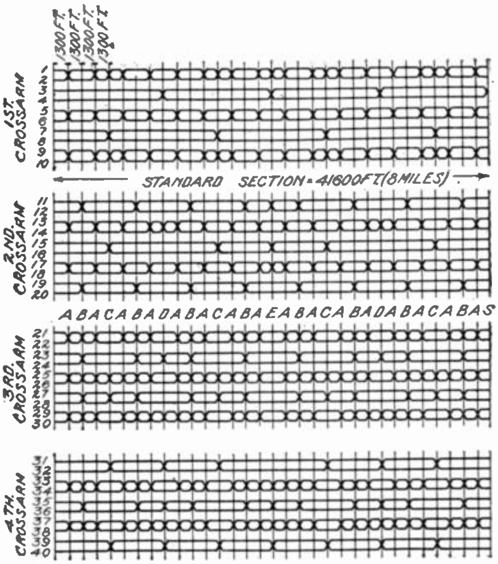


Fig. 543. Transposition Scheme

There are two general methods of making transpositions, one of which requires the dead-ending of both wires at the transposition pole and the crossing over of their free ends. With this method double-groove insulators are employed at the transposition point, each of the right-hand wires being dead-ended in a groove on each of the insulators and the two left-hand wires in the other grooves of the insulators. This method is shown in Fig. 544, the dead-ending and splicing of the free ends being done by means of McIntyre sleeves.

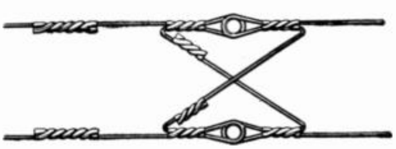


Fig. 544. Two-Pin Transposition

The other method of transposing, known as the *single-pin* or *running* transposition, may be done in two ways, as shown in Figs. 545 and 546. Of the two methods, the one shown in Fig. 545 is to

LAYING LONG SUBMARINE TELEPHONE CABLE ACROSS SAN FRANCISCO BAY
Home Telephone Co.

be preferred, since it does not involve cutting the wires; however, it can only be made when the wires are being run out. When it is neces-

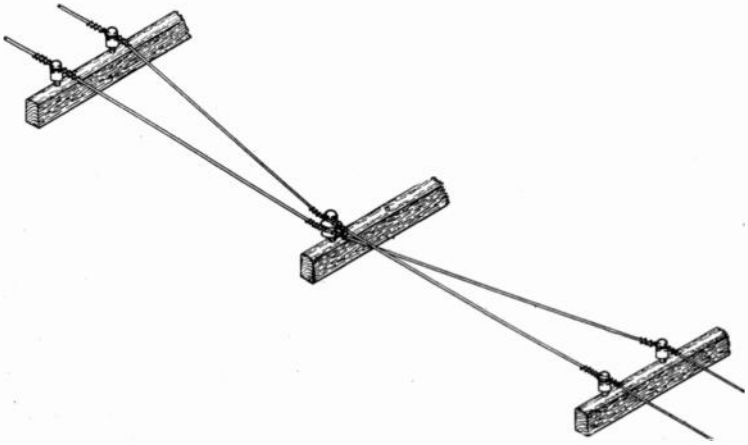


Fig. 545. Running Transposition

sary to make the transposition after the wire has been strung, the method shown in Fig. 546 is employed.

In the running transposition the wires on the transposition arm

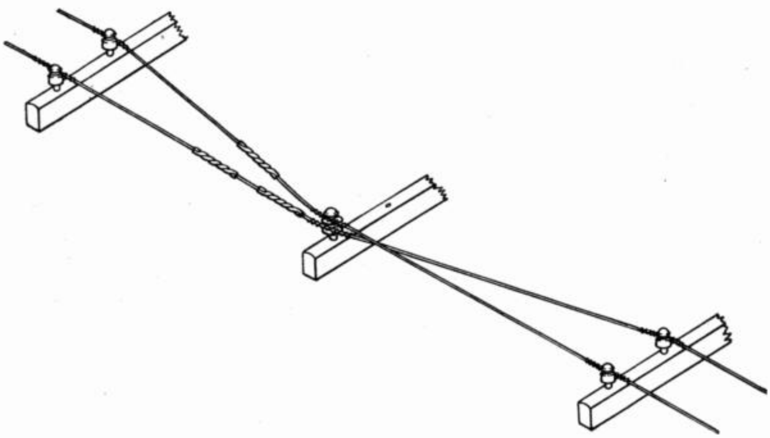


Fig. 546. Running Transposition

and the arms adjacent to it on each side should pull on the pins and not on the tie wires. On straight sections of the line, the outside pin is used for transpositions and the inside pin is left idle.

Rural Lines. For the connection of rural subscribers in the outlying districts of cities or towns such a high grade of construction as is employed on through toll lines is not warranted. The number of wires carried on such lines is small and the service is relatively unimportant. By this it is not meant that there is any justification for the miserably constructed lines often found along country roads and aptly termed "bean-pole lines." It is perfectly feasible to build lines for such rural service of shorter and smaller poles than those required for more important lines, and to space the poles farther apart, thus securing a cheaper yet adequate line.

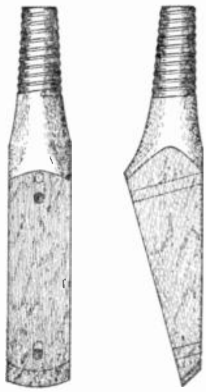


Fig. 547. Insulator Bracket

For such work the Bell operating companies in certain sections have adopted as a standard what they term a 22-foot line. Other companies employ 20-foot poles. A fair sized pole for this work is a 20- or 22-foot pole with a 5-inch top. A fair spacing is thirty to a mile.

Where the line is to carry but two or three wires, as is often the case, there is no need of cross-arms at all, the wires being supported from brackets nailed directly to the pole. The details of such a bracket are shown in Fig. 547. For a two-wire line, the location of brackets on the pole, on straight sections, and on curves is shown in Fig 548, the view at the left showing the arrangement on straight sections and that at the right, on curves. The reason for placing the brackets both on the same side of the pole on curves is so that both wires may pull towards the pole. If more wires are to be carried, a 6- or 8-pin cross-arm, or, if the poles are heavy enough, a 10-pin cross-arm may be employed.

The wire on such a line, if short, may well be of iron, although there are certain localities having much coal gas in the atmosphere where it has been proven that iron wire will last only a few years. In other places iron wire may easily have a life of from ten to fifteen years, and it is often to be expected that before this time shall have elapsed, the cheap pole line will have been replaced by one of more substantial construction, owing to the extended requirements of the growing community.

City Exchange Lines. The requirements for modern city aërial lines differ from those of cross-country toll lines, in that they are generally required to carry fewer or no bare wires and to carry cables. Frequently, and this practice is growing, city lines carry no bare wires at all and no cross-arms unless cross-arms are needed for supporting the cables.

Poles. All that has been said regarding the preparation of the pole in the first portion of this chapter will apply to poles for use in city lines. In addition to this it is considered good practice to paint all poles with one, or better two, coats of good oil paint, an excellent paint for this purpose being known as Acheson graphite. A few words may be said as to the color of city poles. It is

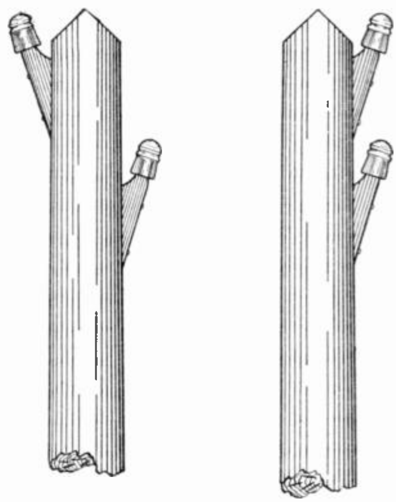


Fig. 548. Location of Brackets

usual to paint them white, or the upper portion of them white and the portion 6 feet above the ground, dark green or black. Such practice makes the poles as conspicuous as possible, and while this may be gratifying to the construction man or to the exchange owners, it is seldom so to the nearby property owners. It is believed that a better practice is to paint them a dull black or very dark green all over. This renders them inconspicuous and takes away the startling appearance of newness which often serves to fan the flame of dissatisfaction of the citizen.

TABLE XXVII

Pole-Step Data

25 foot poles	7 iron steps
30 foot poles	10 iron steps
35 foot poles	13 iron steps
40 foot poles	16 iron steps
45 foot poles	19 iron steps
50 foot poles	22 iron steps
55 foot poles	25 iron steps
60 foot poles	28 iron steps
65 foot poles	31 iron steps

Stepping:—As has been said, city poles should be stepped as they have to be climbed more frequently than those in cross-country runs and the marks of the climbing spurs of the linemen are detrimental, not only to the appearance of the pole, but to its life, and this is particularly true where the pole is painted. The method of spacing the steps is shown in Fig. 519.

For guidance in boring the holes for the iron steps, and for making the estimates as to the number of steps required Table XXVII is given. This table is frequently convenient in another way. In poles that have already been set it is often difficult to judge their height, and it may be necessary to ascertain this either in planning other construction that is to go over or under a given lead or in making appraisals. A knowledge of the number of iron steps for given heights of poles will, therefore, enable one to arrive quite accurately at the height of the pole by merely counting the steps.

Locating:—In setting poles along streets, the general location will be within the curb line. Where no curbing exists at the time of setting, or in case the present curb line is likely to be changed, its ultimate location should be obtained from the city engineer or proper city authority.

In setting poles within the curb, it is desirable to maintain a separation of at least 6 inches between the nearest point of the pole and the curb to avoid throwing the curb out of alignment by movement of the pole.

In setting poles on streets where their is an existing pole line of another company, it is, of course, preferable to take the opposite side of the street; but where the two must be placed on the same side of the street, the two sets of poles should be set in the same line so as to preserve as far as possible a sightly appearance for both leads. In alleys the poles should in general be set outside of and as close as possible to the abutting private property. When placed on private property the poles should be set to conform with the requirements stated in the permit from the owner.

Crossings:—When a pole line for cables must cross from one side of a street to the other, the crossing is preferably made at a street or alley intersection and parallel with the intersecting street or alley, as shown in Fig. 549. The reason for this is that the intersecting street or alley affords room for guys, and if an intersecting line is to be constructed on this cross-street the two poles on which the crossing is made will be available for that line.

The poles at steam railroad crossings should, if possible, be so located that the span over the crossing will not exceed 100 feet in

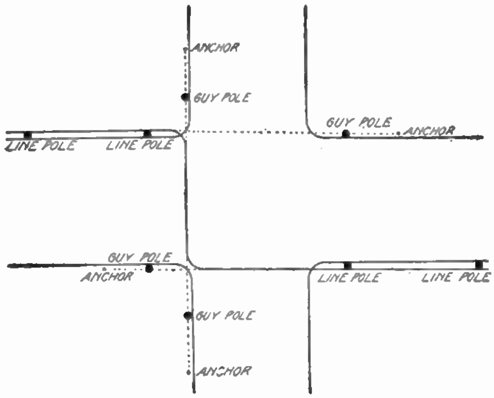


Fig. 549. Changing Sides of Street

length, and in all cases it must conform to the municipal regulations or agreements with the railroad company. The poles at such crossings should be no closer than 7 feet from the nearest rail, and, if possible, the crossing should be at right angles to the tracks.

Grading:—On comparatively level ground in cities, the poles should be graded so as to avoid changes of more than 5 feet in the level of the wires and cables on adjacent poles. In general, in city work it is good practice to make poles as low as possible. This is directly contrary to the plan that has been followed in many eastern cities where lines of 30- and 70-foot poles are an eye-sore and a menace to the public. It is, of course, necessary to make all poles of such height as to give the cables and wires which they support the clearance required by city ordinances. Cables and wires should clear all obstacles, and electric light and power wires, by at least 4 feet if possible, and enough separation should be always allowed to prevent swinging contacts.

Distributing:—The same considerations as to the distribution of poles should be given in city work as set forth for cross-country work, with the additional consideration that the most sightly poles should be placed on the streets and the worst looking ones in the alleys. A keen consideration for the personal feeling of property owners is not only morally right, but it has been amply proven to be the best of commercial policies.

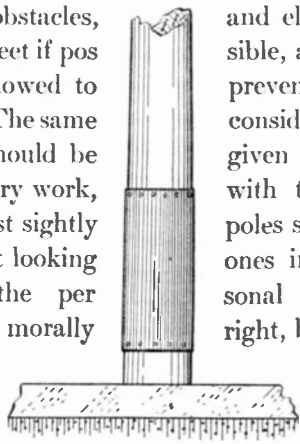


Fig. 550 Butt Protector or Hub Guard

Mechanical Protection:—Where there is danger of poles being injured by hubs of wagons, butt protectors, consisting of half cylinders of heavy sheet iron, should be attached to the pole at such a height as to receive the impact from the hubs of passing wagons. Such a butt protector on a pole is shown in Fig. 550. Where poles are so erected as to make them likely to be used as hitching posts for horses, particularly in village streets, cribbing guards should be installed to prevent the horses gnawing them. A pole so protected is shown in Fig. 551.

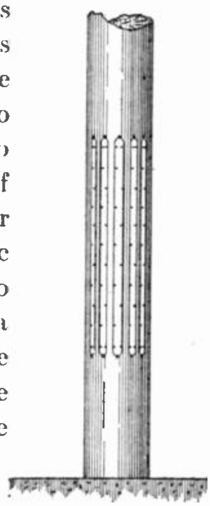


Fig. 551. Cribbing Guards

For the protection of persons and teams against injury which might occur from running into guy wires and for the protection of the guy wire itself, it is customary in cities to place a protecting guard over the guy wire for a distance of about 8 feet above the ground. Sometimes this is done by sliding an iron pipe over the guy wire before it is tied in place, but the more usual method is to put a cheap wooden box around the guy wire, this having the advantage of being readily applied after the guy is in place. A guy so protected is shown in Fig. 552.

Where guys pass close to electric light or trolley wires, they should be encased in a rubber hose for a distance of about 4 feet on each side of the point of crossing. The hose should be lashed in place by marline bound tightly to the wire at each end of the hose. Where it is possible to put the protecting hose on before erecting the wire, it is preferable to merely slide the hose over the wire, but where, as is usual, the protector is put up after the erection of the guy wire, the hose may be split and slipped over the guy wire, and then lashed in place with marline, the lashings extending throughout the entire length of the hose and occurring about every 4 inches.

Alley Arms:—Where bare wires are to be carried on the poles in city construction, the method of mounting and equipping the cross-arm and of stringing and tying the wires, as already described, is employed. Frequently, in city work, particularly in alleys, the pole line must necessarily be located so close to walls of buildings abutting the alley as to leave insufficient room to use the standard mounting of cross-arms. For this purpose the so-called alley arm or side arm is used consisting merely in an arm of standard length and pin spacing, attached to the pole at one end so as to project out over the alley, and secured by a suitable angle-iron brace. A pole so equipped is shown in Fig. 553.

Messengers. Usually in city work the bulk of the line wires on a pole is carried in cables. As cables have not sufficient mechanical strength to support themselves when hung between poles, it is necessary to provide supporting strands consisting of steel wire or steel wire rope supported by the poles.

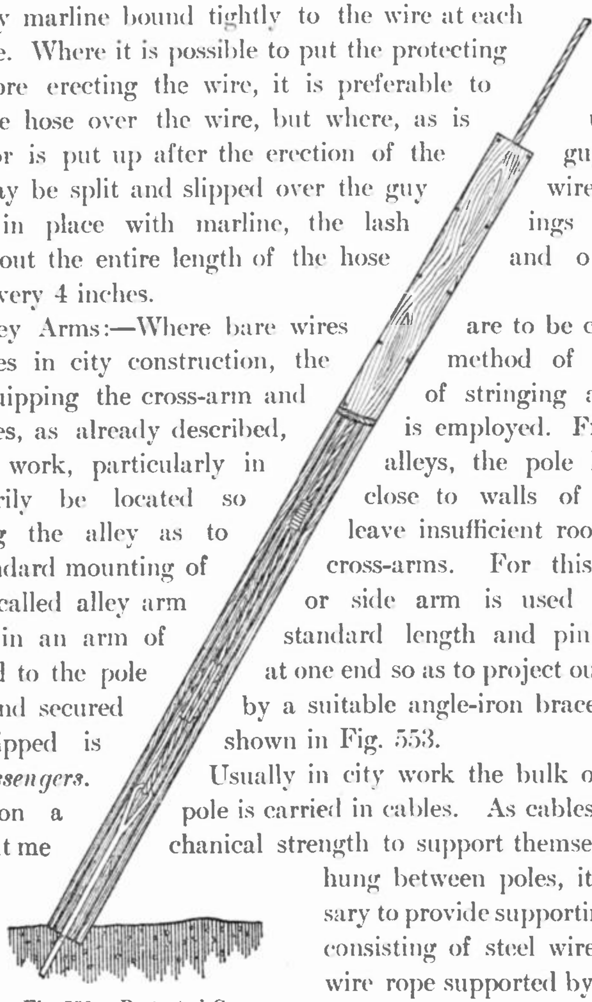


Fig. 552. Protected Guy

To this "messenger wire" the cable is fastened at short intervals, usually of about 18 inches, by some form of "cable hanger."

Sizes and Grades:—The sizes of stranded messenger wire range from ½ inch to ¼ inch in diameter and, for supporting smaller cables, a solid steel wire No. 4 or No. 6 B. W. G. is frequently used. Such

TABLE XXVIII

Size and Breaking Weight of Messengers

	STRANDED					SOLID	
SIZE	$\frac{1}{2}''$	$\frac{7}{16}''$	$\frac{3}{8}''$	$\frac{5}{16}''$	$\frac{1}{4}''$	.225″	.192″
Weight per 1000 feet	520	400	300	220	1[illegible]0	134	98
Bessemer Steel	9800	7600	5700	4200	2500		
Siemens-Martin Steel	11000	9000	6800	4860	3056	3500	2500
High Strength Steel	18000	15000	11500	8100	5100	5900	4300
Plow Steel	27000	22500	17250	12100	7600	8000	6000

messenger wire, whether stranded or solid, is made in different grades, which vary greatly as to breaking strength. The principal standard market grades are Bessemer, Siemens-Martin, "high strength" and "plow steel," these increasing in strength in the order mentioned. The weights per thousand feet and the breaking strengths of each of these grades in different sizes, both stranded and solid, are given in Table XXVIII.

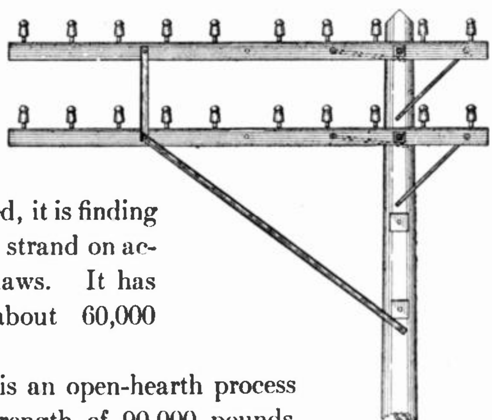


Fig. 553. Side or Alley Arms

Bessemer steel strand is the cheapest, and although frequently employed, it is finding less favor as a messenger strand on account of its liability to flaws. It has a tensile strength of about 60,000 pounds per square inch.

Siemens-Martin steel is an open-hearth process steel, and has a tensile strength of 90,000 pounds per square inch, and sometimes considerably more. It is very uniform and the likelihood of flaws is remote. This is a thoroughly satisfactory steel for messenger wires in all cases, except where the very greatest strength is necessary.

The other grades, known as the high strength and plow steel, have tensile strengths of approximately 150,000 and 220,000 pounds per square inch, respectively.

Good practice in respect to the sizes and the grades of messenger wire for all ordinary spans may be outlined as follows, the grade of messenger in each case being Siemens-Martin.

For 10 to 30 pair, 22-gauge cables inclusive, or their equivalents in weight, No. 4 B. W. G. solid wire.

For 40 to 100 pair, 22-gauge cables inclusive, or their equivalents in weight, $\frac{3}{8}$-inch steel strand.

For larger cables up to 200 pair, 22-gauge, or their equivalents in weight, $\frac{7}{16}$-inch steel strand.

For all cables heavier than 200 pair, 22-gauge, $\frac{1}{2}$-inch steel strand.

This practice provides for a very large factor of safety, the strands being of ample strength to provide for changes in temperature, wind and sleet storms, and for other contingencies.

Methods of Attaching:—The messenger is attached to each pole, except the poles on which it is dead-ended, by means of messenger supports of various forms. Most pole lines in city work carry but a single cable and the messenger support in such cases is usually of malleable or wrought iron secured directly to the pole by lag or through bolts. Standard forms of messenger supports for this class of work are shown in Figs. 554 and 555.

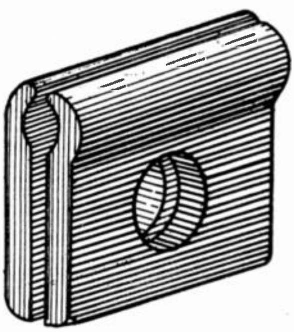


Fig. 554. Messenger Support

Under ordinary circumstances on new pole lines the messenger may be attached 12 inches from the top of the pole, except in cases where the poles are of extra height, so as to provide for the other fixtures, such as distributing terminals, in which case the messenger may be mounted as far below the top as is desired. The messenger wire should be graded as far as possible to avoid too abrupt changes in level. It should always be attached to the pole at such a height as to afford a clearance of not less than 20 feet over the crown of roadways when the cable is in place, and a greater distance may be required by city ordinances. Where messengers intersect each other, as in the case of pole lines crossing at right angles, care should be taken in placing the messengers on the four corner poles so that they will cross on the same level.

Where a messenger is erected on a pole line carrying open wires or cross-arms, it should not be less than 18 inches below the lowest arm unless the clearance over the roadway demands that it be placed higher up. This clearance below the arm is desirable so as to afford room for placing terminals and distributing brackets for service wires extending to subscriber's premises. Where it is impossible to attach the messenger this far below existing cross-arms, it must, of course, be placed where available space exists.

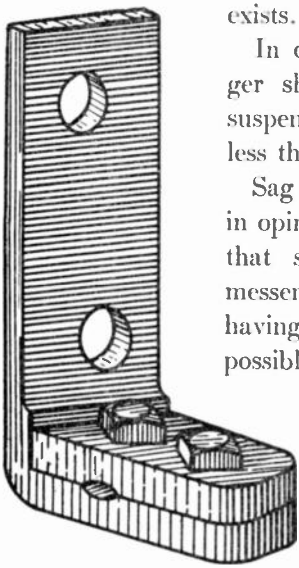


Fig. 555. Messenger Support

In crossing steam railroad tracks, the messenger should be so placed that the cable, when suspended, shall clear the top of the rail by not less than 28 feet.

Sag and Strains:—There is much difference in opinion and practice as to the amount of sag that should be allowed in cable supporting messengers. Some construction men believe in having the messenger wire initially as tight as possible. This has been referred to as "fiddle string" construction. There seems to be no good reason for it. It subjects the entire pole-line structure to an unnecessary initial strain, and is particularly severe on guys and anchors. About the only thing that can be said in its favor is that it presents, as long as it remains in place, a trim, ship-shape appearance. The extreme in the other direction is to hang the messenger loosely between poles with a very large sag, so that the cable is, as it were, festooned along the pole line. The resulting construction is not so pleasing in appearance and it is subject to the criticism that it permits a considerable swinging of the span by the wind, which may eventually injure the cable sheath. Whether there is any real cause for this criticism is to be doubted, as this loose construction method is extensively practiced in some large cities and no injury seems to result. Its advantage is greatest in short runs, consisting of but a few poles each, where conductors of an underground cable are led up to aërial cables for distribution. Where the aërial cables are light.

TABLE XXIX

Minimum Sag in Regular Spans

Span in Feet	Main Lines	Distributing Lines
50	4½″	3½″
60	6 ″	4½″
70	8 ″	6½″
80	11″	9 ″
90	1′1½″	11½″
100	1′5 ″	1′ 1½″
110	1′8½″	1′ 5 ″
120	2′0 ″	1′ 8 ″
130	2′3½″	2′ 0 ″
140	2′9 ″	2′ 3 ″
150	3′1½″	2′ 6½″
160	3′6 ″	3′ 0 ″

the very loose suspension makes it possible to do away largely with all guying, the poles being made, in all cases, sufficiently heavy and well set to be self-supporting.

Under ordinary circumstances where terminal guys are used, Table XXIX represents an intermediate practice in the matter of allowable sag, it being understood that the sag mentioned is that after the cable has been put up. These sags are worked out to give uniform tension in all spans.

For short pole leads carrying light cables, No. 4 or No. 6 B. W. G. wire may be used. Table XXX of sags has been worked out for various spans and for 10, 20, and 35 pair cables, with the idea of in no case subjecting the supporting strand to more than 700 pounds stress, which, under normal conditions, would not place a stress of more than 1,000 pounds on the terminal guys.

Where this practice is followed the No. 6 Siemens-Martin wire is of sufficient strength for both messenger and guying, since this wire has a breaking strength of about 2,500 pounds. It will be understood that unless the terminal guy on such a lead is in the same direction as the suspension strand, both vertically and horizontally, the stress on the terminal guy is always greater than that on the suspension strand or wire. This stress on the guy increases as the angle between the guy and the pole becomes smaller, and Table XXXI gives a factor by which the strain on suspension strands should be

TABLE XXX

Sags for Various Spans

Length of Span in Feet	Sag in Feet For		
	10 Pr. Cable	20 Pr. Cable	35 Pr. Cable
50	.35	.45	.6
60	.51	.65	.85
70	.7	.87	1.15
80	.91	1.15	1.5
90	1.1	1.41	1.9
100	1.43	1.8	2.3
110	1.75	2.15	2.8
120	2.06	2.6	3.3
130	2.5	3.	3.9
140	2.8	3.5	4.5
150	3.2	4.	5.2
160	3.66	4.6	6.
170	4.	5.15	6.75
180	4.6	5.8	7.5
190	5.15	6.4	8.4
200	5.7	7.15	9.3

multiplied in order to give the strain on the guy.

It goes without saying that where the poles are self-supporting the stresses on them should be reduced to a minimum and the cables

TABLE XXXI

Factor for Strain on Suspension Strand

When Distance From Anchor Guy at Ground Equals	Factor
The height of guy on pole above ground	1.4
Two-thirds the height of guy above ground..................	1.8
One-third the height of guy above ground	3.2

should be supported as low down on them as possible. The proper sag will depend upon the size of the poles, the height of the cable above the ground, and the character of the setting of the pole. Table XXXII will be found useful in determining the strain that may be expected, due to any given sag on a given size of cable.

To find the sag for any other span such as will give the same tension in the wire, divide the new span length by 100, square the result, and multiply by the sag given in Table XXXII.

TABLE XXXII

Strain at Center of 100 Foot Span

Using No. 6 B. W. G. Steel Wire

Sag	10 Pr. Cable .8 Lb. Per Ft.	20 Pr. Cable 1 Lb. Per Ft.	35 Pr. Cable 1.3 Lb. Per Ft.	60 Pr. Cable 1.7 Lb. Per Ft.
2.0 feet	500 pounds	630 pounds	800 pounds	1070 pounds
2.5 feet	400 pounds	525 pounds	650 pounds	845 pounds
3.0 feet	340 pounds	420 pounds	560 pounds	720 pounds
3.5 feet	280 pounds	360 pounds	470 pounds	600 pounds
4.0 feet	250 pounds	320 pounds	400 pounds	550 pounds
4.5 feet	220 pounds	280 pounds	360 pounds	470 pounds
5.0 feet	200 pounds	250 pounds	325 pounds	425 pounds
5.5 feet	180 pounds	225 pounds	300 pounds	390 pounds
6.0 feet	165 pounds	210 pounds	270 pounds	350 pounds

Example. What sag should be given a 150-foot span to give the same tension that a 2-foot sag gives to a 100-foot span in Table XXXII?

$$\frac{150}{100} = 1.5$$

$$(1.5)^2 = 2.25$$

The desired sag $2 \times 2.25 = 4.5$ feet. Answer.

The weight of cable given above includes that of the supporting wire and the marline hangers.

Pole Shims:—In pole lines carrying cables, good practice demands that, in dead-ending messenger wires on poles and in attaching all guy wires to poles, guy shims be used. These shims consist merely of short rectangular strips of iron about $\frac{1}{4}$ inch thick, 1 inch wide, and 6 inches long, with a nail hole at each end for attaching them to the pole. The guy shims are placed around the pole at such a point that the attaching messenger or guy wire will engage them at their middle. In the case of guy wires where there is an abrupt angular pull downward from the pole, 5-inch lag screws may be placed on both sides of the pole to prevent the guy from slipping down.

In some cases it is desirable to insulate the guy strand from the messenger strand for safety and for the prevention of electrolysis of the guy wire and anchor, in which case the guy strand should be attached to a different set of shims from that used in dead-ending the messenger. Where no such necessity exists, the guy wire may be attached to the same shims as the messenger. The two views in Fig. 556 will make this clear.

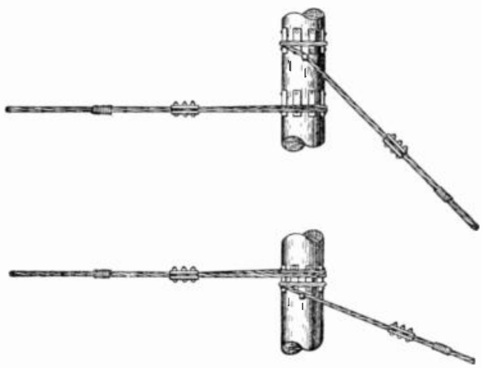


Fig 556. Guy Attachment at Terminal Poles

Splices:—In new work, where it is necessary to join ends of messenger wire, it is better to do so by dead-ending the two lengths on a pole rather than by making a joint at an intermediate point between two poles. Where stranded messenger wire must be spliced in the span, it may be done by making a wrapped splice, as indicated in Fig. 557. This method has the advantage of presenting a com-

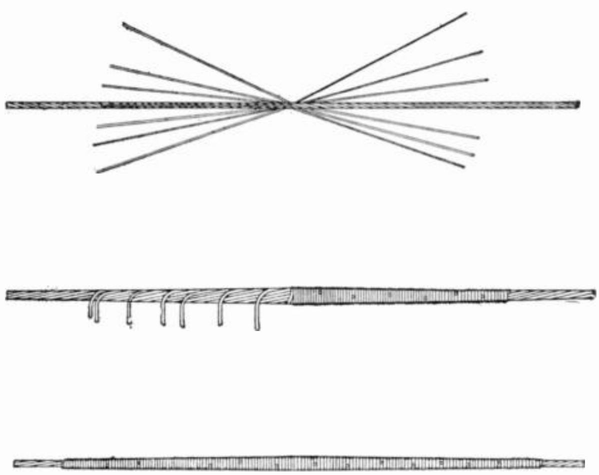


Fig. 557. Wrapped Splice

paratively smooth surface on the messenger wire in the erection of the cable, but it should not be practiced unless the proper skill is available for making a good job of it. The usual way of making splices is by means of regular guy clamps, the two wires being merely laid side by side and clamped together.

Cable. Erection:—In erecting aërial cable, the reel containing the cable is placed about 50 feet beyond one of the poles of the lead upon which the messenger strand has already been erected. A running-up wire, usually of the same material as the messenger strand, is fastened to the pole and to a stake in the ground near the reel. This running-up wire serves to support and guide the cable while it is being pulled up to and along the strand. The general scheme of erecting is shown in Fig. 558. In setting up, the reel should be so placed that the cable will always unroll from its top and be as nearly

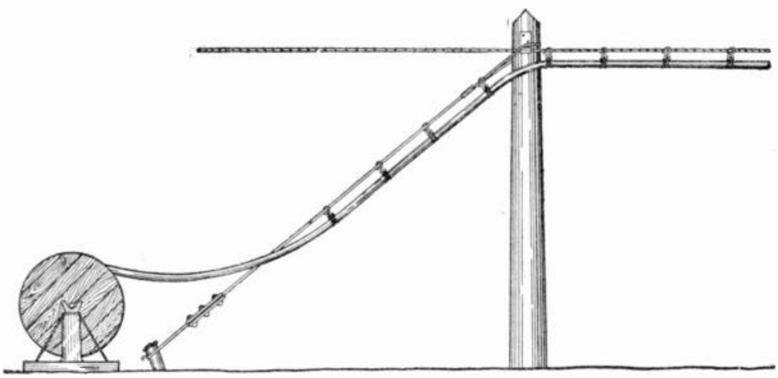


Fig. 558. Erecting Aërial Cables

in line with the running-up wire as possible. It is not generally desirable to pull up more than 1,000 feet of cable in single lengths, and that only in small sizes.

After the reel is set up on suitable jacks so as to allow it to turn freely, the pulling rope is fastened to the end of the cable. In fastening this rope a wrapping of wire or marline may be used, particular care being taken not to subject the end of the cable to such treatment as will break through the lead sheath. The cable rope should be provided with a swivel hook or ring so as to avoid twisting the cable. The cable may be pulled up by hand-power, horse-power, or by an engine-driven winch. The winch, or capstan, or whatever device is used, is placed at the distant end of the run and securely braced. The end of the cable pulling rope is then carried to the capstan drum and wrapped about it and the cable is slowly and evenly pulled into place.

Various methods are in vogue for supporting the cable while it is being pulled up. Some of these involve the placing of temporary trolley wheels on the messenger from which the cable is supported, these wheels running along the messenger wire as the cable progresses. In other cases the supporting trolley wheels are mounted on each pole adjacent to the messenger and the cable rolled over these as it progresses. Still another way is to employ no trolleys or temporary supports at all, but to apply the cable hangers to the cables and to the running-up wire as the cable runs off the reel, the hangers running along the messenger strand as the cable is moved. Unless provision is made, by means of special attachments at each pole, by which the cable hangers may ride past the messenger supports, it is necessary to station a man at each pole to lift each hanger hook off the messenger wire as it passes each pole.

Fig. 559. Marline Cable Hanger

Hangers:—No matter what method is used the cable should be slowly and evenly pulled into place, and after it is all up care should be taken that all hangers are in place. The distance between hangers on a cable should be uniform. For 200 pair, 22-gauge cable or its equivalent in weight, the hangers should be about 15 inches apart. For smaller cables this distance may be increased, but in no case should it be over 24 inches.

Numerous forms of cable hangers exist, but the one that today seems best to meet the requirements of practice in practically all sections of the country is the marline hanger. This consists merely of an S-shaped hook of galvanized steel wire to which is attached

AN UNDERGROUND CABLE TERMINAL FEEDING TO AËRIAL

a loop of marline. Its construction is shown in Fig. 559, and the method of supporting a cable by it, in Fig. 560. In placing the hangers on the messenger, the points of the hooks should be faced toward the pole.

The length of the loop in marline hangers varies for different sizes of cables. Table XXXIII illustrates good practice.

Splices:—A subsequent chapter will be devoted to the subject of splicing cables. It may be said at this point, however, that where it is necessary to join two cables so that one will form a continuation of the other, the wires in them are individually spliced together, taking extreme pains to maintain the insulation and particularly to keep the core dry. After this a lead sleeve is placed over the joined wires and secured to each end of the cable by a plumber's wiped joint, so as to maintain the continuity of the enclosing sheath and keep out all moisture. This is called a *straight splice.* It is also frequently necessary to tap a cable, that is, to lead out from it certain conductors which are to be made available for connection at an intermediate point on its length. This requires a *tap splice.* Again it may be necessary to join the conductors of one large cable to those of two or more smaller cables, this practice being followed where the larger group of wires is to be divided so as to enable them to follow different routes. When a cable thus branches out into smaller ones,

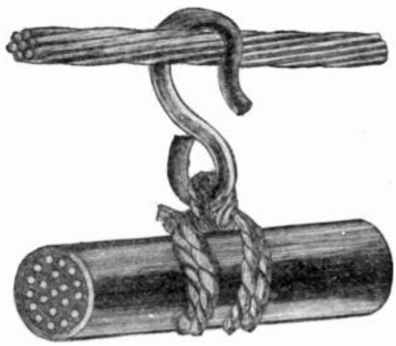


Fig. 560. Marline Hanger Supporting Cable

TABLE XXXIII

Loop in Marline Hangers

Less than 25 pair	22 gauge cable	9 inch loop
25 pair	22 gauge cable	11 inch loop
50 pair	22 gauge cable	14 inch loop
100 pair	22 gauge cable	16 inch loop
200 pair	22 gauge cable	19 inch loop

the resulting splice is a **Y**-*splice*. If the large cable connects with two smaller ones, it is a *two-way splice;* and so on

Supporting Splices:—In aërial work the supporting of the splices should be given particular attention. While the covering of

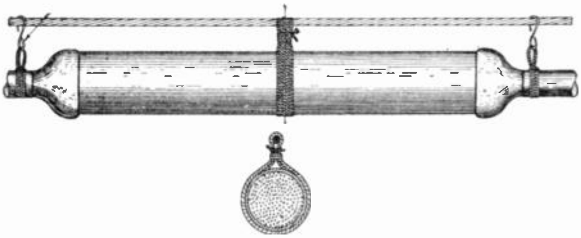


Fig. 561. Cable Splice Support

a *well-made* splice is just as capable of keeping out moisture as is the ordinary sheath of the cable, it should always be looked upon with suspicion, due to possible defects in workmanship. Therefore, great care should be taken to subject the cable to no unusual stresses at splices, particularly such stresses as would result in a bending of the

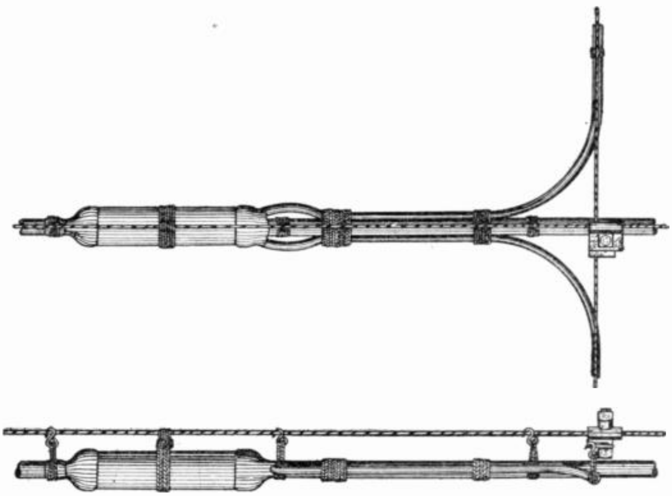


Fig. 562. Y-Splice Support

cable at the splice. An excellent way of supporting a splice is to provide a wrapping of marline around it, as shown in Fig. 561. If the cable is a heavy one, such a marline wrapping may be provided at each end of the splice, omitting the one in the middle.

The same practice may be followed in the supporting of tap and Y-splices. Sometimes it becomes necessary to make a Y-splice at a point where two messenger wires cross and where no pole is at the intersection. In such cases the messenger wires, which cross at the same level, should be rigidly secured to each other by a messenger clamp, and the splice and the cables leading from it supported by marline in addition to the usual hangers, as shown in Fig. 562. It will be noticed that the splice is made some distance back from the intersection on the main lead and that the two smaller cables leading from it are lashed to the main cable by marline, so as to make it impossible for any side stress on the cables which follow the intersecting messenger wire, to come on the covering of the splice itself.

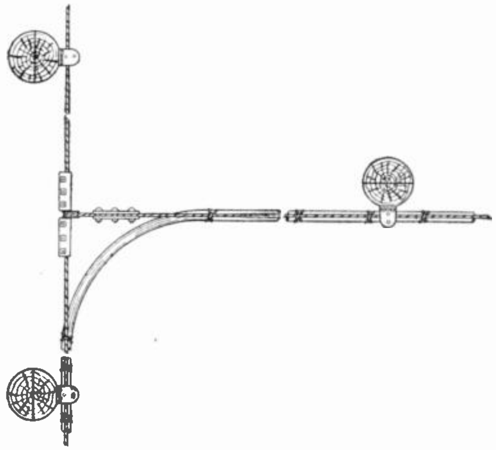


Fig. 563. Aërial Cable Turn

In turning corners with aërial cable, even where no splice occurs, particular care should be taken to avoid kinking the cable and also to avoid its chafing against the pole. If the turn occurs on a corner pole, the cable should pass on the inside rather than on the outside of the pole, and should be lashed to the messenger wire by a wrapping of marline in the same manner as used in supporting the cable splice, illustrated in Fig. 561. If the turn is made on an intermediate point between poles, it may be done as shown in Fig. 563. In this case plenty of slack should be left in the cable at the point of turning to allow for any drawing up that may occur, due to changes in temperature or to any influence that might cause the cable to creep.

In cases where the cable is subject to possible chafing from trees, poles, buildings, or other objects, it may be protected by wooden cleats lashed to it by marline or wire as shown in Fig. 564.

Terminals. The subject of terminals for aërial construction is one about which much has been written and said, and until recently no standard practice has resulted. This subject particularly is one which has required time to afford the necessary experience for determining what was desirable and what was not, and the art is so young that it is only recently that engineers have approached anything like agreement.

There are two purposes of the cable terminal for aërial construction: First, to provide access to the wires in the cable for connecting uncabled wires, such as those leading to the subscriber's premises or to bare wire leads. Second, to afford means for inserting protective devices in the line conductors at points between a section that is exposed to electrical hazards and one that is not.

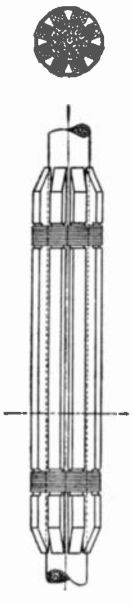


Fig. 564. Cable Protector

In any event the cable terminal must possess the following requisites:

It must afford ready means, such as binding posts or terminal clips, for attaching the wires that are to form the continuations of the cable conductors.

It must afford desired protection against the entrance of moisture to the core of the cable or cables which terminate in it.

It must afford high insulation between all of the terminal posts or clips and the wires leading to them, so that the insulation of the cable conductors as a whole may be maintained.

It must afford ready access to the terminal posts and connecting wires and to the protectors, if such exist.

It should be as compact as is consistent with the requirements for insulation and good mechanical construction.

It must be capable of protecting, in a reasonable degree, against the entrance of dust, moisture, and insects.

It should be as sightly as it is possible for such things to be.

For tap terminals at intermediate points on aërial cables, the usual requirement is for a relatively small number of conductors to be made available. This number ranges from ten to fifty pairs. At such points it is usual to continue the line wires by means of rubber-insulated twisted pairs which extend from the terminal pole to the premises of the subscriber. Such terminals are protected or unprotected according to the hazard of the continuing wires.

Unprotected:—An excellent form of unprotected terminal for such work, manufactured by the Western Electric Company and largely employed by the Bell operating companies, is shown in Fig. 565. This consists of a cast-iron box forming a chamber, from the

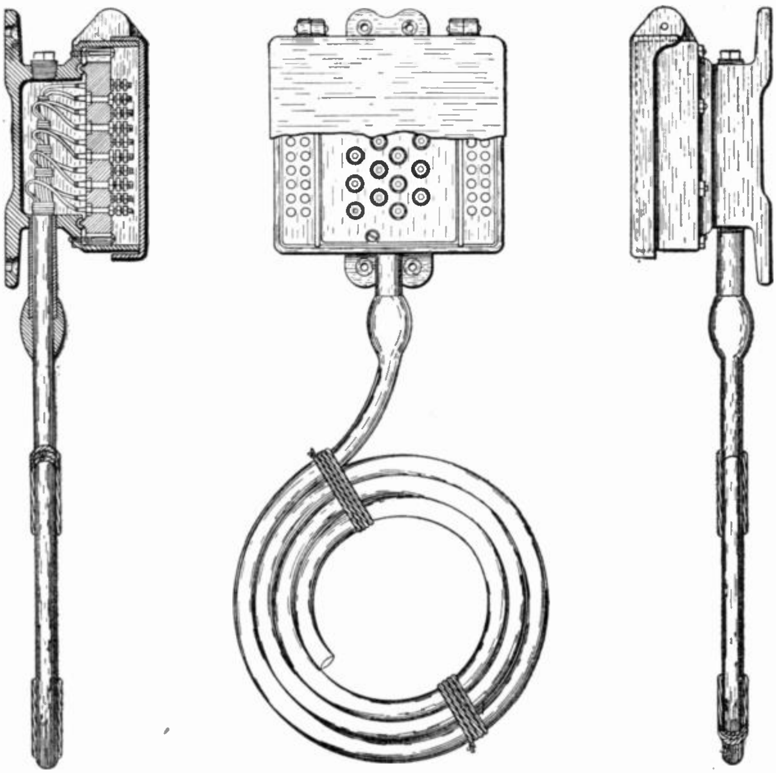


Fig. 565. Western Electric Terminal

lower portion of which there extends a brass tube of sufficient diameter to just admit the lead sheath of the tap cable. The front of this chamber is closed by a porcelain slab into which the lock-nut terminal binding posts are secured. To the rear end of the binding post studs, the individual cable wires are soldered, and the whole chamber is then filled with a hot insulating compound so as to hermetically seal the end of the cable and prevent the entrance of moisture to the insulated wires leading to the binding posts. By this means the terminals of the tap cable are continued to the lock-nut binding posts on the front of the porcelain slab, with no liability of the entrance of moisture to the cable. The whole device is compact, and owing to the high insulation resistance of porcelain and of the insulating compound used in filling the chamber, the very high degree of insulation required is maintained. As furnished by the Western Electric Company, this terminal has a length of lead-covered cable attached and its conductors properly connected, the joint between the brass sleeve and the sheath of the cable being made by a plumber's wiped joint. The box is provided with a hinged iron cover which guards against the entrance of moisture, dust, and insects.

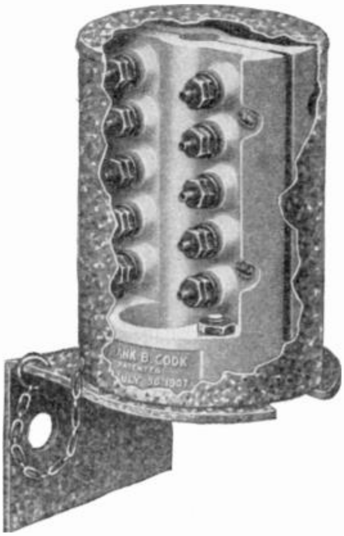


Fig. 566. Cook Unprotected Terminal

Another excellent form of cable terminal for this class of work, manufactured by Frank B. Cook, is shown in Fig. 566. In this the binding posts are mounted on two porcelain blocks. Two of these blocks are adapted to form a chamber between them for the insulating

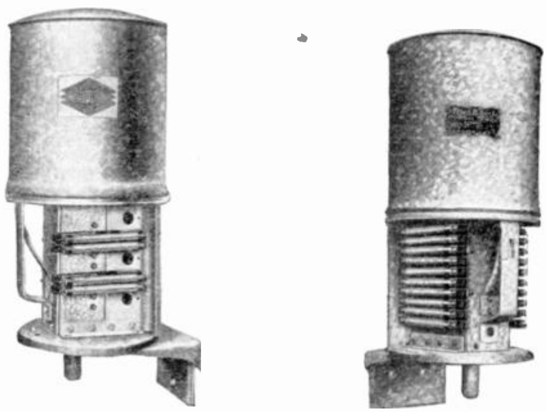


Fig. 567. Cook Protected Terminal

compound. This terminal may be procured either with or without a length of tap cable attached, according to whether the user desires to do this work for himself or not. In this form of terminal a cover, consisting of a cylindrical galvanized iron can, is provided, which, when raised, exposes all of the binding posts, and when lowered, affords them adequate protection.

Fig. 568. Wooden Terminal Box

Protected:—Where the wires leading from a cable terminal are bare and of considerable length, or where they pass through territory exposed to electrical hazards, the cable terminal should be provided with protectors. This point has already been dealt with in Chapter XIX. Cook protected terminals, providing fuse and carbon arresters for each wire, are shown in Fig. 567.

The type of terminal shown at the left in Fig. 567 is only partially equipped with protectors in order to show more clearly the method of mounting them in units. The one at the right is completely equipped. This general type of terminal is easily adaptable for use at the junction point between aërial and underground cable.

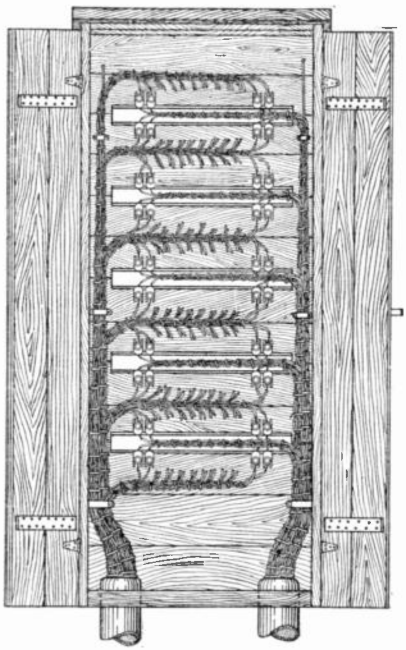


Fig 569 Wooden Terminal Box

Another form of protected terminal—commonly used where aërial cable leads and bare wire leads of considerable sizes join—consists in fuse and air-gap protectors mounted in wooden boxes. A view of such a wooden terminal box is shown in Fig. 568. For use in such boxes, strips of combined air-gap and fuse protectors are procurable, the strips being added in units of ten, twenty, or more, as required.

This wooden terminal box has the advantage of being able to accommodate a large number of line conductors, and for that reason is the most common form of protected terminal box for use between the junction of aërial and underground cables. The details of wiring within such a box when used for joining aërial to underground cable wires through protectors, is shown in Fig. 569.

These wooden terminals, whether used at the outer terminal of an

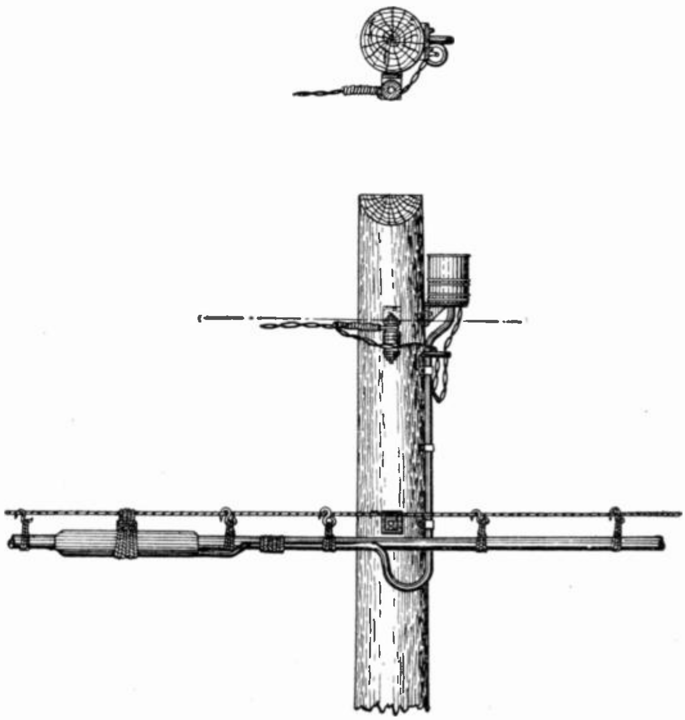


Fig. 570. Tap Cable Terminal

aërial lead or for joining underground and aërial cables, provide no means for sealing the cables which terminate in them. For this reason, it is necessary to "pot-head" the cables; that is, they are terminated in a special form of splice which serves to connect all of the cable conductors with uncabled rubber-insulated conductors, and at the same time completely to seal the end of the cable against the entrance of moisture. The matter of pot-heads will be considered in the chapter dealing with cable splicing.

Position:—The relation as to position between the cable terminal and the other features of aërial construction merits attention.

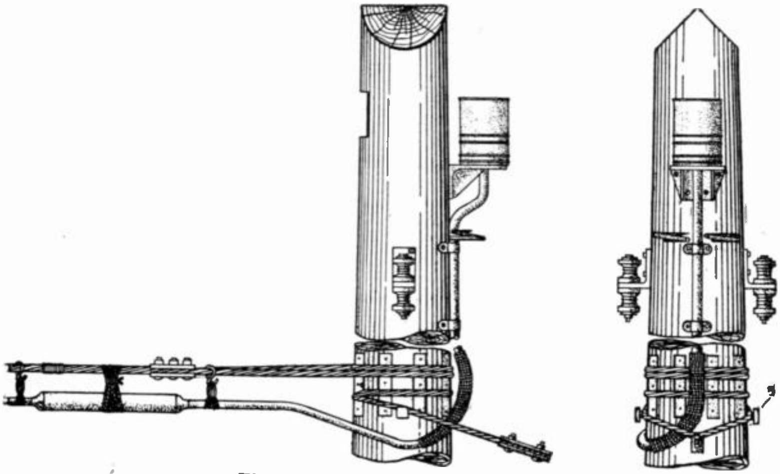


Fig. 571. Aërial Cable Terminal

Where terminals are used for the purpose of distributing the cable conductors to the drop wires which extend to the adjacent subscrib-

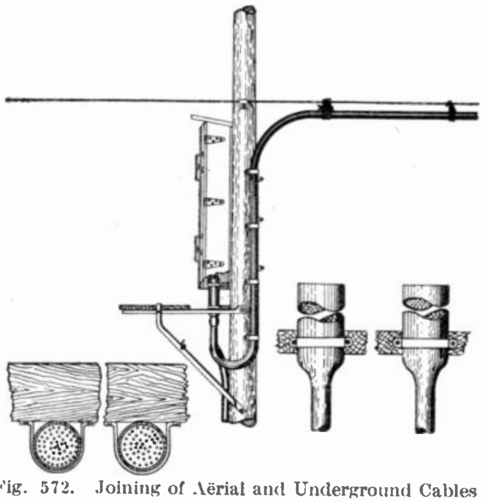


Fig. 572. Joining of Aërial and Underground Cables

er's premises, it is desirable that the terminals shall be mounted as high up on the pole as possible, and at any rate at a point from which there will be the most direct and clearest run to the neighboring houses or adjacent poles.

Fig. 570 shows a terminal of a tap cable and the method of supporting the splice and the tap cable. The tap cable is lashed to the main cable beyond the point where it emerges from the splice and is then looped down and up vertically along the pole, being held to the pole by straps of sheet iron.

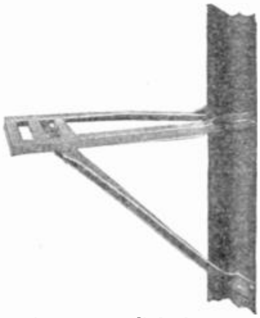


Fig. 573. Pole Seat

In Fig. 571 is shown the terminal at the outer end of an aërial cable, this showing also the dead-ending of the messenger wire and guying of the terminal pole. It also shows how the cable where it bends around the pole adjacent to the guy shims and guy and messenger strands may be served with a wrapping of marline to guard against abrasion.

The details of the most common method of inserting protection between aërial and underground cables is shown in Fig. 572. The cable leading up from the underground conduits is shown at the bottom of this figure, and the aërial cable is shown extending from a messenger wire down the pole and then up to the terminal box. This figure also shows details of the mounting for the pot-heads, in which both the aërial and the underground cables terminate. The rubber-covered wires leading out of the pot-heads pass upwardly within the box alongside of the terminal strips of the protectors and are there soldered into place so as to form permanent connections.


Fig. 574. Pole Balcony

Pole Seats:—Where 50 or more pairs of wires terminate in an aërial terminal, it is convenient to equip the pole with some form of seat or balcony for convenience of the cablemen. This is particularly true where protected terminals are used. This may be a simple seat for the workmen, as shown in Fig. 573, or for larger and more important terminals it may assume the form of a "balcony," as shown in Fig. 574.

CHAPTER XLV

UNDERGROUND CONSTRUCTION

Reasons for Placing Wires Underground. The demands of the public and the welfare of telephone companies alike require the placing of wires underground in the most densely built-up portions of cities. The view given in Fig. 575 is in itself a sufficient argument for the placing of wires underground in such places. Usually

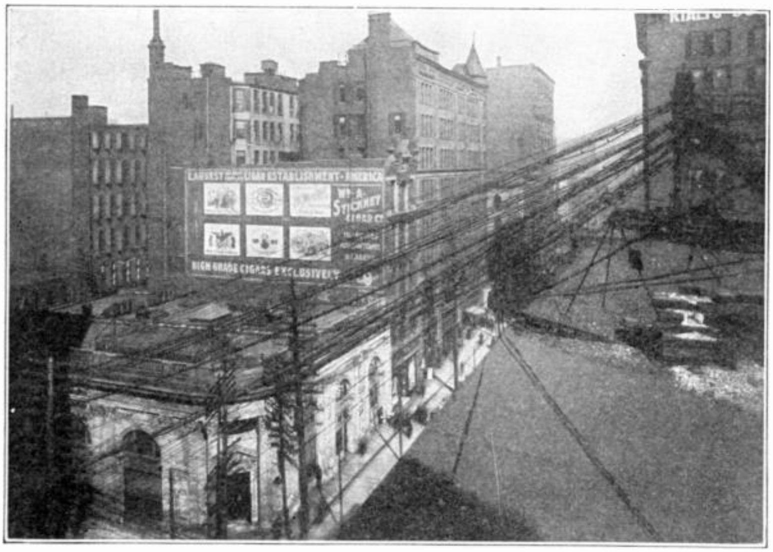


Fig. 575. An Argument for Underground Wires

the "enlightened self-interest" of the operating company dictates a greater area of underground construction than that required by the public through city ordinances.

Interests of the Public. From the standpoint of the public, overhead wires are objectionable for several reasons: They are unsightly; they are dangerous to workmen and passersby; they interfere with the work of firemen; and when down in the streets they obstruct traffic.

Interests of the Operating Company. The wisely managed telephone company will choose to place its wires underground in congested districts for still other reasons, of which the principal one is that of economy. Where a large number of wires are involved it is cheaper under average city conditions to place them underground than overhead; but the main feature of economy is from the standpoint of maintenance. Well-constructed telephone conduits are almost as durable as the foundations of buildings and require comparatively small expense for up-keep. Wires contained in such conduits are subject to a minimum amount of electrical hazard, and are less exposed to the elements and to the acts of careless or malicious persons. The depreciation of underground conduits is almost *nil*, and that of underground cables very much less than of those overhead.

Buried Cable. The very early practice in underground cable work involved the placing of the cable in a trench and filling in the earth on top of it. The main objection to this was that the cable was not accessible for repairs or changes. A cable once buried in this way was often virtually lost if it became faulty, since the cost of digging it up was more than its salvage value. This method provided no facilities for growth and necessitated the frequent digging up of the streets. Another objection was that the cable was unprotected from the tools of workmen engaged in making subsequent excavations.

Underground Conduit. The method that is now universally practiced involves the building of an underground conduit into which cables may be drawn and from which they may be withdrawn as occasion requires. Such conduit, once wisely planned and properly constructed, affords the required mechanical protection and provides not only for the present demands but for those reaching far into the future.

The conduit, irrespective of cables, consists of one or more permanently installed ducts or openings extended between manholes through which access is afforded to the ducts. These ducts or openings are made of sufficient internal diameter to accommodate the largest cable that it seems probable ever will be used. The number of ducts installed at the time of building the conduit is made equal to the largest number of cables that it seems probable will be required along that route within a given period of years. Such a degree of flexibility is provided by this plan that only those cables which are required by the present needs of the system are installed at the outset, others being added from time to time to meet the growth or changed requirements.

Duct Material. The materials available for conduit ducts are vitrified tile, creosoted wood pipe, iron pipe, paper or wood pulp pipe impregnated, cement lined pipe, concrete pipe, and sometimes the ducts are formed in the concrete structure itself as it is being laid. Of these materials the most used are vitrified tile, impregnated fiber pipe, iron pipe, and creosoted wood pipe. Clay tile and paper or fiber pipe are perhaps the most used in main conduit runs in city streets or alleys, where many ducts are required. Clay tile has the advantage of being known to be practically everlasting under the action of the elements. It has the disadvantage of being heavy and, therefore, somewhat expensive on account of transportation charges in those localities that are far removed from the source of supply. It is fragile and, therefore, subject to a considerable breakage loss in handling.

Fiber pipe has the advantage of being light and easily handled and transported, and, therefore, in some localities cheaper than tile. Its breakage loss is less than that of tile. No one knows how long it will last, but when properly made and laid it has proven its ability to stand, without appreciable deterioration, throughout long periods of time. Both clay tile and fiber pipe have so little ability to withstand shock—as from the pick axes of workmen—as to make it usually necessary to provide for them an envelope of concrete which wholly or partially encloses them.

Iron pipe has the advantage of needing no protecting envelope, as a rule, but has the disadvantage of being very expensive and of gradually deteriorating under the action of certain soils. It is, however, largely used in main conduit work for cases requiring special treatment, and for the subsidiary or branch runs from main conduits where but one or two ducts are required.

Creosoted wood or "pump log" conduit is more expensive in first cost than clay or fiber, but less expensive than iron and it has such resisting power against ordinary shocks and strains as to make it feasible to lay it directly in the ground without an enclosing envelope.

Well-impregnated wood is known to have a life of many years in all ordinary soils, and the consensus of opinion is that creosoted wooden pipe has a long enough life to make it satisfactory in that respect as a duct material.

Vitrified-Clay Conduit. Taking under consideration, first, the construction of conduits employing vitrified clay, it may be said that

Fig. 576. Single- and Multiple-Duct Clay Tile

tile of this material is obtainable in a variety of forms, which may be classified as single-duct and multiple-duct. Illustrations of these forms, furnished by McRoy Clay Works, are given in Fig. 576.

Single-Duct Tile:—In laying, these are piled together side by side and tier on tier in the trench in order to make up the desired number of ducts and the proper cross-section. The ends are butted together, the joints being staggered and the whole mass set in concrete so as to form a practically continuous structure.

In order to maintain the proper alignment between the abutting ends of these single-duct tiles, it is customary during the process of

Fig. 577. Dowel Pin

laying them to employ a mandrel, about 3 inches in diameter and 30 inches long. This is laid in the duct and pulled along through it by workmen as each additional section is laid. Otherwise the laying of this single-duct tile is about the same as that of ordinary brick.

Multiple-Duct Tile:—Another form of tile that is largely used is the so-called multiple-duct, several forms of which are shown in Fig. 576. In laying this, after providing a proper foundation usually of concrete, the tiles are placed together so as to form the proper cross-sectional arrangement of ducts. The butt joints are held in

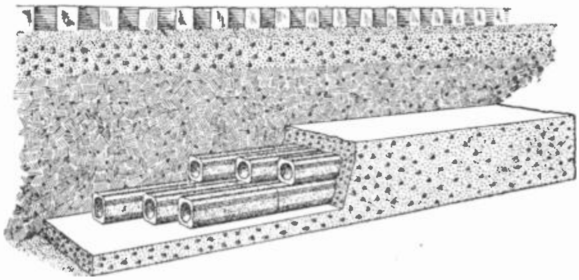


Fig. 578. Conduit of Single-Duct Tile

alignment by dowel pins of the form shown in Fig. 577. This pin is of iron 3 inches long, of such diameter as to loosely fit the dowel pin holes in the duct ends, and having a washer formed at its center so as to divide it equally between the abutting sections of conduit. In order to prevent dirt or concrete from entering at the joints in the

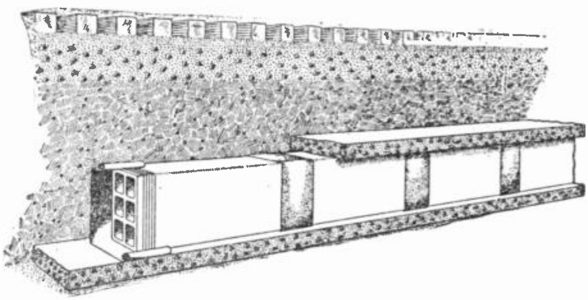


Fig. 579. Conduit of Multiple-Duct Tile

ducts, each abutting joint is wrapped with a layer of muslin or burlap cut into strips about 8 inches wide and long enough to surround the conduit and lap over several inches. This strip is saturated with water to make it cling to the conduit, after which it is plastered with cement mortar. In Fig. 578 a good idea is given of the formation of a conduit composed of single-duct vitrified clay, and in Fig. 579 of one built of multiple-duct.

Use of Concrete with Clay Tile:—Until comparatively recently it has been customary to completely surround the line of conduit—top, bottom, and sides—with a concrete envelope about 3 inches thick, as shown in cross-section in Fig. 580. During recent years there has been a growing tendency to curtail the expense in concrete work and several arrangements have been tried and each has its advocates. One of these, shown in Fig. 581, is to lay about a 4-inch foundation of concrete in the bottom of the trench and then build up the tile on this. This is covered with a layer of heavy creosoted plank and the earth is then tamped in on sides and top.

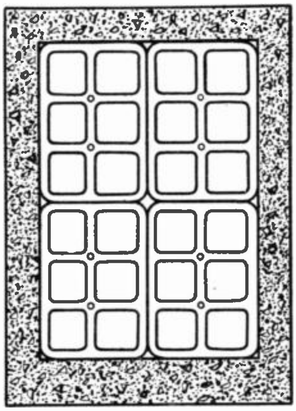


Fig. 580. Conduit Cross-Section—Complete Concrete Envelope

Another method consists in laying the foundation as just described, then building up the line of ducts and tamping in the earth on the sides only, and finally covering this with another layer of concrete about 3 or 4 inches thick so as to give protection at the top against the pick axes of workmen. Both the top and bottom layers of concrete serve also to provide the necessary mechanical rigidity. This construction is shown in Fig. 579 and indicated in cross-section in Fig. 582.

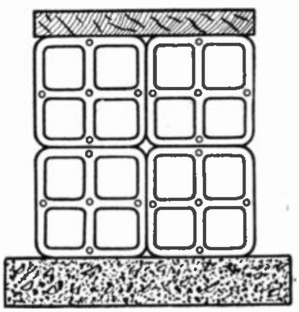
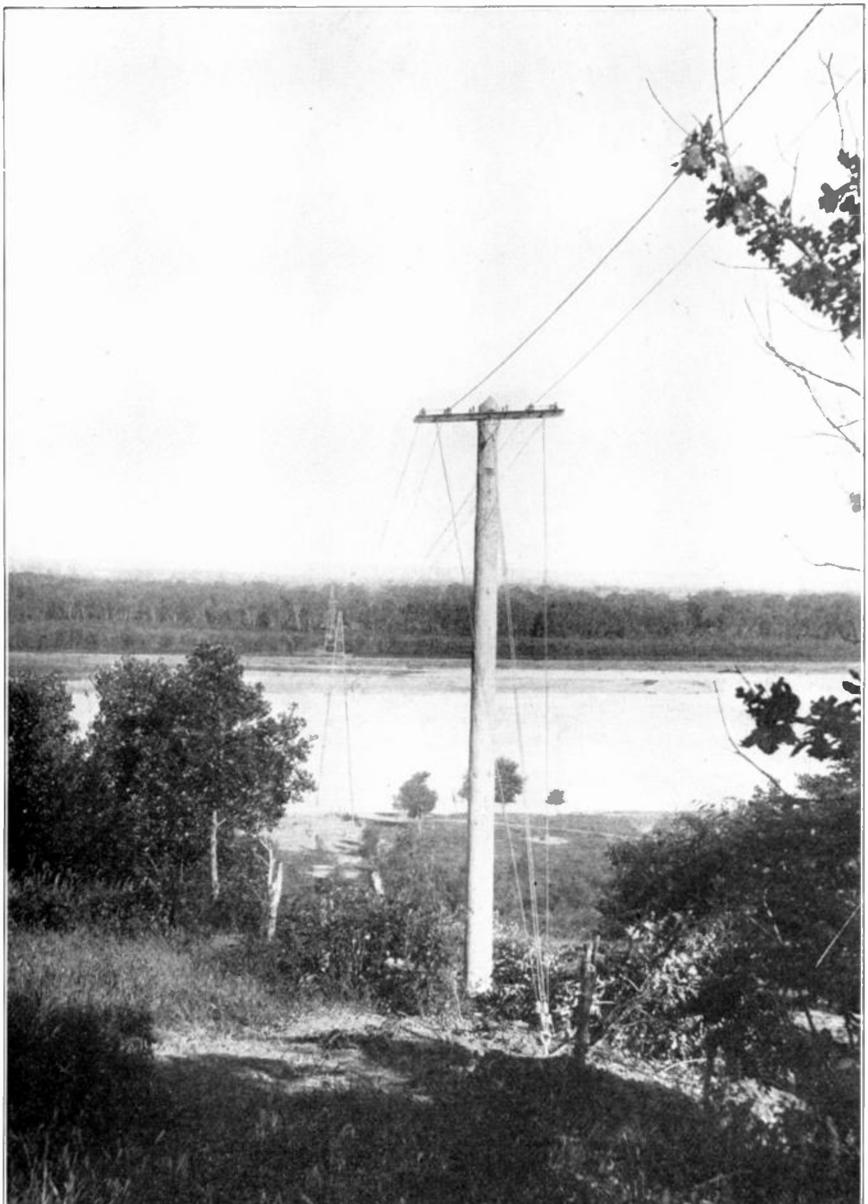


Fig. 581. Conduit Cross-Section—Concrete Bottom and Plank Top

Still another method is to place no concrete on the bottom of the trench, this being made to grade and tamped to a proper degree of hardness and smoothness. On this the tiles are laid without other foundation and earth filled in at the sides to a point a few inches below the level of the upper tiles. Concrete is then thrown into the remaining space on the sides and top to a depth of about 3 inches above the upper tile, as



A RIVER CROSSING SPANNING THE MISSOURI RIVER AT COUNCIL BLUFFS, IOWA
Note the Two Steel Towers on Banks.

shown in Fig. 583. This forms an inverted channel of concrete which gives a considerable sidewise rigidity as well as the necessary protection on top.

Undoubtedly the best way, where one wishes to be perfectly safe, is to make the concrete envelope entirely surround the vitrified tile—top, bottom, and sides. This makes a more rigid structure and one less liable to injury in the event of settling of the earth from any cause.

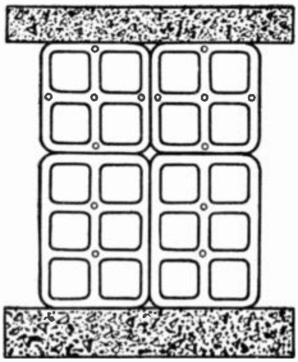


Fig. 582. Conduit Section—Concrete Top and Bottom

Fiber-Pipe Conduit. The bituminized fiber pipe employed for duct material is sometimes made of paper, being wound on a mandrel of proper size to give the requisite internal diameter and thoroughly impregnated with asphaltum or bituminous compound. It is necessary to exercise care in laying this so-called paper pipe in hot weather that it is not squeezed out of its cylindrical form under the pressure imposed by tamping the concrete into place.

Another form of fibrous conduit is made by wrapping very thin layers of wet wood pulp or fiber on a forming mandrel, under great pressure, until the desired thickness of wall is obtained. This conduit, unlike the paper pipe, has its individual fibers felted and formed into a solid homogeneous wall, which is then taken off the mandrel, thoroughly dried, and placed in a vat of impregnating compound.

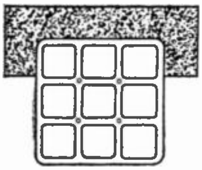


Fig. 583. Conduit Section—Concrete Top

This compound permeates the entire structure and acts as a preservative, and also renders the wall impervious to moisture. The black hard material which results, somewhat resembles hard rubber and is of such texture as to permit its ends being dressed in a lathe to form the desired mortise or tendon joints, by means of which the alignment is secured when the ducts are laid in the trench. This material has been used in large quantities by the writers and has not been found subject to the fault of distortion under pressure, mentioned above. Two lengths of this fiber conduit are shown in Fig. 584.

The length of the standard duct is 5 feet, its internal diameter, in the sizes most used for telephone work, 3 or $3\frac{1}{2}$ inches, and the thickness of wall $\frac{1}{4}$ inch.

Recently a type of duct formed of the same material, with the length and internal diameter the same, but the thickness of wall

Fig. 584. Fiber Pipe

being $\frac{1}{8}$ inch, has been produced. This is too thin to permit of the socket joint formation, so the joints are made by merely butt-ending the two lengths and slipping over the joint a sleeve of the same material about 4 inches long. A good idea of this duct and of the joining sleeve may be had from Fig. 585.

Laying Fiber Ducts:—Fiber-pipe conduit when used in main conduit runs must be set in concrete, as the strength of the wall is not sufficient to make it safe to do otherwise. In laying it, after the trench has been properly opened and graded, a foundation layer of concrete about 3 inches deep is laid and tamped, the upper surface being well graded. Upon this foundation the first layer of duct is laid, the horizontal separation between the outer walls of the ducts being about 1 inch. This separation is readily provided by driving stakes in the ground or by employing so-called combs. These combs consist merely of wooden strips slightly less in length than

Fig. 585. Fiber Pipe and Joining Sleeve

the width of the trench and having short strips secured at right angles to them; the distance between these strips being just sufficient to include the external diameter of the duct, and the width of the strips being equal to the required horizontal separation between the ducts when laid. After the first layer of ducts is in place and temporarily held by the stakes or combs, concrete is slushed in and tamped lightly. If there is to be more than one layer of ducts, the depth of the concrete thus applied is made sufficient to cover the first layer about 1 inch deep. The surface of this concrete layer is then leveled and tamped so as to form the foundation of the second layer, after which the same operation is repeated until the required number of ducts are

Fig. 586. Laying Fiber Duct

laid. After the top layer of ducts has been laid, a layer of concrete is thrown in and tamped to a depth of about 3 inches above the top of the ducts. In tamping the concrete in place, care must be taken to prevent ramming stones through the walls of the ducts, particularly where the $\frac{1}{8}$-inch pipe is used.

The process of laying runs of fiber conduit is shown in Figs. 586 and 587. It is not usually necessary to line the sides of the trench with planks, as shown in Fig. 586; but this is sometimes done where

Fig. 587. Laying Fiber Duct

the character of the soil is such as to make it difficult to excavate so as to leave proper vertical side walls.

Wooden Conduit. Creosoted-wood or pump-log conduit is usually laid without any concrete whatever, the bottom of the trench

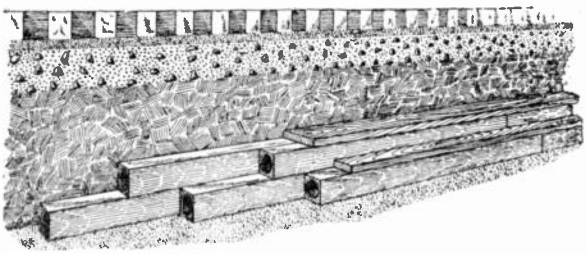


Fig. 588. Creosoted Wood Conduit

being properly graded and tamped and the ducts laid directly on the bottom of the trench without other foundation. Sometimes a foundation of 2-inch creosoted planks is used and the ducts laid on this;

and on top of the ducts a single layer of 2-inch creosoted plank is placed to afford protection in case of subsequent excavation. In treacherous soils it is always well to provide the foundation layer of 2-inch creosoted plank at the bottom of the trench. The usual construction, without the bottom layer, is shown in Fig. 588.

Iron Conduit. Iron pipe is not usually employed for main-line conduit work except in places of especially difficult construction Where it is used in main conduits, it is completely encased in concrete. A large amount of the general conduit system, employed by the telephone and signaling companies in New York City, is of 3½-inch iron pipe laid in concrete. This is used in the downtown districts where almost unparalleled congestion occurs, and where economy of space and great rigidity of construction are essential features. Where used as subsidiary or lateral ducts branching off from main conduit runs, it is customary to lay the iron pipe directly in the ground without any protecting covering whatever. This is the main use of iron pipe in underground conduit work.

Conduit Cross-Sections. The cross-sectional arrangement of the ducts in the main lines of conduits deserves some attention. It is common practice to pay little regard to this, but it is our belief that, except in conduits having a very large number of ducts, and except where it is difficult to make the trench sufficiently deep, it is far more convenient to so arrange the cross-section that the conduit will be no more than four ducts wide and as many high as the total number requires. The reason for this is that this arrangement permits a more systematic disposal of the cables in manholes or vaults than would be the case if the width of the conduit was greater than four ducts.

Fig. 589 shows conduit cross-sections made from standard multiple-duct tile varying in number of ducts from two to twenty-four. In no case within this range need the conduit be more than four ducts wide, except where unusual conditions as to digging or obstructions are met. Fig. 590 shows economical arrangements as to cross-section of fiber pipe conduits of various sizes.

General Features of Conduit Work. Having outlined the various kinds of duct material and the methods ordinarily employed in laying them, we will discuss briefly the more general features of conduit construction, including that of manholes and laterals.

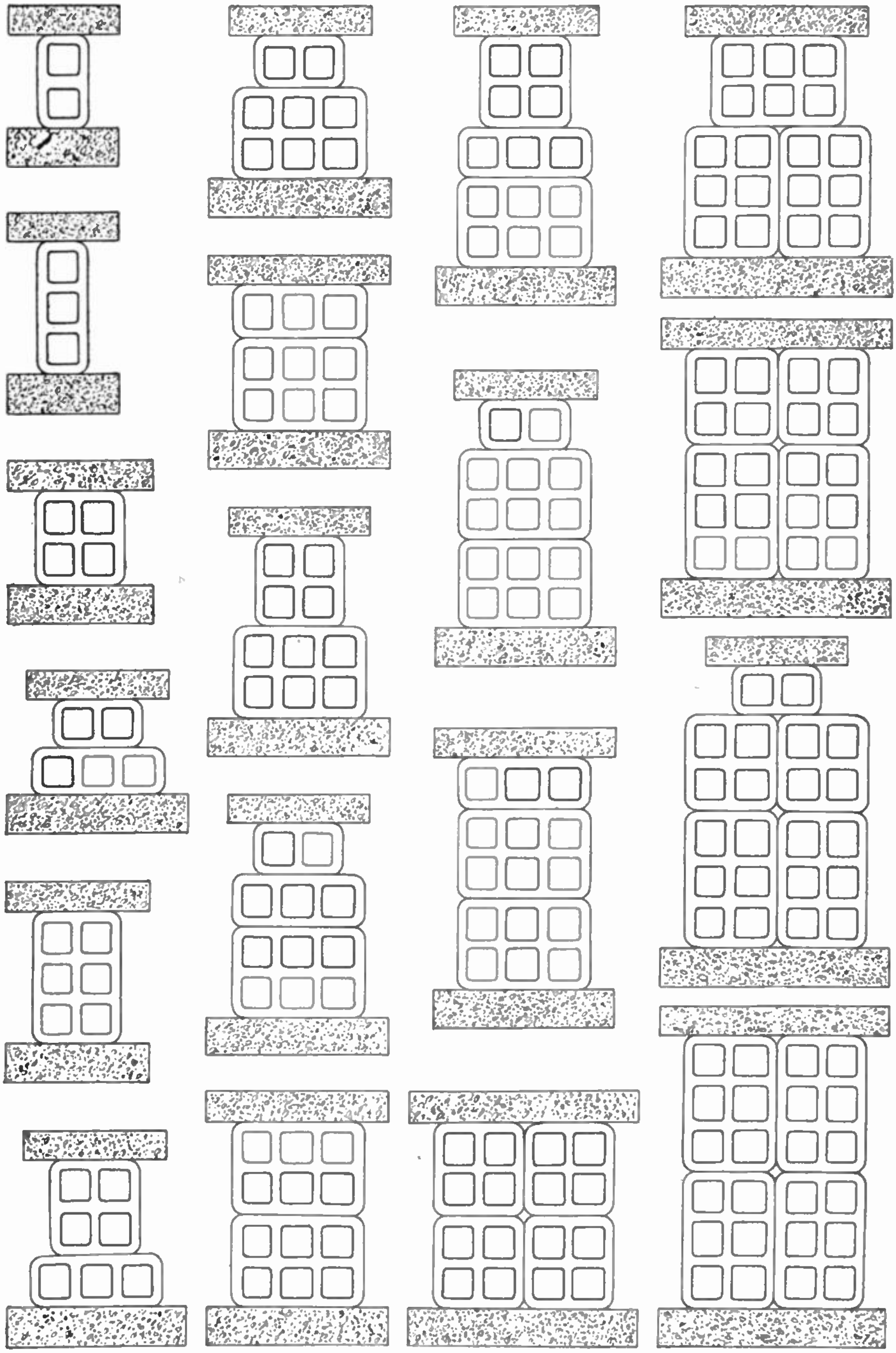


Fig. 589. Cross-Sections of Tile Duct

Main Line and Lateral Conduit. As has been stated, manholes are necessary at frequent intervals along a line of conduit to provide means of access to the cables. This access is necessary, first, for

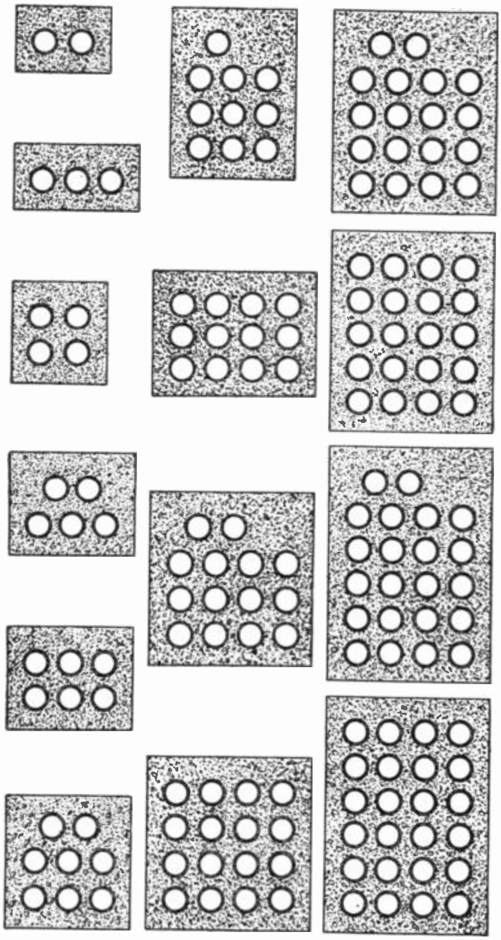


Fig. 590. Cross-Section of Fiber Conduit

drawing the cables in or out as required; and second, for leading off branch cables through lateral pipes to poles or other aërial structures or to the basements of buildings. The main conduit line, therefore, consists of one or more ducts leading between adjacent manholes, and the subsidiary conduit consists in lateral ducts or pipes leading from the manholes or sometimes from intermediate portions of the conduit either to poles or buildings for affording con-

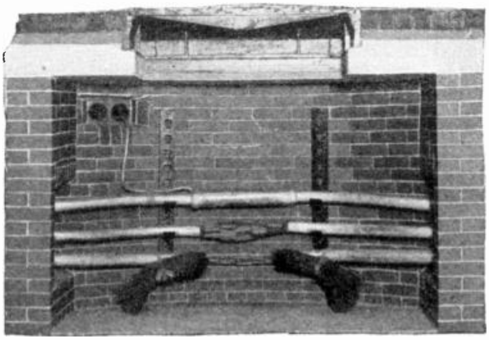


Fig. 591. Section of Brick Manhole

nection either with aërial or interior wires leading to the subscriber's premises.

Manholes. These consist merely of holes in the ground, lined on top, bottom, and sides with brick or concrete. They have a suitable opening at the top for the access of workmen and have in their side walls openings into the various ducts.

The choice between concrete and brick as the material of which to construct manholes depends upon the following considerations.

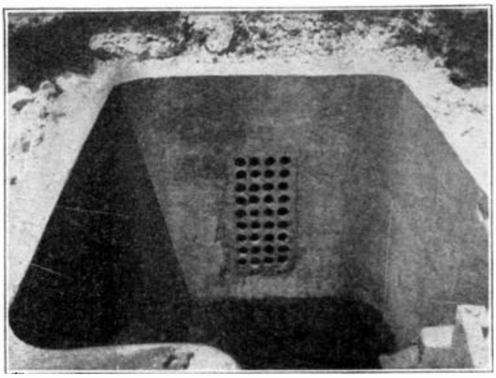


Fig. 592. Concrete Manhole

Ordinarily there is not a great difference as to cost, but this will always depend in part on the market and labor conditions in the locality in question. A factor of considerable importance that favors the employment of concrete is, that skilled bricklayers are not required, and this makes it possible to employ the same class of labor for constructing manholes as is used on the conduit itself. For this reason, if for no other, the concrete manhole is usually to be preferred in places where the underground conditions are such as to permit the construction of the manholes in standard sizes and shapes. In the down-town districts of large cities, however, this is usually not possible, since the presence of pipes and other underground properties often demands the building of manholes of irregular shapes and sizes. Brickwork lends itself much more readily to the requirements of such conditions than does concrete. A good idea of the interior of a brick manhole is given in Fig. 591, which shows a cross-section taken through a completed manhole. Fig. 592 shows a concrete manhole before the top has been placed.

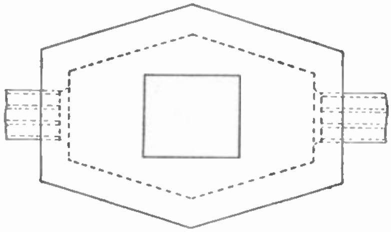


Fig. 593. Plan of Manhole

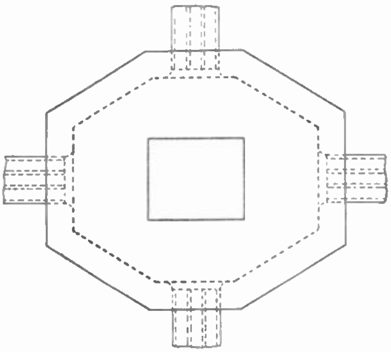


Fig. 594. Plan of Manhole

Shape of Manholes:—The shape of a manhole will always depend to some extent on the number and the directions of approach of the various conduit runs leading to it. It will depend also upon the character of the obstructions found in excavating for it. Where the manhole occurs between two adjacent runs of conduit in the same line, and where there is no intersecting run, the general shape shown in plan in Fig. 593 is a good one. Where the manhole occurs at the

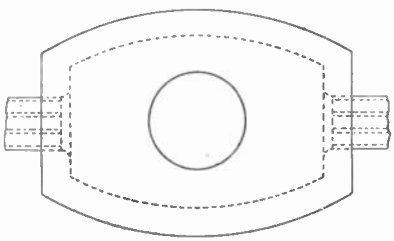


Fig. 595. Plan of Manhole

junction between a main line and an intersecting line this shape is necessarily slightly altered, as shown in plan in Fig. 594. These

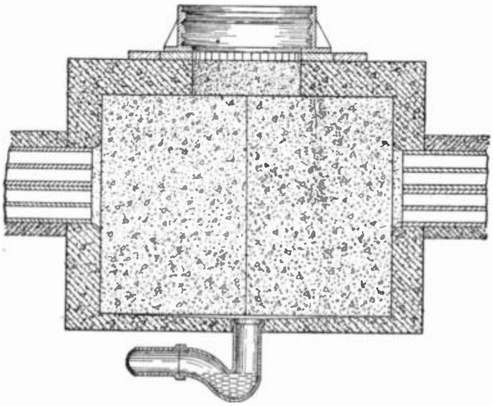


Fig. 596. Section of Concrete Manhole

shapes lend themselves readily to the employment of simple wooden forms around which the concrete is poured, in the case of concrete construction, and are also equally desirable from the standpoint of simplicity where brick is the material employed.

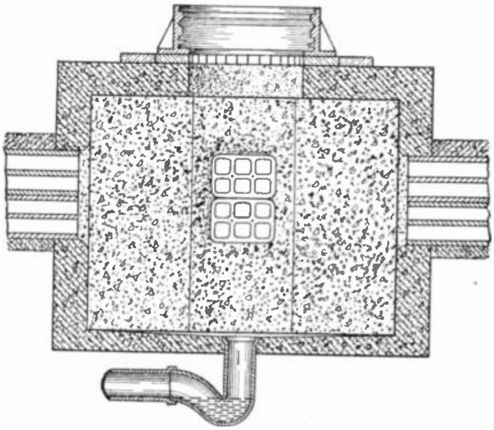


Fig. 597. Section of Concrete Manhole

Some prefer, in the case of a manhole occurring in a straight run, to curve the sides, giving a resulting plan as shown in Fig. 595. The details of construction of the non-intersected and the intersected types of manholes are shown in Figs. 596 and 597.

TABLE XXXIV

Inside Dimensions of Manholes

No. of Ducts	Length	Width	Height
Straight Runs Not Intersected			
1 to 6	4′6″	3′6″	4′6″
7 to 15	6′	4′	5′
16 to 24	8′	5′	5′6″
Intersected Runs			
1 to 6	4′6″	4′6″	4′6″
7 to 15	6′	5′	5′
16 to 24	8′	5′	5′6″

Sizes of Manholes:—The size of manhole will, of course, vary with the number of ducts entering it. No definite rules may be laid down, but the sizes as given in Table XXXIV are suggested for different sizes of intersected and non-intersected runs.

Location of Manholes:—In laying out a conduit system the location of the manholes is an important factor. It is not always possible to locate a manhole exactly where originally planned, because upon excavation it may be found that pipes or other obstructions that cannot be moved will necessitate a change. In general, however, manholes should be located at street or alley intersections, since this allows a single manhole to serve for intersecting runs, and also places them at the most convenient points from which to distribute lateral pipes. This rule is by no means universal, however, and frequently manholes other than at street intersections are necessary or desirable.

The distance between manholes should, of course, not be so great as to make it impossible to draw single lengths of cable into the intervening ducts. However, the req rements for distribution in cities laid out in the ordinary way usually demand the spacing of manholes at distances considerably shorter than the limiting lengths set by the possibilities of cable drawing. In general, it may be stated that manholes are placed at distances apart of about 400 or 500 feet or less. It has been found possible, however, to draw with success and safety lengths of cable considerably in excess of this distance, and we have without difficulty or danger, in special cases, drawn in pieces of 400-pair cable, 800 feet in length.

Construction of Conduit. *Test Holes.* In laying out the main conduit, after its general method of construction and the streets and alleys on which it is to be located have been determined, it is frequently necessary to dig test holes at street intersections to disclose the nature of the existing underground obstacles. These test holes are usually in the form of narrow trenches across the streets. If the engineer is fortunate enough to find city records of underground structures that are to be relied upon, or, if the city is so small or new that chances for such obstacles existing are small, the digging of test holes may be dispensed with. As a rule, conduits should not be located in the center of the street on account of the possibility of interference with subsequent sewer or electric railway work, and not too close to the curb line on account of the greater exposure to surface drainage.

Trenching. In opening the trench the paving or surface material of the roadway is to be placed on one side so as to be available for re-surfacing when the work is completed. Sometimes the trench is excavated in parkways, between the sidewalk and the curb, or across lawns on private right-of-way, in which cases care must be taken to cut and preserve the sod and to replace it upon the completion of the work. Occasionally it is required to spread a cloth on the grass to receive the excavated dirt, so that as little of the grass may be injured as possible.

In general, the trench for the main conduit is to be excavated to such a distance as will leave not less than 24 inches from the top of the protecting envelope to the ultimate grade of the street. The width of the trench will, of course, vary according to the width of the conduit run. When the character of the soil will permit, the sides of the trench should be cut clean and vertical from the bottom of the trench to a level that will correspond with the top of the conduit when laid. From this point up to the surface of the ground it is frequently convenient, in some kinds of soil, to allow a considerable slope. In some soils it is necessary to provide shoring to prevent the sides of the trench from caving in.

Where blasting is required, as in rock soils, it should always be done by a person competent in the use of explosives. In such work the blast is covered with heavy logs and chains to prevent injury to life and property, and only moderate charges of explosives should be used. It is a wise precaution to study the requirements of local authorities before doing any blasting. Where gas, water, or other pipes or underground property of any nature is met, the work, if possible, is to be conducted without interfering with them, care being taken to properly protect and support by temporary braces or chains any such properties which it may be necessary to undermine.

Grading. It is desirable to open an entire section of trench between adjacent manholes before laying the ducts so as to show the nature and location of all obstructions. The final grade is then determined and the bottom of the trench graded and tamped, if necessary. The grading is to be so done as to avoid sumps or traps in which water may accumulate. This means that the grade should be a descending one from one manhole to the other, or from a high intermediate point to both manholes. A grade of at least 6 inches for each 100 feet will do, but more is desirable.

Where possible, the various runs of ducts should enter a given manhole at about the same level, those entering one side of a manhole being preferably located directly opposite those in the other side. This is a convenience in rodding ducts, as will be subsequently described, permitting the rods to be pushed from one section to the other without uncoupling them.

Curves in Conduit Line. The trench should, if possible, follow a straight line between manholes. Often, however, this is impossible. Wherever curves are unavoidable, they should be of as great radius and as small deflection as possible. If the section of the conduit is not more than 100 feet in length, a 60-degree curve may be permitted, but it should have a radius of at least 25 feet. In sections between 100 and 200 feet in length a 60-degree bend is allowable, but its radius should be at least 50 feet. For sections longer than 200 feet the curvature should be less than 60 degrees, and the radius should be proportionately longer. If a double curvature is necessary it is desirable that neither of them should be more than 15 degrees nor have a radius less than 50 feet. It goes without saying that the longer the run the more undesirable is any curvature.

Lateral Runs. The lateral pipes by which a cable is led from the main conduit line to a pole or building for distribution purposes are usually of iron, unprotected by concrete, although sometimes fiber pipe or creosoted wood may be used to advantage.

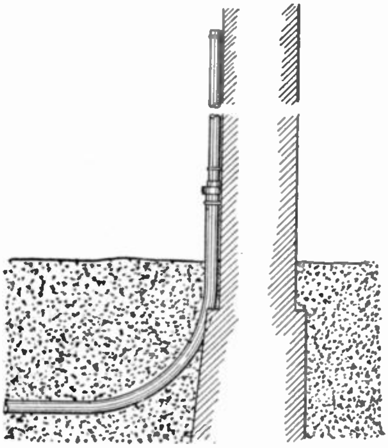


Fig. 598. Lateral Riser up Building Wall

Frequently, when the lateral pipe is to reach a point on the street intermediate between manholes, it is convenient to lay it for a certain distance in the same trench with the main conduit. Where this is done it is preferably enclosed in the concrete envelope with the main conduit, and may be of the same conduit material as the main conduit, or of the material of which the lateral pipe branching off from the main conduit is made. As the cables in lateral pipes are usualy smaller than those in the main conduits, it is frequently permissible to use smaller diameters of ducts for lateral pipes than for main conduit ducts. 2-inch iron pipe suffices in most cases, but where the cable to be accommodated is large, it is well to make the lateral duct of the same size of pipe as the main-line duct. Except where large cables are to be installed in lateral pipes, it is permissible to make right-angle bends in such pipes on a 30-inch radius.

Connections between the laterals laid in the main trench and the continuation of the lateral laid in a separate trench are made by means of bends in the duct material. Iron pipe may readily be bent, and fiber conduit and some other types of duct material provide specially bent lengths of duct for this and similar purposes.

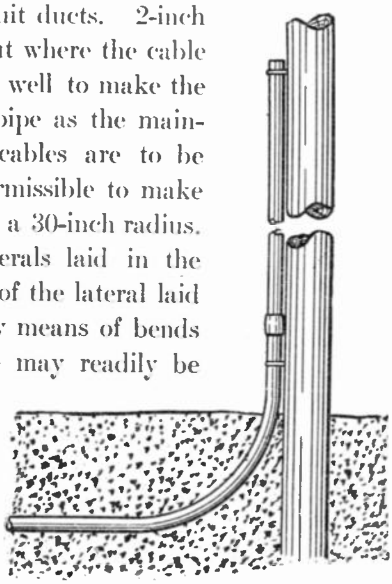


Fig. 599. Lateral Riser up Pole

Ordinarily it is not necessary to dig the trench for lateral pipe as deep as that required for a main trench—a trench 18 inches deep and as narrow as a man can dig with a spade being sufficient. If iron pipe is laid, all protection to it may ordinarily be omitted; but if fiber or wood pipe is used, it is a good plan, outside of the property lines, to fill in the space between the duct and the side of the trench and over the duct to a depth of about 3 inches with concrete lightly tamped in place. Inside of the property lines on private property this protection may be omitted.

Where possible the lateral should slope toward the manhole. This is particularly important in northern localities, where much trouble has been experienced due to the freezing of water in lateral iron pipes, resulting in a consequent compression of the cable, which causes the short-circuiting of its conductors.

Lateral Risers. Where the lateral cable is to extend up a pole or up the outside wall of a building, it should make connection with a wrought-iron pipe bend not having less than 30 inches radius, and a straight length of wrought-iron pipe should continue up the pole, preferably to a distance of 8 feet above the ground. This lateral riser, as it is called, should be strapped to the pole or to the wall of the building by standard pipe hooks or straps. The method of ending a lateral at a building is shown in Fig. 598, and of extending it up a pole in Fig. 599.

Cable Supports. Some form of support is necessary for the cables leading around the walls of the manhole. A cable support manufactured by the Standard Underground Cable Company is shown in Fig. 600. This is of sectional construction and may be extended as desired. It is frequently found convenient to provide cable supports by inserting into the wall of the vault during construction short lengths of $\frac{3}{4}$-inch pipe at the proper heights. The ends of these are set flush with the inner surface of the wall. When cables are installed a $\frac{5}{8}$-inch wrought-iron rod 12 or 14 inches long is inserted into this

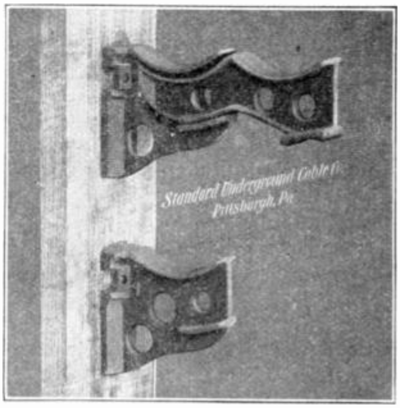


Fig. 600. Cable Support

pipe, on which is placed a wooden shoe for supporting the cable. The details of this support are shown in Fig. 601. This has the advantage of not requiring the installation of the support until the cable is installed, and of permitting its installation without any drilling of the walls of the manhole.

Concrete. The matter of the proper kind of concrete for use in conduit construction is one concerning which there is much difference in opinion and practice. Some engineers employ the same strong mixture of sand, stone, or gravel and cement that would be employed where the greatest strength is required. The later tendency, however, has been to employ a much cheaper mixture, realizing that under no ordinary circumstances will the concrete be subjected to very great strains of any nature. Any good building cement will do. The ordinary concrete is made of a mixture of sand, broken stone or gravel, and cement in various proportions. Frequently "run-of-crusher" stone is procurable, which contains about the right quantity of small pieces to pack well, and if this is found upon experiment to make a good concrete when mixed with the proper portion of cement, the use of sand may be dispensed with. Frequently, also, gravel as it comes from the bank or bar has about the right proportion of sand, in which case, after experimenting, this may be used with cement to form the concrete.

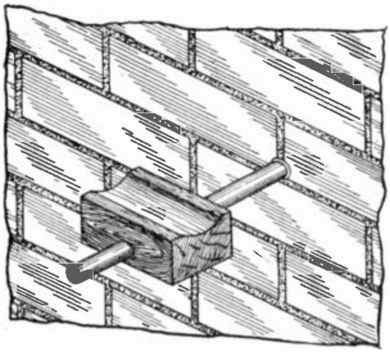
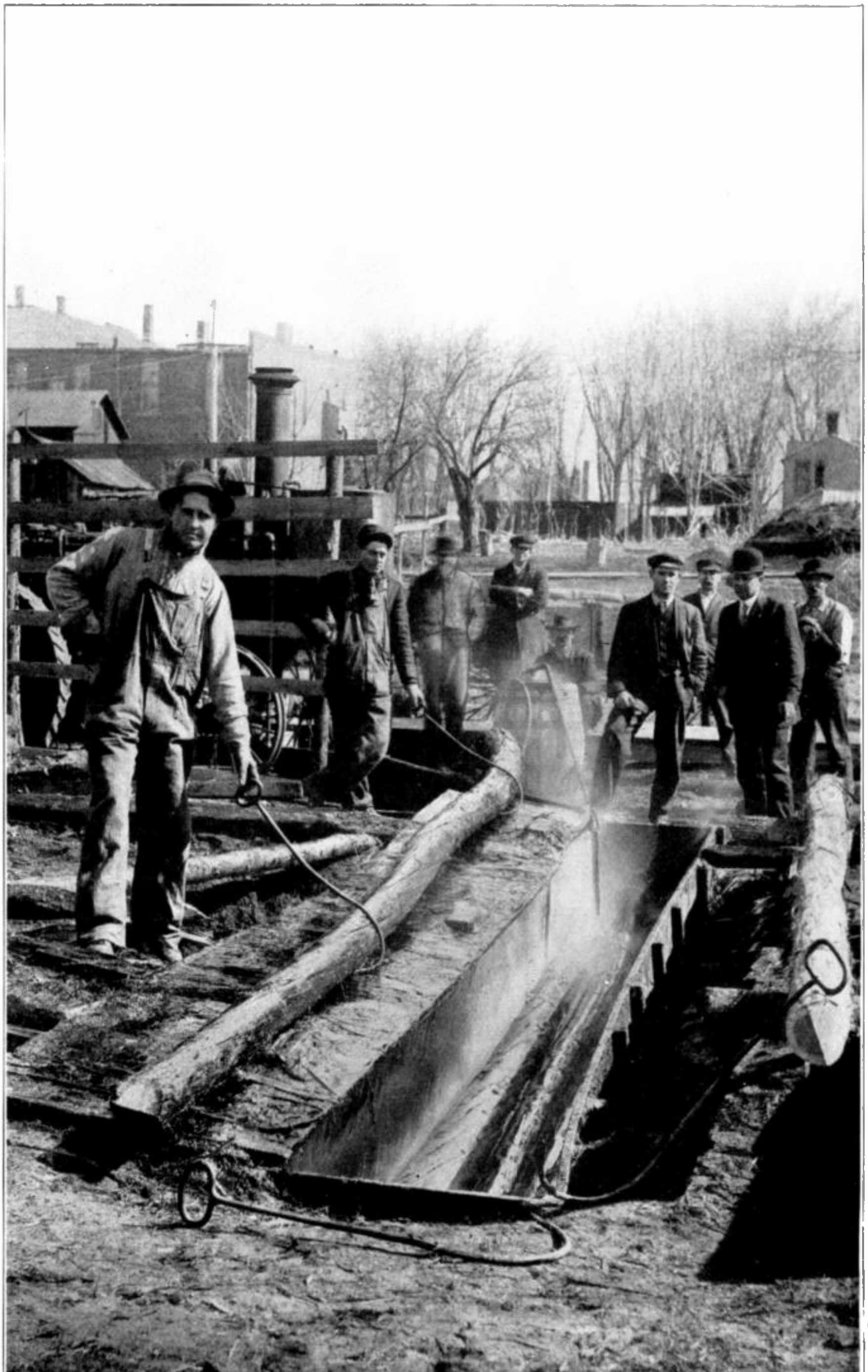


Fig. 601. Cable Support

The general subject of concrete construction is too large a one to treat of here, and much good literature is available on it. It may be repeated, however, that the demands of underground conduit structures are not such as to require an exceedingly strong or expensive mixture. For the concrete envelope surrounding the ducts, a mixture as weak as 1 part of cement and 4 parts of sand and 8 parts of stone or gravel, known as a 1-4-8 mixture, is considered by some sufficient. 1-3-5 or 1-3-6 mixtures may be considered standard practice. For manhole construction a 1-3-5 mixture is good. Frequently



CREOSOTING PROCESS — TANK TREATMENT

much money may be saved by a careful study on the part of the engineer of the cost of the materials available at the point where the construction is to be done and by a few simple experiments to determine the mixture that will give the best results with these materials. Concrete should be used within one hour of the time it is gauged in mixing.

Mortar. Cement mortar consists of a mixture of cement and sand or screenings. A mixture of 1 part of cement to 3 parts of sand or screenings makes a good strong mortar. Mortar should be used within thirty minutes of the time it is gauged in mixing.

Safeguards. It is necessary always to guard the excavations wherever made, for the protection of the public. This is done by means of fences or barriers carried as a part of the construction equipment. The location of all excavations, fences, barriers, or of material piled in the street, should at all times between sunset and sunrise be indicated by a sufficient number of red lanterns.

All construction work should be done with due regard to the rights of the public, temporary bridges being provided where necessary to facilitate traffic across trenches. No excavations should be made or material piled where they will interfere with the access of the public to fire-alarm boxes or of firemen to water hydrants.

Installing Underground Cables. The drawing of cables into underground ducts is a very simple matter, but owing to the fragile nature of sheaths and to the necessity for keeping their cores always absolutely dry, it must be done with great care.

Rodding. It is first necessary to have some sort of a pulling connection through the duct into which the cable is to be drawn. Sometimes a "fish wire," consisting of No. 9 galvanized steel wire, is drawn into the duct as it is being laid. Where this is done, the pulling rope or cable that is to be used in actually drawing the cable into the duct may be attached to one end of the fish wire and drawn by it into the duct. Where there is no fish wire, the process of rodding is necessary. This consists ordinarily in pushing short wooden rods into the duct from one manhole to another, these rods being provided with connecting sockets by means of which they may be joined together end to end. As each rod is pushed into the duct another is joined to it and pushed in, until the first rod emerges from the duct at the distant manhole, the chain of rods is then used in place of a fish wire to pull the pulling rope or cable into the duct.

The process of rodding in this way has the disadvantage of being slow. Where the interior of the ducts is smooth and where the length is not prohibitive, it is feasible to use a heavy, stiff steel wire instead of the rods, this being pushed through from one manhole to the other. A No. 6 steel wire is desirable for this purpose. Before actually pulling in the cable a mandrel should be pulled through the ducts to make sure that the passage is clear.

Drawing In. The power used for drawing in the cable may be that of man, horse, or engine. For small installations and light

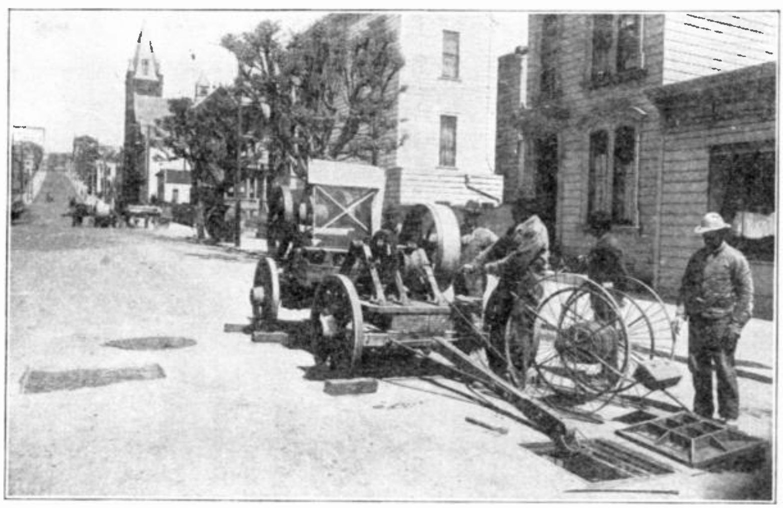


Fig. 602. Cable Pulling Apparatus

cables a man- or horse-driven capstan is frequently employed. Sometimes the direct pull of a horse or team or of an automobile is employed. Where much and heavy work is to be done an engine-driven capstan is much to be preferred. It is more powerful, more easily controlled, and is capable of exerting a steadier pull and of drawing with greater rapidity than any of the other devices. For such work the capstan may be driven by an electric motor, connected by flexible insulated leads to the nearest trolley wire or other source of power current where the distribution of such is sufficiently universal to make it always available within a reasonable distance.

A better way is to employ a gasoline engine, since then no connections have to be provided for electric wires. Such a cable pulling outfit is shown in Fig. 602. This particular equipment has a 6-horse-power engine connected by belt and gear to the cable pulling drum. The reel from which the cable is being pulled may be seen in the distance.

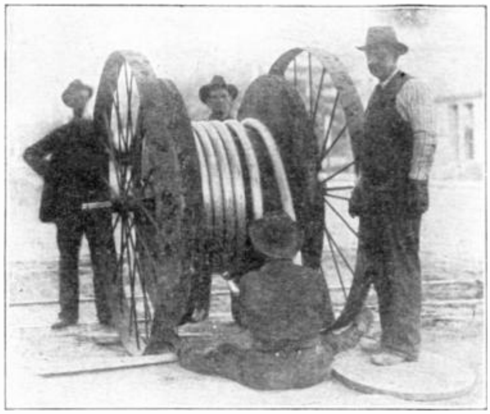


Fig. 603. Reel Supported on Wheels

For handling the reel from which the cable is to be pulled, the simplest and most convenient device consists of a pair of large wagon wheels, greater in diameter than that of the largest reel head. A heavy steel shaft passes through these as an axle, also passing through the hole in the center of the reel. This device may be used as a cart in transporting the reel through the streets and as a stand to support the reel while the cable is being drawn off into the duct. Such an arrangement, set up for drawing in, is shown in Fig. 603.

In setting up for pulling, the reel should be in line with the duct and ahead of the vault openings rather than back of it, the reel turning in such direction that the cable will feed from its top. Usually a steel rope is employed for pulling. The end of the pulling rope

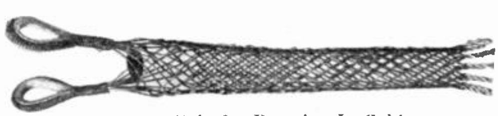


Fig. 604. Grip for Drawing In Cables

is attached to the cable either by a lashing of wire or by cable grips designed to clamp the end of the cable securely without subjecting the sheath to injury. One form of such a cable grip is shown in Fig. 604, this being a device which increases its grip on the cable as the lengthwise pull of the rope increases.

Skids and sheaves should be set up in the manhole so as to guide the cable into the mouth of the duct from a direction as nearly in a line with the duct as possible. Likewise, sheaves and skids should be provided in the manhole toward which the pulling is being done, so that the rope will not chafe against the side of the duct.

The general arrangement of the cable reel and of the apparatus employed in pulling in cables is shown in Fig. 605.

Lubrication. In pulling in heavy runs of cable, the work is greatly facilitated and the strain on the cable is greatly reduced by lubricating the cable as it passes into the duct. Grease, soap, graphite, and other forms of lubricant have been used, but in our experience powdered soapstone is the best, and it has the advantage of being cheap and cleanly. It may be fed into the duct opening as the cable enters by a funnel and scoop, or sprinkled on the top of the cable at the point where it is entering the duct.

The greatest care should be taken to inspect the cable as it is being pulled in, the man at the reel watching for any imperfections

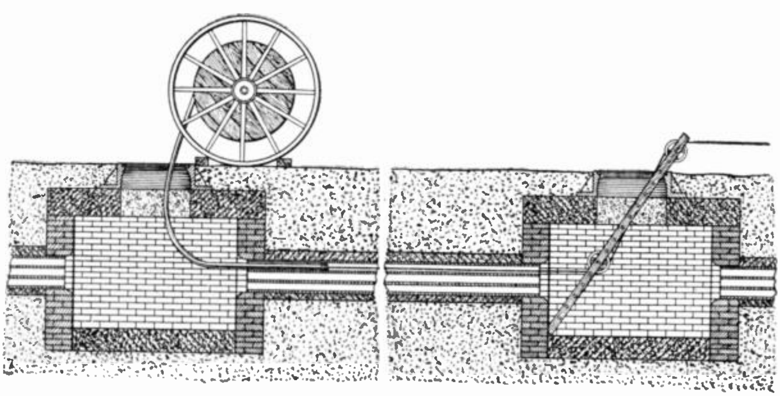


Fig. 605. Pulling In Cable

in its sheath. Care also should be taken that the reel turns at uniform speed, since if it runs ahead it is likely to cause sharp kinks in the cable.

After the cables are drawn in, their ends should be left projecting in the manholes a proper distance for making the splices. The forward end of the cable, where the hitch was made to the pulling rope, if at all damaged, should be cut off and resealed with molten solder to prevent the entrance of moisture.

Speed of Drawing In. John M. Humiston has recorded some tests made on the power required to pull a cable into a duct at varying speeds with and without lubricant. A 300 pair, No. 19 gauge,

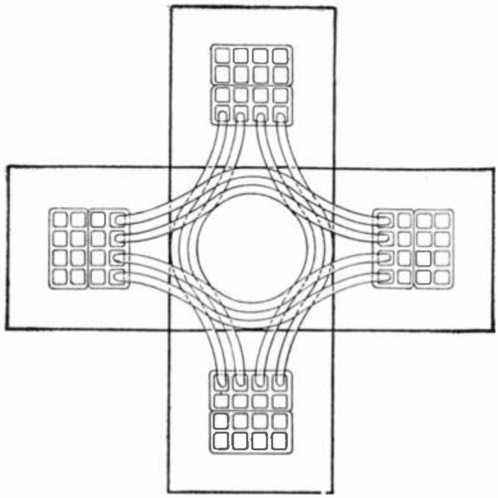


Fig. 606. Arrangement of Cables in Manholes

lead-covered paper-insulated cable, weighing 7 pounds and 7 ounces per foot, and having an outside diameter of $2\frac{5}{8}$-inches, was used. The duct was of vitrified clay rectangular in cross-section, 682 feet in length. The cable was first pulled in by a capstan turned by a horse. The maximum stress on the rope noted was 3,500 pounds, this occurring about 50 feet before the finish was reached, and being due to the drawing having stopped and started again. The maximum stress during continuous drawing occurred at the end of the pull and was 3,200 pounds. The rate of pulling in this experiment was 25 feet per minute. The same cable was then drawn in at a higher

TABLE XXXV

Drawing In Stress on Cable

Weight of Cable Pounds	Length of Section Feet	Speed Feet per Minute	Lubricant	Stress Pounds
5060	628	25	None	3200
5060	679	120	None	2800
5060	682	120	Soapstone	1200

rate of speed by means of a heavy automobile truck. The maximum stress in the cable when being drawn at the rate of 120 feet per minute, was 2,800 pounds. Thus practice indicates that a higher rate of travel resulted in a lower friction, as theory would indicate. The same cable was then pulled into the duct, using powdered soapstone as a lubricant. In this case the stress was only 1,200 pounds, showing

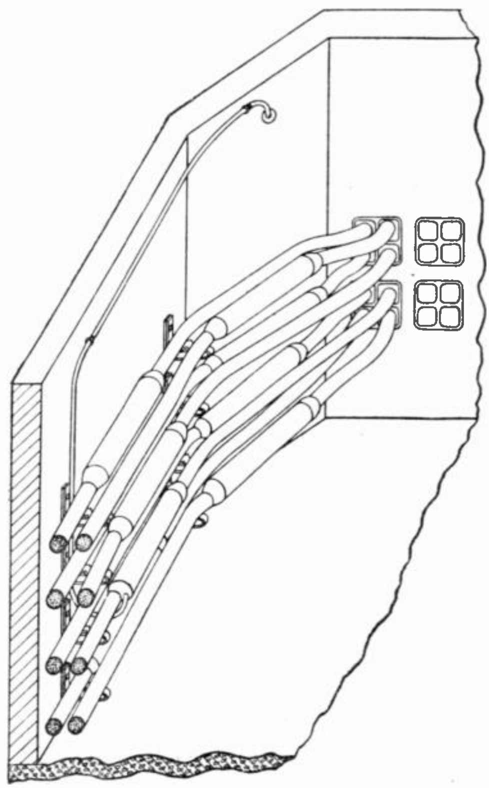


Fig. 607. Arrangement of Cables in Manholes

marked saving in power by this very simple scheme of lubrication. Table XXXV summarizes these experiments.

Long Conduit Sections. Humiston also gives some information as to successful drawing in of heavy cables into very long runs of conduit. He concludes from these that where no street obstructions intervene, it is entirely feasible to locate the vaults as far apart as 800 feet. He cites one example where heavy cables have been pulled into a section of conduit 882 feet in length with two reversed curves or offsets in it. These instances are interesting as illustrating possible extremes in this phase of underground cable practice.

Arrangement of Cables in Vaults. Practically all of the splices in underground cables occur in manholes. A well-made splice may be spoiled by subsequent misuse. Much depends, therefore, on the way the cables are stowed away in the manholes. It has already been stated that where possible it is preferable to have the conduit runs not more than four ducts wide. This makes possible a very systematic arrangement of cables in the manholes as suggested in Fig. 606, which shows the sides of a square manhole laid out flat for purposes of illustration.

When the conduit is not more than four ducts wide it is possible to arrange the cables on each side of the vault in not over two tiers, thus making the cables next to the wall more easily reached. This way of arranging the cable is indicated in Fig. 607, which shows the cables leading from the two left-hand vertical rows of ducts around that side of the manhole. The splices are staggered. This arrangement is somewhat idealized, since it is not always practicable to accomplish it, especially where old work has to be dealt with. It is good, however, at least to have an ideal at which to aim.

Another feature to be borne in mind in the arrangement of splices and cables in manholes is the disposal of small tap cables leading to laterals. If the proper thought is given before making the tap splice, it is easy to lead the small cables from the splices to the lateral duct around the wall of the manhole, and behind the large cables, as shown in Fig. 607, and in this manner the smaller cables, which are least able to stand rough usage, are protected by the larger ones.

CHAPTER XLVI

CABLE SPLICING

Necessity for Dryness. On no feature of telephone work is the proper condition of a telephone plant more dependent than on the use of proper methods and care in splicing of its lead-covered paper-insulated cables. Dry paper, by virtue of its low electrostatic capacity, its high insulation resistance, and its low cost, is the only material that has been found suitable for the insulation of cable conductors where such conductors form considerable portions of the length of telephone lines. It is subject, however, to the grave objection that even a very small amount of moisture will destroy the insulation between the conductors. The avidity with which this paper will absorb any moisture makes it necessary to keep it completely isolated from atmospheric conditions, and, in fact, in a state of *extreme dryness.* The difficulties in the way of doing this would seem to the uninitiated to be unsurmountable. Aërial cables are exposed to rain, snow, sleet, and ice, and underground cables are sometimes completely immersed in water for considerable periods of time, as when the manholes and the conduit system are flooded. A pin-hole anywhere in the lead sheath of a cable will permit enough moisture to enter to make it unfit for use.

The cables employed for both aërial and underground work differ in no respect except, perhaps, in size; cables with 400, 600, and, in rare cases, 900 pairs of conductors being employed in underground work, while those having more than 300 pairs are seldom, and more than 400 pairs are never, so far as we know, suspended aërially.

The rule that must govern the cable splicer, first, last, and always, is—*Keep the core of the cable dry.* This does not merely mean that no noticeable moisture shall be present, but that it shall be dry in the sense that a thing is dry after it has been baked in an oven for a long time.

Whenever possible, splicing should be done in a dry place in dry weather. If conditions demand that it be done in a damp place, as is frequently necessary, extreme care should be taken to guard against the entrance of moisture and to expel whatever moisture does enter, as will be explained.

General Method of Splicing. In general, the method of making a splice consists in stripping back the lead sheath from the two ends to be spliced for a sufficient space to afford the proper working length of the exposed conductors, then the individual wires are joined together and covered with paper sleeves. Before beginning the splicing of the conductors, and during its progress if necessary, and always after its completion, the exposed conductors are subjected to a boiling-out process to expel all moisture. After the conductors are spliced and boiled out, they are bunched together and enclosed in a lead sleeve of sufficient diameter not to crowd the wires too much together, and of sufficient length to lap over the lead sheaths of the joined cables. Then the edges of the sleeve are beaten down to the cable sheath at each end and secured thereto by a plumber's wiped joint.

Straight Splice. A lead sleeve of proper size is first slipped over the end of one of the cables to be joined and pushed back out of the way. A mark is then made on the sheath of each cable to designate the point at which the sheath is to be cut and removed. The distance from the end of the cable at which this mark is made should

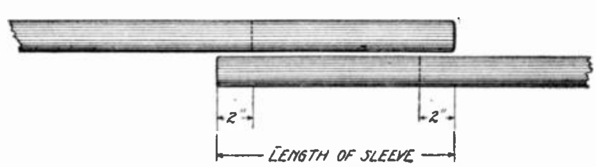


Fig. 608. Preparing Cable for Splice

be for all sizes of cable about 2 inches less than the length of the lead sleeve employed, as indicated in Fig. 608. A portion of the cable sheath about 4 inches back from this mark is then scraped bright so as to afford a proper surface for making the wiped joint at the end of the splicing operation, and this brightened surface is then rubbed with tallow to keep it bright during the subsequent operations. The reason for doing this scraping and brightening operation at this point in the work is to prevent the small particles of lead, scraped off, from getting in the splice, and endangering the insulation.

Preparing the Conductors. The lead sheath is then removed from the end of each cable back to the mark previously made. This is readily done by indenting the cable around its circumference with the edge of a cable knife, after which a slight bending back and forth will break the lead sheath on this mark and permit the end to be drawn off. The core of the cables is now exposed, and from this time on the greatest care should be taken not only to keep it dry, but to guard against mechanically injuring the insulation. The core of each end should now be bound tightly with narrow strips of dry muslin, just at the end of the cable sheath, packing this muslin back under the sheath for a slight distance to prevent the sharp edges of the sheath from injuring the insulation of the outer layer of wires. As soon as possible after this is done the cable ends should be boiled out. In the case of a small cable this may be done by immersing the exposed ends of the core in a kettle of hot paraffin, but for larger cables this is not feasible, the process then consisting in pouring hot paraffin over the exposed portions of the core, the drippings being caught in a pan placed directly beneath. This boiling-out process should include the entire length of the exposed core and the muslin wrapping under the end of the sheath. Great care should be exercised as to the temperature of the paraffin. It should be very hot, and yet not hot enough to scorch the paper. Overheated paraffin not only injures the insulation of the cable conductors, but is dangerous to life, since it may take fire. Underheated paraffin will not expel the moisture. If the paraffin is so hot that white fumes rise from it, it should be allowed to cool slightly before being used.

In boiling out, one should begin at the cable sheath and work toward the core end, or if the wires have been spliced, one should begin at the ends of the cable sheath and work toward the middle of the splice. This prevents a tendency for the heat to drive what moisture there is in the exposed ends back into the core within the lead sheath. The hot paraffin itself should soak back into the core covered by the sheath for some distance to keep moisture out during the splicing. After the ends are boiled out, the two cables should be placed in proper alignment, the distance between the ends of the sheaths being about 4 inches less than the length of the lead sleeve, as indicated in Fig. 608. The conductors are then bent back close to the sheath out of the way and spliced in the following manner:

Joining the Wires. Starting with the center wires of the cores, or with the lower back sides of the cores, two pairs, one from each cable, are loosely brought together with a partial twist, as shown in *a* of Fig. 609. The bend thus made in each pair marks the point at which the joint is to be made. A paper sleeve is then slipped over each wire of the pair and pushed back out of the way so as to make room for the joint, as shown in *b* of Fig. 609.

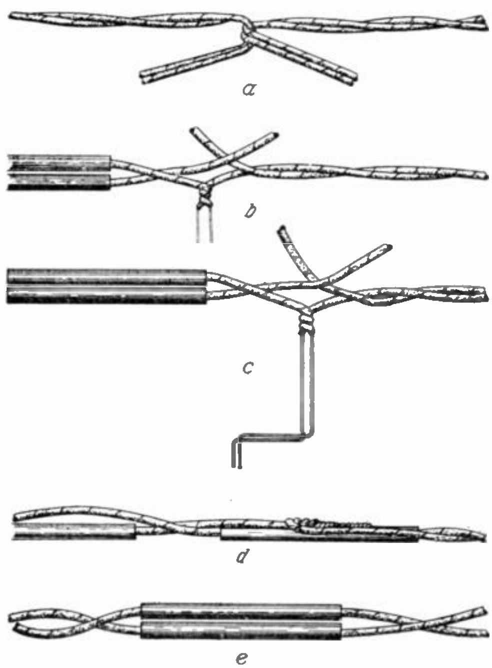


Fig. 609. Splicing Cable Conductors

The two colored wires of the pairs chosen are then twisted together for about three twists, as indicated in *b*, and the insulation stripped off beyond this twist. This twist is made at the points indicated by the bends previously made, as in *a*. In removing the insulation, care should be taken not to nick the conductors. The reason for including the insulation in the twist of the joint is to prevent its stripping back and exposing the wires. The exposed ends of the wires are then twisted together, and the method of doing it is indicated in *c*. The wires are bent so as to form a crank, the handle of the crank being held between the thumb and finger of the right hand, while the portion of the wires just beyond the insulation is similarly held with the left hand. The twisting is accomplished by merely turning this crank. There is a knack about it which requires practice to acquire. After the wires themselves are twisted together, they are cut off so as to let the twisted wire project about 1 inch from the end of the insulation. The twist is then bent down along the insulated wire, as shown in *d*, and the paper sleeve slipped over it. The completed joint is shown in *e*.

This process is repeated until all of the pairs are spliced. In order that all of the wire joints shall not occur at the same point in the splice, they are staggered, thus preventing the splice attaining too great a diameter at any one point. By reasonable care in distributing the wire joints along the length of the splice, it may be kept uniform in size and shape.

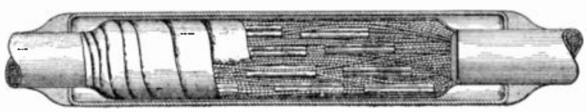


Fig. 610. Sections of Completed Splice

Final Boiling-Out. When all of the wire joints have been made, the splice is again boiled out in hot paraffin until all moisture has been expelled. It will usually be found that some moisture has been gathered by the paper insulation from the hands of the workman or from the air.

Immediately after this final boiling-out and while the splice is still "piping hot," it should be wrapped with strips of dry muslin 2 or 3 inches wide, so as to compress the wires only to a sufficient extent to permit the lead sleeve easily to be slipped over them. Unless there is a suspicion that some moisture may have entered during this binding process, no further boiling-out need be done.

Enclosing the Splice. The lead sleeve is then slipped into place while the splice is hot and its ends, which will overlap, are dressed down so as to engage the cable sheath. After this a plumber's wiped joint is carefully made at each end of the sleeve and the splice is complete, as shown in section in Fig. 610.

In making the wiped joints, strips of gummed paper are used to limit the flow of the wiping solder on the sheath. Inspection of the completed wiped joints is an important feature, and sometimes a mirror will aid in examining the underside of the joint. As an inducement to proper workmanship, each splicer working on a job should be given a number and a steel stamp bearing this number,

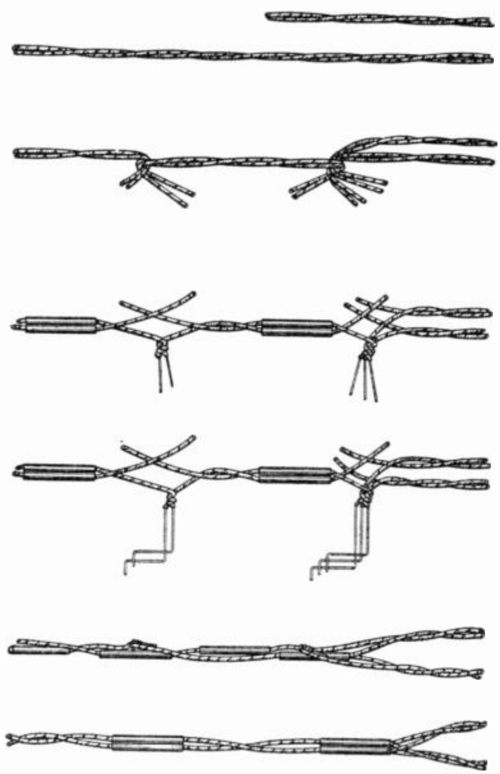


Fig. 611. Tap Splice

which number must be stamped on each splice when completed. By this method careless work may often be traced back to its proper source.

Tap Splice. The method of making a tap splice where the wires of a branch cable join those of a continuous cable, differs somewhat from that just described, since three wire ends have to be handled rather than two. The method to be followed in this will be clear from an inspection of Fig. 611. It will be seen in the second operation that a short piece of wire must be inserted in order to give sufficient length of wire to make the splice with the branch conductor.

The external appearance of a finished tap splice is shown in Fig. 612. The tap cable should always lead out from one end of the splice and should be lashed to the main cable with marline about 6 inches

Fig. 612. Finished Tap Splice

beyond the end of the splice to prevent any side strain being exerted by the tension of the tap cable on the splice itself.

Y-Splices. For Y-splices that are not in the nature of tap splices, but in which the conductors of a large cable are spliced into two smaller cables, the same method of procedure is followed as in the straight splice, so far as the joining of the wires is concerned. Frequently a larger cable will be spliced into two smaller ones where the sum of the conductors in the smaller ones more than equals the number in the larger. In this case certain of the conductors in the larger cable will be spliced straight through to the respective conductors in the smaller cables, and certain others in the larger cable will be joined to two conductors, one in each of the smaller cables. This results in some of the conductors in the large cables being made available at the terminals of both of the smaller cables, this being one of the phases of multiple-tap distribution.

Sizes of Lead Sleeves. Table XXXVI gives the sizes of lead sleeves for straight and Y-splices in various sizes of 22-gauge cable, the sleeves in each case being of pure lead, $\frac{1}{8}$ inch in thickness.

Where a branch cable is spliced into a continuous cable, and under certain other conditions of practice, it is necessary to employ split sleeves, *i. e.*, sleeves that are cut through one side of their length so as to enable them to be opened and slipped over the cable. Of course, when such a sleeve is used, the joint along its side should be carefully closed by solder so as to make it a continuously closed pipe. The paper sleeves for the individual wires are usually about 3 inches long and approximately $\frac{1}{8}$ inch in diameter. They should always be boiled in paraffin before using.

Pot-Heads. The pot-head, as already stated, is a special form

TABLE XXXVI

Lead Sleeves

STRAIGHT SPLICES 22 GAUGE			Y-SPLICES 22 GAUGE		
No. Prs.	Inside Diam. in Inches	Length Inches	No. Prs.	Inside Diam. in Inches	Length Inches
10	1	16	10	1	16
15	1	16	15	1	16
20	1	16	20	1½	16
30	1½	16	30	1½	16
40	2	18	40	2	18
50	2	18	50	2½	18
60	2	18	60	2½	18
80	2½	18	80	3	20
100	2½	18	100	3½	22
200	3	20	200	4	22
400	3½	22	400	4½	22
600	4	26	600	4½	26

of splice. Instead of joining two lead-covered paper-insulated cables, it joins the wires in one such cable with an equal number of individual rubber-covered wires, its purpose being to terminate the paper cable in wires that will not be injured by exposure to the atmosphere. Briefly, a pot-head is made by opening the end of the paper-insulated cable and splicing to its conductors rubber-insulated wires, and then enclosing the splice in a chamber filled with insulating compound, so that no moisture can enter the core of the cable.

The method of making a pot-head is as follows: A lead pot-head sleeve of proper size is slipped over the end of the paper cable and run back out of the way. The end of the paper cable is then prepared in the same manner as described for making a straight splice, the same care being exercised in boiling it out. The core is then wrapped with muslin at the point where it emerges from the lead sheath, this wrapping being tucked in under the edges of the sheath to prevent injury to the conductors, as in the ordinary splice. Rubber-covered twisted-pair pot-head wires, usually of the same gauge as the wires of the cable, are then spliced to the cable wires in exactly the same manner as described in making a straight splice, paper sleeves being used in the same way. To do this, the pot-head wire is skinned for a distance of about 1½ inches, the colored or otherwise distinguished wire of the rubber-covered pair being spliced to the colored wire of the cable. The same care as to staggering of the joints is also necessary to prevent the splice assuming unequal diameters along its lengths.

After the wires are spliced, they are neatly bunched and wrapped with twine or wicking, this being drawn only tight enough to compress the bunch so that the lead sleeve will readily slip over it. In no case, however, should the twine or wicking extend higher up on the splice than a point about 3½ inches below the top of the pot-head sleeve, after the latter has been put into place. This same instruction as to twine or wicking will apply to paper sleeves and to any other material of a fibrous nature, none of which should be allowed to extend further up than about 3½ inches below the top of the sleeve after it is in place.

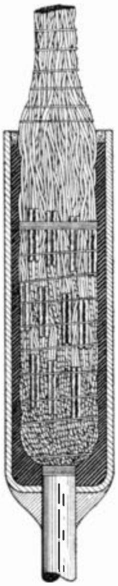
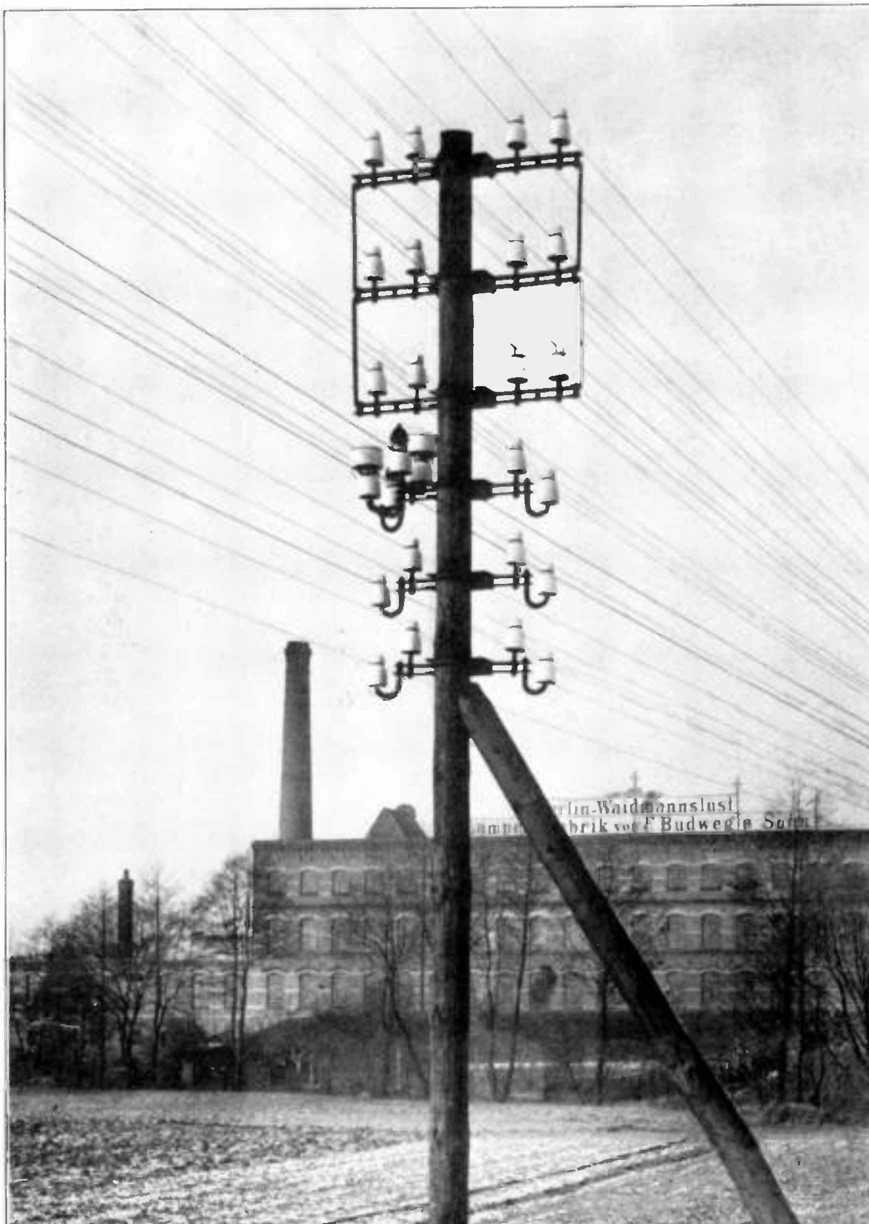


Fig. 613. Section of Pot-head

After the wires are joined and bunched in this manner, the pot-head sleeve is drawn up over the splice and its lower end beaten or dressed into form against the cable sheath, after which it is secured in this position by a regular wiped joint in exactly the same manner as a straight splice.

Filling. The method so far described results in a splice that is open at one end and from this end projects the bunch of rubber-insulated conductors. The splice is now secured in a vertical position, open end up, and is ready for filling. Before pouring, the wires in the top of the sleeve should be loosened as much as possible so as to allow the insulating compound to flow freely between them. The entire sleeve is then warmed thoroughly with a blow torch, and the insulating compound, which has been heated so as to flow freely, is poured in it within ½ inch of the top of the lead sleeve. As the compound settles, more should be added to keep it to the height mentioned, the sleeve being kept hot to facilitate the process of settling. Sometimes after the pot-head has cooled it will be found that the compound has settled slightly, and in this case more should be added to bring the insulating surface to the required height. After the pot-head, Fig. 613, has been filled and allowed to cool, the remaining space in the top of the sleeve may be filled with Cimmerian asphalt, which has been heated so as to flow freely. Cimmerian asphalt is a compound which does not be-



SIEMENS-HALSKE LOADING COILS IN SERVICE ON EUROPEAN LINE
Note Porcelain Insulators in Vogue in Europe.

come hard and brittle with age and is, therefore, used as an added precaution to insure a perpetual seal.

Central-Office Pot-Heads. In making central-office pot-heads or splices for joining the conductors of the incoming paper cables to those of the silk and cotton cables or the wool cables, which lead to the distributing frame, the same general practice as to making the joints in the conductors is followed. Where a large line cable is joined to many silk- and cotton-insulated lead-covered cables, the resulting splice or pot-head, illustrated in Fig. 614, is formed as follows: The pot-head sleeve is first slipped over the main cable and back out of the way; likewise, the terminal cables are passed through the holes in the wooden disk shown in the drawing, and this is slipped back out of the way. The lead sleeve is then removed from each of the terminal cables and from the main cable, and splicing is done in the same manner as in a straight cable splice. After the splicing is completed the lead sheath is put in place, the joint is wiped, and the wooden disk is slipped down on the terminal cable so that its lower surface will be flush with the ends of their lead sheaths. If the cables do not completely fill the holes in the wooden disk, muslin should be crowded in around the cables. The top of the wooden disk is now about 1 inch below the top of the pot-head sleeve, and upon it is placed a layer of fine dry sand about ½ inch deep to form the foundation of the wiping solder to be used in sealing the top of the lead sleeve. This wiping solder is filled flush with the top of the sleeve and its surface wiped so as to join perfectly and continuously with the lead sheath of each terminal cable and with the walls of the pot-head sleeve.

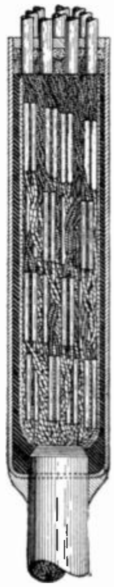


Fig. 614. Section of Pot-Head

Splices should always, if possible, be finished the same day they are begun. If the surroundings be dry and are of such a nature as to continue so, then a splice may be left unfinished over night, but it should always be protected from the atmosphere by a rubber blanket completely enclosing it and bound tightly against the cable ends. Wherever paper cable is cut, its ends should be sealed with solder before leaving it.

CHAPTER XLVII

OFFICE TERMINAL CABLES

In a modern plant the line side of the main distributing frame may be considered as the dividing point between the outside cable plant and the inside apparatus plant, since it is at this point that the conductors of the outside plant may be said properly to terminate. The matters now to be considered are: the method of leading the outside cables into the central-office building, and the method of so terminating the conductors of these cables that their insulation will not be impaired, either by the entrance of moisture or by mechanical injury to the insulation of the wires where they emerge from the lead sheath.

The entrance of the outside cables to the office building may be either aërial, underground, or both. Only in small plants, if they are modern, will the entrance be aërial, since if there is any underground work at all in the exchange, it will probably occur in the immediate vicinity of the central office where the cable runs are always heaviest.

Aërial Cable Entrance. Where aërial cables enter the central office, a heavy pole is set near the wall of the building, and all of the aërial cables are run to this pole. From this pole the cables are led, usually on an iron rack, to the wall and into the building, where they are connected to suitable terminal apparatus.

In very small towns, where only bare-wire lines exist, the line wires are brought to the office pole and there joined to the various conductors in an office cable which leads into the building. For this purpose rubber-insulated cable is usually employed, since by its use special treatment of the cable ends is avoided. Owing to the very short lengths of cables so used, the relatively high electrostatic capacity of the rubber-insutated wires is not a serious factor.

Underground Cable Entrance for Small Plants. Sometimes when the wire plant is almost wholly aërial, a short length of under-

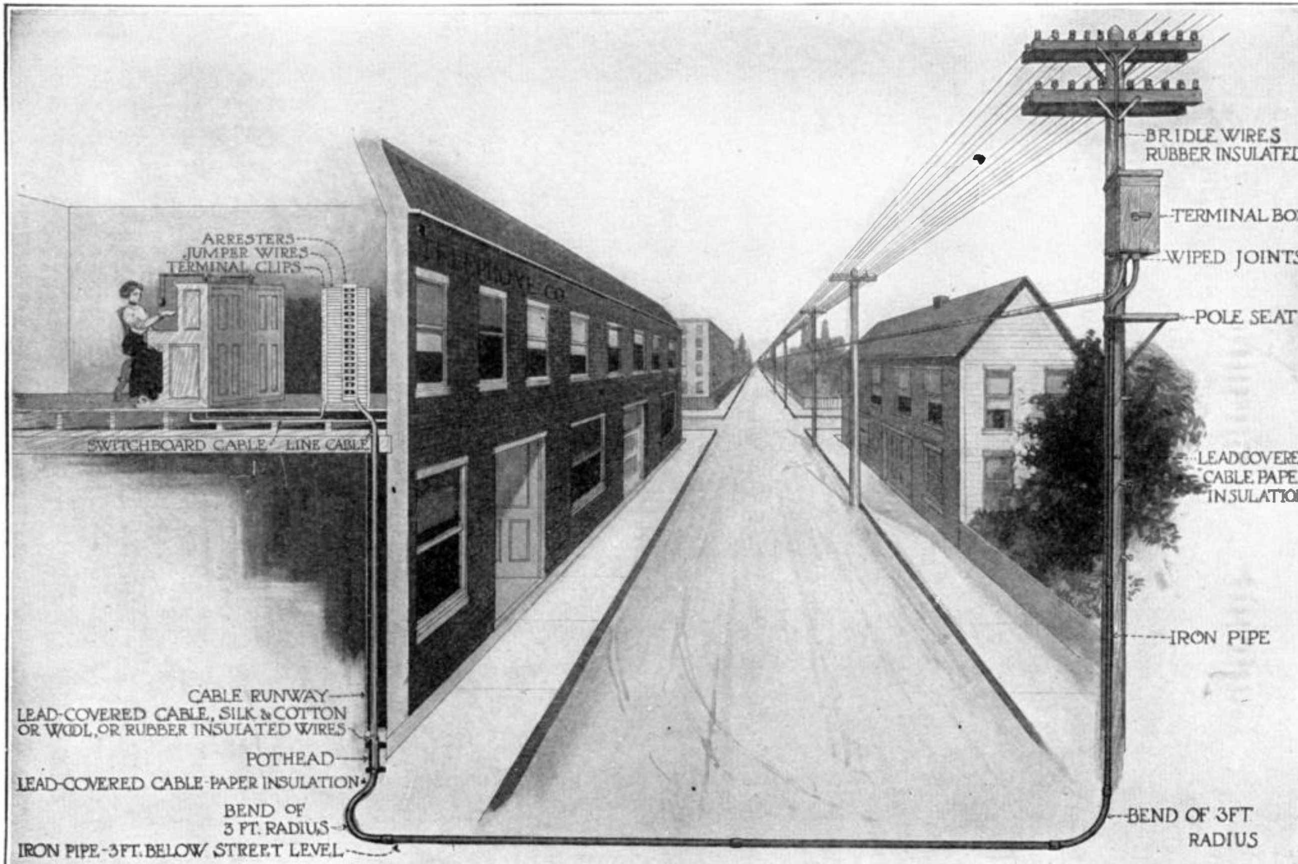


Fig. 615. Underground Cable Entrance for Small Exchange

ground conduit will be used, and underground cables led through this to the central office. A somewhat idealized arrangement for a very small exchange, embodying an underground entrance for a wire plant that is otherwise all aërial, is shown in Fig. 615.

Underground Entrances for Larger Plants. Either of two general plans may be followed for effecting the entrance of the cables of an underground conduit system into the office building. An office manhole may be employed to which all lines of conduit lead, and from which all cables pass through a tunnel or regular conduit ducts to the basement of the building, Fig. 616. Or, the office manhole

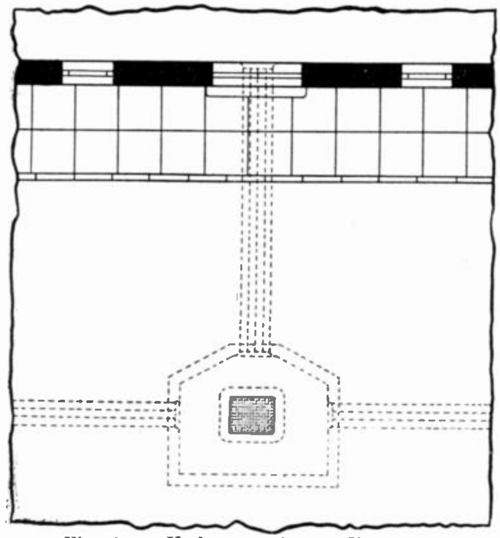


Fig. 616. Underground Cable Entrance through Office Manhole.

may be dispensed with and the conduits extended directly to the basement of the building, which, in this case, forms in itself the office manhole, Fig. 617.

Where the building is located directly on the street and where the conditions in the street are such as to permit the approaching ducts to extend directly to the basement, as required by the scheme shown in Fig. 617, this practice is simpler, cheaper, and better. Often the basement or cellar may be extended out under the sidewalk and street so as to intersect the conduit lines, without the necessity of curving the conduit approaches or running them diagonally, as was done in the installation shown.

By using the cellar of the central-office building as the office manhole, a large amount of splicing that would otherwise be done in a street manhole is done within the walls of the building, and generally the amount of splicing is reduced—both advantageous features.

Treatment of Cable Ends. There are three principal reasons why it is not good practice to run the paper-insulated cables to the distributing frame: First, the cable end, if thus exposed, would be likely, during wet weather, to absorb sufficient moisture to lower the

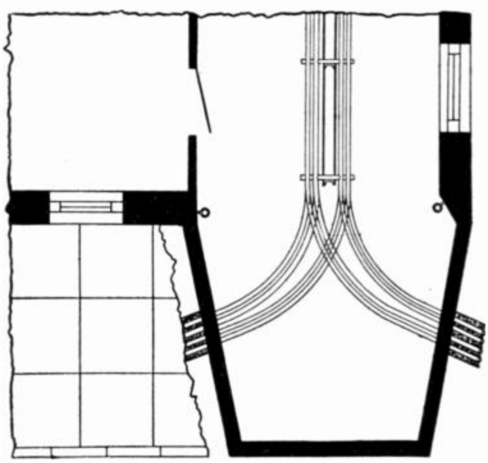


Fig. 617. Basement Cable Entrance.

insulation of the conductors; second, paper-insulated wires are not well adapted to stand the handling necessary in the work of fanning out the conductors and leading them to their respective terminals; and, third, the line cables entering the central office are usually of large size, having 400 or 600 pairs, and it is not convenient, as a rule, to subdivide such large units at the distributing frame. This latter fact makes it desirable to subdivide the large cables entering the central office before leading them to the distributing frame, entirely aside from any considerations as to the maintaining of the insulation.

Two general methods of overcoming these difficulties are practiced. One is to splice on to the paper-insulated cables, at a point some distance from the main distributing frame, cables of such character that moisture will not be likely to work back through them. Such cables are made of wool-insulated wires, lead encased. They are well adapted to stand the necessary exposure and handling at the distributing frame and they serve as a seal for the paper cables. The other method is to terminate the paper cables entering the office in pot-heads, which form the seal for the paper cables. From these pot-heads, cables, either of wool or of silk and cotton insulation—either of which are not so susceptible to moisture and are better able to withstand rough treatment than paper cables—are led to the distributing frame. The making of pot-heads for such use is con-

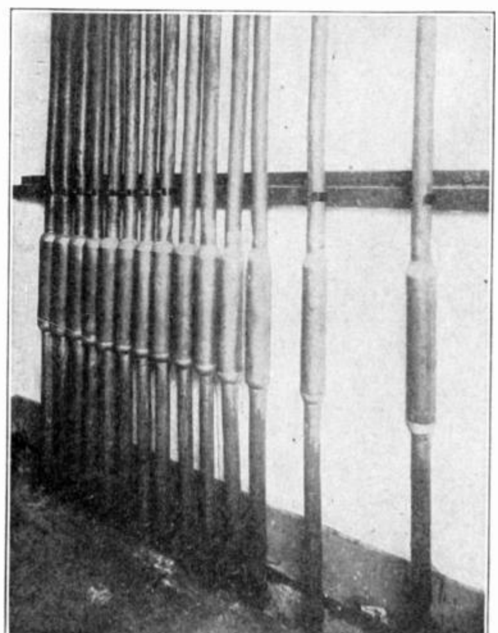


Fig. 618. Cable Splices.

sidered in another chapter; the general arrangement employed for disposing of these splices and pot-heads and of the cables leading from them to the distributing frame will, however, be considered here.

Wool Cable Ends. In using wool-insulated terminal cables, the splices may be made of ordinary form in the office manhole, or at the point where the cables enter the central-office building, or in fact at any point that is not so close to the main distributing frame as to leave a distance of less than about 25 feet in the length of each wool cable. It is not considered necessary to fill the splices with insulating compound, the length of wool cable being relied on to keep moisture out of the paper cable. The wool insulation on the wires, after they are exposed by the removal of the lead sheath at the distributing frame, is well adapted to withstand the necessary handling, being much tougher and less easily damaged than paper insulation.

In Fig. 618 are shown the splices between the 400-pair paper cables entering the Howard Street office of the San Francisco Home Telephone Company. These splices are made within the building

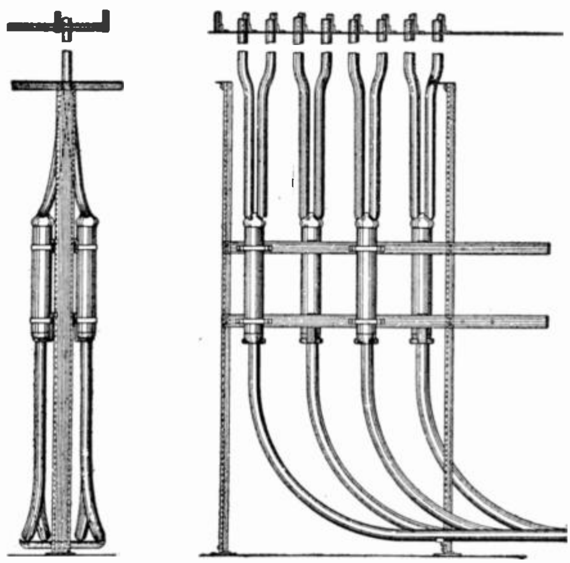


Fig. 619. Pot-Head Rack

in the vertical part of the cable run between the basement and the distributing frame room. The arrangement of the cables in a single row gives ready access to all of the splices.

Pot-head Method of Terminating. Where pot-heads are employed at the central office, the terminal cables that are spliced on to the paper cables are lead covered, and usually insulated with silk or cotton and less frequently with wool. It is customary to make these carry a relatively small number of conductors, as small cables are much more convenient to handle and may be led with greater neatness and with a smaller amount of exposed wire to their relative distributing frame terminals.

It is convenient to support the pot-heads vertically on an iron rack in the basement of the building, from which rack the smaller cables are led to the distributing frame room above. The details of such an office pot-head rack are shown in Fig. 619. In this installation each 400 pair of paper cable was spliced to two 200 pair of wool cables. The vertical terminal strips on the line side of the main distributing frame were equipped for 200 pairs, and consequently each of the wool cables occupied all the terminals on one of the vertical distributing frame strips.

The pot-heads in this case are each supported on a cast-iron shoe or bracket, as shown, the shell of the pot-head being held in vertical alignment on this shoe by means of iron straps bolted to the horizontal members of the frame.

Subdivision into Small Terminal Cables. Frequently the main line cables are subdivided into very much smaller cables than 200 pair. The terminal strips on the line side of the main distributing frame commonly carry blocks of 20 or 40 pairs of terminals. A neat arrangement is to subdivide the main cable at the pot-head into as many 40-pair silk- and cotton-insulated lead-covered cables as are necessary to carry the total number of wires, and then to lead each one of these 40-pair cables to a different one of the 40-pair terminal strips on the frame. In this way the conductors of the line cables are carried in lead sheaths right to the connecting strips on which they terminate, rather than having the lead stripped off at a point a greater distance from the ends of the conductors, as is necessary where larger terminal cables are employed.

Cable Runs. The method of conducting the terminal cables to the distributing frame is a matter which must always be carefully worked out in view of the particular requirements of each case, and should be provided for in detail in the design of the building. This is one of the important points of conference between the architect and the engineer. The method chosen will depend on the relative locations of the cable entrance, the pot-head rack, and the distributing frame. These all enter into the design of the building. It is also dependent on the vertical height of the main distributing frame, since the number of terminals in a strip or in a column is a matter which affects the size of the terminal cables. This also affects, and is affected by, the design of the building.

The general method to be employed in running from the pot-head rack to the main distributing frame depends usually on whether the two racks are on the same floor, or on adjacent floors, or on floors separated by intermediate stories.

Where they are on the same floor the terminal cables may be run in the most direct manner from the top of the pot-head rack to the top of the distributing frame and then fed down. Usually, however, these racks are not on the same floor. Where the main frame is on the floor immediately above that of the pot-head rack, the simplest

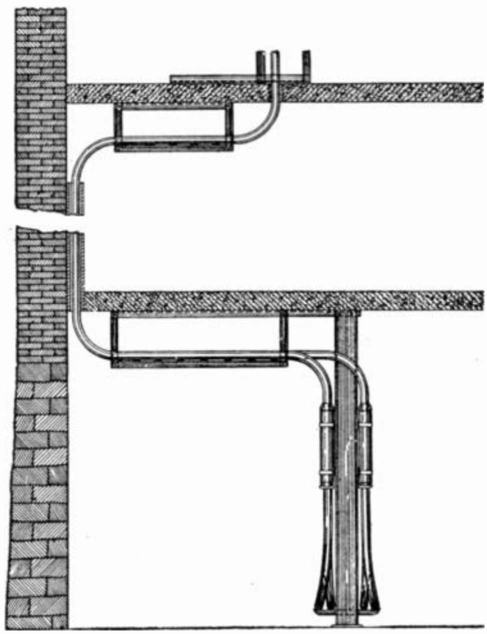


Fig- 620. Cables to Main Distirbuting Frame

way is to mount the main frame immediately above the pot-head rack and run the cables straight up to the main frame, as shown in Fig. 619. A good way of doing this is to provide a slot in the floor extending the entire length of the main frame, and care in disposing the longitudinal spacing of the pot-heads on the pot-head rack will result in each main cable being terminated directly under the corresponding vertical strips of the main frame.

Where there are intervening stories between the pot-head rack and the main frame, it is usually not possible to run the cable straight

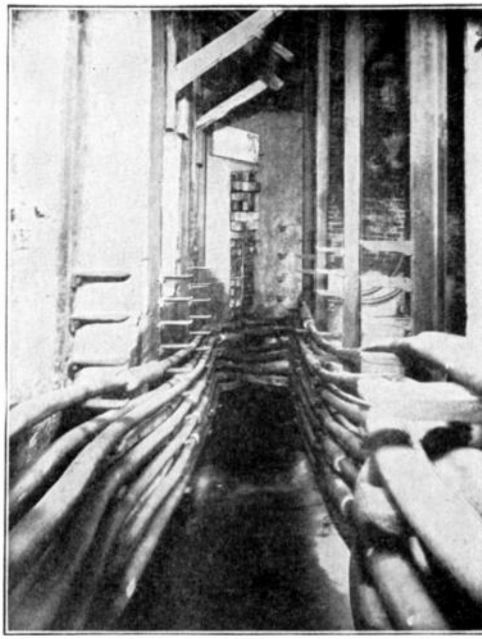


Fig. 621. Cable Entrance of the Grant Avenue Office of the San Francisco Home Telephone Company

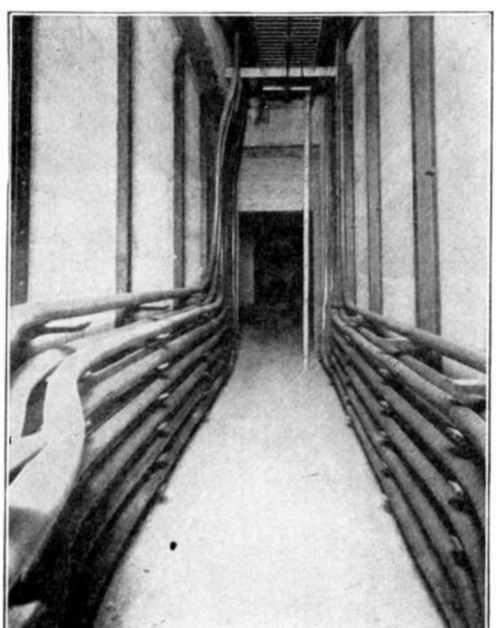


Fig. 622. Cable Entrance of the Grant Avenue Office of the San Francisco Home Telephone Company

up on account of interfering with the space on the intervening floors. One good way, which usually results in a minimum length of terminal cables, is to mount the pothead rack parallel with and near to one of the walls of the building and provide in this wall a sufficient number of ducts, either of iron pipe or fiber conduit, leading vertically to the distributing frame room. The terminal cables are led up from the pot-heads to a horizontal iron rack and passed over this to the lower ends of the wall ducts, through which they pass to the ceiling of the floor below the main frame, thence through an iron rack to a point beneath the main frame, and thence up through holes in the floor to the terminal strips which they are to feed. From this point the individual cables are led along the vertical members of the iron rack of the distributing frame to the proper horizontal member, and thence horizontally along that to the terminal strip. Such an arrangement, employing wall ducts, is shown in Fig. 620.

Where a cable shaft is employed rather than wall ducts, a good way is to build an iron rack or lattice work, extending from the pot-head rack horizontally to the vertical shaft leading to the distributing frame room, the cables being supported in this shaft by strapping them at frequent intervals to iron supports.

In Figs. 621 and 622 are shown details of the cable entrance of the Grant Avenue office of the San Francisco Home Telephone Company. Fig 621 shows the cables passing from the conduit to the bottom of the cable shaft, and Fig. 622 is a view in the other direction, showing the cables turning up to enter this shaft. Note that in supporting the cables on the side walls no more than two vertical tiers are used.

CHAPTER XLVIII

SERVICE CONNECTIONS

In gas- and water-supply systems individual pipes are run from the main in the street to the consumer's premises, and these are called service connections. In electric-light and power-distributing systems, and in telephone systems, the service connections consist in individual pairs of wires leading from the line wires of the pole or conduit route to the subscriber's premises.

Telephony, unlike all the other public utility systems wherein the commodity distributed is furnished by means of wires or pipes extended from a central station, requires that the line supplying each subscriber, or party-line group of subscribers, be individualized the entire distance from the central station to the subscriber's premises. In water, gas and electric-light, and power systems, the service connector is ordinarily the only part of the supply line that is individual to the consumer.

Connections from Bare Wire Lines. Where a line drops off a bare wire lead to reach a subscriber, the service connection may be made by means of bare or insulated wires, strung from the main pole line to the house, where they terminate on brackets. If the line from which the connection is made is a party line, and the station is not the end one on the line, the service wires are merely tap-connected to the line wires. If the station is on an individual line or the end one on a party line, the service wires are merely a continuation of the line wires. In all cases the service wire should be properly dead-ended to resist stress, both on the line pole and at the house.

Connections from Cable Lines. In cable construction several methods may be employed for connecting the cable terminal with the subscriber's house wiring. These naturally fall into three classes: aërial or drop-wire distribution; wall or fence-wire distribution; and distribution from underground terminals.

Drop-Wire Distribution. A drop connection or drop is an aërial pair of wires strung from a distributing pole near the subscriber's premises to a point on his building, from which they lead to the terminals of the house protection apparatus and interior wiring. Drop wires may be bare, but modern practice has proven that they are better of insulated wire. In some installations the drop connection consists of two separate wires, one bare and the other insulated, the idea being that even if they swing together there will still be an insulating protection. Consensus of opinion now, however, is that both wires should be insulated, and there has resulted a form of wire known as drop wire, consisting of two rubber-covered and braided wires twisted together. As has been pointed out, this rubber-covered twisted-pair drop wire may be of iron, copper, or of copper-clad steel. It should always be of sufficient strength to be self-supporting in rather long spans, even under the most severe conditions of weather. Obviously, therefore, the climatic conditions affect the requirements as to its strength, and it may be said, therefore, that for northern climates, where sleet and wind storms are to be expected, the drop wire, if of copper, should not be smaller than No. 14 B. & S. gauge. In those climates where sleet is not to be expected and wind storms are not severe, No. 16 B. & S. gauge copper suffices. Owing to the low cost of iron wire, the saving in using smaller sizes than No. 14 is not enough to warrant doing so. No. 18 copper-clad steel wire may be made with such a proportion of steel as to have a strength approximately equal to a No. 16 hard-drawn copper, but where this bimetallic wire has been used for drop-wire purposes, it has usually been of No. 17 B. & S. gauge. High conductivity in drop wires is not an essential and any of these wires may be considered as satisfactory in that respect. The great difficulty with iron wire for drop purposes is its liability to rust at the terminals and at exposed portions.

Fig. 623. Drop-Wire Insulator

Stringing Drop Wires. The attachment of the drop wire to the distributing pole and to the cable terminal, already shown in Fig. 570, is again referred to. Usually an iron bracket is bolted to the pole carrying one or more porcelain insulators. These porcelain insulators are preferably provided with double grooves to accommodate the twin wires. For dead-ending on distributing poles, the insulators are sometimes provided with two pairs of grooves, so that each may accommodate two drops. Such an insulator is shown in Fig. 623.

A common form of bracket, adapted to hold two of these insulators, is shown with the insulators attached in Fig. 624. Some trouble has been experienced in attaching the insulators to the brackets, due to the fact that if the nut was tightened sufficiently to bind and prevent its unscrewing, there was danger of cracking the insulator. It is for this reason that the four round leather washers are used.

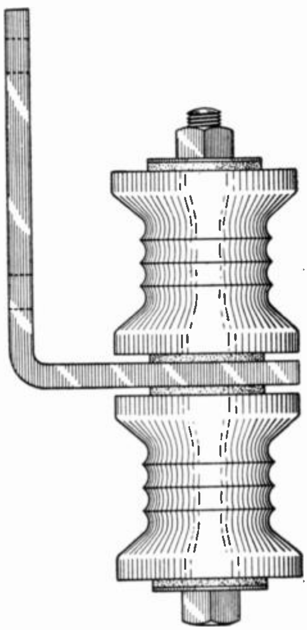


Fig. 624. Drop-Wire Insulators and Bracket

The method of tying the drop wire to such insulators deserves attention, since if this is improperly done the drop wires are likely to become crossed, even though a good grade of material is used. These knobs are used not only for attaching the wire to the distributing pole where the drop swings off, but also to intermediate poles—where such exist in the path from the distributing pole to the subscriber's premises. They are also attached to the house wall of the subscriber at the point where the span ends and at other points on the wall, in order to lead the wires along the house to the place where they pass through the wall.

The principal point to be remembered in making any of these ties to the insulators is that the two separate grooves are intended to hold separately the two wires of the pair. The two wires should not cross each other in passing around the grooves, but should lie as far as possible parallel with each other in the grooves.

The method of dead-ending the drop wire on the distributing pole is shown in Fig. 625. It will be seen that the drop is bent once around the insulator and then the free end of it is wrapped about five times around the portion that is to lead off into the span. On distributing poles, the wire may thus be wrapped about itself easily, because there is always a short end that is to lead up into the terminal box or can.

Where the drop wire is to be tied but not dead-ended on an intermediate insulator, as between two spans that are in the same straight line, or nearly so, the drop is laid in the insulator groove, but not passed around the insulator. It is tied in place by a tie wire cut

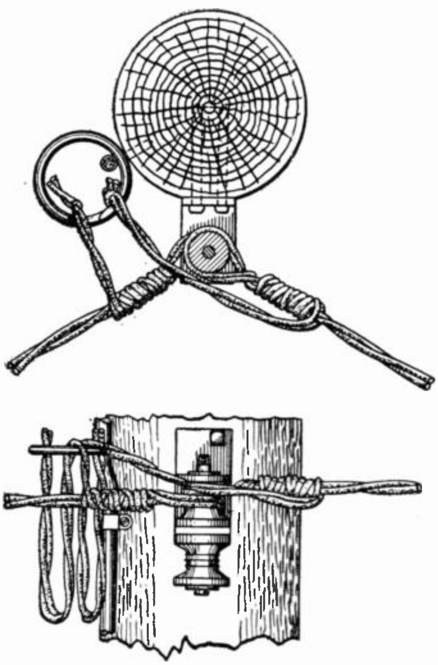


Fig. 625. Dead-Ending Drop Wire on Distributing Pole

from the scrap ends of the regular twisted pair drop wire. The method of making this tie is shown in four successive steps in Fig. 626.

At the point on the subscriber's wall where the span ends, it is necessary to dead-end the wire, but it is not usually feasible to make the same sort of dead-end tie that is illustrated in Fig. 625, because of the fact that it is not desirable to cut the wire at this point, as would be necessary in order to wrap it around itself. It is necessary, therefore, to dead-end the wire without wrapping it about itself, and the method of doing this is shown in Fig. 627. In this case the wire is wrapped once about the insulator and tied in place, as shown, by a tie wire of the same material which is also passed once around the insulator and then given about eight turns about the twisted pair. In both the regular tie and the house dead-end, each end of the tie wire, after wrapping, should be inserted between the two wires of the

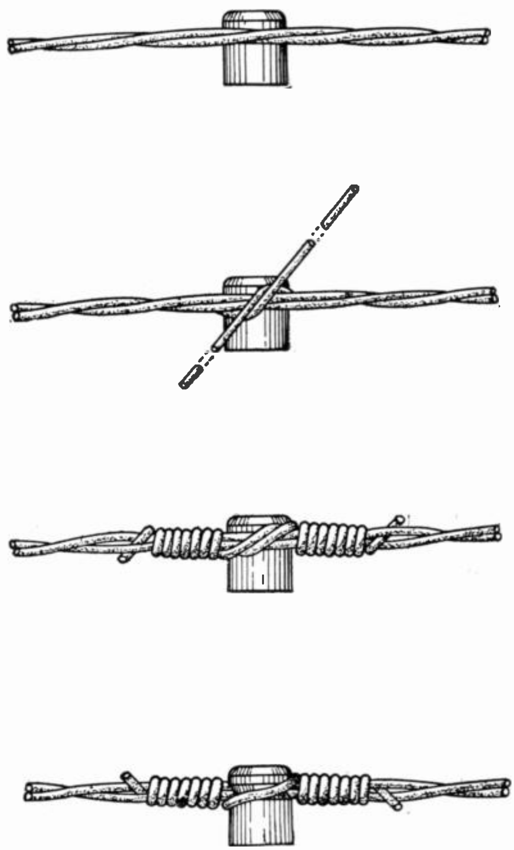
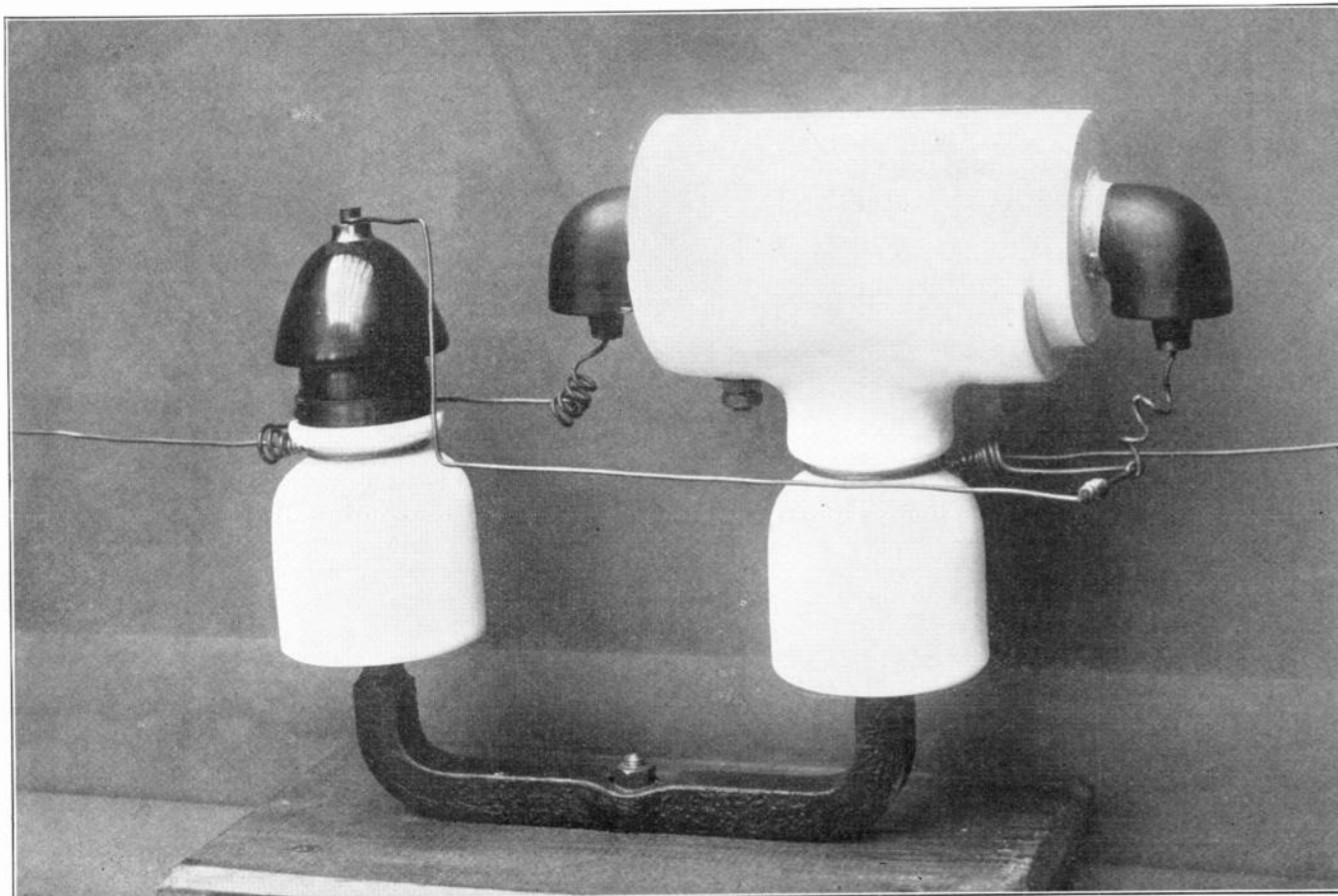


Fig. 626. Tie for Drop Wire

strand and then cut off. This prevents the tie wire from unwrapping.

At the distributing pole, after dead-ending the drop wire, the free end is looped down through a bridle ring screwed into the pole below the terminal, and its free end is passed up into the terminal can, where the wires are attached to the proper binding posts. The bridle ring



SIEMENS-HALSKE LOADING COIL FOR AËRIAL LINES
European Practice. Lightning Arrester at Left. Loading Coil at Right.

used for this purpose is usually a 3-inch enameled iron ring with a screw shank for fastening it to the pole. The looping of the drop-wire ends down through these rings disposes of the slack in the drop-wire ends in a neat manner. This arrangement has already been

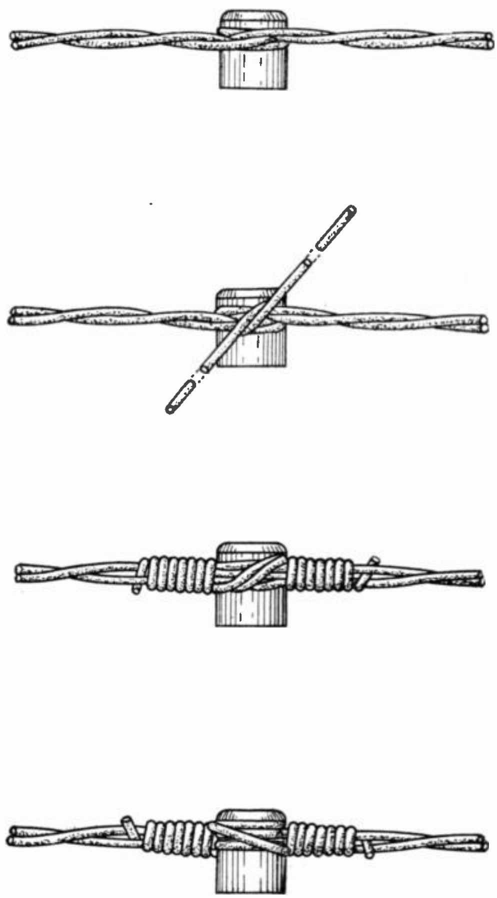


Fig. 627. Tie for Drop Wire at House End of Span

referred to in connection with Figs. 570 and 625. Another example is shown in detail in Fig. 628.

In Fig. 629 are shown the details of the connections of the drop wire to the outside wall of the house. Where the span leading to the house terminates, the house dead-end, shown in Fig. 627, should be used, and at all other insulators on the house, the regular tie of Fig. 626 should be used, these insulators being placed not further than 7 feet apart on horizontal runs, and not over 15 feet apart on vertical runs. The drip loop is provided just below the point where the wires enter the house to prevent moisture from following the wire into the house. The details of passing the wires through the wall are given in Fig. 630.

Splicing Drop Wire. It is preferable that continuous lengths of drop wire be used from the distributing pole to the subscriber's

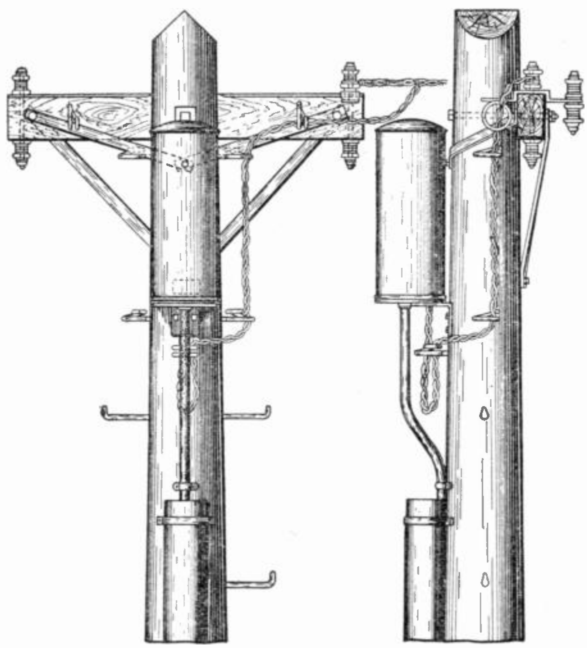


Fig. 628. Connecting Drop Wires to Cable Terminals

premises, but nevertheless economy of material makes other demands and a carefully prepared splice need cause no trouble. The method of splicing a twisted-pair drop wire is shown in Fig. 631. It is well not to use all of the scrap ends of the drop wire on any one connection, and this may be prevented by limiting the number of splices to two in any run of ordinary length.

Circle-Top Distribution. In districts where the buildings are of such a nature as to warrant the installation of individual underground terminals, it has been the practice in the past to provide, usually on the interior of the blocks, very high distributing poles on which the

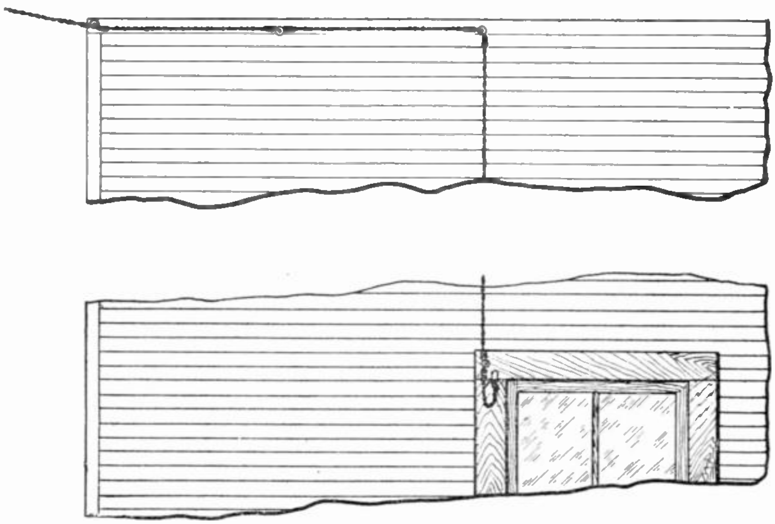


Fig. 629. Attaching Drop Wire to House

cable terminal was placed and from which the drop wires radiated to the various houses within reach, much like the ribs of an open umbrella. Often these poles are required to be of very great height and the drop-wire insulators are mounted on large rings encircling the pole and secured thereto by iron brackets. This is called "circle-top distribution," and an excellent example of it is shown in Fig. 632. The expense of these poles, the cost of up-keep, their equipment, and their general unsightliness, are all objectionable features.

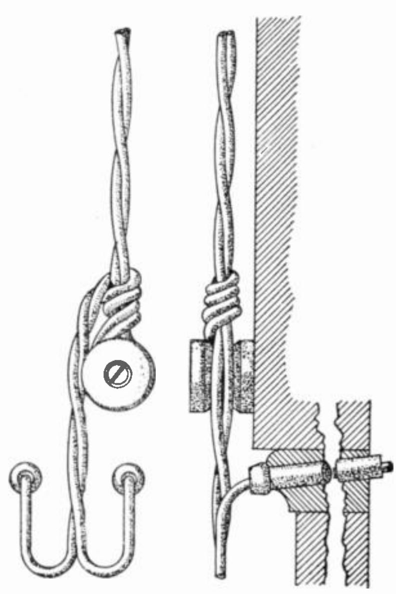


Fig. 630. Drop Wires Entering House

Rear-Wall or Fence Distribution. The better method of interior block distribution, where it is possible, is to terminate the cables on the walls of the houses, or on back fences, or on medium height poles near the rear walls or fences, and to lead from these terminals either paper cable or small gauge rubber-covered wire carried on rings, or both, along the walls or fences to the points of entrance to the various buildings.

Wall-Ring Wiring. Where the wall wiring is done by means of open wire rather than cables, a wire very similar to the ordinary drop wire, but of smaller gauge, is used. It is usually a No. 18 B. & S. gauge, rubber-covered and braided, twisted pair. The wire is carried along the walls in split bridle rings of the form shown in

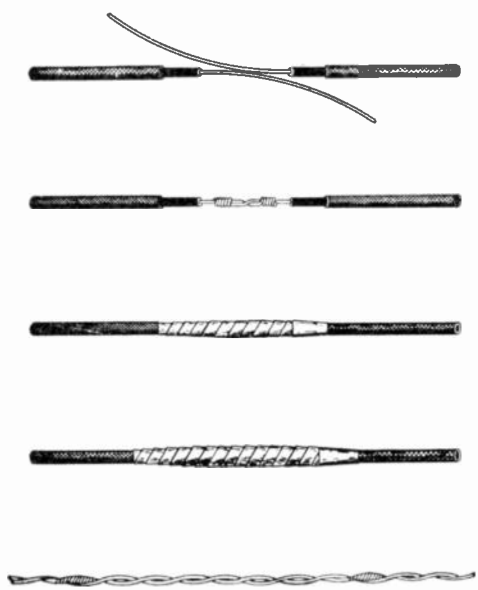


Fig. 631. Splicing Drop Wire

Fig. 633. The size of the ring is determined by the number of pairs of wires that will ultimately follow the routes, good practice in this respect being to use a 3-inch ring for all runs that will ultimately carry more than ten pairs and for the slack loop ring at all terminals; a $1\frac{1}{2}$-inch ring for all runs that will ultimately carry not less than three and not more than ten pairs; and a $\frac{5}{8}$-inch ring on all runs that will carry one, two, or three pairs. A $\frac{5}{8}$-inch ring is also well adapted for the final connection of the single pair at the point where the wires enter the building.

Where rings are to be secured to wooden walls, they are screwed directly into the wood. Where attached to brick, concrete or stone walls, a hole is drilled into the wall and this may be plugged with

Fig. 632. Circle-Top Distribution

wood, into which the ring is screwed, or it may be fitted with any one of several forms of standard expansion screw plugs that automatically tighten and hold against the interior of the hole. In all cases the rings should be turned so that they are at right angles to the direction of the run. When the run is horizontal the open sides of the split rings should be at the top, and at all corners the open side should be at the outer side of the bend. In horizontal runs the rings should be placed not over 4 feet and on vertical runs not more than 8 feet apart.

The method of mounting a terminal on a wall is shown in Fig. 634. This illustration not only shows the lead-covered cable leading up from the underground lateral to the terminal can, but it also shows the method of leading off the twisted-pair wall wires through the rings.

The method of dead-ending the individual pairs of wires at the bridle ring is shown in detail at the left of Fig. 634, while the method of running the wire through the wall of the house, preferably in the upper casement of the window, is shown in Fig. 635. Other details of wall-ring construction are shown in Fig. 636.

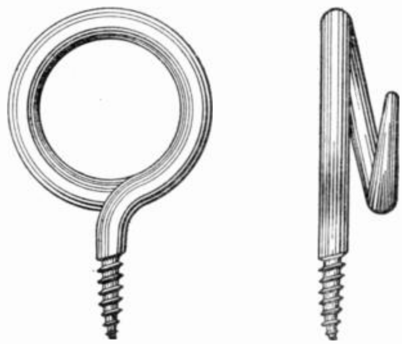


Fig. 633. Bridle Ring

Aërial Conduit. Often it is convenient to mount the cable terminal on a pole in the interior of the block so as to be able to reach the rear walls of several houses. Where this is done an aërial conduit is provided for supporting the wires from the pole to the nearest wall of the house. This is readily done by extending a messenger wire from

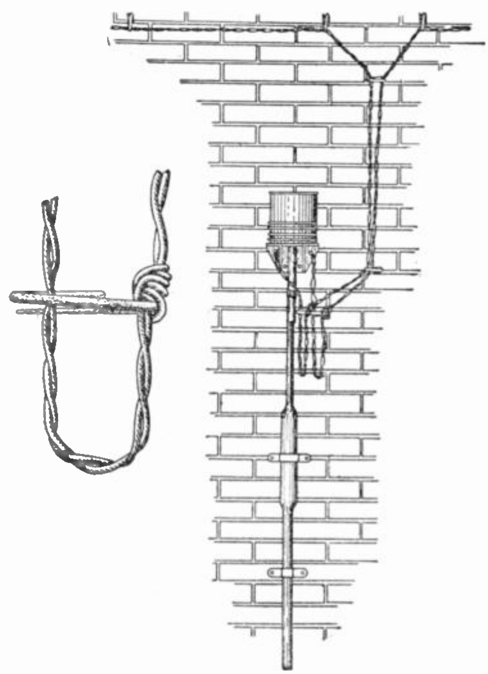


Fig. 634. Wall Terminal and Wiring

the pole to the house. As such construction is always relatively light, a No. 4 or No. 6 messenger wire is amply strong. The messenger wire may be dead-ended on the pole in the ordinary way, and on the house in a heavy screw-eye bolt. This messenger wire so run may support a lead-covered cable leading from the pole to a terminal on the house; and from this terminal on the house; the rubber bridle wires may be run, as already described. Usually, however, it is preferable to place the terminal can on the pole and to extend the bridle wires from it along the messenger wire. For this purpose aërial conduit rings are used, Fig. 637, which are clamped directly to the messenger wire so as to hang below it. They are usually spaced about 18 inches apart, and the bridle wires are carried through them along the messenger wire to the wall of the house. A general idea of this construction is given in Fig. 638.

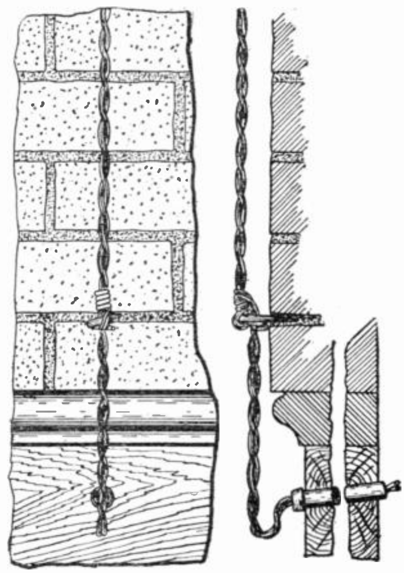


Fig. 635. Wall Wire Entering Building

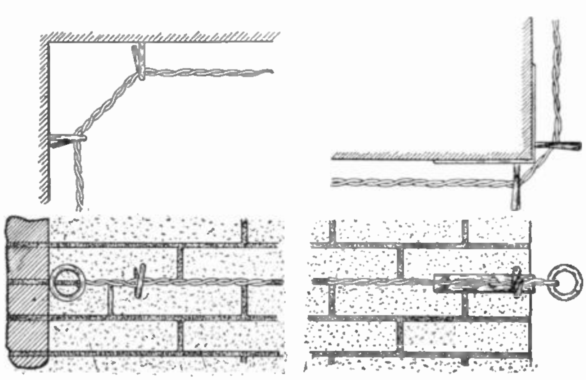


Fig. 636. Details of Wall Wiring

Fence Wiring. The same general methods that have been outlined for wall wiring will apply to fence wiring, except that on fences greater care must be taken to protect the wiring. Where the terminal is placed on the fence, it should be in as inconspicuous a place as possible and at the same time reasonably accessible to linemen, who should be able to reach it, if possible, without the necessity of annoying the occupants of the property on which the terminal is located. It should always be so placed that it will be least liable to injury by children walking or playing on the fences. Where necessary, it may be suitably housed in a wooden cabinet provided with lock and key. The underside of the upper fence stringer forms the best place for the bridle wires, and if a cable is also run along the fence for any distance, it is preferably run underneath the bottom stringer. Details of this construction are shown in Fig. 639. Where it is not possible to mount a fence cable

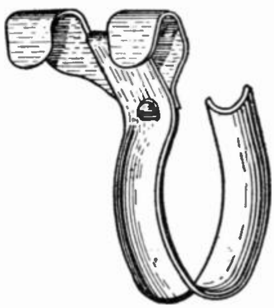


Fig. 637. Aërial Conduit Ring

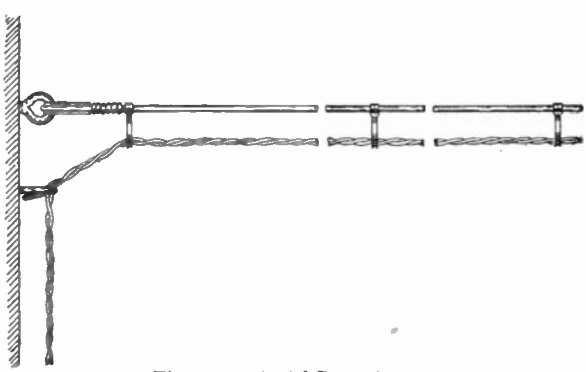


Fig. 638. Aërial Ring Conduit

under the stringer of the fence, it should be enclosed in a simple wooden moulding.

Back fences form almost the only available way of distributing wires and cables in some congested districts in large cities like New York and San Francisco, where back yards are small and where, in many cases, no alleys exist. This method allows a malicious or mischievous person to tamper with the cables or wires, but is not as unsightly as aërial block distribution.

Distribution from Underground Terminals in Buildings. Large office buildings are practically always found in localities fed by underground cables. The proper way of making the service connections in such buildings is to run an underground lateral from the nearby conduit manhole directly to the basement of the building, and to draw into this lateral a cable having a sufficient number of pairs to serve all the subscribers in that building. Some of the large office buildings in New York and Chicago have as many as 1200 cable pairs thus entering them directly from the underground conduits. In small office buildings and business blocks, the question as to whether the service connections shall be made directly from an interior terminal or by the rear-wall method must always be governed by the size of the

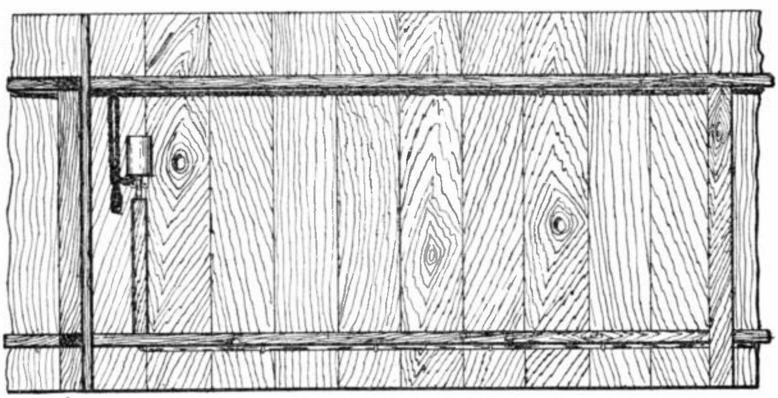


Fig. 639. Fence Wiring

building, by the ease of access to the basement of the building for the underground cable, by the provision of proper runways for the wires in the building, and by the character of the outside of the building as affecting the feasibility of using rear-wall wiring. Underground service connections are to be preferred, in many cases are the cheapest, and in other cases are the only practical way.

Where the distribution is from an underground terminal within the building, the cable leading into the building should be terminated at some point where it will not be liable to injury and where it will be reasonably accessible to the workmen of the telephone company. The same sort of a terminal that is employed for aërial cable work may be used for terminating the cables, unless they are of very great size, in which case special terminal racks are provided.

CHAPTER XLIX

SUBSCRIBERS' STATION WIRING

The simplest case of subscriber's station wiring is that of an unexposed open wire line, such as a private line in the open country, entering a dry wooden house to connect with a telephone. In this case the outdoor line is terminated on insulators on the outside of the house at such a point as to make the wiring to the telephone within as short as possible. A twisted pair of wires insulated with a good grade of rubber with a braid over each wire is then run into the house through a hole slanting inwardly upward and is carried to the instrument along vertical and horizontal lines of the woodwork of the house. It is attached to that woodwork by means of insulating nails or staples.

General Conditions. All telephones in subscribers' stations may be classified as exposed or unexposed, depending on the character of the line outside. Protectors are required at exposed stations, but none are required at unexposed stations.

The construction rules of governing fire-insurance bodies prescribe that the wiring of an exposed line shall be considered high-tension wiring up to the point of the protector, but that between the protector and the telephone the wiring may be considered as without exposure to hazard and may be run in any desired way.

The wires from the exposed line to the protector, therefore, if the latter is within the building, are to be supported on insulators. From the protector to the telephone, "inside wire" shall be used. As so much of the success of telephone service and the securing of low maintenance costs depend on the quality of inside wire, the following condensed specifications for such wire are offered:

> The wires shall be of No. 19 B. & S. gauge and shall be of soft copper, well tinned. Each tinned copper conductor shall be evenly and smoothly covered with an approved rubber insulating compound to an outside diameter not less than $\frac{3}{32}$-inch. The insulated covering shall

be flexible and not liable to deteriorate under ordinary conditions nor to act injuriously on the conductor. Each insulated conductor shall be covered with a close braid of cotton. This shall either be polished or shall be treated with a paint or compound, insoluble in water, and this shall not act injuriously on the insulating compound. The braid on one wire shall have a raised thread or an approved equivalent marker so that the wires may be easily distinguishable from each other. The two insulated braided conductors constituting a pair shall be twisted together. The twists shall be regular and uniform. The length of the twists shall be not less than 1¾-inches nor more than 2½ inches. The completed wire shall be capable of withstanding a pressure of 1,000 volts alternating current and shall have an insulation resistance of at least 200 megohms per mile at a temperature of 60° Fahrenheit. The resistance of each conductor shall not exceed 50 ohms per mile of completed wire at 60° Fahrenheit.

Where a protector is required, if the chosen type mounts inside the house, it shall be located as close to the entrance as possible. It shall be mounted on a wall 7 feet from the floor, shall be placed so as to avoid dampness and inflammable material, such as window shades and curtains, and never shall be mounted in a show window.

The ground wire from the protector shall, if possible, be run to a water pipe; if this is not possible, a gas pipe is next preferred, connection being best made between the meter and the street. A ground rod not less than 6 feet long driven into permanently damp earth is the third choice. A good ground clamp is the most convenient way of attaching a ground wire to a pipe, however, soldering the wire to the pipe is as good practice but less convenient.

Where a protector is not required because the line is unexposed, it is good practice to install a connection block in its place, as this is a handy way of joining the entrance wires to the inside wires. A connection block is merely a small slab of insulating material with binding posts on it. Two connected pairs of such posts may be used, or a single pair, each post taking one inside and one outside wire.

The inside wire of two insulated and braided conductors should be carried around rooms in picture mouldings where possible, if this does not require crossing open plastered walls. To reach wall telephones, it is generally possible to drop the wire from the picture moulding to the instrument within a plastered wall and to bring it out at the telephone so as not to show at all.

In carrying the inside wire along other woodwork than a picture moulding, the best fastening is an upholsterer's tack. This is a small, sharp-pointed steel nail with a large head of insulating material.

The stem of the tack is slipped between the two wires of the pair. Care should be taken never to drive the tack through the insulation. The next best fastener is a staple having a saddle of insulating material. For ground wires, which are single, staples are necessary. Neither ground wires nor twin wires shall have spirals in them. Ground wires carry away lightning best if entirely straight.

The more complicated cases of wiring office buildings, hotels, and apartment houses require some use of inside wire in these ways. It is not possible, however, to bring the outside lines to the telephones as simply as in the case of isolated houses. The preparation for wiring an office building or hotel should begin at the time the architect makes his first preliminary sketch, and telephone wires should be considered and arranged for during all the processes of planning and constructing the building. Owners, architects, building contractors, and wiremen should have exact knowledge of the needs of modern telephone installations. For this reason, the following fundamental matter is presented.

There are three classes of buildings which require particular attention in preparing for telephone service: Office Buildings; Hotels; and Apartment Houses.

Other buildings which require consideration are: Flats and Private Dwellings.

Office Buildings. Assume that office buildings will require about one telephone per office. While the number of telephones so figured often is exceeded, the excess stations are taken care of by private exchanges, having fewer lines to the central office than to local substations. Since the location of telephones cannot be determined in advance, it is necessary that a very flexible arrangement be provided and one that will permit wires to be run to *any* part of *every* room. Such an arrangement in nearly all cases can be obtained best by the use of raceway mouldings in halls, picture mouldings in rooms, and by the proper distribution of hall terminal boxes. These boxes are served by riser cables and provision is made for the riser cables to be carried vertically from the basement to the top floor.

Raceway Mouldings. Common and good forms of raceway mouldings are shown in Fig. 640. In the hall a larger moulding is required than in the individual rooms, the moulding in each room being connected with the hall moulding by a short piece of $\frac{3}{4}$-inch conduit which will make any subsequent boring of the walls unnecessary. Mouldings in adjacent offices should be similarly connected, in which case, the conduit shouldbe placed in the dividing wall as close to the hall as possible. This interconnection of room mouldings will be found particularly useful in wiring a suite of offices for a private exchange with a switchboard in some one room. The mouldings should be continuous along the entire length of a hall and around the walls of a room and preferably should be above all doors and window sashes, or, at the lowest, on a level with their tops.

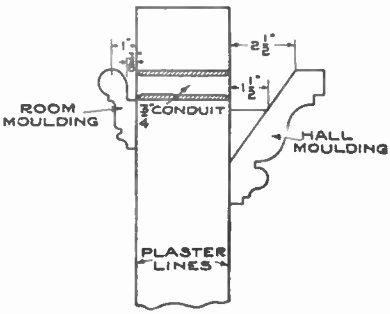


Fig. 640. Race-Way Mouldings

Ceiling Conduits. Where terminal boxes are not placed on both sides of the hall, the mouldings on each side should be connected by 1½-inch conduits, placed in the ceiling, as shown in Fig. 641. Where very long halls exist, even with terminal boxes on both

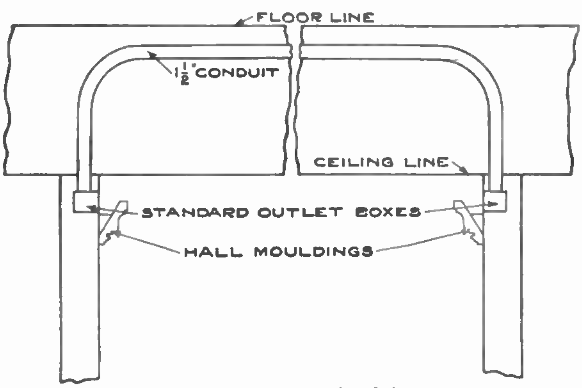


Fig. 641. Ceiling Conduits

sides, connecting conduits 1½ inches in diameter, and in duplicate, should be placed at intervals not exceeding 100 feet. The total length of a hall should be considered as that measured throughout its entire length on all sides of a building.

In placing conduit under these conditions and elsewhere, the usual precautions should be taken to round the exposed edges at the ends so as to remove all burrs which might injure the insulation of the wires or the covering of the cables.

Hall Terminal Boxes. It is distinctly desirable to use but one size of hall terminal box throughout a building. This can be done with ease, if the following simple rule is adhered to: *Always place enough boxes on each floor so that not more than ten to thirteen offices will be served from one box.*

A good form of hall terminal box suitable for the above arrangement is shown in Fig. 642. The boxes should be placed just below the hall moulding, the back of the box projecting up behind the moulding to afford a means of connection between the moulding and the box. In placing the boxes along a hall, an effort should be made to have the box as close as possible to the center of the group of offices which is to be served by the box.

In order to connect the terminal strips in the hall terminal boxes with the riser cable, the cable shaft, or closet accommodating the riser

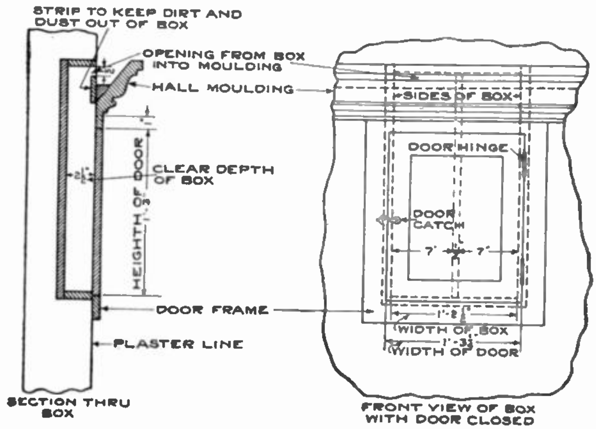


Fig. 642. Hall Terminal Box

cable, should itself be connected with the hall terminal box directly by means of the hall moulding, or by a special conduit-run, or directly by placing the hall terminal box in the shaft close to the hall moulding.

Hall terminal boxes should be located with reference to the offices they are to serve and, if a choice exists, the location of the riser-cable shafts should be made with reference to the location of the hall terminal boxes so as to reduce the length of distributing cable from the riser shaft to the hall distributing boxes to a minimum.

Riser-Cable Shafts. In all except the smallest buildings (four to five offices in the longest side) at least two riser-cable shafts should be provided for at diagonally opposite corners of the building. There

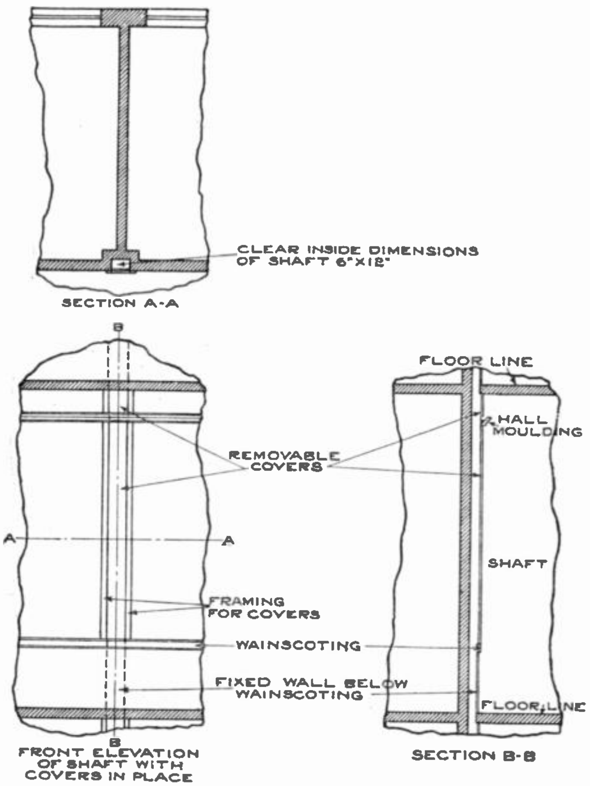


Fig. 643. Riser-Cable Shaft

should be as many shafts as necessary to keep the distance from the shaft to the farthest terminal box under 75 feet. Enclosed shafts are preferable to open ones, elevator ways and vents being classed as open shafts. Cables in open shafts, even though covered, are unsightly and in danger of injury.

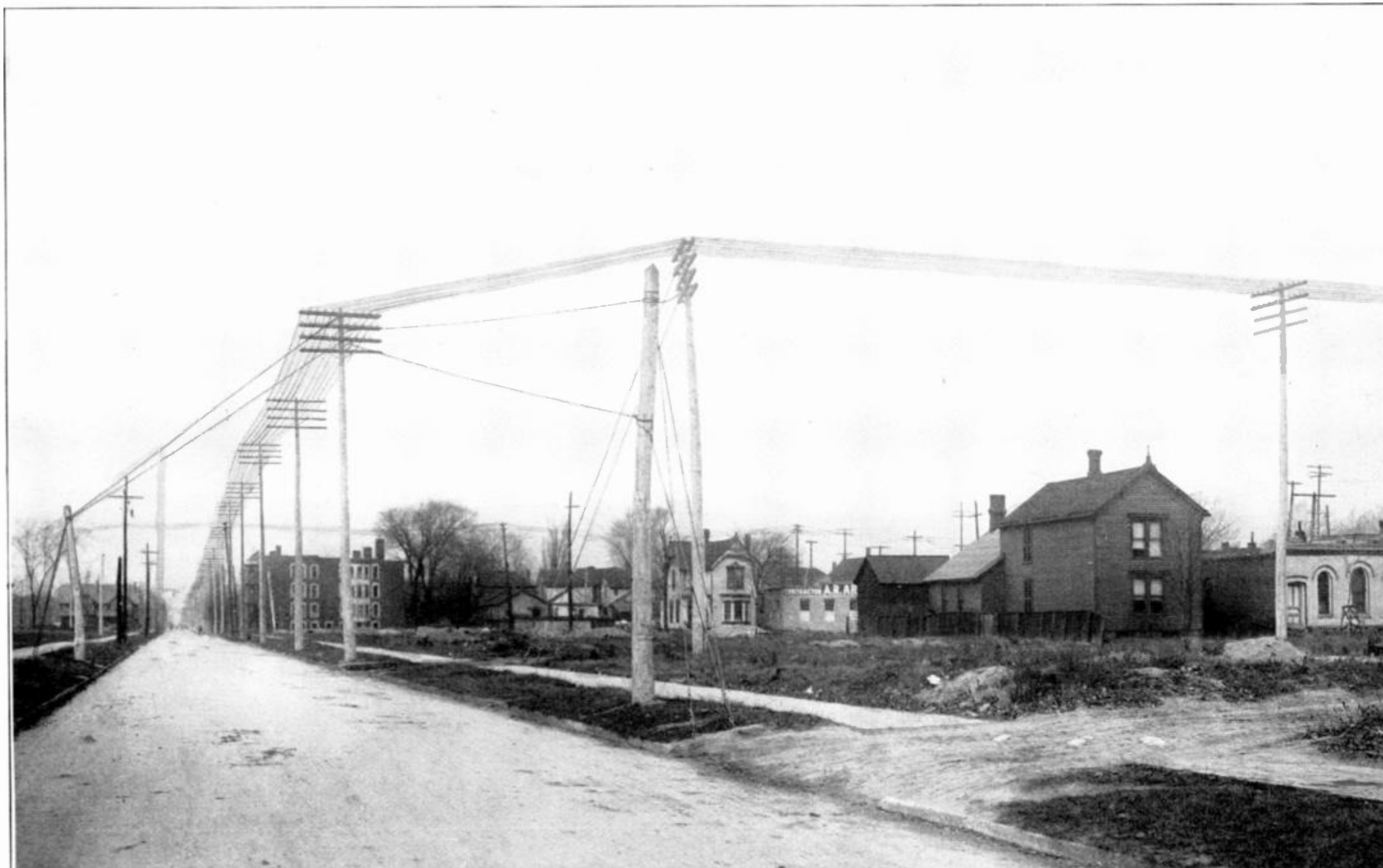
Separate shafts of small dimensions are recommended and they may be located in some part of the hall walls so as to be nearly midway between the hall terminal boxes they serve. Such a shaft is shown in Fig. 643, in this particular case it being in the hall wall opposite a partition between offices. In many cases such a shaft may be recessed into a wall of the janitor's closet, elevator shaft, toilet room, or other space, so as to be inconspicuous. The shaft should have an inside dimension of *at least* 6 by 12 inches. It may well be somewhat larger. The long dimension preferably should be parallel with the hall; however, this position of the shaft may be reversed if necessary. The shaft shown is provided with a removable paneled cover on each floor, extending from the wainscoting to the ceiling, but cut at the hall moulding. If the location of the shaft permits, one of the hall terminal boxes, Fig. 642, may be placed in the shaft directly below the moulding.

As riser cables generally are not self-supporting, means must be provided to permit the cables to be strapped to the walls of the shaft. This may be arranged by sinking flush with the walls of the shaft near the top and the bottom of the opening on each floor, 2-inch by 4-inch wooden sleepers. Where tile walls are used, the sleepers may be omitted and toggle bolts used. It is not generally possible to extend all cable shafts to the basement, as the arrangement of the first floor generally is different from the rest of the floors; this condition may easily be met, however, by extending to the basement from the bottom of each cable shaft, two 3½-inch conduits.

Cable in Elevator Shaft. Where it is not possible to construct separate shafts for telephone purposes, other shafts—such as elevator shafts, pipe shafts, and vents—may be used, providing they are within a reasonable distance of the hall terminal boxes. They are distinctly not the best way, however.

When an elevator shaft must be used, provision should be made at each floor so that the distributing cables may be run from the riser cable to the hall distributing boxes. This may be accomplished either by running the hall moulding to the shaft or by connecting the shaft to the hall moulding by a conduit run. Where possible, the riser cable should be enclosed, both for appearance and for protection. This being done by means of a small box with removable doors, extending vertically from the basement to the top floor. This box should have an internal cross-section approximately 6 by 12 inches.

Combined Pipe-and-Wire Shaft Where a combined pipe-and-wire shaft is to be used, an effort should be made to separate the tele-



A RIGHT-ANGLE TURN ON TWO POLES

phone wire portion from the rest by a substantial partition, preferably fireproof. Telephone cables and wires may not be kept close to steam pipes. Provision should be made so that access may be had to the cable at each floor. The shaft should be properly connected

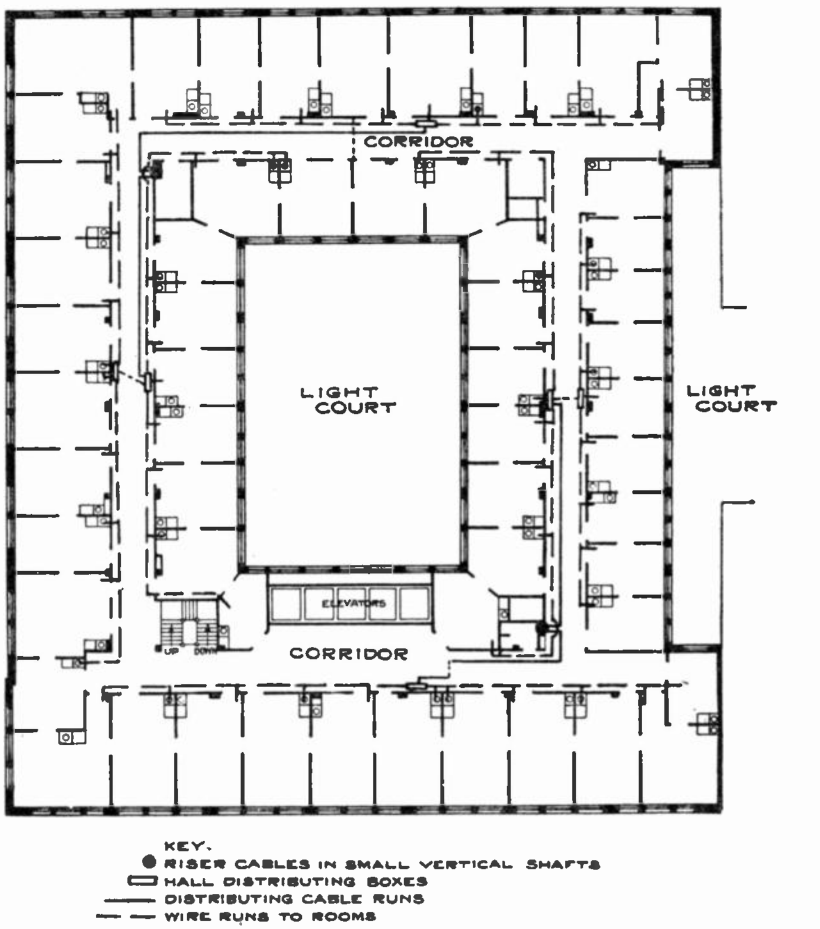


Fig. 644. Office Building Wiring

with the hall moulding or to the distributing boxes. A separate door for each part of the shaft is not necessary.

Cable in Vent Shafts. Where vent shafts exist in suitable locations, they should be treated the same as elevator shafts, the cable being accessible at each floor. As lead-covered cables are used in riser shafts, it is not necessary that the vent shaft should be waterproof. Care should be taken, however, that the connection to the hall moulding is waterproof on the hall side. Where conduit is used, this result may be obtained by slanting the conduit up from the outside.

Main Distributing Terminals. In order that wires within the building may be connected to the outside wires coming from the central office, it is necessary that both sets of wires be carried to some common distributing point. The place at which this occurs is either a main terminal cabinet or main terminal room.

The main terminal, except for special reasons, always should be located in the basement and the location should be dry and not too close to steam pipes and the like, but convenient to vertical riser-cable shafts and to the point or points at which the service cables will enter the building.

If the vertical riser-cable shafts do not terminate at the main distributing terminal they should be connected to the latter by $3\frac{1}{2}$-inch conduits, two conduits being run to each shaft. Should it be evident that a shaft will never have to accommodate a full cable of four hundred pairs of wires, smaller conduits may be used.

Typical Arrangement. Fig. 644 shows a typical office building floor plan, laid out for wiring.

Hotels. The entire telephone traffic of hotels generally is handled by a private-exchange switchboard. This switchboard must be connected with practically every room in the hotel and with a telephone central office, the latter by a few trunk lines. The location of the telephone outlet in each room of a hotel may be determined readily; therefore, it is always possible to install permanent wiring at the outset for the entire telephone system. This distinguishes hotel wiring from office-building wiring, since the permanent wiring in the latter must terminate at the hall terminal boxes.

In a degree, the wiring of a hotel for telephone purposes is similar to wiring it for electric lights, the difference being that for telephone service a separate pair of conductors must be carried to each telephone, while in electric-light work, all lights may be connected in one way or another to a single source of current.

The method of wiring best suited to the average hotel is: A riser cable, which is installed at a convenient point, is properly connected at each floor by smaller cables to suitable floor distributing boxes. From the proper box a pair of twisted wires is run to each telephone in each room. More than one riser cable may be needed in a large hotel. As in office buildings, the economy of such a system will depend very largely upon the care exercised in choosing the locations of the riser-cable shafts and the floor distributing boxes, which locations should be such that the length of conduit, wire, and cable runs will be a minimum.

The first thing to do in preparing wiring plans for a hotel is to decide upon the location of the private exchange switchboard. A good location generally is found in or close to the office. This, in most cases, brings the switchboard on the first floor and in occasional cases on the second or third floors.

All house lines, incoming and outgoing trunks from and to the central office, and all lines to the private exchange switchboard should end at the main distributing terminal. The terminal affords a means of cross-connection, so that any room line or trunk line may be connected as desired to a chosen circuit in the private exchange switchboard. It will be seen that in this way the number of wires between the private exchange switchboard and the main distributing terminal will be large, and to reduce cost to a minimum the distance between the main distributing terminal and the switchboard should be made as short as possible.

Arrangement of Apparatus. In hotels of moderate size, not exceeding 150 rooms, it is good practice to arrange for a main distributing terminal directly at the rear of, or close to, the private exchange switchboard. Where this is not advisable, and in the larger hotels, the main distributing terminal should be located in a separate room. This room, in the larger hotels, will also be required to care for certain power apparatus and other telephone accessories in addition to the wiring.

Where the switchboard is located on the first floor, an ideal location for the terminal room is directly below it in the basement. Where the private exchange is not located on the first floor, the terminal room, from a cost viewpoint, should be located on the same floor as the switchboard. Where a separate room—or a room used in conjunction with electric fuse cutouts, etc.—is to accommodate the main distributing terminal, a cabinet is not necessary. If the terminal must be located in a hall or other room, or at the back of the switchboard so as to be exposed to general view, a cabinet should be provided which should be approximately 1 foot deep in the clear. The entire front of the cabinet should be fitted with removable doors, and its design should harmonize with its surroundings. Provision also should be made to carry the incoming wires from the point where they enter the building to the distributing cabinet. A 2-inch conduit generally will suffice for this purpose.

Location of Outlets. If ordinary wall telephone sets are to be used in rooms, the telephone outlet, consisting of an ordinary conduit outlet box, should be placed 4 feet 10 inches above the floor. If sets mounted flush with the wall are to be used, a special conduit outlet box is required.

Where portable telephones are used, the outlets in most cases may be located with advantage in the baseboard. This location and the outlet box required must be considered special and should be given special consideration in each case. It is often desirable to arrange for telephone service in dining rooms and grills, from part or all of the tables and such provision requires the use of floor or wall outlet boxes and special apparatus.

From the individual outlet or outlets in each room, there should be run to the proper floor distributing box a twisted pair of No. 19 B. & S. gauge, braided, rubber-covered, tinned, soft copper wire. Where a separate circuit is run to each outlet—the usual case—a third or ground wire is not necessary unless coin-prepayment or other special service is desired; in the latter case, a third wire tap should be brought out at each outlet. The third wire taps from all outlets should be spliced to a common wire at the distributing box or other convenient point. For mechanical reasons this common ground wire should not be smaller than No. 12 B. & S. gauge and should be of the best quality of braided, rubber-covered, tinned, soft copper wire. At each floor distributing box, the wires from the various outlets should be connected to the distributing cable, preferably by means of suitable binding posts mounted on strips of suitable insulating material.

Distributing Cables. The distributing cables from the riser-cable shafts should be lead-covered and should consist of a number of twisted pairs of No. 22 B. & S. gauge, double silk- and cotton-insulated, soft, tinned, copper wires. The size of the distributing cable is determined by the number of outlets it is to serve. An extra pair or so should be allowed where possible. This will naturally follow where a 15-pair cable serves from twelve to fourteen rooms.

Even where one conduit serves more than one distributing box, only one cable should be placed in a conduit where practicable.

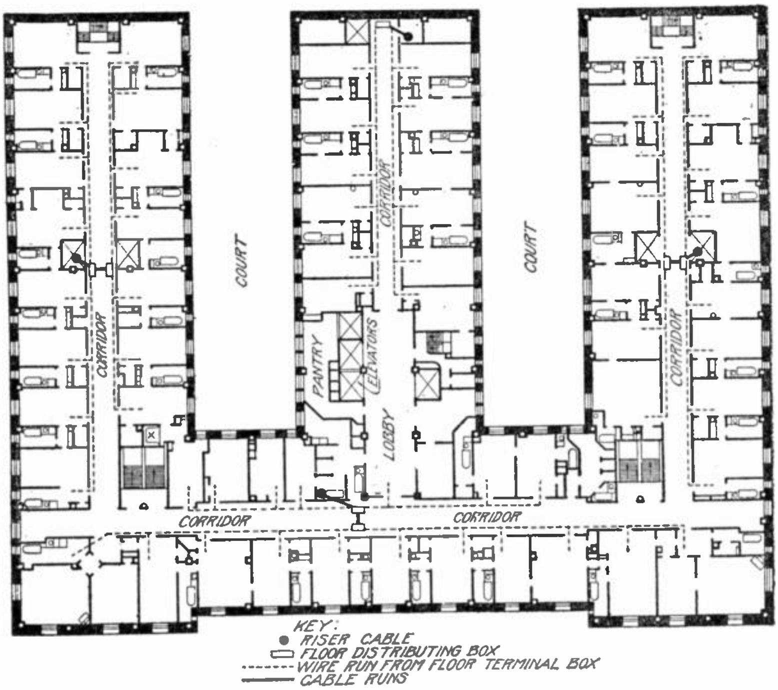


Fig. 645. Hotel Wiring

This may be done in most cases by tapering the cable at each box so that only the wires actually required will be carried ahead. At the riser-cable shaft or shafts, the distributing cables should be permanently spliced to the riser cable or cables, as the case may be.

Riser Cables. The capacity of the riser cable or cables should be made to equal the combined capacity of the distributing cables unless there is an unusually large number of dead wires in the latter. In case this number is large, the capacity of the riser cable or cables may be decreased as required and certain of the dead wires in the distributing cables on each of the floors connected to the same conductors in the riser cable or left dead, if desirable.

In hotels of not over five or six stories, the riser cable should preferably be of the same kind as the distributing cables; namely, lead-covered, with No. 22 B. & S. gauge, double silk- and cotton-insulated wires. The distributing cables then may be spliced to the riser cables at each floor.

In the larger hotels, especially where a large number of rooms are to be served on each floor, the first cost may be materially reduced by using lead-covered cables with paper-insulated conductors such as are used in underground conduits. Where this type of riser cable is used, it is better to make one splice to the distributing cables at every fourth or fifth floor, thus paralleling certain of the distributing cables for a floor or so, rather than to splice the distributing cable to the riser cable at each floor. The reason for this is that splices to paper cables are expensive to make and must be made with great care, since the paper insulation of the conductors will not stand rough usage or exposure to moisture.

To convey the riser cables to the main distributing terminal where silk and cotton riser cables are used, they are attached directly to the terminal strips on the main terminal rack, the exposed insulation first being dipped in hot beeswax. Where paper-insulated cables are used, the cable must be pot-headed before being attached to the terminals.

Typical Arrangement. Fig. 645 illustrates an actual example of the method of wiring for hotels.

Apartment Houses. The following notes refer in particular to those apartment houses which are of sufficient size, or of such a type as to warrant a private exchange. The requirements of this class of apartment houses are similar to the requirements of hotels.

In apartment houses, one telephone generally is required for each apartment. This makes the ratio of telephones to rooms considerably less than in hotels. It is for this reason that the method of wiring best suited for hotels is not generally the most economical or the best suited for apartment houses, except in cases of very large buildings or where the arrangement of the apartments on each floor is irregular.

In most apartment houses, the apartments on the several floors are arranged similarly. Should the telephones in each vertical tier of apartments be located in the same relative position, it will be seen that one vertical riser conduit running from the basement to the top floor can be made to serve all telephones in each tier of apartments, and in many cases, one conduit can be made to serve *more* than one tier of apartments.

Most of the preceding, relative to the location of the private exchange switchboard and the main distributing terminal in hotels, applies equally well to their location in large apartment houses.

Conduits and Outlets. Care should be taken not to overlook the conduit that may be required between the main distributing terminal and the private exchange switchboard. The size of this conduit will depend on the size of the cable it is to accommodate. Where possible, the conduit also should be run from the main distributing terminal to the point at which the service wires will enter. A 2-inch conduit generally is sufficient for this purpose.

To permit the use of the system above described, it is essential that there be an outlet in each apartment of each vertical tier, in line with the common vertical riser conduit. In most cases, the telephone may be located at this outlet. Should another location be desirable in certain apartments, an additional outlet box should be installed at the desired location and connected to the outlet box referred to above by a suitable run of conduit. Whether the outlet box is to be of standard or special design such as required for flush sets, or whether it is to be located for a wall set, or a portable set, will depend upon the type of instrument desired.

The size of each of the vertical riser conduits, which is determined by the number of wires it is to accommodate, may be tapered from floor to floor as the number of wires to be carried by the conduit decreases. All riser conduits should be carried to the main distributing terminal.

Main Distributing Terminal. The type of main distributing terminal best suited to most apartment houses is one which mounts in a cabinet, the size of which is determined by the number of apartments the terminal is to serve.

The telephone outlet in each apartment should be connected to the main distributing terminal by a twisted pair of No. 19 B. & S.

gauge, rubber-covered wires, which wires may be fished easily through the conduit after the latter has been installed. In some of the larger apartments, it will be found economical to splice the individual wires, at the bottom of each vertical conduit, to a lead-covered cable containing a proper number of No. 22 B. & S. gauge double silk- and cotton-insulated wires, thus conveying the circuits from the splices

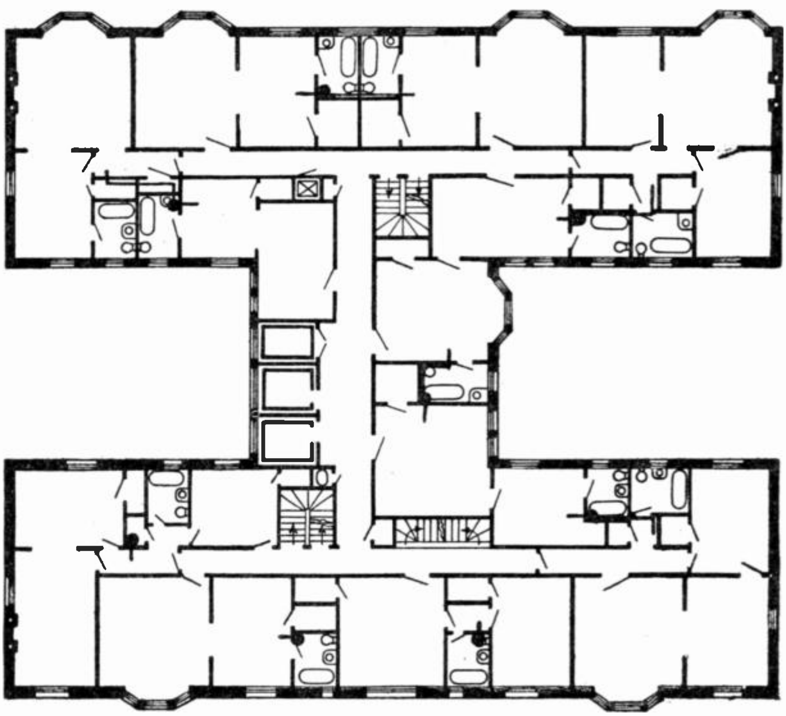


Fig. 646. Apartment House Wiring

to the main distributing terminal in the cable. Similar cable should be used to connect the main distributing terminal to the private exchange switchboard.

Typical Arrangement. Fig. 646 illustrates the wiring of a typical apartment house. In this case, a number of risers have been located so as to serve more than one apartment each.

Flats. Small apartment houses may be considered as flats, in that both classes of buildings do not, as a rule, require private exchanges. It may be said further that intercommunication between such apartments or flats generally is not necessary and sometimes is undesirable.

Location of Outlets. The location of each telephone outlet having been determined, there should be run to each outlet from the predetermined common distributing point a pair of No. 19 B. & S. gauge, braided, rubber-covered copper wires.

Distributing Point. The common distributing point preferably should be located in the basement. Should the building be served by an underground system, further provision for wiring need not be made unless the basement walls are finished, in which case conduits should be run through the finished portions of the basement, avoiding the necessity of carrying exposed wire or cable through a finished room. Should the building be served by an aërial lead, either at the front or at the rear of the building, two conduits should be run from the common distributing point to a point or points on the front or on the rear of the building, directly opposite the aërial leads from which the service wires or cables will be taken.

In small buildings of not over six or eight apartments, a distributing cabinet is not necessary. In larger buildings, a distributing cabinet should be arranged for at the common distributing point. It should have a removable door, hinged or otherwise, and should be approximately 6 inches deep.

Special Facilities. When desired, special facilities for local service can be provided which will permit a caller in the vestibule to ring and speak with the occupant of any apartment or with the janitor. The occupant of each apartment also may call the janitor or be called by him. To provide for such a system of course will require some additional wiring and special apparatus, but such apparatus does away with the usual tin speaking tube and push button.

Private Dwellings. The setting of the protectors and instruments, and the running of the wires may be carried out in private dwellings in accordance with the instructions already given. Whether or not concealed wiring is to be used will depend on the character of the dwelling and the desires of the owner.

CHAPTER L

ELECTROLYSIS OF UNDERGROUND CABLES

The practical result of the electrolytic hazards described in Chapter XVIII is, that if currents are allowed to flow away from cable sheaths or other metallic property in the presence of moisture for a long enough time, the metals will be injured. Fig. 647 is a

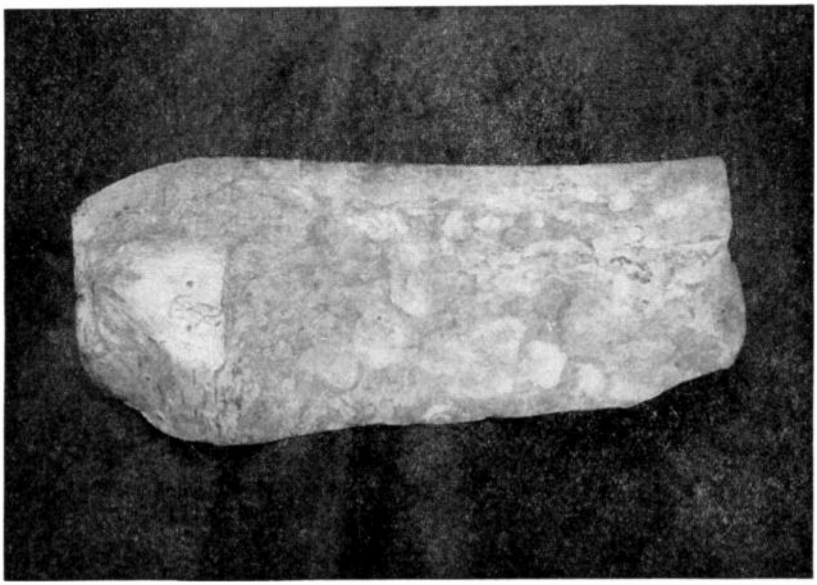


Fig. 647. Part of Cable Sheath Corroded by Electrolysis

photograph of a piece of cable sheath from which current at a pressure of 5 volts flowed to moist earth for a few months. If it had flowed a few months longer, the pitting would have perforated the sheath and moisture would have entered the cable core.

Early Controversy. As the principal, if not the only cause, of this hazard is the return current from ground return electric railways, it will be instructive briefly to recall certain phases of a controversy between telephone and electric-railway interests in the early days of each of these industries. It was not known then that this controversy involved the electrolytic hazard, and it was fought out on other lines; but the point of particular interest is that, had the controversy been decided the other way, electrolysis of underground cables would not be a serious enough matter to write about here.

It has been stated that all telephone lines were single-wire circuits in the beginning of practical telephone development, and for a number of years thereafter. It was the advent of electric light and electric street-car systems, particularly the latter, which made grounded circuits unsuitable for the best telephone service, the high-tension circuits while in operation making these single-wire telephone circuits noisy, and the street-railway systems causing not only noises but false signals as well, the annunciators of the subscribers' lines being frequently dropped by stray currents flowing over the lines.

As the street-car systems became more extensive in the cities, and particularly as their traffic grew heavier, the difficulties from these two troubles became quite serious. No remedy was discovered to be reasonably possible so far as changing the street-car system was concerned, except to provide each car line with two trolley wires, and each car with two trolley poles, making the street-car system wholly metallic circuit, the rails not being used at all for the return of the current to the power station. Such systems have been installed abroad, and such was the plan adopted in Cincinnati, Ohio. In that city, grounded telephone lines were successfully operated for a considerable time after the establishment of the electric-traction system. So long as the car trucks and wheels were kept insulated from the electric circuit of the motors, the telephone lines passing or ending near the trolley line were free from disturbances. If, by any defect in the car, a cross occurred between some part of the motor circuit and the truck, the progress of that car through the streets could be traced by one listening upon the telephone lines, and it was by means of this detective work of the telephone system that such defective cars were located, the listening subscribers observing from their windows the numbers of the noisy cars as they passed by. These cars were then withdrawn from service and repaired. The double trolley system with its distinct freedom from being the cause of trouble is still extensively in service in Cincinnati.

The existence of a so thoroughly possible traction system with its absence from disturbances to the telephone system caused legal action to be instituted in Ohio, wherein it was contended by the telephone company that as the traction interests possessed a means of operating their cars without interfering with the telephone system, the former should apply that method, or be compelled to continue it if they had applied it. The decision of the lower courts was favorable to this contention, and it seemed at that time as if the single-trolley rail-return traction system must disappear.

Court Decisions. In the higher courts this decision was reversed, it being held that the telephone company did not possess such a right to the use of the streets and the earth under the street, as to permit it to interfere with the proper use of the streets for transit and transportation. The ruling in effect was that the telephone company did not own the earth, as some phases of the attitude of the original monopolists have indicated they were inclined to believe. From this time the growth of single-trolley traction systems continued without further opposition from the telephone interests, and the burden of relief lay upon the latter.

McCluer System. One of the measures of relief was that devised by McCluer of Richmond, Virginia, and consisted in the simple expedient of providing for each main and branch route of the telephone system, a copper return wire to which the telephones of that district were connected, instead of being connected to ground. For a given route of 100 lines, for example, there would be 100 line wires plus one common return wire. The office of this was merely to provide a return path to the central office quite as the ground had provided such a path before, and its success depended upon its being kept clear of ground. In a sense, an exchange having single-wire lines and a common return wire on each route—the other returns being united in the central office—might be called a *metallic-circuit system,* because if the circuit is not grounded in any degree it must necessarily be metallic. In the accepted sense, however, a system utilizing a common return is only to be called metallic circuit by an excess of courtesy, because it partakes in a large degree of the disadvantages of a grounded system, the chief disadvantage being the lack of similarity in the two sides of the line, one side being its actual line wire, and the other the common return. As the latter has many lines connected to it, and as it is usually of copper and the line wire frequently of steel or of iron, the conductivity and electrostatic capacity of the two sides of a given line were distinctly unlike. The common return wire did, however, successfully cure the trouble due to the falling of drops from stray traction currents. These troubles, as they were due wholly to currents flowing between separated points of the earth, would no longer exist when the use of the earth as a return had been abandoned.

Metallic Circuits and Cables. Following this partial cure of new difficulties, the existence of metallic-circuit long-distance lines assisted in introducing the present general practice of making all subscribers' lines of two wires, with the consequent advantages, assuming proper transposition, of complete balance, complete quietness, and absence from false signals. This made it further advantageous to combine many lines in one cable, even though it must be of considerable length, because the complete balance of the subscribers' metallic circuit rendered it free from cross-talk troubles as well as from inductive noises. When it became possible to place many wires in one cable, it was further possible to place the cables underground, and such practice became general.

Electrolysis Troubles. In 1895, I. H. Farnham, chief engineer of the New England Telephone Company, observed the beginning of an epidemic of underground-cable troubles. In all of these new troubles, the difficulty was a failure of the underground cable due to loss of insulation, and the loss of insulation was found to be the result of the entrance of moisture due to an unaccountable appearance of holes in the lead sheath. With characteristic thoroughness, Farnham investigated all the elements accompanying this new trouble and conducted a series of experiments which led him finally to discover that the cause was the eating away of the lead sheath of the underground cable at a certain point, or at certain points in its length, which destruction of the sheath was due to the passage of current from the sheath to the earth in the presence of moisture, as has already been stated.

Causes. The corrosion of a lead sheath by currents passing from it to the earth must not be confused with any electrical use of the conductors of the cable, as it is entirely independent of such actions. The reasons the lead sheath is attacked at all are several: First, the existence of a single-trolley traction system, using the rails of the track as a return for current, does more than that statement implies. Whatever may be the condition of the soil in any city, the rails laid upon the earth will be assisted in carrying current by the earth's mass itself. This is true, however well the rails may be supplemented by copper return wires connected to them at intervals. Second, the cable sheaths themselves, being formed of a considerable amount of lead, a fairly good conductor, and laid in quite good contact with the earth itself, necessarily assist the rails and the rail-return in carrying current toward the power station. Perhaps this is as well told by saying that in any traction system, an examination of the territory covered will show that different points in the territory have different potentials with relation to the earth at the power station; and it is obvious that where differences of potential exist, and these are connected to each other by a conductor, current will flow. The amount of current which will flow is an immediate result of the amount of the difference of potential and of the conductivity of the connecting conductor, which in this case is the cable sheath. It is further evident that the difference of potential depends largely upon the number of cars which are in use at a given time, upon their location, and upon the amount of current they are drawing from the power station.

In almost all underground situations, moisture is present, and in addition has dissolved in it salts or acids of various kinds, which assist in the electrolytic process. A simple experiment of passing current from a piece of lead through moist earth to another conductor will establish the certainty of pitting the lead, while no such effect whatever results when the current is passed from a conductor through the moist earth to the lead.

Underground Conditions. Some idea of the conditions to which an underground cable is subjected may be gained from Fig. 648, in which it is assumed that, as is usual, the negative pole of the electric-railway power-station generator is connected to the rail and, therefore, to the earth, and the positive pole to the trolley wire; and that the telephone cable passes through the territory in such a way that one part of it is nearer the power station than the other. Indeed, it is not essential that this condition exist, because, due to the existence of other pipes and to natural conditions of the earth, a cable may be laid in such a way as to be always equally distant from the power station, and yet be subjected to the carrying of return current, because it passes through regions having different potentials with relation to the power station and, therefore, to each other. It is evident that, in a condition such as is shown in Fig. 648, no destruction of the cable sheath would take place at the point where current enters, near the ends of the portion shown, but that its sheath would be attacked in a greater or less degree at a point nearer the power station where the current is indicated as leaving the sheath.

An idea of the relative conditions of this destruction may be gained from the statement that a few volts difference of potential between two points of the cable sheath will cause a large current to flow therein, the resistance of the sheath being so very low. The

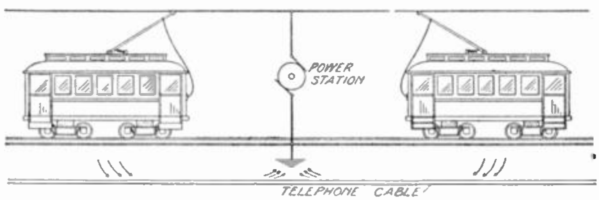


Fig. 648. Conditions Causing Electrolysis

destruction at the point where the current leaves it can be accomplished with a difference of potential between the sheath and the surrounding earth of less than one volt. In many cities there are differences of potential between different parts of the city of as high as twenty volts.

Remedies. As it has been accepted that single-trolley systems may be used and that differences of potential between points in cities must be expected, the prevention of cable-sheath damage must evidently come from work done upon the cable system itself. If the cable sheaths could be of some non-conducting material; or if the cables could be carried in dry and non-conducting underground pipes; or if the current entering the cables might be carried by their sheaths and caused to leave at a point where there was no moisture contact; or if some easily renewable metallic mass could be attached to the cable at each point where it has had a tendency to be destroyed, the problem might be considered solved.

Insulating Joints. It has not been found possible at all as yet to enclose the cable wires in anything but a metal sheath; nor is it generally feasible to occasionally insert insulating joints in the cable sheaths, which, while they seal the core satisfactorily, interrupt the continuity of the metal sheath. This remedy is being used with apparent success in a few places, and if it proves that it may be applied with practical certainty as to the tightness of the joints, it should result in at least a very considerable reduction of electrolytic hazard.

Moisture-Proof Conduits. To enclose cables having continuous metal sheaths in wholly dry and insulating conduits has been the fond dream of manufacturers and constructors, but so far as proof has been given, it is yet unrealized. Conduit material of paper or other fiber, saturated with asphaltic or bituminous compounds, may be presumed to be of better insulating character than clay-conduit material; but when in the earth, exposed at manholes, it has not been shown that a conduit system of this kind really and completely protects the cables from electrolytic damage.

Bonding. To attach to the cable sheaths at danger points some metal intended to be destroyed, is a precaution which is a practical one, with the simple objection that such an attached mass will itself be destroyed in time and will require replacing. The ideal cure is, of course, one which is applied once for all.

In general, the method that is employed is to provide dry metallic paths over which the current may flow from sheaths tending to be positive to other things, instead of flowing from them through moisture. Its application is called "bonding," as metallic bonds are provided as substitutes for moisture paths. This is the method that survives in general practice.

Two steps are required in applying a system of cable bonding: First, determine the areas of the city in which bonds are needed, and second, apply them and test the result. The first is done by a system of observations to determine the amount and the sign of the potential of each cable to the surrounding earth and things in it and on it. These things are, for example, the near-by rails of the traction system, water pipes, gas pipes, and other cables. It is convenient to record these observations on maps. Usually the cables in a region surrounding each power station of the traction system will be found positive to the negative bus-bar of that power station. Outside this critical area surrounding each power station, the cables

TERMINAL POLE FOR LONG SPACE ACROSS OHIO RIVER AT GALLIPOLIS, OHIO
A Better Practice is to Use Steel Towers.

usually will be found negative to the rails and to other conductors in their neighborhood.

Cables so negative are not in danger of corrosion, but cables which are positive are in danger of corrosion. Guided by the map record, copper bonds are attached to the cable sheaths at one end and

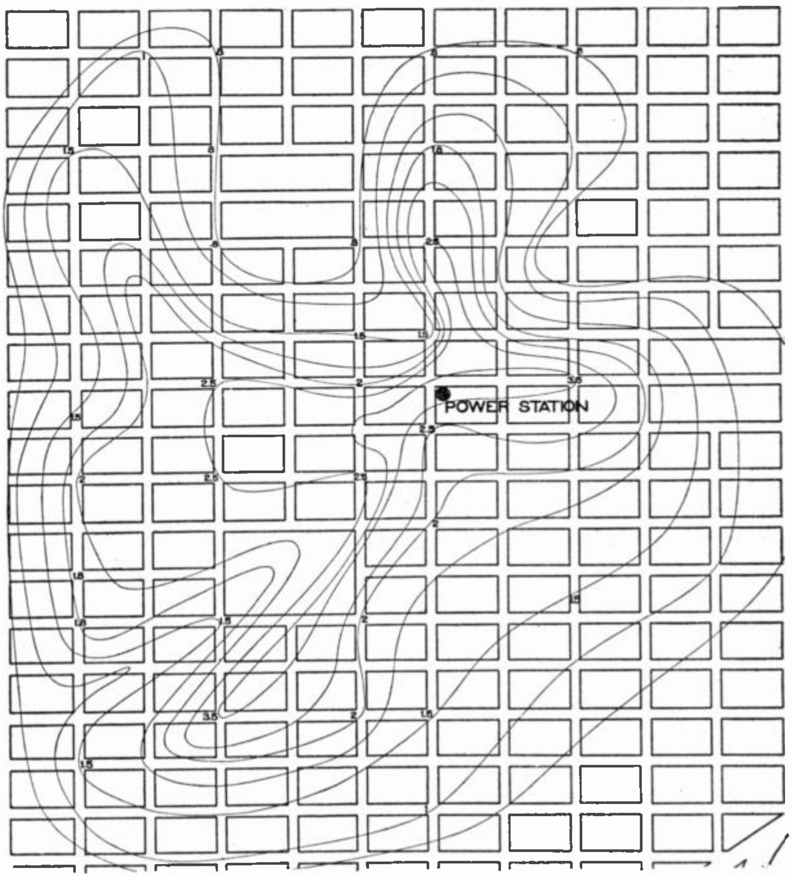


Fig. 649. Potential Map Surrounding Power Station

at the other to the negative bus-bar of the station or to something leading to it. Many traction companies use negative feeders to supplement their rails, as well as positive feeders to supplement their trolley wires. These negative feeders, therefore are admirable circuits to which to carry cable bonds. Bonding to the rails themselves is less likely to be permanently useful.

Fig. 649 is a map of a portion of a city in which lines join the points of equal cable potential and of similar sign. If copper enough be used in bonds between the cables of this area and the negative bus-bar of the power station of this area, these danger-indicating potentials may be reduced within negligible limits. A regular system of re-inspection and re-arrangement is imperative to keep them so.

CHAPTER LI

DEVELOPMENT STUDIES

A development study is an examination of the physical, commercial, and social conditions of a region to determine its present and future need of telephone service. Consciously or otherwise, a development study always is made before the construction of a new telephone system or part of a system. This study may be very simple, confining itself merely to a forecast as to how many telephones shall be arranged for at the time a very small switchboard, or even a single telephone, is placed in a village. Or the study may be very elaborate, as in the case of an entire reconstruction of the central offices, the equipments, and the wire plant of a large exchange covering many districts.

Long-Distance or Toll Line. Development studies address themselves to determining telephonic needs in and between cities and towns. The building of a long-distance line between two points, known to have little communication with each other because of small population and little mutual interest, might be assumed to be so simple a matter as not to warrant an investigation deserving the name "development study." No one would build such a line, however, without giving *some* thought as to whether one or two circuits should be erected at the outset. No one should build such a line without giving some thought as to whether the number of circuits to be required at a future time will be few or many. For if the general growth of the region should indicate that forty or fifty pairs of wires would be needed on that line during the life of the poles, good judgment would indicate that the poles chosen should be large enough and heavy enough to carry that many pairs. If it were obvious at the outset that the pole line never would need to carry more than three or four pairs within its life of twelve to fifteen years, it would be unwise to use heavy poles.

Long-distance development studies, therefore, are seen to address themselves largely to the amount of traffic which may be expected to develop in the future and to undertake to make such forecasts as will enable a conclusion to be reached as to the type of construction most economical for the case. If a development study in some form be not made, or if incorrect conclusions be drawn, the line may be built too light and have to be supplemented or rebuilt while its poles are still good; if it be built too heavy, it will carry throughout its life a greater investment than its earning warrants. A money loss occurs in both cases. Development studies are intended to limit these money losses as much as possible.

Exchange. If one should say: "Here is a town of one thousand inhabitants; let us install one hundred and twenty-five telephones, which will just about meet present needs," he would have made a development study. If the estimate should prove to be correct, he would have made a development study with little labor and at low cost. If the nature of the town should be that seventy-five telephones were all it could support at the outset, the development study would have been too sanguine, and its carrying-out too costly.

The construction and reconstruction of exchanges in cities over about twenty-five thousand inhabitants involves investments large enough to warrant the expense for painstaking care in examining the conditions as they are, forecasting conditions as they will be, and reaching conclusions from both. Experience in such study is increasing the knowledge and skill in the forecasting required. That phase of telephone engineering today has reached as high a development and those practicing it are as dextrous as are found in transportation and other forms of public service.

Scope of Study. An exchange development study undertakes first to determine what will be the population of the city at some selected future time; the distribution of that population over the area of the city; how many telephones it will require; where they will be located; how much traffic they will originate, and how much and what kind of wire plant, equipment, and housing will be necessary to handle that traffic.

The future date for which population, telephones, and traffic are to be forecasted usually is fifteen or twenty years from the time of the study. The further ahead the forecasting is done, the less accurate it will be. The intention is to have the time long enough to include the useful life of much of the property.

Estimates of future population are made by determining what the population has been during the past. In the United States and Canada, this is easier in the East than in the West, because the cities are older, have more recorded data, and also because they now grow more steadily.

Ratio of Telephones to Population. The ratio of the number of telephones to the population may be determined from the history of the exchange as it exists, although few elaborate development studies are made in cities having no telephones whatever. Notwithstanding the fact that the ratio of telephones to population has been increasing in most cities, a forecast may be made to estimate what that ratio will be at a future time. The product of this ratio and the estimated population will give at once a forecast of the telephones which may be expected at the future date.

House Count. Setting aside this general forecast for later reference, a "house count" is undertaken. A house count is, as its name implies, a count of the buildings in a city and is accompanied by an estimate of the telephone-using ability of the occupants. As the city is canvassed, the estimators determine, block by block, not only the character of the present population, but the probable tendency of the future population, its amount, and its distribution. As the study is made, it is customary to enter on a map, figures denoting the present possibilities, those in five years, and those in fifteen or twenty years.

Ratio of Telephones to Buildings. In residence areas of the best class, it is estimated that each residence will have one telephone at the ultimate time. In residence areas of other classes, some fraction of a telephone per residence is estimated. In business areas the sizes of office buildings are recorded and an estimate of future telephones is made from the probable number of ultimate offices. The ability of offices, hotels, and apartment houses to utilize private exchanges is estimated upon.

Comparison of Estimates. The result of a house count is an estimate of the ultimate telephones, and this now may be compared with the first estimate, which was the product of the forecast of the population and the ratio of telephones. It is likely that the two estimates will not agree. If they are widely at variance, one or the other may be re-studied until they harmonize. When the two estimates have been harmonized, the house-count record is taken as the distribution of telephones for which the future plant is to be designed. The first step is to determine the proper number of office districts and central offices within them.

Single-Office District. In manual practice, one central office usually is chosen for reasonably compact cities requiring under ten thousand lines at the ultimate time. By "ultimate time" is meant fifteen or twenty years hence or other term, depending on the chosen period of study. Ten thousand lines can be handled in a single multiple board without undue smallness of jacks and plugs.

If the city, or a part of it, has very great congestion, two or more ten-thousand-line manual switchboards may be placed in a single office. These conditions are unusual and are less likely to be found in America than in other countries.

Single vs. Multi-Office Districts. The greater the number of central offices in a city, the smaller the total length of subscribers' lines. For example, a city having ten thousand lines centering in a single office might have such an area as to make the average length of line two miles; this will require a total of twenty thousand miles of subscribers' lines, if these all are carried to a central office. If the city were divided into fifty districts of two hundred lines each, the average length of line might be one-tenth mile, requiring only one thousand miles of subscribers' lines. So far as subscribers' lines are concerned, therefore, the subdivision of the city into fifty districts instead of one has saved ninety-five per cent of wire.

But it is necessary to interconnect the fifty offices by means of trunk lines, and two kinds of circumstances determine whether these trunk lines will require much or little of the wire which has been saved from subscribers' lines by making so many districts—(1) the amount of traffic originated by the subscribers and requiring to be carried by the trunks; (2) the topographic form of the area of the city. In almost all practical cases, the more office districts there are, the fewer total miles of wire will be required for both subscribers' lines and trunks, because trunks *can* carry so many more messages than subscribers' lines *do* carry.

Multi-Office Districts. With any arrangement of offices, where there are more than one, the number of trunk lines varies directly as the number of calls originated by the subscribers. While the variation is direct, the ratio of originating calls to trunk lines is not, of course, a fixed one. As was shown in the chapter on Telephone Traffic, the call-carrying ability of trunks varies with the number of trunks in a group; the number of calls trunked out of an office depends partly on its size relative to the total number of lines in the city and partly on considerations local to the district of that office. The greater the number of offices in the city, therefore, the larger the proportion of calls trunked out of each and the greater the number of trunks which must be provided. For both reasons, the greater the saving in subscribers' lines by increasing the number of districts, the greater the cost of trunk lines.

The cost of maintaining, operating, and supervising manual equipments is greater with many offices than with few, the number of lines served being the same. The increase of cost, of maintenance, and of operation is less rapid with automatic equipment when the number of offices is increased.

Number of Office Districts. The operation of determining the proper number of central-office districts for a city is experimental. It is usually done by plotting the distribution of ultimate telephones on a map, arbitrarily dividing the city into districts, and successively comparing the arrangements with each other as to investment costs (*first costs*) and costs of owning, maintaining, and using the several arrangements (*annual costs*).

As the number of districts is increased in this experimental study, the first costs of subscribers' and trunk lines fall. Very likely this will be found to be true of first costs of manual equipment also, due to the lessening of the number of multiple jacks required. Costs of power plants and other things which vary with the number of offices will tend to increase equipment costs. When several arrangements with different numbers of districts have been made, one of them will be found to have the lowest annual cost when all elements of interest on investment and costs of operating and maintaining are included. Perhaps this lowest annual cost will be for one office rather than for several. If two arrangements of different numbers of districts are equal in annual costs, the one having the lower first cost shall be chosen because of that hazard of changing styles which is of such strong influence in telephony.

Central-Office Locations. The most economical district arrangement having been determined, a point is located in each district where the least wire will be required for the lines. Taking as an example a rectangular district in which the ultimate telephones are evenly distributed, the proper office location for the least wire would be at the crossing of the diagonals of the rectangle.

But districts are likely not to be rectangular in shape, and it is also probable that the ultimate telephones will not be uniformly distributed; hence this simple method of determining the ideal place for the central office is usually not feasible. For irregular shapes and developments of districts the ideal location for the central office is determined by dividing the district by two straight lines at right angles with each other in such manner that each line will bisect the total number of stations to be reached. The intersection of the two lines so placed is the ideal location in that it results in the minimum amount of wire. In such a determination trunk lines leading to other offices should be given the same weight as so many subscribers' stations.

It is not always possible to locate the central office at the ideal district center for greatest wire economy—for the excessive cost of property at the center might more than overbalance the added wire cost involved in having the central office elsewhere. The principal purpose of development studies is to teach one how to decide just such questions. It is obvious that when the study has shown where the central office *should* be, the next step is to learn where it *can* be, and to lay out the conduit plan and other details of the distributing system in harmony with the possible central-office position.

Conduit and Pole-Line Routes. Central-office locations being determined for each district, conduit routes are laid out. Speaking generally, it is good practice to provide a main or "backbone" conduit passing the determined central-office point, this main run having cross-routes extending from it at right angles. A good plan is to run these cross-routes on each alternate street, causing them to follow alleys if alleys exist. The cross-section of each conduit run is then determined from the house-count map, providing ducts enough in each run to accommodate the ultimate subscribers' lines to the central office, allowing also for trunk lines and such extra ducts as may be required for municipal purposes. In practice it is found that conduits of many ducts will accommodate more wires per duct in the average than conduits of fewer ducts; and in forecasting the number of ducts a conduit requires, more allowance has to be made for possible error in estimating the smaller runs.

Pole lines then are laid out in the area which surrounds the underground district. Distribution from conduits within the underground district is laid out to fit the local requirements, whether they call for direct entrances into buildings, distribution from terminals on back walls and fences, or distribution from poles in alleys or on private property within the blocks.

Ultimate Sizes. Central-office buildings and conduits when originally built usually should be of their ultimate sizes. It is generally not economical to add stories to a central-office building, although in some very large cities, where enormous development is expected and where real-estate values are high, the buildings are sometimes planned with foundations and walls of sufficient strength to sustain additional stories in the future. In cities of ordinary size, it may be economical to provide for extending the ground area of the central-office building, but it is not economical to reopen a conduit line in order to increase its numbers of ducts. When a conduit line is filled, it is often best to lay its relief ducts in the next parallel street.

A cable plan, made consequent to the completion of the conduit and pole-line plans, undertakes to show the general arrangement of ultimate cables and the exact arrangement of immediate cables. It is of advantage to utilize a definite system of multiple-cable distribution. One of the basic principles of such a system is that it undertakes to cause the number of wires leaving a central office to grow steadily as the wire requirements grow, while the terminal facilities of those wires are more generous at the outset and grow less rapidly.

As a practical example of what is meant, four thousand wires might leave a central office and by branching appear in twelve thousand terminal building posts or soldering clips. These twelve thousand available points could receive drop wires or back-wall wires or be connected by jumpers to cables in buildings. As the requirements of the district increase, additional wires will be run from the central offices, but most of them will be joined to the existing twelve thousand terminal points. Under ideal conditions no increase in the terminal points might be required during all the time when the four thousand wires were increasing to twelve thousand wires. At the latter time, in such a case, there would be no longer any multiple distribution, each wire from the central office going to one, and only one, terminal binding post.

Subdivision of Exchange Districts. In automatic practice it is becoming possible to furnish an acceptable telephone service with two kinds of districting in the same exchange. Assume a city to be divided into certain major districts, each containing a central office and a full complement of selector switches. Assume each of these major districts to be divided into a further number of minor districts, each containing merely individual line switches and connector switches. Each subscriber's line, with this arrangement, will have a district-office line switch. This line switch will have access to a plurality of trunks leading to the major office, terminating therein in a first selector. All second or third selectors, as the case may be, in major offices will have trunks leading to connectors in the minor offices.

By this arrangement practically all power-plant devices are located in the major offices. The smaller the minor districts, the shorter the average length of subscribers' lines will be, and the more minor districts the greater the trunk mileage leading from minor to major centers. Unless the character of the apparatus makes it require too much human attention, the saving in wire plant by this method will more than overcome the expenses which are added by the greater subdivision.

Broadly speaking, there is no reason why this major- and minor-district method is not applicable to manual practice. A full utilization of the economics of minor districting, however, requires that some automatic apparatus supplement the manual apparatus. The minor district centers, in such an arrangement, will have some counterpart of line switches and connectors; the major centers may contain manual switchboards which will make connections between lines as at present, but all the lines will be trunks.

Undoubtedly one of the most promising fields of development now offered to the telephone engineer is in the greater use of this sub-district plan of working and in the devising of systems of switching and operating adapted fully to harmonize therewith.

CHAPTER LII

CARE OF PLANT

Maintenance and Depreciation. Whatever be the cost or the value of a telephone property at the outset, its value at a later time depends on the care which is given to it as well as on the extent and kind of additions which are made to it. Circumstances may determine that the additions may be slight. Age affects inanimate telephone property as surely as it affects life. Economy and effectiveness in the care of a plant constitute the largest technical task in the management of a growing telephone system.

No element or general division of a telephone plant ever is as good again as it was on the day it was put into service. Each thing has some useful life; it may wear out, break, or be destroyed by accident, or it may lose its relative usefulness by the invention of something better. The economic loss due to the changing of styles in the art of telephony has been enormous. Viewing the art broadly, and particularly the ultimate good of the telephone-using public, most of the sacrifices in value by the adoption of newer and better things and methods have been warranted.

No amount of expenditure in maintenance charges can ever keep things new. One plan of maintenance may be so comprehensive and so exhaustive as nearly to do that, yet it may cost so much as to be most unwise to use. Another plan or way of executing a plan may spend too little and bring sections of the property too soon to their time of required replacement. The problems of deciding upon and carrying into effect wise methods of plant-care are as grave as those of good design, construction, and management.

Maintenance expense, properly viewed, is a cost for keeping property in as nearly as may be its original condition without replacement or reconstruction. The term "current repair" expresses the same thought. When a property has been maintained—kept in a proper state of repair for a certain length of time—its condition becomes such that economy requires making it over or putting something else in its place. These acts are respectively reconstruction and replacement. Neither is at all the same as maintenance or current repair.

The reason a property is replaced or reconstructed is because it has lessened in usefulness to a critical degree and a more useful or usable property needs to be put in its place or needs to be made out of it. "Lessening in value" is only another way of saying "depreciation." Speaking broadly, all telephone properties except real estate depreciate in value as time passes. The price of copper may advance, yet copper wire in use in lines usually depreciates in value as time passes. Insulated, outdoor copper wire depreciates in value steadily from the time of its erection, principally because rubber insulating materials and cotton braids are destroyed by the actions of air, sunlight, and moisture. Wood poles may last fifteen or twenty years before requiring to be replaced by others. When so replaced, those which have rotted at their lower ends may be cut off and used again. Such expense as was required to keep the poles in serviceable condition before replacement is maintenance cost. Such expense as was required to replace them, less the value of the poles replaced, is replacement cost. The shrinking in values of properties generally, due to the passage of time, is a depreciation expense. The cost of keeping them in usable condition while they shrink in value by the passage of time is a maintenance expense.

The hazards which passing time brings to bear upon telephone properties are principally those of decay, wear, and adjustment. Good design and construction limit these actions. Good maintenance practice repairs damage caused by decay, replaces parts made inefficient by wear, and restores adjustment.

The quality of telephone service is intimately connected with maintenance methods and maintenance costs. When an element needs repair it should be repaired so as to stay so and with as short a service-interruption as possible. The fundamental rules of maintenance are: *Be thorough* and *Be prompt.*

Thoroughness of understanding begets thoroughness of execution; knowledge of the functions (and reasons for functions) of apparatus and circuits begets a love of workmanlike handicraft. Workmanlike repair endures; slovenly repair has to be done over.

The largest reason for telephone service is time-saving. Multiple and automatic switchboards are the outcome of effort toward promptness in getting lines connected and disconnected. Promptness in restoring service is of as great importance as promptness in giving it.

The following are some general kinds of troubles and their remedies.

Outside Plant. *Supports.* Pole lines suffer principally by decay of pole butts; decay of cross-arms; gnawing of poles by horses; abrasion of poles by wheel-hubs; corrosion of anchors by electrolysis and by rust; and, in general, supports suffer by accidents. The preventive measures are creosoting; strip guards against gnawing, plate guards against wheels; strain insulators against electrolysis and good galvanizing against rust. Corrective measures are obvious.

Conduits. Underground structures suffer principally from the work of others than the owners. The most effective maintenance measure is watchfulness, seconded by prompt support of conduit lines undermined by excavation. Keep idle ducts plugged; if otherwise, sand, soil, and small stones will wash in. Watch manhole covers. Replace broken ones promptly. Clean out scrap left after cable splicing. It has value, and is a hazard if left in.

Open Wire. Bare wires on insulators suffer principally from two causes: slack and foliage. Slack wires cross with each other by wind. The tension on all wires of a span should be uniform. This lessens likelihood of crossing. The allowable tension is controlled by the temperatures of the region. Wires in foliage have low insulation, making their lines noisy and otherwise less efficient. Trim the trees, insulate those spans, or put the wires in cables. Open wires suffer from grounding by contact with suspension strand and guys. Clear such troubles by *permanent* measures. Twin drop wires (twisted pairs) under heavy strain, where wires overlie at supports, cut through rubber insulation and short-circuit the pair. Clear the cause by placing the wires side by side at such points of support.

Cables. Aërial cables suffer from punctures, bullets, beetle-borings, burns, and cracking. Such openings in the sheaths let in water from the air or from rain. Water destroys the insulating quality of the paper wrapping of the wires. Such a fault is called a "wet cross." It is repaired by stripping off the sheath as far as the core is wet, pouring on melted paraffin till it flows off without bubbling, and putting on a lead sleeve, split lengthwise to allow it to be placed over the uncut core. The split is soldered up and the ends wiped to the cable sheath.

Preventive measures are few. Arrange aërial cables so they do not bend and unbend by change of temperature, or by swaying. Do not place them where they will be subject to vibration. Be sure cables are firmly supported where they enter terminals. Keep them clear of contact with power circuits. Limit the flow of earth currents over them.

Underground cables are subject to the same "wet cross" troubles when sheaths are damaged. They are less exposed to punctures and flexures. They are more exposed to electrolytic corrosion. Keep them so connected to traction systems of distribution that little such current *leaves* them in the presence of moisture. Make and remake observations on these conditions. Change the corrective means as the conditions change. Watch the sheaths in danger areas. Support the cables in workmanlike fashion in manholes. Let each splice be freely accessible. Keep inflammable things out of cable shafts, vaults, and runways.

Subscribers' Equipment. In wall sets, receiver cords are the perishable element. Test them at every visit. In common-battery sets having magneto receivers in a wholly local induction-coil circuit, an open receiver cord means the subscriber can be heard but can not hear. In most other circuits, it means impairment or prevention of both hearing and talking. In portable sets, broken transmitter mouthpieces and receiver shells are chief troubles. Replace them promptly, look for unusual causes of falling of the set, and advise a suitable support. Inspect other things at every such visit. Recommend change of entire set when its appearance is such that you feel that *you* should have a new one if it were in *your* premises. But perhaps you could clean it somewhat and make a change unnecessary. The most practical sanitary mouthpiece is an ordinary one, frequently washed with soap and water. A patron often copies so good a habit. Clean carbon arresters on suspicion, understand thoroughly the proper functions and relations of the telephone set, and the rules of repair *always* will be obvious.

Manual Office Equipment. Cords are a source of trouble in central offices, as in subscribers' sets. Test them regularly. Tinsel cords become "scratchy" by breaking gradually; wire and metal-ribbon cords break abruptly. Breaks in a switchboard cord usually occur near the plug. Cut off the defective end and refit the plug.

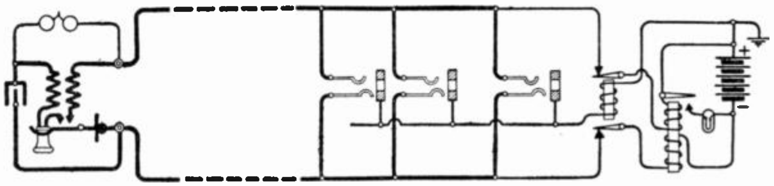


Fig. 650. Relay Multiple-Board Line Circuit

Put a good cord in place of a defective one, repair the latter ready for use, and keep up the process. The key shelf of a switchboard is the operator's workbench. It is not a repair shop. Use good tools and keep them in order.

Manual and automatic central-office equipments are growing more alike in their fundamental circuits. Understand them. All troubles are consequences of causes. Know the causes.

Because of its wide use, and because it is typical of all manual switchboards, the American Telephone and Telegraph Company's

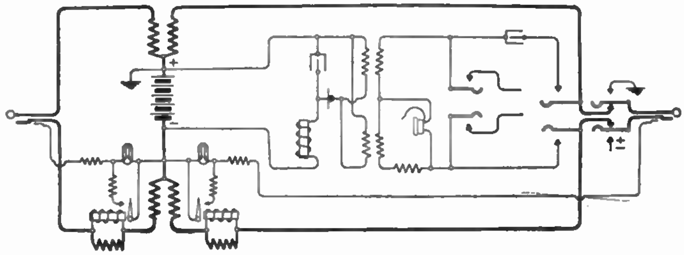


Fig. 651. Relay Multiple-Board Cord Circuit

multiple equipment is shown in Figs. 650 and 651. Some of the principal troubles and remedies follow. A study of the circuits in figure and in fact will be of more value to the student than reading many chapters in a book. In the cases of trouble, the causes given are several in each instance. Any one of them *may* be the cause. The tests are to show which *is* the cause.

Line lamp does not glow when subscriber calls. Lamp burnt out. Lamp terminals do not make contact with lamp socket springs. Line-relay lamp contact does not close. Line relay defective. Line is open. Test the line at the main distributing frame, determining whether the trouble is in or out. Test line relay. Examine lamp and socket.

Line lamp does not go out when operator answers. Cut-off relay defective; contacts of cut-off relay do not open. Test-strand of answering cord is open, failing to operate cut-off relay. Try several cords. Examine the common path for current to test-strands of that switchboard position. Test cut-off relay.

Line lamp glows steadily, though the subscriber is not calling. Line is short-circuited. Negative side of line is grounded. Line relay is out of adjustment, closing lamp circuit though relay is not energized. Test the line in and out at main distributing frame.

Line lamp glows when subscriber calls but operator can not hear subscriber. Defective subscriber's set; receiver cord broken; defective receiver. Answering jack defective; wiring to answering jack open. Try answering in multiple. If successful, answering jack trouble is proved. If unsuccessful in multiple, test from main distributing frame.

Line lamp glows when subscriber is being called. Line relay is not cut off because test-strand of calling cord is open; or supervisory lamp of calling cord is open; or cut-off relay is defective.

Supervisory lamp of calling cord does not glow when calling plug is inserted. Line in use, busy test absent or ignored. Line is short-circuited or negative wire grounded. Supervisory lamp of calling cord defective. Supervisory relay of calling cord has contact closed though relay is not energized. Try other cords. Test line.

Line tests busy when it is not busy. Improper local or foreign potential on test wire, giving differences of potential between test rings and plug tips Test wire is crossed.

Line does not test busy when it is busy. Test wire grounded. Test-strand of cord open at position where line is in use. Supervisory lamp open at that position.

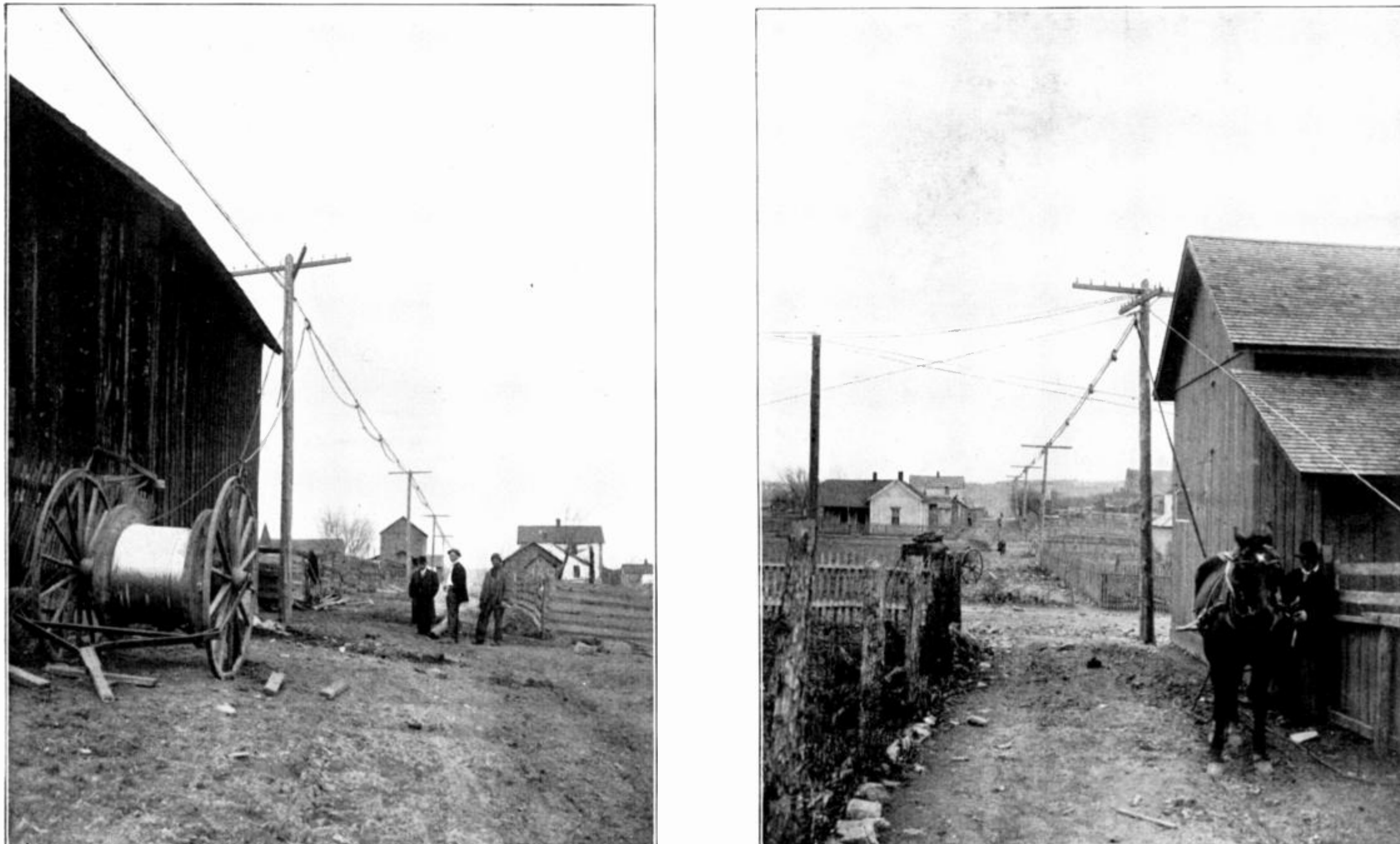
Line open in multiple. Test the line with regular cords; begin at section nearest main distributing frame; normal operation ceases when the open point is passed. To test for open without using the line, bridge a receiver in series with battery between successive points of wire in trouble. Clicks will not be heard when open point is included in series with receiver and battery.

Line or test wires crossed in multiple. Place tone or clicks on the crossed wires so the cross will shunt the interrupted current. Bridge a receiver across the crossed wires at different points. Sound will be heard *least plainly* nearest the cross. Watch for solder, wire clippings, and bent terminals in jacks.

Operator can not ring. Trouble in ringing current supply or in ringing branch to operator's position, because it is open, short-circuited, or grounded.

Operator can not hear or speak. Defective receiver cord, transmitter cord, plug, or jack of operator's set. Listening key troubles. If confined to one cord circuit, the latter. If common to all, the former.

Permanent signals. This is a colloquial term given to the condition where the line lamp glows even though the subscriber is not calling. As the sub-



ERECTING SMALL AERIAL CABLE USING MATTHEWS CABLE TROLLEY
Scenes at Beginning and End of Run.

scriber's call is shown by the lighting of the lamp, he can not call if current enough is passing through his line relay to hold it closed. Permanent signals may show when the line is otherwise operative, that is, a subscriber may be called and may talk, though his line may be short-circuited through a resistance low enough to operate the line relay.

In such cases, partial service may be given by transferring the line to a hospital board or other arrangement having a relay with a lamp on its back contact, which lamp will light when the trouble is cleared, thus advising that the line may be restored to service on the multiple board. Calls for lines so in trouble may be referred to positions so equipped and such calls often can be completed when they would fail if handled in the regular manner.

Automatic Systems. Systems of the Automatic Electric Company vary in nature. Those requiring successive contacts between the line wires and ground in order to operate selectors and connectors are called *three-wire systems.* Those requiring successive makes and breaks in the line to operate selectors and connectors are called *two-wire systems.* No ground connections at subscribers' stations are required in the two-wire systems.

In early types of automatic systems, each subscriber's line is connected permanently to an individual first selector. Second and third selectors and connectors are common devices, being chosen for use when required. In later types of automatic systems, individual line switches less elaborate than first selectors are permanently connected to subscribers' lines, and selectors and connectors are chosen when required. All selectors and connectors of the Automatic Electric Company's systems, either two-wire or three-wire, with or without individual line switches, are of one general type as to mechanical motions. In all of them the connection between the calling and called portions of the line is made by metal wipers (seeking contact-pieces), which pass over sets of punchings (waiting contact-pieces), stopping on a desired or an available set.

The mechanical motions of selectors and connectors are two: vertical and rotary. The wipers make no connection with contacts during vertical motions; they sweep over contacts during rotary motions. Most selectors and connectors change their functions several times during a set of operations of connecting and releasing. These changes principally are caused by motions of a side switch or its equivalent. A side switch is a device adapted to repeal one set of electrical conditions and establish another. Each position of a side switch represents the conditions of one particular set of functions.

Wipers carried by the shaft of a selector or connector are either four or six in number. Always they represent three conductors.

The analogy is close between line circuits in automatic systems and in multiple manual systems. Each has two line wires and a test wire. The latter in automatic systems is called the *private wire* and like the test wire in manual systems, it is local to the office. Its principal duty is to guard a line in use against intrusion by another line calling it. In some automatic systems it is called a *guard wire.* The bank of private (guard, test) wires usually is mounted above the bank or banks of line wires. Line wires may be in one bank of 100 pairs or two banks of 50 pairs each.

Opens, crosses, and grounds in automatic multiples may be tested for the same as in manual multiples. These problems usually are simpler in automatic systems, as the multiples are limited to 100 lines (300 wires).

Selector and connector switches require their shafts to be kept clean and lubricated. Wipers are required to be kept adjusted so as to engage and disengage contacts freely. Side switches require adjustment tight enough to ensure good contacts in each position, yet weak enough to move freely; these two requirements being opposed, a compromise is necessary. Better side switches or equivalents would avoid this compromise. Fine graphite on side switches is a great help and causes no trouble.

Automatic equipments require that switches be kept *warm, dry,* and *clean.* If the switches be cooler than the air around them, they will condense water from the air for the same reason that dew forms Moist switches operate less freely than dry ones. Freedom from dust is essential in all telephone equipment.

Soldering. Soldering is the most important handicraft of the telephone repairman. The first rule in using soldering tools is that the tip of the copper, or "iron" as it is called, shall be kept clean and well tinned. By the latter is meant that the surface of the copper shall be kept evenly coated with solder thoroughly united with it. Good work is impossible unless this tinning exists, and it cannot exist unless the iron be kept reasonably smooth and free from corroded spots. From time to time the iron must be dressed up by filing, and occasionally during use should either be dipped in sal ammoniac solution for an instant or wiped on a pad of cotton waste which is saturated wtih sal ammoniac solution. This tends to clean off the copper oxides which gather on the metal and thus "insulate" it from tinning. The copper must be hot when dipped in or wiped on the sal ammoniac solution, and there should be some solder on the iron at the time; it will be found to spread easily, with a little rubbing, all over the surface of the tip.

With a clean, hot copper it is easy to solder together two pieces of metal already coated with solder, unless they be so large that they cannot be well heated by the copper. If both parts are tinned or coated with solder, then the only flux required to make the applied solder flow is rosin, and in telephone work most soldering is done with solder already provided with powdered rosin in it. Good results cannot be expected in soldering untinned metals together with rosin only, so that it is unwise to use untinned copper wire in connection with switchboard apparatus. The reason for using no other flux than rosin about apparatus is that none has been discovered which will serve its purpose as a soldering flux and leave the insulating parts in any sufficient state of insulating quality after the work is done. Many fluxes also tend to corrode the wires and apparatus parts after the soldering has been done.

The code of the National Board of Fire Underwriters specifies a flux composed of chloride of zinc, alcohol, glycerine, and water. This is a good material for soldering untinned surfaces, as it is easily applied and remains in place, causes the solder to flow freely, and is not the most corrosive of chemical fluxes after the soldering is done. But useful as this flux may be in such work as mending tinware and patching up mechanical devices, it is *absolutely to be prohibited* in the soldering of conductors to each other and to apparatus in telephone systems. Equal condemnation must be given to all forms of *paste* and *soldering sticks,* none of which is more suitable in these particulars than is the chloride of zinc solution.

If parts of apparatus can be soldered together and then washed before assembling, there is no more hurtfulness in using acid or alkaline soldering fluxes than in the use of chemical solutions in the process of plating. But one must appreciate exactness of division between a rosin flux on the one hand, and all other fluxes on the other, as being suitable and unsuitable, respectively, for use in soldering conductors in the assembling and repairing of telephone apparatus.

CHAPTER LIII

TESTING

Electrical tests are used to determine the qualities of working lines and apparatus, the same fundamental principles being applied also to the latter during the process of manufacture.

Implements. Tests of lines are made by voltmeters and galvanometers. In both, one magnetic field is created by the current and another by a permanent magnet. In the D'Arsonval galvanometer and in the commercial direct-current voltmeters of the same type a suspended or pivoted coil moves in the field of a permanent magnet. In the Thomson type of galvanometer, however, a suspended permanent magnet moves in the field of a coil. In all three cases, the current in the coil moves an index pointer which, in voltmeters, is a flattened aluminum wire, while in galvanometers, it is such a flattened aluminum wire or it is a beam of light reflected upon a scale or into a telescope. Voltmeters have scales graduated in volts and fractions of volts while galvanometers have scales arbitrarily graduated.

Although magnetic voltmeters do not measure true differences of potential, they do measure currents. But currents are consequences of differences of potential, so a magnetic voltmeter measures volts within close limits of error if the resistance of the voltmeter coil is high, relative to the resistance of the circuit external to it. Electrostatic voltmeters measure true differences of potential, but they are not commercial for low pressures.

Faults. Voltmeter tests of telephone lines cover all necessary measurements except accurate *location* of faults, and tests for acceptance of cables and line materials. They are adapted for the use of the wire chief of an office, as they are more rapid than galvanometer tests. Wire chief's tests cover:

Insulation resistance (grounds)
Continuity (breaks; opens)
Crosses

Conductor resistance
Discharge capacity
Foreign currents (earth potentials)
Talking, ringing, and adjustments

These tests usually are made from the wire chief's desk, which has voltmeter, relay, sounder, and key circuits, and, in automatic equipments, has test switches for observing the performance of impulse-sending mechanisms (calling devices).

Galvanometer tests cover:

Conductor resistance
Insulation resistance
Capacity
Opens
Grounds
Crosses

The last three are "faults." Finding them is "fault location."

Continuity. Figs. 652 and 653 are tests for continuity. If the wire under test is continuous, the voltmeter will show almost the full voltage of the test battery. Consider the pair tested in Fig. 652

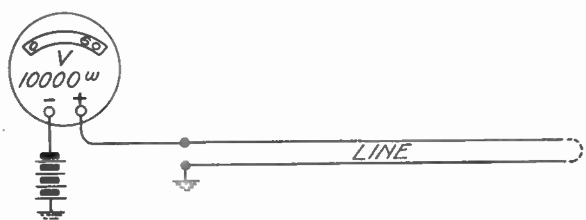


Fig. 652. Test for Continuity

to be open at the distant end; the test then is for insulation between the upper wire and all grounds. Its insulation is inversely as the deflection—high if the deflection be small, low if the deflection be large. If the deflection be half the full voltage of the test battery, the insulation of the tested wire is the same as the resistance of the voltmeter. In the case cited, if the test battery is of 60 volts, the deflection through the wire 30 volts, and the voltmeter's resistance 10,000 ohms, the insulation resistance of the wire is 10,000 ohms.

Insulation. Tests for insulation and continuity are made also by means of a relay and sounder. With a fixed voltage and adjustment of relay, the sounder of Fig. 654 will respond for insulations below a certain amount.

Foreign Potentials. Foreign potentials are read on the voltmeter by the circuit of Fig. 655. Be sure the potential to be read is

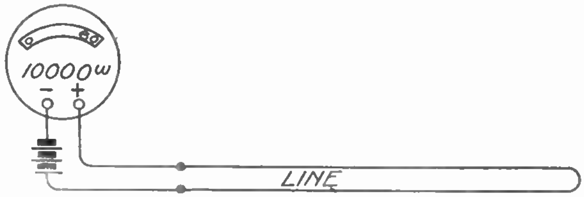


Fig. 653. Test for Continuity

not greatly in excess of the voltmeter's scale. A lamp of higher voltage is a convenient device for a first test, for if it is damaged, the

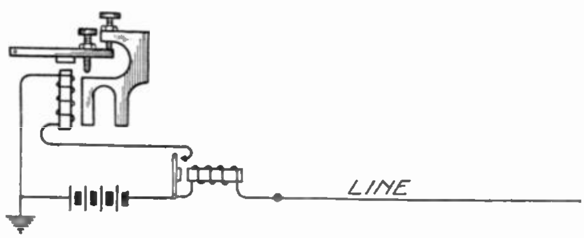


Fig. 654. Sounder Test for Insulation

loss is small. The key of Fig. 655 enables the voltmeter's connection to the line to be reversed if the foreign potential requires it.

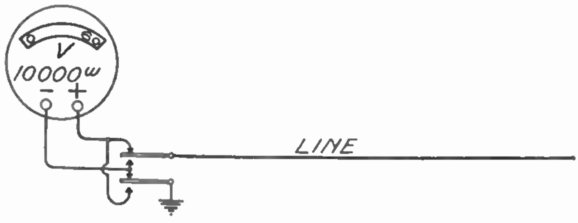


Fig. 655. Test for Foreign Potentials

Capacity. Capacities of lines usually are measured by galvanometer methods. Often it is useful, however, to check the condition of a line by taking a discharge reading on a voltmeter. The condenser in the subscriber's telephone, if the line is in good condition, will give a large deflection on the voltmeter. If the line is not in good condition, the deflection will be less. The key of Fig. 656, when depressed, allows the battery to charge the line and the condenser.

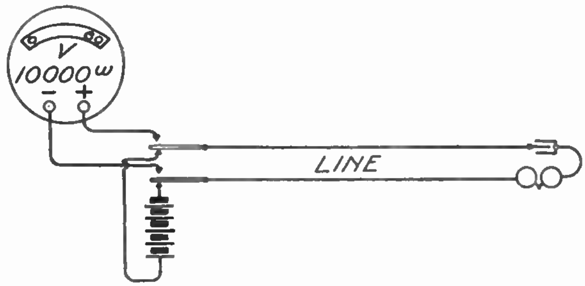


Fig. 656. Discharge Test for Capacity

When the key is released, the condenser and the line discharge through the voltmeter, the degree of deflection indicating the capacity. This method is used for measuring the capacities of condensers as they are made.

Opens. Open wires in cables may be measured in the same manner as are capacities. A good wire being available, the discharges from the open and the good wire may be compared, their lengths being as their discharges. Fig. 657 shows a simple method using

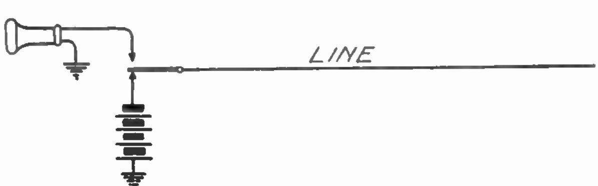


Fig. 657. Telephone Test for Capacity

a telephone receiver. The larger the capacity, the louder the click when the key is released. Expert workmen can estimate the distance to a break by this simple test.

Resistance. Resistance of a wire or loop is measurable by voltmeter methods. The process is: Read test-battery voltage E. Read voltage with line in series D, as in Fig. 658. Let R be the line resistance desired and V the voltmeter's resistance. Then

$$R = V\left(\frac{E-D}{D}\right)$$

which in words is: *Deduct voltage with line in series from full test-battery voltage; multiply this remainder by the resistance of the voltmeter; divide by the voltage with line in series. The result is the line resistance.* In Fig. 658 with the voltmeter resistance 10,000,

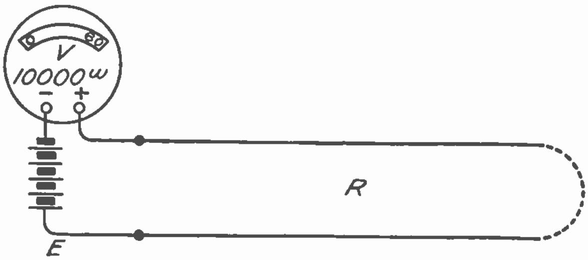


Fig. 658. Test for Resistance

consider test-battery voltage to be 60; deflection through line, 25. Then the line resistance is 14,000 ohms.

Low resistances are more accurately measured with low-resistance voltmeters. That is, it is obvious that the full test-battery voltage and that through, say, 300 ohms of line wire, would give similar deflections on a 10,000-ohm voltmeter, but when the voltmeter is shunted so as to give it an effective resistance of the desired amount, this difficulty disappears.

For example, in Fig. 659, a shunt of 416.66 ohms is placed across a 10,000-ohm meter, making the joint resistance 400 ohms. Using this

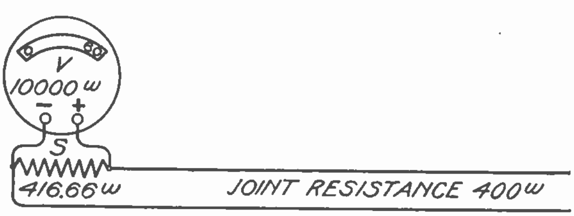


Fig. 659. Shunted Voltmeter

as in Fig. 660, a lower resistance may be measured with greater accuracy than with the unshunted instrument. Assume the test-battery deflection to be 40 and the deflection through the line to be 25; then, by the formula given, the line resistance is six-tenths of 400, or 240. With the unshunted voltmeter the deflections would have been much closer together, viz, 40 and 39.06, making the difference—.94 volt—less easy to read accurately than in the case of Fig. 660 for the same line resistance.

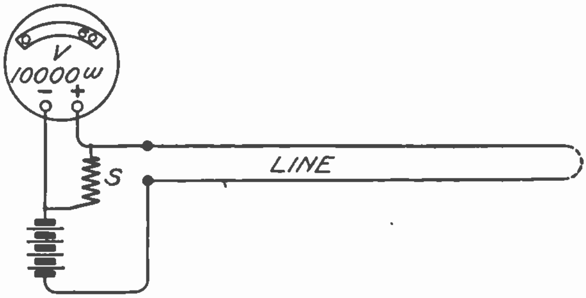


Fig. 660. Loop Resistance Test

Crosses. Tests for crosses, as in Fig. 661, are made by observing one of the suspected wires while ground (or the pole of the battery not joined to the voltmeter) is applied to the other suspected wire. If the ends of the crossed wires are in offices equipped for testing in this way, as in the case of trunks, both can measure resistance in-

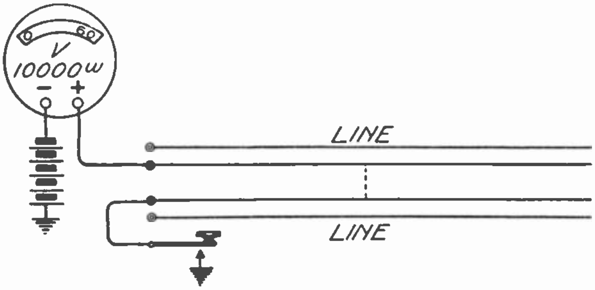


Fig. 661. Test for Cross

cluding the cross. The loop resistance of a good pair being known accurately from records or actual test, it is easy to know just where the cross lies. For instance, assume that the loop resistance of the wire is 160 ohms. One wire chief measures the loop through the cross to be 1,195 ohms; the other finds it 1,125 ohms. Each has included all the wire from his office to the cross, and the cross itself also. Each has measured a different part of the loop but the same cross. The difference between the resistances observed by the two wire chiefs is 70 ohms. This is the difference between the two parts of the loop. The sum of the two parts is 160 ohms, for that is the known whole loop resistance. The sum being 160 and the difference 70, the two parts must be, respectively, half of (*160 plus 70*) and half of (*160 less 70*), or 115 and 45. These are the loop resistances to the cross from the two offices.

Wire-Chiefs' Desks. Facilities for the tests illustrated in Figs. 652 to 661 are combined in modern wire-chiefs' desks. The voltmeter, sounder, and telephone set, in such equipments, are associated with cords, plugs, lamps, and keys so that all the tests are available quickly.

Tone Methods. Mutual inductive action enables grounds to be located with great accuracy by means of the simple apparatus of Fig. 662. This method was first used by power companies for the loca-

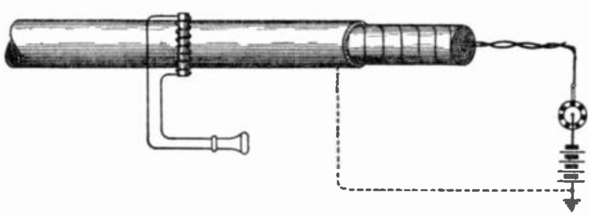


Fig. 662. Fault Location with "Jigger"

tion of such faults in underground cables. It has been re-invented in several forms for telephone purposes, marketed as a trade secret, and published by at least three persons—L. R. Hoffmann, William Maver, Jr., and Donald McNicol. The exploring device is called by many a "jigger"

The apparatus consists of two parts: a tone-producer—indicated in the figure as a commutator interrupting a battery circuit—and a receiver joined to an exploring coil. The latter is held with its turns parallel to the cable. The tone on the grounded wire can not be heard in the receiver beyond the fault, but can be heard between the fault and the end where the tone is applied.

Identification. Identifying the conductors of a cable is the kind of testing most often necessary in construction and installation. The methods are simple. In testing an aërial or underground cable for the identity of its conductors, connect the wires to the office terminal first. Identify the various groups of pairs and connect them in a recorded order. These groups are the fixed parts into which the whole number of pairs is divided, and their existence greatly simplifies the work of testing out. A telephone receiver, a buzzer, a vibrating bell, or a polarized ringer, may be used to identify the wire upon which the testing current is placed; the latter naturally should be that of a battery or generator, depending on which of the detecting devices is chosen. As pair by pair of the cable is identified, it is placed in position on the terminal to which it is to be fixed, and when a given group or the whole cable has been tested out, the whole test should be repeated rapidly to discover any error which may have crept in. In order to make the identification of pairs rapid and easy, switchboard cables are laid up of pairs in which one wire of each differs in color or marking from the rest.

Cable Testing. When an aërial or underground cable is placed in position and terminated, the tests for identifying the conductors will have shown whether any of the wires are open and whether any of them are crossed with each other. The fact that they are open or grounded on the sheath will be shown by a failure to get the testing potential from the distant end. The fact that they are crossed together will be shown in the first or final test for identification by the fact that current is received over more than one wire when it is sent from the distant end on only one. For this reason the final test should be made, running over the whole group in checking the identification of each conductor.

Cable Quality. When this part of the work has been completed, it is necessary to know whether the conductors are in good condition and whether they comply with the guarantee of the manufacturer. This guarantee, or requirement of the specifications under which the cable was made, provides that it shall have an insulation resistance not below a certain number of megohms per mile and an electrostatic capacity not above a certain fraction of a microfarad per mile. The insulation resistance per mile is simply the resistance of the insulating material, and with reference to testing and the quality of lines is often referred to as "insulation." Because it is simpler, insulation resistance is usually expressed in megohms. The insulation resistance ordinarily required by specifications and usually guaranteed by manufacturers, is 500 megohms per mile or more, and it is not difficult to make and install cables which will have much more than this degree of insulation resistance.

The method of finding out the amount of insulation resistance of a cable is, in principle, simpler than that of finding the resistance of a wire and simply involves the allowing of the current to flow through a galvanometer into the wire under test, from which it will then flow through the insulation resistance to the earth or to the cable sheath. In all the accompanying drawings of testing methods a ground is shown. It is to be understood that the sheath of the cable may be considered to be that ground in case it is the testing of cable conductors which is considered with reference to the drawing.

Thomson Galvanometer. Because the insulation resistance of cable conductors in reasonably short lengths is very high, and because the potentials to be used in testing must be kept within reasonable limits for conditions of safety, the galvanometer for insulation-resistance tests must be of high sensibility. The first successful form of high sensibility galvanometer was that designed by Lord Kelvin and was used for receiving signals over the early Atlantic cables. He changed the form of earlier galvanometers having a compass needle and a coil, by making the needle very light, suspending it by a single fiber of unspun silk, attaching a very light silvered glass mirror to the needle, and surrounding it with a large coil of very fine wire. This arrangement makes it possible for very feeble currents in the wire to move the needle and the mirror in some degree. In addition to these advantages the mirror reflected a beam of light upon a scale, thus multiplying the mirror's movement. As a beam of light so used as a pointer is always straight, as it can be of considerable length, as it has no weight, and as the angle of the mirror's movement is always doubled, the Thomson reflecting galvanometer was a remarkable step forward. It enabled things to be done which could not be done before—and this is the measure of the value of invention.

D'Arsonval Galvanometer. For two reasons the Thomson galvanometer is a particularly annoying device. The silk-fiber suspension of the mirror system is so delicate that it often is found to be broken at the critical moment of use, also the instrument is sensitive to mechanical vibration and to external magnetism. D'Arsonval reversed the arrangement of elements of the Thomson instrument, and used a light *movable* coil and a powerful *fixed* magnet. The coil can be suspended in different ways, but always by means of wires or other conductors, so that current may be carried to the coil even though it is movable. A mirror carried by the coil throws a beam of light upon a scale, or allows the use of a telescope, which is pointed at the mirror, and receives the *reflection* of a scale, usually attached to the telescope stand. The telescope forms a magnified, inverted image and hence the scale is marked with reversed figures and is placed in an inverted position on the stand. What the observer sees, therefore, is some portion of the scale, erect and non-reversed. The sensibility of this type of galvanometer is not as great as that of the Thomson form, but its many advantages make it the best existing form.

Galvanometer Shunts. For all purposes of measuring insulation resistance, the galvanometer must have a means of reducing the current passing through it; this is accomplished in the use of a shunt. Commercial galvanometer shunts are small resistance boxes containing coils, of resistances proportional to that of the galvanometer. A common form has four coils in one box, with arrangements for selecting any one of the four, the resistances of the coils being respectively 1/9, 1/99, 1/999, and 1/9999, of the galvanometer resistance. When the galvanometer is shunted by one or the other of these coils, 1/10, 1/100, 1/1000, or 1/10000 of the current will pass through the galvanometer coil, and the remainder through the shunt.

Insulation Resistance. In addition to the device already mentioned, other essential things for insulation-resistance tests are, a key which normally short-circuits the galvanometer, some kind of a switch, a battery or other source of potential, and a standard high resistance. The arrangement of these parts is shown in Fig. 663, and the method of using such an arrangement is as follows: First find the deflection which the galvanometer will give through the standard high resistance of known amount; then the deflection with the same battery through the insulation resistance to be measured. If the standard high resistance were of many megohms, this comparison would be simple. However, as a standard resistance of many megohms would be expensive and bulky, it is customary to have the standard resistance 100,000 ohms, which is 1/10 megohm, and to make a preliminary test-reading through that resistance with the assistance of the galvanometer shunts. Making such a test-reading to determine conditions for testing the unknown insulation resistance is called "getting a constant."

To find this constant, place the switch in Fig. 663 in the proper position, use the largest shunt, press the short-circuit key and observe the deflection; if it is very small, release the short-circuit key and choose the next lower shunt; again press the short-circuit key and observe the deflection; if the deflection is on the scale, and is fairly large, note it as soon as it is well settled; if not, take a lower shunt

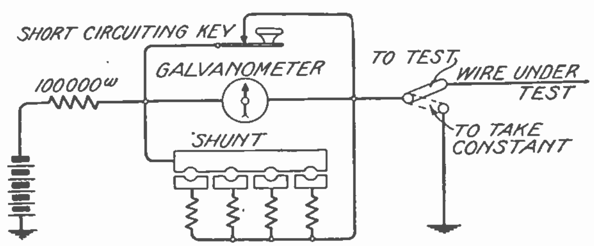


Fig. 663. Insulation Test

and when a satisfactorily large reading is secured multiply it by the multiplying value of the shunt and by the resistance in megohms of the standard. For example, suppose the following conditions to exit:

Shunt, 1/999

This will let only 1/1000 of the current through the galvanometer; the multiplying value of this shunt is 1000.

Standard resistance, 100,000 ohms (1/10 megohm)

Deflection, 85 scale divisions

The constant is, therefore, $85 \times 1000 \times 1/10 = 8{,}500$

That is, the insulation resistance through which the same battery would give one scale division deflection is 8,500 megohms. The result of this preliminary operation is to give a constant number which may be used through a series of tests and which only needs to be re-secured at intervals to make sure the conditions have not changed.

The constant secured, throw the switch shown in Fig. 663 to the position required for testing, select a shunt, depress the short-circuit key, hold it down one minute, note the deflection, and if necessary repeat the process, selecting lower and lower shunts or cutting out the shunt altogether. In most cases the first trial will tell whether any shunt is necessary. Suppose that with no shunt a reading of five divisions is secured. The insulation resistance of the wire under test will then be found at once by dividing the constant 8,500 by the observed deflection 5, giving 1,700 megohms as the actual insulation resistance of the wire under test. Similarly, if the deflection with no shunt had been found to be 10 scale divisions, the insulation resistance of the wire would have been 850 megohms. If the wire had been in such condition as to give 15 scale divisions with the $\frac{1}{9}$ shunt on the galvanometer, the multiplying power of that shunt tells us that 150 scale divisions would have been given with no shunt. Therefore, the insulation resistance in such a case would be 8,500 divided by 150, which equals $56\frac{2}{3}$ megohms, the insulation resistance of that conductor.

In all these cases the observer was getting the insulation resistance of the wire irrespective of its length, and it is necessary to know the result in megohms per mile, as the guarantee and the specifications were written in such terms. When it is remembered that the reason the insulation resistance is not immeasurably high is that current is leaking from the conductor through its insulating material, it will be seen that with other conditions equal, the longer the wire the lower its insulation resistance; so that the insulation resistance of one mile of such wire will be greater than that of two miles or less than that of a fraction of one mile. To determine the insulation resistance per mile, therefore, of any conductor, learn its actual insulation resistance as described, and multiply this result by the length of the conductor in miles. For example, in the case first cited, having an actual insulation resistance of 1,700 megohms, suppose the length to be $\frac{3}{8}$ mile. Multiply 1,700 megohms by $\frac{3}{8}$ and the result, 637.5 megohms, is the insulation resistance of that conductor per mile.

In case short lengths of cable, found by preliminary tests to have high insulation resistance, are to be tested merely to discover whether the manufacture and erection can be passed, a number of wires can be tested at once, thus shortening the operation greatly. Taking the case of the cable which had a conductor testing 1,700 megonms actual insulation resistance, if 50 pairs (or 100 conductors) had been tested at once, the result would have been 17 megohms instead of 1,700 megohms, assuming the character of all the wires to be the same.

In all measurements of cables for insulation resistance it is customary to test each wire against all the rest grounded with the sheath. If the wires are tested in groups, all except the group under test should be connected with the sheath and to ground. Measurement of insulation resistance by means of galvanometers and voltmeters is the most usual way.

The "Megger":—A device known as a "megger" nas come into some use and deserves more. It consists of a hand-driven generator, a coil moving in a permanent field, a pointer, and certain stationary coils, not required to be adjusted. The circuit whose insulation is

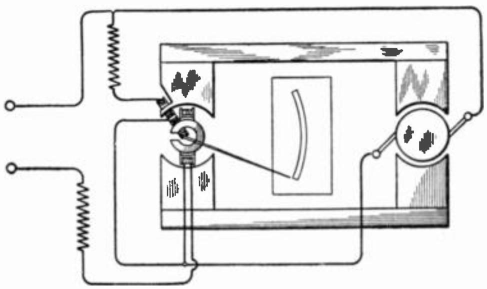
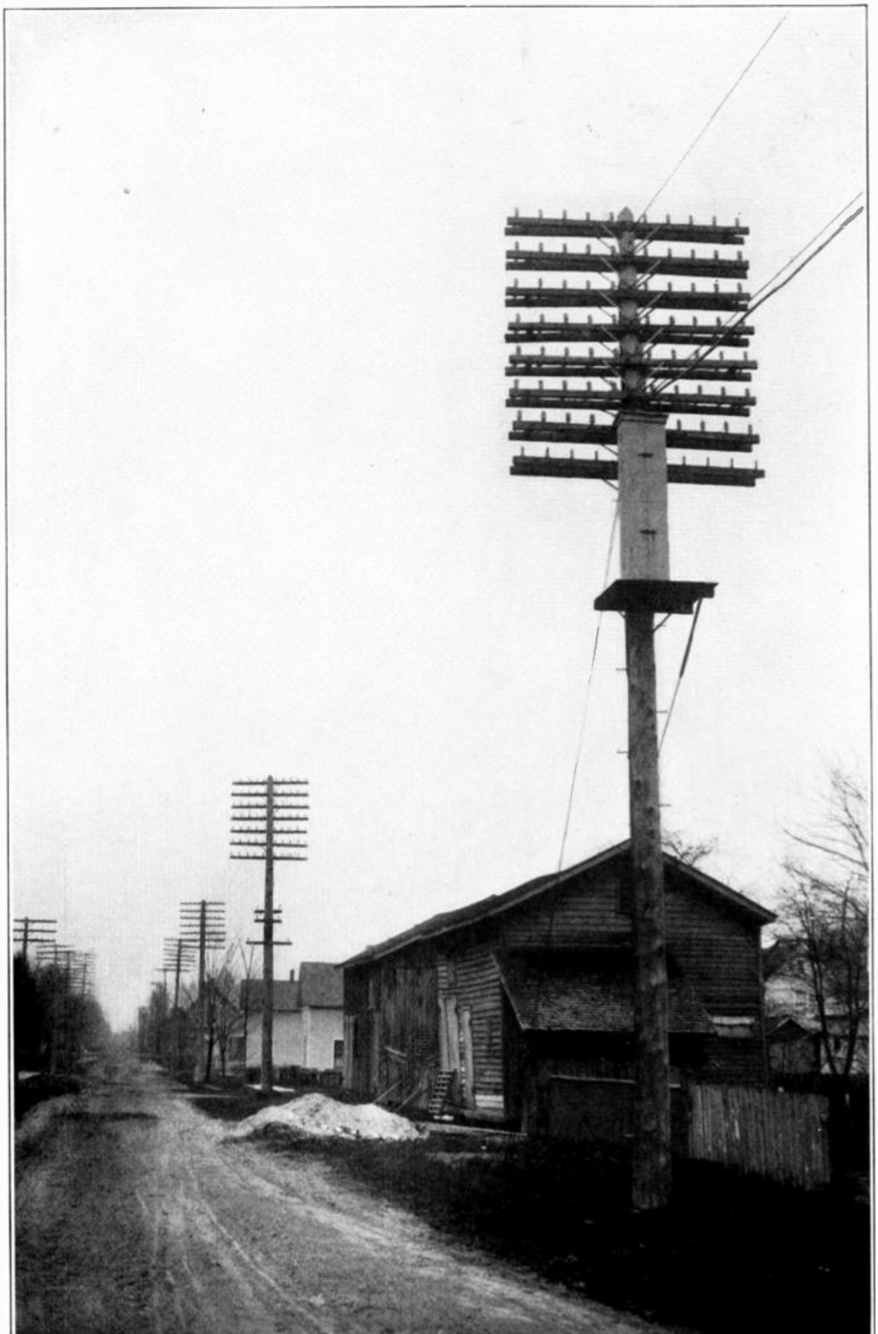


Fig. 664. The Megger

required is connected to the external terminals of Fig. 664, and the generator driven, when the resistance is read directly on the scale. The megger reads directly in terms of ohms or megohms; its pointer is dead-beat; the handle may be turned as fast as wished, a friction clutch slipping beyond a critical speed. The results given by the megger require no calculation whatever to know the resistance of the circuit connected to the test terminals.

Capacity. The second thing required to be known in testing cables for general condition is the electrostatic capacity of each wire. Specifications usually call for an average mutual capacity of about .065 microfarad per mile more or less. As it is of advantage to have the insulation resistance as high as possible, it is also of advantage to have



A TERMINAL POLE AT END OF HEAVY OPEN WIRE LEAD

the capacity as low as possible. A statement of the mutual capacity of a wire and its mate is merely a statement of how large a condenser the two wires form. As two wires with the insulating material between them do form a condenser, although one of small capacity, the effect is to short-circuit the voice currents in the line to just that extent, acting as if the wires had no such quality, but that a condenser—small perhaps, but none the less a condenser—had been bridged across the pair. If the pairs were used not for talking but for telegraphy, or some other electrical use with direct current, the capacity would have a less harmful effect, as alternating currents pass through condensers with much freedom, and the voice currents sent over the line will pass through the condenser formed by the wires and thus be lost from usefulness at the distant end.

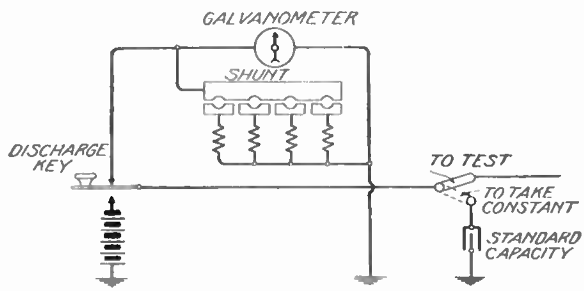


Fig. 665. Capacity Test

In Fig. 665 are shown the conditions for capacity tests, using the principal items shown in Fig. 663 for insulation tests. The discharge key is one which has two contacts, one above and one below, and is usually arranged so that it may be locked in the lower position and released quickly when desired. The condenser is one of accurately known capacity and is usually either of $\frac{1}{3}$ microfarad or is adjustable in small fractions up to about $\frac{1}{2}$ microfarad. For tests such as we are now considering, the $\frac{1}{3}$ microfarad standard is as good as any and is cheaper than the adjustable form. The procedure for capacity measurements is as follows:

Place the switch in the position to take the constant; depress the discharge key, holding or leaving it down for a few seconds, thus causing the battery to charge the condenser. Release the discharge key and note the galvanometer deflection. If but two or three cells of dry battery are used, the deflection will be on the scale with no shunt, and the galvanometer movement simply makes one steady swing, then stopping and returning to zero. The figure thus found is the deflection which $\frac{1}{3}$ microfarad will give with no shunt and with the battery used. Throw the switch to the testing position, depress the discharge key for a few seconds, and release as before, noting the deflection now given. The capacity of the wire under test is now found by multiplying $\frac{1}{3}$ microfarad by the last deflection and dividing by the first.

For example: Suppose the deflection to get the constant were 50 scale divisions with the $\frac{1}{9}$ shunt; as this shunt has a multiplying power of ten, the deflection is equal to 500 scale divisions with no shunt; suppose the test deflection were two divisions with no shunt; then $\frac{1}{3}$ microfarad times 2, divided by 500, equals .00133 microfarad, which is the capacity of the wire under test.

As a condenser has greater capacity when the conducting surface is increased, so a pair of wires has greater capacity as its length is greater, if other things are equal. Insulation and separation being the same, large wires have greater capacity per length of pair than small ones; size, length, and separation of the wires of a pair being the same, the capacity is lower or higher, depending on the kind of insulating material used. Dry paper is the standard insulating material for telephone cables, because lower capacity is secured with it than with any other convenient material.

Fig. 665 shows conditions for capacity between a wire and earth. To measure capacity between two wires (mutual capacity), connect one wire as shown and the other, instead of to the ground, to all three of the points shown grounded in the figure.

It often is necessary to practice insulation tests on lines which are not yet brought into a building and as one may have to go from town to town on such work, it is of advantage to have the testing outfit light enough to be portable, and strong enough to stand handling and shipment. Improvement is still going on in testing apparatus, although it was reasonably well developed long before the invention of the telephone. Much instruction may be had from the catalogues of instrument makers, and the student is recommended to study them.

Testing Sets. A typical form of insulation testing sets is that made by Nalder Brothers, London. The arrangement of the parts and the circuit are shown in Fig. 666. A notable feature is the absence of keys. The only parts requiring to be moved by hand are two switches, one controlling the taking of the constant and the actual testing, and the other applying the galvanometer shunt in its varying degrees. The shunt is subdivided in smaller units than usual, and the switch method enables it to be used with much greater speed than if the plug form were chosen. With such a set, the operation is to take the constant by throwing the main switch to the left and moving the shunt switch until the largest deflection which will be on the scale, is found. Suppose that this deflection is 320; sup-

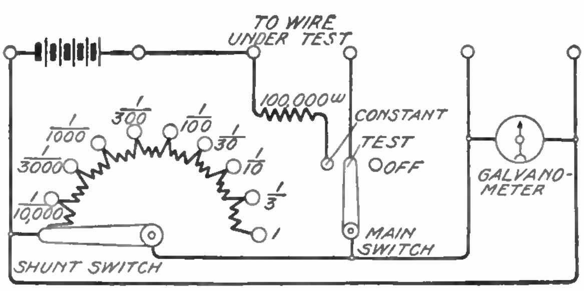


Fig. 666. Insulation Test

pose the shunt to be on the 1/1000 point at that time; then the constant will be 32,000, because the resistance through which the constant was taken was 1/10 megohm ($320 \times 1000 \times .1 = 32{,}000$); throwing the switch to the position marked "test", deflections may be taken on the various wires and their insulation found at once by dividing 32,000 by the observed deflection, multiplied by the shunt multiplier used. For instance, if after taking the constant as above, one were to test a wire upon which the shunt switch stopped at the 1/10 point, giving a deflection of 64 divisions, 640 would represent the deflection which would have been given with no shunt, and this is contained in 32,000, fifty times; therefore, the insulation of the wire under test is 50 megohms. For convenience in other tests the galvanometer terminals are brought out to binding posts, as well as being permanently wired into the circuit of the set.

A minor, but attractive feature of this set is its compactness; the reading of the galvanometer deflection is by means of a telescope, through which the worker sees the image on a scale rather than by watching the movement of a spot of light on a scale. The telescope is small—only about 3½ inches long—and the scale is short and finely graduated, however, the high power of the telescope enables the divisions to be clearly read.

In any of the reflecting types, the use of the apparatus requires reasonably intelligent care not to pass large currents through the windings. With such precautions, pressures of several hundred volts may be used with safety.

In Fig. 663, the 100,000-ohm standard resistance is left in the circuit during the test as well as when taking the constant. This prevents injury to the apparatus by getting on a very poorly insulated or grounded wire, and it is customary to arrange sets in this way for that reason. Where it is necessary to get very accurate results, 1/10 megohm must be deducted from the result when the test is completed.

Loss-of-Charge Test. In the foregoing method of testing insulation resistance, the principle is that of sending current to the conductor and through the insulation, and noting the effect of that current on some movable thing under its influence. In a method described by Carhart and Patterson in "Electrical Measurements," and by Gray in "Absolute Measurements in Electricity and Magnetism," another principle is involved. It is that of loss of charge, and is practiced by charging the conductor under test to a definite potential, allowing a known time to elapse, then testing to see what potential remains. An insulated conductor must form a condenser with reference to something, even if it hangs in air and the other condenser conductor is the earth. But if the conductor under test is not perfectly insulated, the potential to which it is charged must diminish by the leaking away of the charge, so that after a known time the loss may be known by observing how much is left. A calculation then will tell what insulation resistance exists to allow that loss with the known time and charge. The method has the practical advantage that a sensitive millivoltmeter is a suitable instrument for the purpose and is readily portable. A direct-current power-source may be used for the charge. If much work is done with the method tables or curves may be laid out, thus enabling the observer to omit calculations and to read insulations at once.

Varley Loop Test for Grounds. Two of the three things which may happen to working wires are—becoming grounded and becoming crossed with other wires. Both of these troubles may be located by means of the Varley loop test, the circuit of which is shown in Fig. 667. There are many methods of making ground locations, but of them all the Varley test and the similar one designed by Murray are those best adapted for general use, principally because they are free from errors which might result from the existence of earth potentials. The

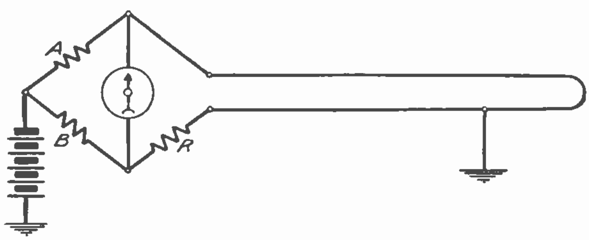


Fig. 667. Varley Loop Test for Grounds

pieces of apparatus used in the Varley test are the usual Wheatstone bridge, rheostat, and galvanometer. It is not necessary that the latter be of the reflecting type, although in some cases it may be found convenient to use one of that sort.

Referring to Fig. 667, showing the Varley tests for grounds, the arrangement is of the Wheatstone-bridge type, in which it is intended that the current from the battery shall flow through two paths, and at the time of completing the test shall cause no deflection of the galvanometer. In the figure, A and B are the two bridge resistances; R is the rheostat (the resistance of which may be varied at will by plugs or switches); the battery, galvanometer, and ground can be recognized by form. The test requires that in addition to the wire having the ground fault on it, an extra wire shall be provided which is clear of faults. Fortunately, in telephone work, wires generally go in pairs, and one often is good when the other is bad. The two wires must be directly connected at the distant end.

If the two wires are alike, and if the resistance of the bridge arms A and B are equal to each other, the galvanometer will show no deflection when the resistance in the rheostat *R* is equal to twice the resistance from the ground to the distant end. This is the simplest form of the test, and on a long line may give valuable help in knowing just about where to find the ground. The rheostat being adjustable in ohms, however, one cannot get results to fractions of an ohm unless the bridge arms are in another ratio than equal. And as the result, in integral ohms, may be half an ohm wrong, with No. 10 B. & S. gauge wire the location may be wrong by 500 feet or so. If this will do well enough, it is simplest to remember the test by the following rule, suitable when the two wires are alike:

Use equal bridge arms; adjust the rheostat till no deflection, or the least deflection, exists; divide the resistance cut in at the rheostat by two; the result is the resistance from the ground to the distant end of the line.

No. 10 B. & S. gauge and No. 12 N. B. S. gauge hard-drawn copper wire have a resistance, roughly, of 5 ohms per mile of wire, or 10 ohms per mile of metallic circuit. For such lines, which are common for toll service, this rule is quick and good:

With equal bridge-arms, balance as usual; divide the resulting rheostat resistance by 10 (or point off the right-hand figure); the result is the distance in miles from the ground to the further end of the line.

Varley Loop Test for Crosses. The Varley test for crosses, Fig. 668, is the same as for grounds, except for a slight difference in

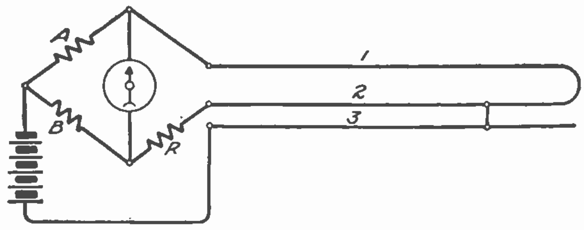


Fig. 668. Varley Loop Test for Crosses

the arrangement of the wires under test. The battery is connected to one of the crossed conductors *3;* the rheostat is connected to the other, *2;* a good wire *1* is connected to the set as in the test for ground, and is looped to the crossed wire *2* at the distant end. The further operations are by the rules given for grounds.

The Varley test with bridge arms of a ratio other than equality will give results to such a fraction of an ohm as may be desired. As the apparatus is usually made, bridge-arm relations may be selected so that A is to B as 10 is to 1, or 100 to 1, or 1,000 to 1, or the reverse. Suppose the arrangements are such that B is greater than A, say, 10 to 100 times, and the two wires in the test are of equal resistance. Then, having adjusted the resistance in the rheostat until there is no deflection in the galvanometer, the equation of the resistance *from the observing point to the ground* is

$$X = \frac{2BC - AR}{A + B}$$

in which C is the resistance of one wire to the distant end. Stated in other terms, the resistance to the fault may be determined thus:

Multiply the resistance of bridge arm B by that of the good wire, and double the result; subtract from this the product of the resistances of arm A and of the rheostat; divide the remainder by the sum of arms A and B.

As a practical example: A line 35 miles long is made of two copper wires of 175 ohms each, and one has a ground on it at some place unknown; the bridge arms, in testing, are 10 for A and 100 for B; a balance is reached with 2,015 ohms in the rheostat. Then, by the rule, 100 times 175 times 2 = 35,000; subtracting 10 times 2,015 leaves 14,850; dividing by 100 plus 10 equals 135; this is the resistance in ohms to the fault. In the case of a cross, the result is figured in the same way.

If the records tell the resistance of all principal lines under good conditions, the location of the fault can be accurately figured. It is hardly enough to know the theoretical resistance per mile of the size of wire used. The actual resistance ought to be known and used.

Murray Loop Tests for Grounds. The Murray loop test is similar to the Varley loop test in its freedom from error due to earth currents. It differs from it in that the bridge ratio is varied instead of the rheostat being varied with fixed bridge ratio.

A dial form of bridge is most convenient for the Murray loop test, one type of which is illustrated in Fig. 669. The dial, the arm of which swings one end of the testing battery, has 101 points in the circle; a resistance coil of 1 ohm is connected across each gap between points; there are thus 100 such coils. The coil A is of the same resistance, 100 ohms, as the total of the 100 coils in the circle. Then with a loop of one good wire and the faulty one, the dial lever is turned till the galvanometer deflection is nothing. If the ground is one ohm or more from the extreme further end of the looped wires, at least one step from zero will be required to balance the needle. The amount the switch is turned from zero is marked C in the figure; the remainder of the circle is marked B; the loop resistance may be called L. Then the equation is

$$X = L \frac{B}{B + C + A}$$

but $B + C + A$ equals the sum of all resistance in the set, or, in this case, 200 ohms. Hence

Multiply the loop resistance by the steps between the switch and the end; divide by 200. The result is the resistance in ohms from the point of testing to the fault.

To trace the following case with the aid of Fig. 669 will aid in clinching the principle in one's mind: Loop resistance, 84 ohms;

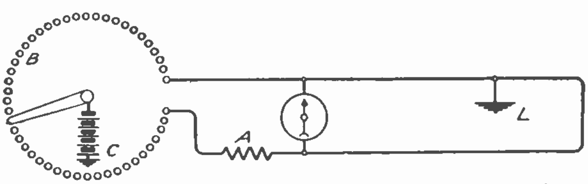


Fig. 669. Dial Set for Murray Loop Test for Grounds

distance switch lacks of reaching the end, 68 coils; then the resistance to the fault is 68 times 84 ohms divided by 200, equaling 28.56 ohms. From this the distance can be computed in feet or miles as desired.

Capacity Tests for Opens. Besides being grounded and crossed with other wires, lines may become open. A break in a wire, if it is a bare aërial one on poles, may result in one or both ends becoming grounded. In some cases, the location of the break can be located by a method for grounds. In some other cases, one of the ends may be crossed with another wire, and the method for locating a cross may enable the location to be made. In cables, however, opens are often merely breaks with no ground or cross to assist the test, in which case the test must be based on a comparison of electrostatic capacities.

By applying a capacity test to the broken wire, and also to a good wire of the same size, route, and of similar surroundings, a comparison of the two results will give the length of the defective piece. The good wire must be open at the distant end. Suppose that a toll line 45 miles long, of two No. 10 B. & S. gauge wires, has one wire broken; this wire is found by test to be clear of ground at the break.

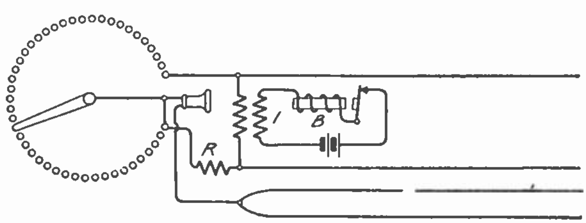


Fig. 670. Dial Set for Tests for Opens

A test for capacity on the good wire, opened at the distant end, gives .2925 microfarads for the whole piece; a test on the broken wire gives .1172 microfarads; then the distance to the break, in miles, is 45 times .1172, divided by .2925, equaling 18 miles and a little over—to be exact, 18 miles, 163 feet. In a word, the rule for the distance to the break is: *Multiply the length of the good wire by the ratio between the bad wire and good wire capacities.*

Another method for locating a break in a conductor, particularly adaptable to conductors in cables, utilizes the apparatus of Fig. 670. For use in locating breaks, the set is associated with a telephone receiver instead of a galvanometer. The current from the battery is supplied to the conductors under test in the form of an alternating current which is generated by means of an induction coil I and a buzzer B. The resistance R is a fixed non-inductive one, and the dial is composed of 100 equal coils connected between the steps, the total dial resistance being the same as that of the fixed resistance. The cable conductor which is broken is joined with its mate at one of the terminals of the set, and two wires of another pair of the same size and length are connected to the set at the terminals of the secondary of the induction coil. Listening in the receiver, the dial lever is turned until silence is reached, or as near silence as is found possible. Then the distance from the point of observation to the break is found by multiplying the total length of the cable under test by the number of ohms between the switch lever

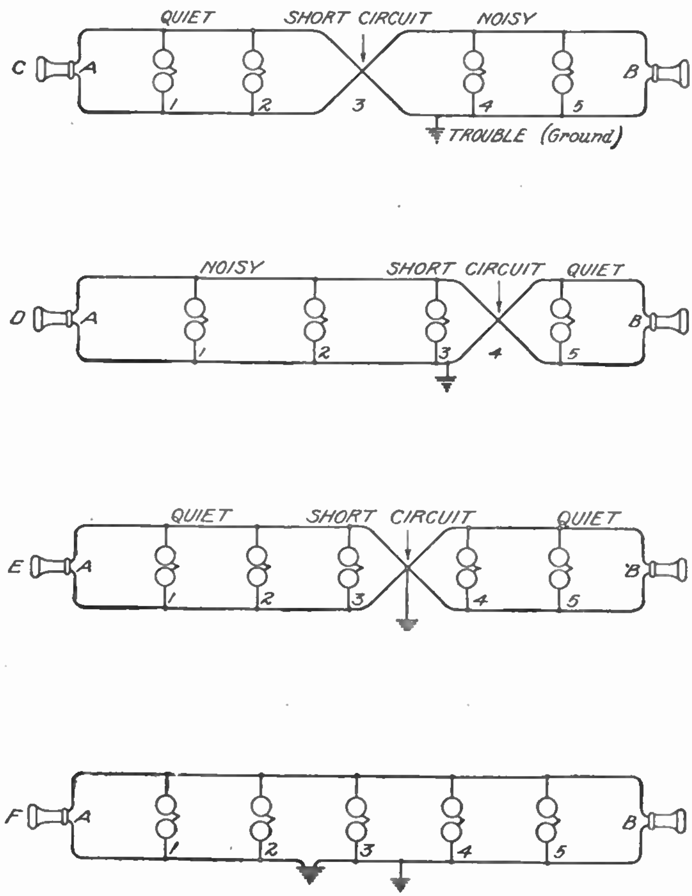


Fig. 671. Short-Circuiting Tests

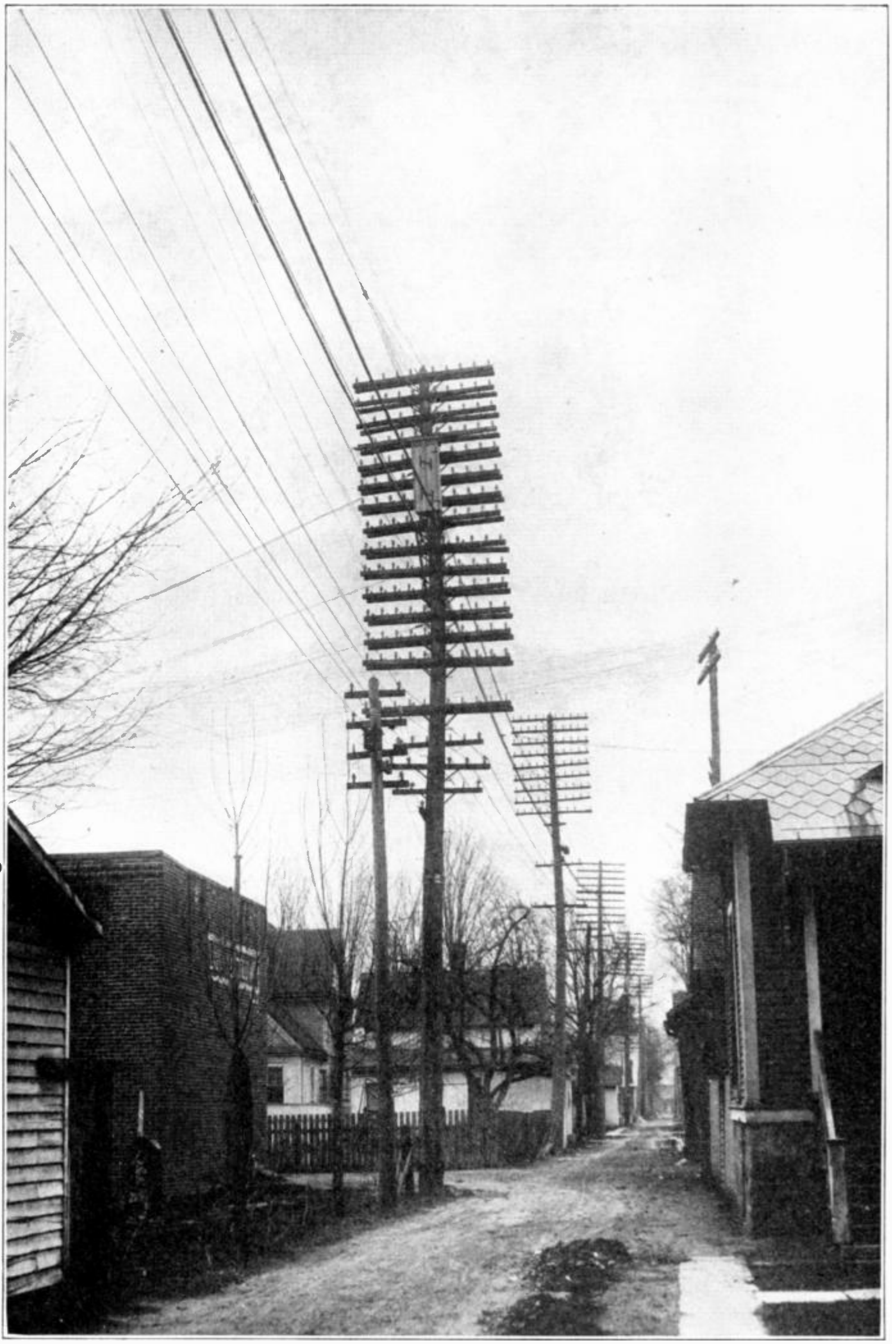
and the end, dividing by 200. In this, as in any capacity test for the location of a break, the wires involved in the test must be open at the distant end.

Listening Tests. When both wires of a long-distance line are equal in resistance, insulation, and capacity of each to the earth and other things, the line is quiet. When one or more of these conditions is changed from the equality, the line is noisy. Only very short lines are quiet when unbalanced, unless in regions where no power circuits exist.

If one wire of a long line is open, grounded, or crossed with another wire, even if the latter is open at both ends, the long line is unbalanced. Long-distance wire chiefs become very expert in detecting the causes and locations of faults by the sounds they hear when lines are noisy, and by the behavior of the noises under changes in the line's connections.

In general, make listening tests while the line is short-circuited at various places. The fault, if an open, a ground, or a cross, is beyond the point short-circuited, if doing so makes it quiet. The Middleton Brothers describe the facts graphically, as in Fig. 671. Four cases are shown, *C*, *D*, *E*, and *F*. In case *C*, placing a short circuit at the point indicated quieted the line for observer *A;* that is, when the ground lay beyond the short circuit, the line was quiet. In case *D*, the line is quiet for *B*, noisy for *A*. In case *E*, the ground and short circuit are at the same point; the line is quiet for both *A* and *B*. In case *F*, short circuit at *2* quiets for *A;* short circuit at *4* quiets for *B;* short circuit at *3* will quiet for neither. A double fault exists, a difficult condition for bridge location, but easy for listening tests.

Quiet local lines may be connected to quiet long-distance lines making a noisy connection. A fault on the local line is indicated. Inserting a repeating coil quiets the connection, but impairs transmission. Short-circuiting the local line at successive points, further and further from the connecting point, will quiet the long-distance line, until the fault is passed.



A HEAVY AËRIAL LEAD CARRYING BARE WIRES AND CABLE

ELECTRICAL MEASUREMENTS

PART I—ELEMENTARY

SYSTEMS OF UNITS

Physical quantities are measured in terms of quantities called units. These units, as a rule, are related to one another and form systems; as, for example, the *British* system and the *C. G. S.* system.

Fundamental Units. The arbitrarily chosen units of a system are called *fundamental* in distinction to the related units depending on them, which are called *derived* units. The C. G. S. system, universally used in electrical measurements, takes its name from three of its fundamental units—the *centimeter*, the *gram*, and the *second of mean solar time.* Besides the three units from which it takes its name, the C. G. S. system includes other fundamental units; for example, the *degree centigrade*, the *calorie*, and the *unit magnetic pole.* Whenever the arbitrary choice of a property of a substance enters into the choice of a unit, the unit itself becomes fundamental. Thus the calorie depends on the thermal capacity of water; the unit magnetic pole depends on the magnetic property of air, etc.

Derived Units. Geometrical units, such as area and volume, are derived from the unit of length. That is, areas are measured in square centimeters, and volumes in cubic centimeters, involving units of the second and third degree with reference to the unit of length. We say that an area has a dimension of 2 and a volume of 3 in terms of a length. Put algebraically, an area may be expressed as L^2, and a volume as L^3 in terms of a length L. In mechanics we use derived units depending on length L, mass M, and time T. Thus velocity, which may be measured by the ratio of length and time, has as dimensions LT^{-1}, and acceleration LT^{-2}. Force is more complicated and may be defined in terms of the acceleration of a mass. The dimensions of force are then LMT^{-2}. The C. G. S. unit of force is called the *dyne.* Work and energy may be measured in terms of force exerted through space, and the unit, equal to one dyne acting through one centimeter, is called the *erg*. The dimensions of the erg are $L^2 M T^{-2}$. In the same way power (time rate of doing work) may be expressed in ergs per second. This unit of power is so small that for practical purposes we use the *watt* which is 10,000,000 ergs per second. Even the watt is small and so we frequently use the *kilowatt* (one thousand watts) for measurement of power. As we shall see later, the watt is used also for the measurement of power for electric circuits. Besides the C. G. S. units we use many units which are multiples or submultiples and so are related. For example, we use the meter (100 centimeters) and the kilometer (100,000 centimeters) and the millimeter (0.1 centimeter). Evidently the meter was intended to be the fundamental unit, the centimeter and the millimeter submultiples, and the kilometer a multiple; but in the C. G. S. system the meter becomes a multiple of the fundamental unit.

In electrical measurements the unit of resistance—the *ohm*—is practically taken as 1,000,000,000 C. G. S. units; the unit of electromotive force (e. m. f.)—the *volt*—is taken as 100,000,000 C. G. S. units; and the unit of current—the *ampere*—is taken as 0.1 C. G. S. unit. These units were originally recommended by a committee of the British Association for the advancement of science in 1873, and were internationally adopted at Paris in 1881. The watt is the practical unit of power and is equal to an e. m. f. of one volt multiplied by a current of one ampere. If the current is constant the product of current and e. m. f. gives the power. If the current is not constant, the average product of current and e. m. f. gives the average power. As we shall see later in the case of alternating currents, the readings of alternating-current voltmeters and ammeters cannot be multiplied together to get the power; but an instrument called a *wattmeter* must be used. The wattmeter gives the correct result. The watt is 10,000,000, *i. e.*, 10^7 C. G. S. units.

The unit of charge (or quantity)—the *coulomb*—is the quantity of electricity equal to a flow of one ampere for one second. The coulomb is 0.1 C. G. S. unit. The *farad* is the unit of capacity. A condenser has one farad capacity if it can store one coulomb with a potential difference of one volt at its terminals. Potential difference, like e. m. f., is practically measured in volts. At higher potential differences a condenser takes a proportionately higher charge. The farad is a very large capacity and condensers are practically rated in microfarads, *i. e.*, in millionths of a farad. The *henry* is the unit of inductance. When a current is started in a coil of wire a magnetic field is produced. This requires more e. m. f. than to maintain the current when once started. If the coil requires one volt more to increase the current at the rate of one ampere per second than to maintain it, we say the inductance of the coil is one henry. The henry is 1,000,000,000, *i. e.*, 10^9 C. G. S. units. These practical units are all related, as is seen above, to the C. G. S. units by factors, of powers of 10. There are other units in the electro-magnetic system for which the reader is referred to more advanced works.

Relation of C. G. S. to British Units. To reduce British to C. G. S. units and *vice versâ*, we make use of the relations between them. One inch equals 2.54 centimeters; one pound mass equals 453.59 grams mass; and a like relation between pounds weight (force) and grams weight. The second of mean solar time is the same in both systems. It should be kept in mind that for equal quantities the number of units is inversely proportional to the size of the unit.

ELECTRICAL MEASURING APPARATUS

Galvanometers. In the year 1819 Oersted discovered that a current flowing through a conductor produced an effect on a magnet. This effect is now explained by saying that lines of force surround the conductor, and that the north pole of the magnet tends to move along the lines of force in one direction and the south pole in the opposite direction. In other words the magnet, if free to move, tends to take a direction across the conductor. In the case of a long, straight wire the lines of force are circumferences of circles with the conductor at the center. The force on the magnet pole in this case falls off in proportion to the increase in the distance from the center of the conductor; *i. e.*, the force is inversely proportional to the distance. If the magnet is already in a magnetic field, such as that of the earth for instance, a current in a north and south wire above or below the magnet, tends to turn the magnet away from the

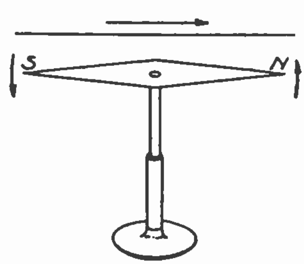


Fig. 1. Oersted's Experiment.

magnetic north and south, the tangent of the angle through which it turns being proportional to the current, Fig. 1. The effect of a single wire is small unless the current is very large.

Tangent Galvanometer. If the conductor is wound in a coil whose plane is north and south and vertical, the effect on a magnet at the center is multiplied many times, Fig. 2. Such an instrument is called a *tangent galvanometer.* If the thumb of the right hand is placed along the outside of the conductor pointing in the direction

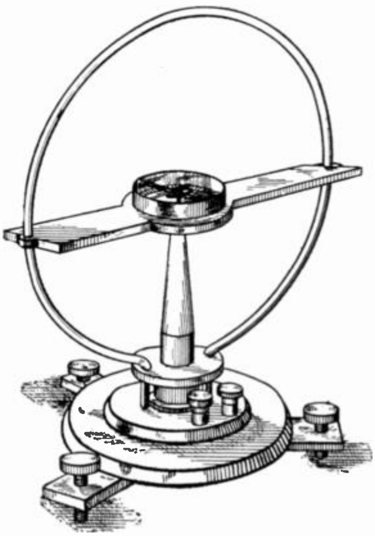


Fig. 2. Tangent Galvanometer.

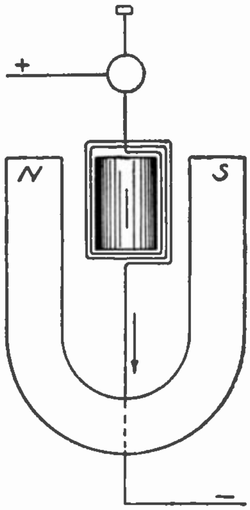
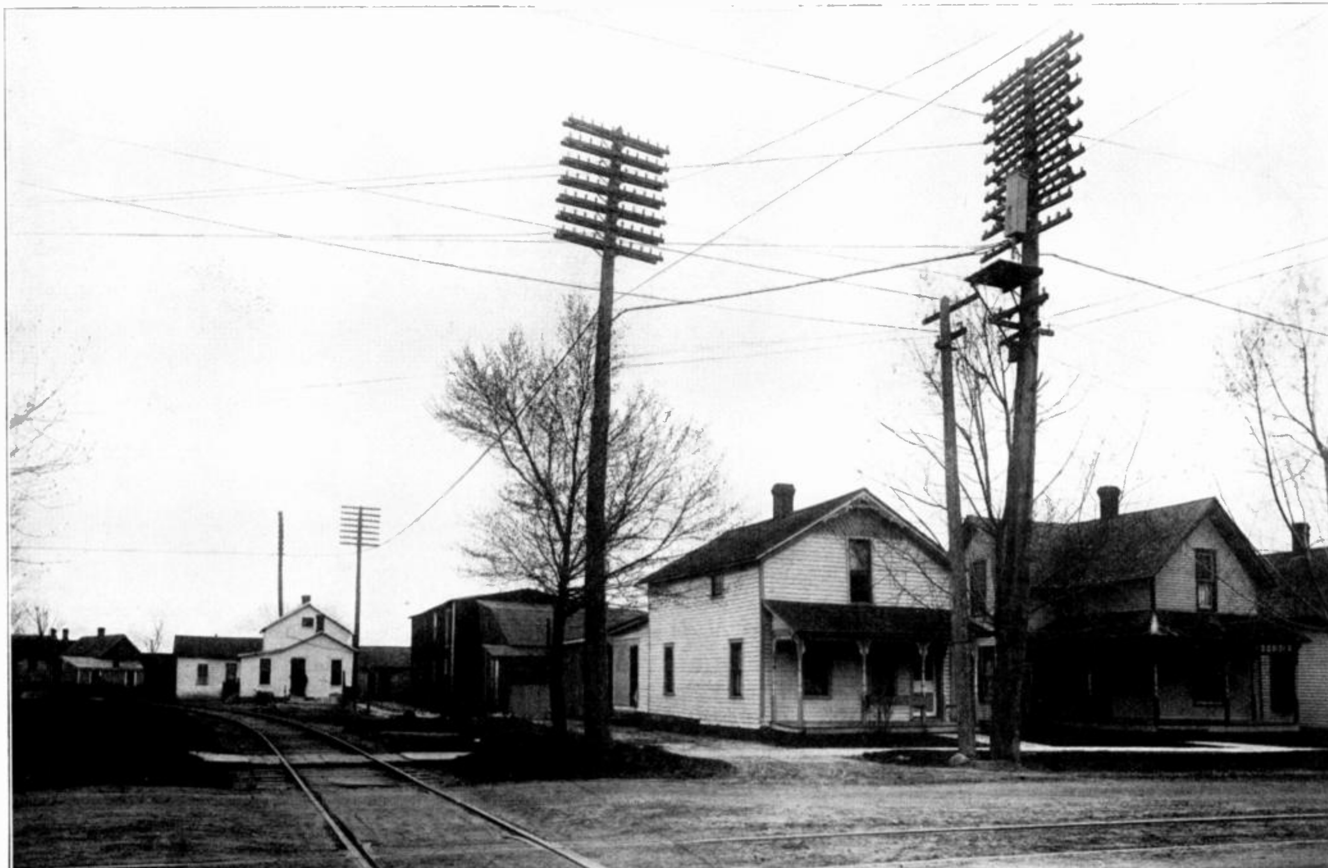


Fig. 3. Diagram of D'Arsonval Galvanometer.

of the current, the fingers of the hand may be curled around the conductor and will point in the direction toward which the north pole of the magnet will be urged by the field produced. A similar arrangement of the left hand will indicate the direction in which the south pole will be urged.

D'Arsonval Galvanometer. If the magnet is fixed and the coil free to turn, the latter will turn in the reverse direction. If the magnet is of the horse-shoe type with the coil of wire between the poles a similar rule will determine the direction of motion. Galvanometers of the moving coil type were invented by D'Arsonval and Deprez, and are usually called *D'Arsonval galvanometers,* Fig. 3.



TYPICAL AËRIAL CONSTRUCTION INVOLVING HEAVY BARE-WIRE LEAD AND CABLES

Astatic Galvanometer. An improvement may be made in the tangent galvanometer, if greater sensitiveness is desired, by mounting on the same support two magnets of nearly but not quite equal strength, care being taken to turn the poles in exactly opposite directions. This is very important. One magnet is placed at the center of the coil through which the current is sent and the other magnet is above or below the coil and influenced relatively little by the current, Fig. 4. The directive action of the earth's magnetic field is little on such a system—called *astatic*—and a small current consequently turns the system more easily from the magnetic meridian. A similar effect is produced if part of the coil is about one magnet and the rest, with reversed direction of the current, about the other magnet. Another way to produce an equivalent effect on a single, suspended magnet is to mount a powerful control magnet near by (above, below, or behind) so as to reduce to a very small amount the magnetic field due to the earth and the control magnet at the center of the coil.

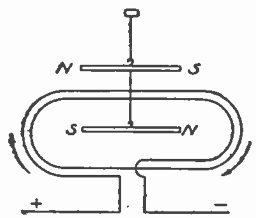


Fig. 4. Astatic System.

An extremely sensitive galvanometer may be made by combining the control magnet with the astatic system of magnets. The magnet (or system of magnets) of tangent and astatic galvanometers is suspended generally either by a fine silk or quartz fiber. The current is led into and out of the coil of the D'Arsonval galvanometer through two wires, both above in the bifilar suspension, one above and one below in the unifilar suspension.

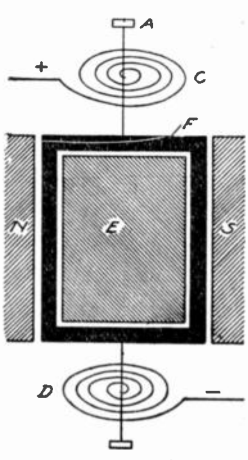


Fig. 5. Section of Suspension of Portable Galvanometer.

Less sensitive galvanometers may have their moving parts mounted on pivots or other bearings, and in such galvanometers of the D'Arsonval type the current is brought in and out through spiral springs which tend to hold the coil in its zero position, Fig. 5. Galvanometers of this type are used for ammeters—to measure amperes of current; or for voltmeters — to measure e. m. f. in volts. Such instruments are provided with some damping arrangement so that they come to rest quickly. The deflection of such galvanometers is indicated by a pointer moving on a scale. If the poles of the magnet are properly shaped the deflection may be made proportional to the current passing.

Mirror Galvanometers. Very sensitive galvanometers must be made with moving parts of little weight. It is, however, very desirable

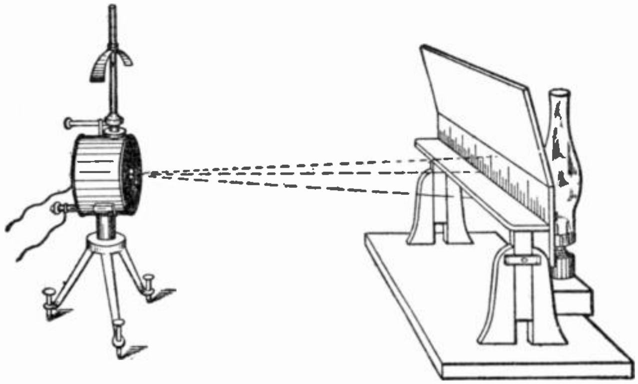


Fig. 6. Thomson Mirror Galvanometer with Lamp and Scale.

that the pointer be very long so that a large number of scale parts may correspond to small deflections. This may be accomplished by using a pencil of light rays for a pointer, as shown in Fig. 6, which illustrates the lamp-and-scale method, in which a lamp is placed behind a slit in a screen on which the scale is mounted. A concave mirror carried on the moving part of the galvanometer focuses an image of the slit at the reference point of the scale (usually the middle). When current passes, the mirror is deflected, thus deflecting the rays of light to another part of the scale. If the mirror turns through 1°, the image is deflected 2°. In place of a slit an opening of another form with cross wires may be substituted. Also if desired the lamp may be mounted at the side, and its light reflected by another mirror to the mirror on the galvanometer. In this last case it is more convenient to have the scale printed on a strip of translucent ground glass or paper, and to view the image through the glass or paper. If a telescope is substituted for the lamp, an image of the reference point of the scale may be made to coincide with the cross wire of the telescope when no current is passing, and other parts of the scale will take the place of the reference point when a deflection is produced, Fig. 7. In this case a plane mirror may take the place of the concave. The telescope-and-scale method is more satisfactory for very sensitive galvanometers than the lamp-and-scale method, though the latter, usually used in a darkened room, is easier on the eyes unless an excellent galvanometer mirror and telescope are used.

Choice of Galvanometers. In choosing a galvanometer for use, it is desirable that the instrument should not be too sensitive for the experiment. As a rule the D'Arsonval galvanometer is the most satisfactory galvanometer for general use, as it is not much affected

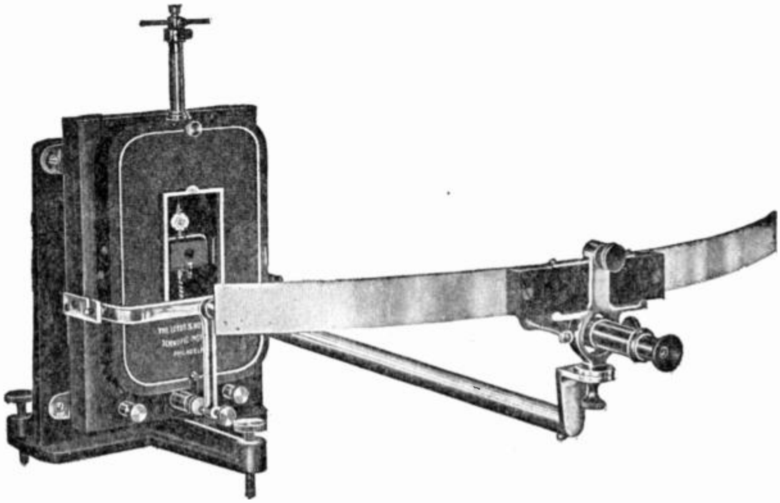


Fig. 7. Ballistic D'Arsonval with Telescope and Scale.

by changes in the magnetic field, even if of as great amount as produced by dynamo-electric machinery or moving of masses of iron in the neighborhood. The astatic galvanometer is, however, as a rule, far more sensitive and for certain purposes must be used.

Use of the Control Magnet. In using astatic or other galvanometers with moving magnets, the use of the control magnet is sometimes very puzzling to beginners. The galvanometer should be set up with its coils in a north and south plane. The mirror then faces to the west (or east sometimes). The control magnet is then placed in position as far away as its support will allow and turned with its north pole to the north. The magnets and the mirror of the galvanometer, as a rule, are somewhat deflected because of the presence of the control magnet. If the latter is slightly turned in one direction, the mirror should turn in the opposite direction. As the control magnet is brought nearer, the period of swing of the mirror should increase, and the sensibility should increase in a greater proportion (as the square). If by chance the control magnet is with its south pole to the north, the mirror will turn in the same direction as the control magnet is turned, and the period of swing will decrease as the control magnet is brought nearer. Control magnets as a rule have the north pole marked in some way, so that there is no need for any mistake. When the control magnet is brought so close that the effect of the earth's field is overcome, the magnets and mirror of the galvanometer will try to turn half way around, thus turning the back of the mirror to the observer, if the construction of the galvanometer will allow. As a rule it does not pay to increase the sensitiveness of the galvanometer to the highest possible limit, as the zero reading will become very easily influenced by slight magnetic changes due to movement of small masses of iron, or the currents in neighboring conductors, or even the variation in the magnetic field due to a cloud cutting the sunlight off from the walls of a red brick laboratory, small as such an effect must be. If the galvanometer is of the astatic type, it is presupposed in the above that the support for the control magnet is arranged to weaken the field of the stronger magnet of the astatic pair more than it does the field of the weaker magnet. In some poorly adjusted galvanometers, the control magnet may produce the contrary result, and it may be necessary to make appropriate allowance. If the magnets of the astatic galvanometer take an east and west position before the control magnet is put on, it is evident that the magnets of the astatic pair are not exactly in opposite directions and that the result is a magnetic system having its effective or resultant north pole about half way between the north poles, and its resultant south pole about half way between the south poles of the two magnets. The line joining these resultant poles lies in the magnetic meridian and the magnets of the astatic pair lie nearly east and west. To correct this error in adjustment is a very delicate matter and should not be attempted by the novice.

Ballistic Galvanometer. When a charge condenser is discharged through a circuit containing a galvanometer, the galvanometer deflects. The period of swing should be long enough for practically the whole charge to pass during the early part of the swing. If the galvanometer has a short period, the return swing may begin before the discharge is complete. It may be assumed that the first deflection is a measure of the quantity discharged; but it is evident that this is an error if the discharge is slow in comparison with the time occupied by the deflection. To be on the safe side the period of swing should be large. Galvanometers which are suitable for measuring discharges are called *ballistic*. Depending on circumstances, their period may be between, say, five and twenty seconds for the complete swing. The D'Arsonval galvanometer may be made with high enough period and sensibility to give satisfaction as a ballistic instrument; but for extreme sensibility an instrument of the astatic type is more generally used. The D'Arsonval galvanometer is more nearly free from the drift of the reference point, which is due mostly to varying magnetic field and somewhat to elastic fatigue or sub-permanent set in the suspension. Freedom from drift is very important, as the deflection is uncertain in proportion as the reference point is in doubt.

Damping of Vibrations. The motion of the moving system of a galvanometer may be impeded by damping. This may be accomplished by mounting vanes on the system so that the air in an enclosed chamber impedes the motion, or by electromagnetic damping produced by eddy currents induced in metal moving in a strong magnetic field. In D'Arsonval galvanometers if the coil is wound on a metal frame, currents will be induced in the frame while the coil is in motion. Such damping ensures a speedy coming to rest after a deflection and is very helpful, especially in ballistic galvanometers where certainty of zero is important. It is evident that any damping reduces the sensibility of a galvanometer. Some galvanometers are provided with so much damping that on the return swing the system does not swing past the zero or reference point. Galvanometers without a period of complete vibration are said to be *aperiodic* (the *a* denoting without). As a rule galvanometers have a complete period, that is, they are damped less than the aperiodic galvanometer. The effect of damping is to shorten the time and amplitude of the outward part of the swing (though it lengthens the complete period), and to this extent damping is objectionable. There are, however, counter-balancing advantages and so for most purposes some damping is considered wise.

Plunger Type Instruments If in place of the magnet of a galvanometer, some soft iron is substituted in such a position that the action of the current is to magnetize the soft iron and to draw it into a stronger part of the magnetic field, we have a *current indicator* of the plunger type. The coil frequently takes the form of a solenoid and the soft iron that of a rod which is drawn by the action of the current into the solenoid. The restraining force may be gravitational or that of a spring. Such an instrument is shown in Fig. 8. It is evident that the direction of the deflection does not depend on the direction of the current. In fact, plunger type instruments may be used to measure alternating currents. There are many possible variations of this type of instrument. As the iron has a certain amount of residual magnetization, the deflection with smaller following large currents is more than would have been produced by the same current following a smaller one. For this reason the plunger type of instrument is less reliable than the usual types of galvanometers. The scale is usually of unequal divisions as the pull increases more rapidly than the current.

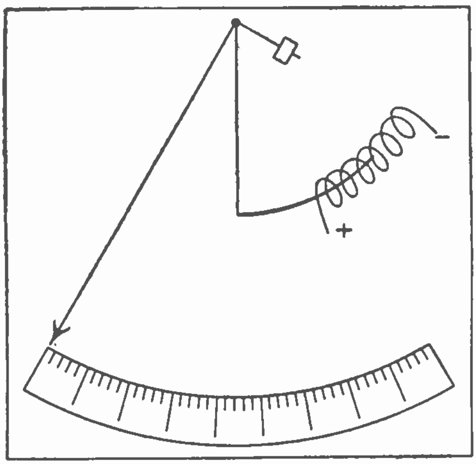


Fig. 8. Diagram of Plunger Instrument.

Electrodynamometers. If the magnet of a galvanometer is replaced by a coil through which the current passes in series with the other coil, we have what is known as an *electrodynamometer*. As in the case of the plunger type instruments, the electrodynamometer deflects in the same direction for all currents unless disturbed by being placed in a magnetic field of outside origin. It is desirable to set up an electrodynamometer with the moving coil (or coils, if more than one) with its axis (or their axes) along the magnetic meridian.

The disturbing effect of a permanent field is negligible when the electrodynamometer is used to measure alternating currents. For direct currents, the action of the outside field is eliminated by reversing the connections. The deflection is approximately proportional to the square of the current. For the best types of electrodynamometers the suspended coil is brought back to its zero position by twisting a torsion head which operates through a spiral spring on the suspended coil. The current in this type of instrument is proportional to the square root of the reading of the torsion head necessary to restore the moving coil to its zero position. A direct current producing the same deflection as an alternating current is said to be the effective value of the alternating current. Fig. 9 illustrates the usual type of electrodynamometer. Fig. 10 illustrates another form invented by Lord Kelvin and called a *Kelvin balance*. The figure shows the connections viewed from the back of the balance. The fixed coil is subdivided into four parts B, and the moving coil into two parts A, placed symmetrically between the parts of B. The parts of A are supported on opposite arms of a balance and the balance is restored to its zero position by displacing a weight along the beam.

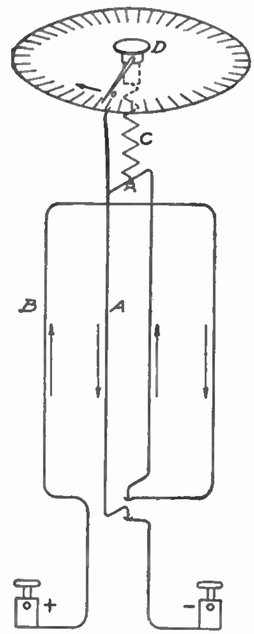


Fig. 9. Electrodynamometer Diagram.

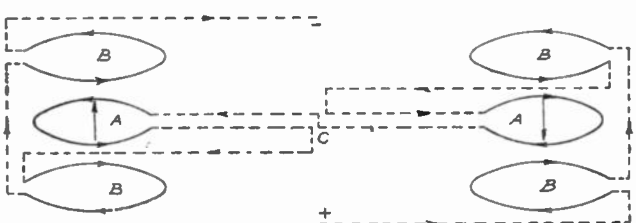


Fig. 10. Diagram of Coils in Kelvin Balance.

The action of the current is thus weighed, and the square of the current is proportional to the distance the weight is moved along the beam. The beam is divided accurately into equal parts and it is possible to obtain the reading with a high degree of accuracy. The current is proportional to the square root of the reading. The effect of dividing the two parts of A is to free the instrument from the disturbing effect of the earth's magnetic field or any other stray field of fairly uniform intensity.

Electrometers. Electrometers depend on the attraction between electrostatic charges of opposite signs. The only electrometer which we shall describe is the *electrostatic voltmeter* which consists of fixed and movable metallic parts of relatively large surface. These surfaces may be plane or curved. The terminals are connected, as a rule, one to the fixed part and the other to the movable part—the vane. These parts take charges proportional to the potential difference between them —e. m. f. applied—and a certain attraction results therefrom. If the vane is allowed to move, the electrostatic capacity of the combination increases somewhat, thus increasing the amount of the charges and the attractive force. If it is desired, the vane may be brought back to its zero position by some counter force. As a rule electrostatic instruments are allowed to deflect and are calibrated by comparison with other forms of voltmeters. More complicated forms of electrostatic instruments may have two sets of fixed surfaces and a movable vane. In some cases a battery of cells of known e. m. f. may be used to charge the fixed surfaces, and the e. m. f. to be measured may be applied between one fixed surface and the vane. Electrostatic voltmeters are generally used to measure high electromotive forces. Fig. 11 shows an electrostatic voltmeter of an old type, which shows

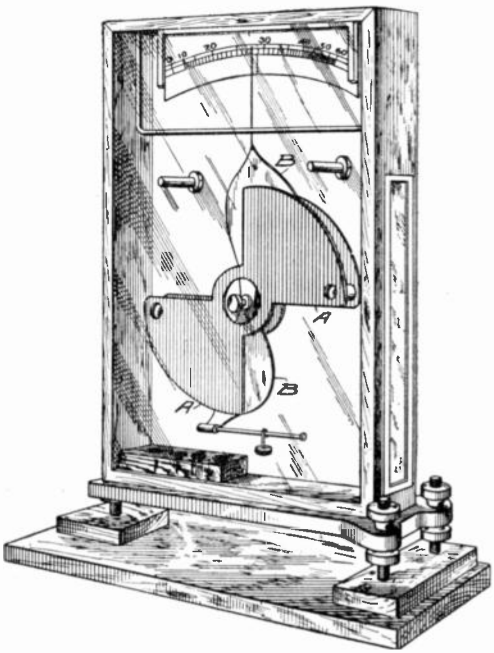


Fig. 11. Electrostatic Voltmeter.

the general scheme more clearly than better and more complicated electrometers.

Hot Wire Instruments. If current passes through a wire, a heating effect results and the wire lengthens because of its rise in temperature. If a pointer is held in a position of equilibrium between turning moments produced by two wires pulling on opposite arms of a lever, the heating of one of these wires by an electric current will produce a change in the position of equilibrium. It is evident that change in the temperature of the room affects both wires alike and produces no change in the zero position. The deflection of a hot wire instrument is dependent on the square of the current (as the heating is proportional to the square of the current). For this reason the hot wire instrument deflects in the same direction for currents in either direction and for alternating currents as well. As the effective value of an alternating current is equal to the square root of the mean square, it is evident that a hot wire instrument calibrated by direct currents, will give proper readings for alternating currents also. Hot wire instruments are made use of as ammeters (low resistance) and voltmeters (high resistance). As a rule hot wire instruments are used for alternating currents. They are usually less accurate than electrodynamometers of the best types.

Wattmeters. We have seen that an electrodynamometer has a turning moment proportional to the square of the current passing through it. If the current passing through the fixed coil is different from that passing through the movable coil, the turning moment will be proportional to the product of these currents. If the power delivered to a line is to be measured, the average product of the volts and amperes gives the result in watts. The current delivered from the line to the load may be passed through one coil (usually of low resistance) whose terminals are A and B, Fig. 12, and the e. m. f. may be applied at the terminals of the other coil (usually of high resistance) whose terminals are a and b, and produce a second current proportional to this e. m. f. In order to avoid measuring the effect of the pressure current it is led backward through coil F shown in dotted line, thus subtracting its effect. The instrument may be calibrated to read watts. As a rule it is easier to make the second coil of moderate resistance and to insert a non-inductively wound high resistance coil R in series. If the wattmeter is to be calibrated by the use of current and e. m. f. in separate circuits, the terminals i and b are used. The resistance of S is equal to that of F. The currents in both coils will reverse if the e. m. f. is reversed, but the deflection will be unchanged. The average power of a varying current equals the average product of current and e. m. f.; consequently a wattmeter calibrated with direct currents gives correct results for alternating currents. If the current and e. m. f. are alternating, the mean product will in general be less than the product of the effective values of current and e. m. f. (as measured by A. C. voltmeters and ammeters); consequently when dealing with alternating current and e. m. f. the product must be multiplied by a factor, called the *power factor*, which is usually less than unity, if the correct value is to be computed from ammeter and voltmeter readings. As a rule the power factor is found by dividing the watts as measured by a wattmeter by the product of volts and amperes.

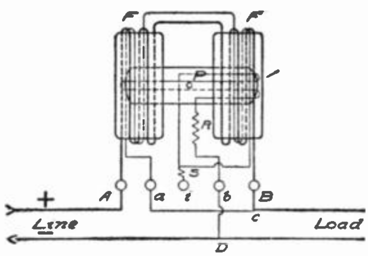


Fig. 12. Diagram of Wattmeter.

Recording Voltmeters and Ammeters. If any of the voltmeters or ammeters described above are arranged with a pen which traces a line on a disk or roll of paper drawn by clockwork past the pen, the instrument will record the variations of e. m. f. or current. There are several good types of recording voltmeters and ammeters on the market. A recording ammeter is shown in Fig. 13.

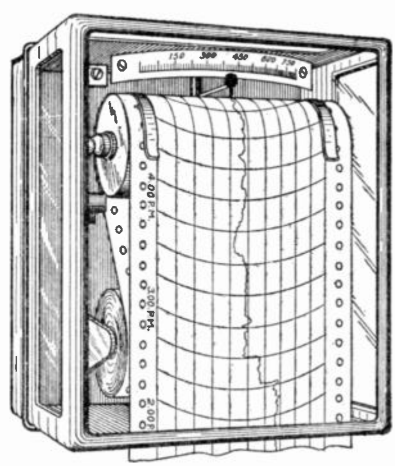


Fig. 13. Recording Ammeter.

Integrating Watt-Hour Meters. Integrating meters show the total consumption of the thing to be measured; for example, integrating gas meters show the consumption of gas in cubic feet. In the same way an integrating watt-hour meter (commonly, though inexactly, called an integrating wattmeter) shows the consumption of energy in watt-hours. Such an instrument is shown in Fig. 14. The instrument is essentially an electric motor geared to a train of wheels moving hands over dials. The speed of the motor is proportional to the power in watts, and the product of the average power and the time in hours (that is, watt-hours) is indicated by the change in the position of the hands on the dial since the last reading. To give correct readings the driving motor must be designed for the circuit on which it is used. The essential factors of the circuit are the e. m. f., maximum current, whether direct or alternating current is used, etc. In a three-wire system a single meter may be designed to measure the power of the two or three circuits involved.

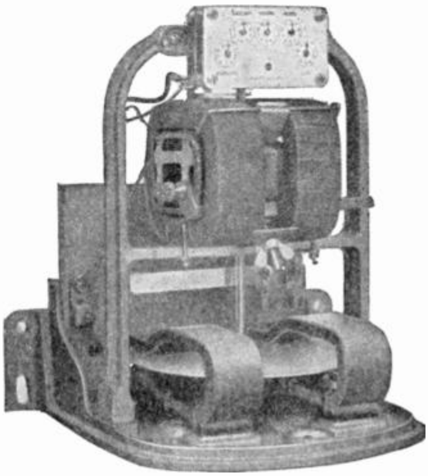


Fig. 14. Watt-Hour Meter.

Integrating Ampere-Hour Meters. An integrating ampere-hour meter (commonly called integrating ammeter) is similar to the watt-hour meter. It is used generally in connection with storage batteries to keep account of the charge and discharge. It is of little general use.

Rheostats and Resistance Coils. The word rheostat means an apparatus for stopping the current. In actual fact it does not wholly stop the current, but only reduces it to a desired extent. Every material interposes some resistance to the flow of an electric current. Substances interposing extremely high resistance are known as insulators, and those interposing relatively little resistance, as conductors. Metals, as a rule, are the best conductors. The metals most used commercially for electrical transmission are copper, aluminum, and iron (or steel). Alloys in general have much higher resistance than the metals of which they are composed. Carbon and solutions of various salts have much higher resistance than metals. Rheostats may be made of any of these materials, but those most generally used are steel wire or sheets, German silver wire or other alloys, carbon rods or plates, and solutions in tanks in which metal plates are immersed, the metal plates being connected to the terminals of the circuit. Such metal plates are known as electrodes. This last arrangement is usually called a *water rheostat*. Pure water has a very high resistance and is never used in water rheostats, but the resistance may be reduced as desired by dissolving salt in the water. The metal plates are usually arranged so that one electrode may be brought nearer the other when it is desired to increase the current. When the word rheostat is used, it is generally understood that the resistance is not exactly known. A rheostat is shown in Fig. 15.

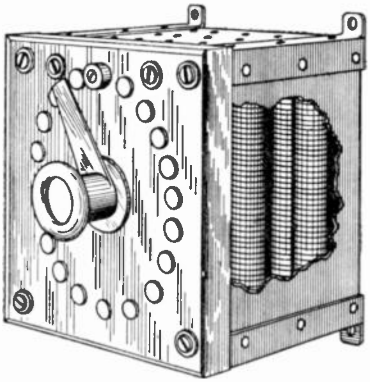


Fig. 15. Rheostat for Varying the Current in Any Circuit.

When it is desired that the resistance have a certain exact value, metals are the only practical materials to use. Coils of wire exactly adjusted are called *resistance coils*. They are adjusted to certain values in ohms. For very low resistances, *e. g.*, small fractions of an ohm, metal strips may be used. As most pure metals increase their resistance with increase of temperature by about 0.4% per degree centigrade, resistance coils are almost always made of certain alloys which change little in resistance with change in temperature. One alloy in particular, manganin, changes so little in resistance with change in temperature that it is usually chosen for standard *resistance* coils. Figs. 16 and 17 show standard resistances in the form of a coil and a strip. As mentioned above alloys have relatively high resistance and for this reason also the alloy manganin is preferable to any pure metal for resistances.

Lamp Rheostats. A very convenient form of carbon rheostat is a bank of incandescent lamps. The usual 16 c. p. lamp for a 110-volt circuit has a resistance when hot of about 220 ohms. Its resistance when cold is about twice as much. Carbon and solutions, unlike metals, are better conductors when hot than cold. It is evident that incandescent lamps, because of their change in resistance from cold to hot, are not suitable for standard resistances. If two lamps are arranged in series, *i. e.*, if the current is made to pass through one after the other, the resistance of the combination is twice that of a single lamp. On the other hand if the lamps are connected in parallel, *i. e.*, if the current divides between them, the resistance of the combination is only half of that of a single lamp. This result is evident as the same e. m. f. produces twice as much current in two lamps as in a single one. In the same way ten lamps in parallel have a combined resistance only one-tenth as much as a single lamp.

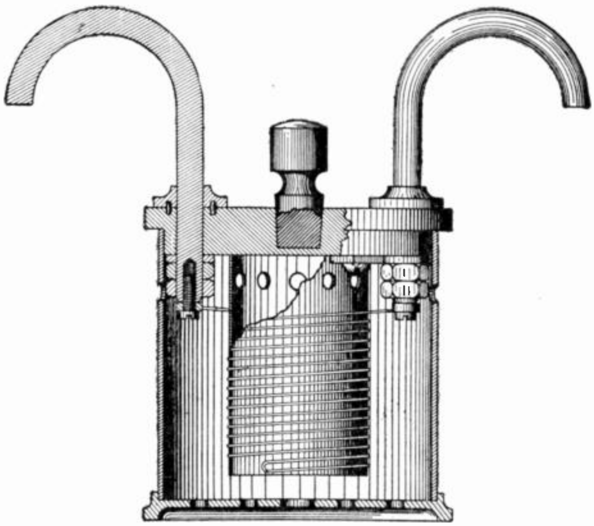


Fig. 16. A Standard Resistance Coil.

Multiplying Power of Shunts. The word shunt is the British name for a side track (or as we would call it, switch) on a railway. Any electrical side path is called a shunt. If the current has two or more paths in parallel offered to it, the current divides in inverse proportion to the resistance or, as more simply expressed, in direct proportion to the conductivity of the various paths. Thus if a galvanometer has a shunt across its terminals whose resistance is one-ninth of that of the galvanometer, nine times as much current will go through the shunt as through the galvanometer and consequently only one-tenth of the current will go through the latter. The total current is then ten times the current through the galvanometer and we

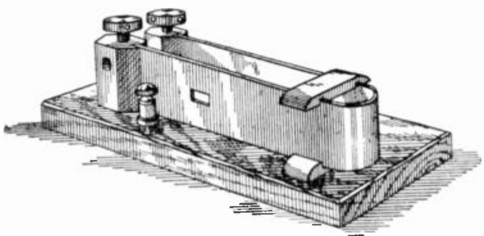


Fig. 17. A Standard Resistance Strip.

say that the multiplying power of the shunt is ten. If the galvanometer has a shunt of one ninety-ninth of the former's resistance, one one-hundredth of the current will pass through the galvanometer and the multiplying power of the shunt will be one hundred. In general, if the resistance of the shunt is $\frac{1}{m-1}$ of that of the galvanometer, the multiplying power of the shunt will be m. The evident effect of the shunt is to reduce the resistance of the galvanometer circuit to $\frac{1}{m}$ of its former value, *i. e.*, to $\frac{1}{m}$ of the resistance of the galvanometer itself; the resulting fall of potential over the galvanometer and shunt is, therefore, only $\frac{1}{m}$ as much as if the shunt were not there. Galvanometers are provided by their makers, if desired, with shunts having a multiplying power of 10, 100, and 1,000, marked to go with the particular galvanometer. It is evident that the usual shunt cannot be used with other galvanometers without recalculation of its multiplying power, which under such circumstances would probably be some inconvenient number.

Professor Ayrton has devised a form of shunt box with extra resistance which is automatically connected in series in proper amount to keep the total resistance constant but allowing only $\frac{1}{10}$, $\frac{1}{100}$, or $\frac{1}{1000}$ of the current to pass through the galvanometer.

OHM'S LAW

In 1827, Dr. G. S. Ohm of Berlin published a treatise, now famous, entitled *The Galvanic Circuit Investigated Mathematically*, in which he announced the fundamental law of electric circuits now known as Ohm's law. This is usually stated in the algebraic formula:

$$I = \frac{E}{R}$$

In words, the current (in amperes) equals the e. m. f. (in volts) divided by the resistance (in ohms). It is truly a surprising fact that the resistance of an electric circuit is a constant not dependent on the current passing. Many experimenters have tried in vain to find any inaccuracy in Ohm's law. If any two of the three quantities involved are known, the third may be found by solving the equation. Thus,

$$I = \frac{E}{R}, R = \frac{E}{I}, \text{ and } E = I\,R$$

As will be seen later, one of the most convenient methods of measuring low resistances, as of a dynamo armature, is a simple application of Ohm's law.

MEASUREMENT OF RESISTANCE

Resistance Boxes. Measurement of resistance is made by comparison with certain standards of known resistance, the different methods of measurement varying to a great degree. The standard resistance coils are made of such alloys as manganin—an alloy of manganese copper and nickel—which has a high specific resistance and changes its resistance with rise in temperature to a much less extent than other metals. It is of course desirable that this change should be as small as possible. The size and length of the coils are such that they have resistances of a definite number of ohms at a certain temperature. The coils are insulated with silk or paraffined cotton and are very carefully wound. Each wire is doubled on itself before being coiled up, and then wound as shown at *A* and *B* in Fig. 18; or, as is sometimes preferred, the wire may be wound single in layers, the direction of winding being reversed for alternate layers. Inductance and capacity effects are by these means reduced to a minimum. The ends of the coils are soldered to brass pieces as *C*, *D*, *E*. Removable conical plugs *F* and *G* of brass are made to fit accurately between the brass pieces. When these are inserted as shown, the coils will be short circuited and a current will pass directly through *C*, *F*, *D*, *G*, and *E* without going through the coils. If *F* is withdrawn the coil *A* will then be inserted in the circuit; if *G* is also withdrawn then coils *A* and *B* will both be inserted, as the current cannot pass from *C* to *E* without going through the coils.

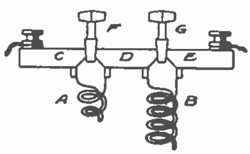


Fig. 18. Resistance Box Coils Showing Non-inductive Winding.

Resistance boxes are constructed consisting of a large number of resistance coils, and of such resistances that by withdrawing plugs varying resistances may be built up. A common form of resistance box has coils of the following ohms resistance: 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000. A resistance of 497 ohms could be made up by withdrawing plugs corresponding to the coils 200 + 200 + 50 + 20 + 20 + 5 + 2 = 497, or 768 by coils 500 + 200 + 50 + 10 + 5 + 2 + 1 = 768.

Resistance by Substitution. By Ohm's law the greater the resistance inserted in a circuit the less becomes the current, provided the e. m. f. remains constant. This gives us a simple although not very accurate method of measuring electrical resistance. If a battery of constant e. m. f., the unknown resistance, and a simple galvanometer are connected in series, the strength of the current passing will be indicated by the latter. Suppose the unknown resistance to be replaced by known resistances, enough resistance coils being inserted so that the deflection of the galvanometer needle is the same as when the unknown resistance was in circuit. The current will then be the same, and as the e. m. f. remains unchanged, the resistances must be equal in each case. The sum of the known resistance coils inserted will then be equal to the unknown resistance.

The advantages of this method are that it is rapid, and that only crude apparatus is required, as the galvanometer and resistance box can be very simple in form. The resistance of the battery and galvanometer should be but a few ohms, otherwise small resistances cannot be measured closely. Only small currents should be used so that the error from heating may be negligible.

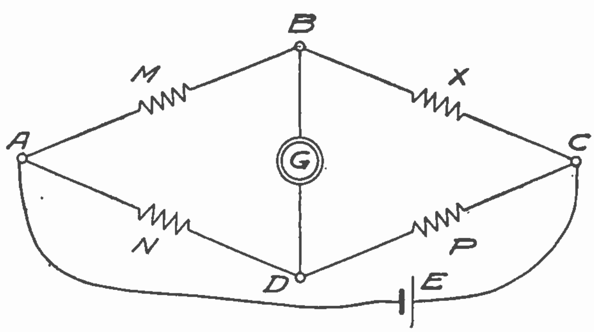
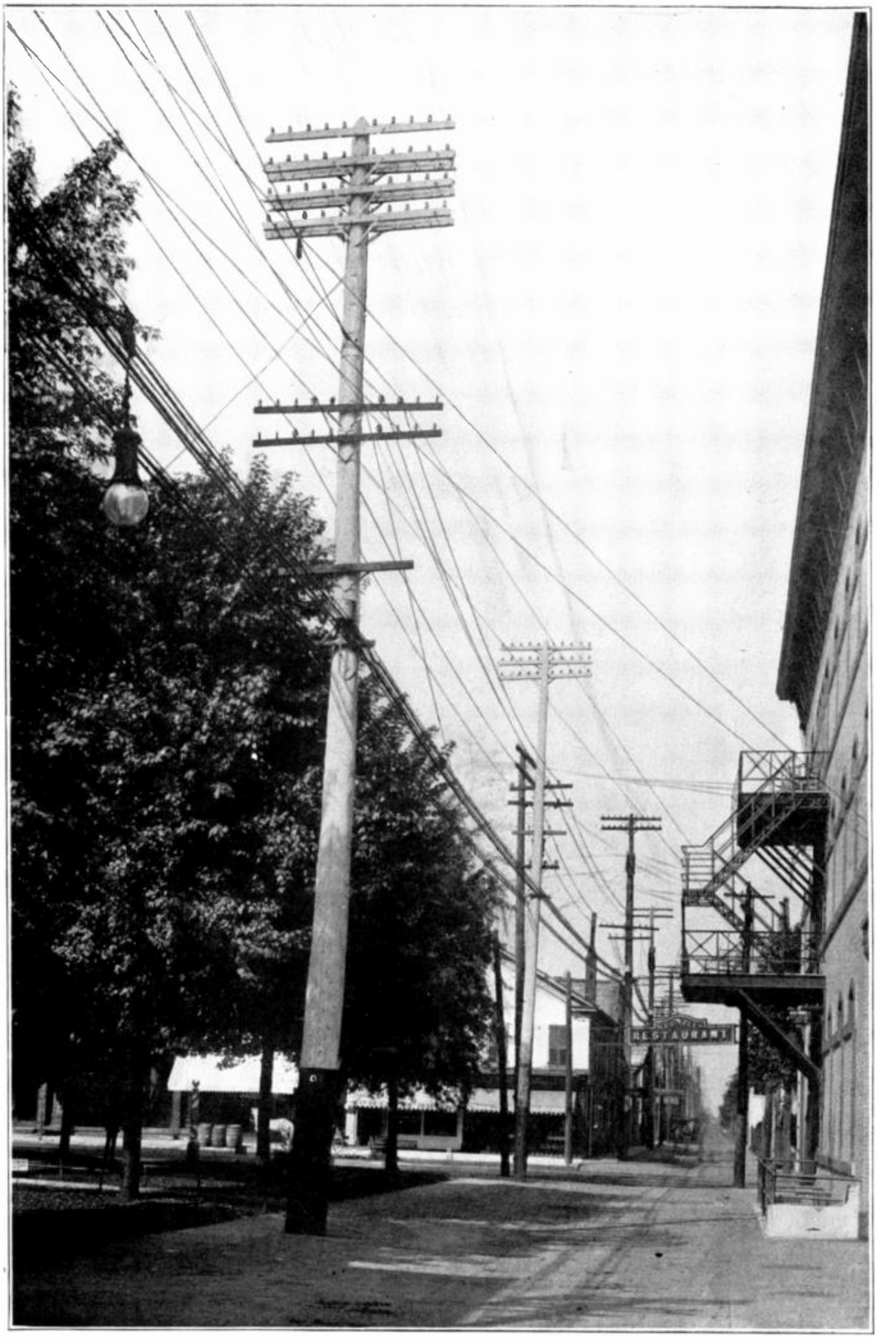


Fig. 19. Theoretical Diagram of a Wheatstone's Bridge.

Wheatstone's Bridge. All ordinary measurements of resistance are usually made by use of a Wheatstone's bridge.

The principles of this instrument will be understood from Fig. 19. There are four arms to the bridge with the resistances M, N, X, and P. From the points of junction A and C, wires connect with a battery E. A galvanometer G is connected between the junction points B and D. The current from the battery divides at A and



AN EXAMPLE OF JOINT CONSTRUCTION. AËRIAL TELEPHONE AND POWER WIRES

passes through the resistances M and X, and N and P, uniting again at C. The fall of potential between A and C must of course be the same in amount through the resistances M and X as through N and P. If no current passes through the galvanometer then the points B and D will be at the same potential, and there will be the same fall of potential in the resistances M and N, and in the resistances X and P. Under these circumstances the ratio of the resistances of M to N will be the same as X to P, or

$$\frac{M}{N} = \frac{X}{P}$$

If M, N, and P are known resistances, the resistance of X is readily found by the formula,

$$X = \frac{M}{N} \times P$$

The method of using the bridge will be better understood from Fig. 20. The bridge arm M has coils of 1, 10, 100 ohms resistance, and arm N, coils 10, 100, 1,000. The series of coils P for obtaining a balance usually has resistances of 1, 2, 2, 5, 10, 20, 20, 50, 100, 200, 200, 500, 1,000, 2,000 ohms, but coils up to 100 only are shown. There is a key K in the galvanometer circuit and a key H in the battery circuit. The battery key H should always be closed *before* the galvanometer key K, and should be kept closed until after K is opened. This not only insures steadiness in all currents when the galvanometer circuit is closed, but also protects the galvanometer from self-induction currents which would occur if the battery circuit were closed after that of the galvanometer. A double successive contact key, Fig. 21, may with advantage be substituted for the two single keys, thus insuring that the battery and galvanometer branches will be closed and opened in the proper se-

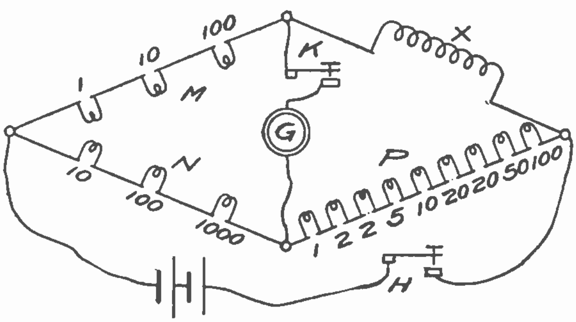


Fig. 20. Diagram Showing Method of Making Bridge Measurements.

quence. A reflecting galvanometer is used for accurate measurement

In making a measurement of an unknown resistance it is first necessary to gain a knowledge of its approximate resistance. For this purpose the 100-ohm plug is withdrawn from both arms *M* and *N*, the unknown resistance being connected at *X*. The ratios of *M* to *N* will then be unity, and hence for a balance the number of ohms required in the resistance coils *P* will be the same as the resistance *X*. The 1,000-ohm plug in *P* should first be drawn and the keys depressed in their proper order for an instant only. The galvanometer needle or mirror, as seen by the light reflected on the

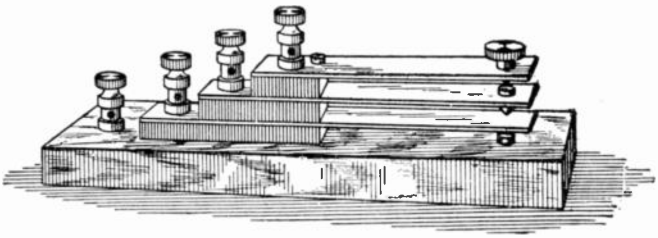


Fig. 24. 4-Point Contact Key.

scale, is deflected—say to the right, and the resistance is probably too large. The plug is replaced and the 1-ohm coil withdrawn. On depressing the keys suppose the spot of light is deflected to the left. Then the 1 ohm is too small and the 1,000 ohms too large; also in this case deflections to the right mean that the resistance inserted is too large, and to the left, that the resistance inserted is too small. The 1-ohm plug is now replaced, and 500, 200, etc., are successively tried until it is found that 12 ohms is too large and 11 ohms too small, that is, the unknown resistance is between 11 and 12 ohms.

Suppose that it is desired to find the correct value of the unknown resistance to the second place of decimals. The ratio of the arms *M* to *N* must then be changed so that the resistance coils *P* will have a value of between 1,100 and 1,200 ohms when a balance is obtained. The ratio of *X* to *P* will then be 11 to 1,100 approximately, or about 1 to 100. To obtain a balance the ratio of the arms *M* to *N* must also be 1 to 100. Hence the 100-ohm plugs first withdrawn are replaced and the 10-ohm plug withdrawn from *M* and the 1,000-ohm plug from *N* giving the required ratio. The same ratio could be obtained by withdrawing the 1-ohm plug in *M* and the 100-ohm plug in *N*.

The bridge is now arranged for the final measurement. As the resistance in P will now be over 1,100 ohms, the 1,000- and 100-ohm plugs are first removed. Suppose the 50-ohm plug to be also removed, and a deflection to the right shows that this is too great. The plug is replaced and 20 withdrawn, which proves to be too small. The next twenty plug is also withdrawn and a deflection to the left shows the resistance to be still too small. The 5-, 2-, and 2-ohm plugs are

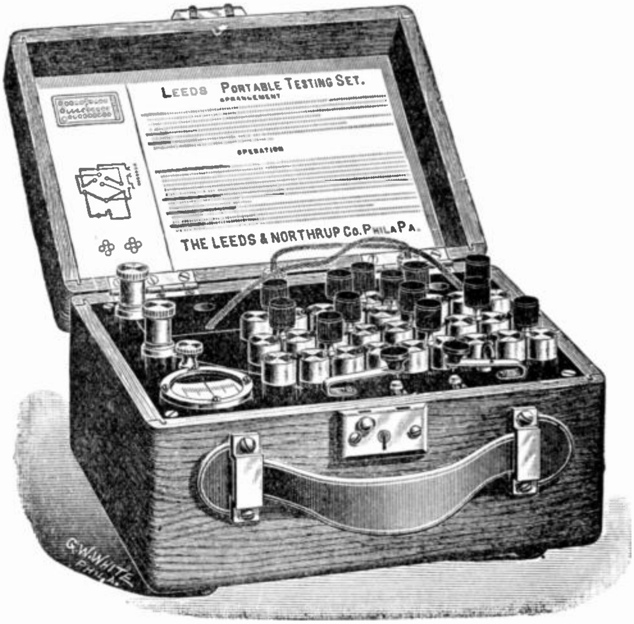


Fig. 22. Portable Testing Set.

successively withdrawn, the last two ohms proving to be too great. This is replaced and the 1-ohm plug withdrawn, and suppose no deflection is then obtained. The total number of ohms in P is now $1{,}000 + 100 + 20 + 20 + 5 + 2 + 1 = 1{,}148$. The value of X is therefore $\frac{10}{1000} \times 1{,}148 = 11.48$ ohms.

The above example illustrates the general method of using the bridge. Usually the resistance to be measured is known approximately and the required ratio between M and N can be determined without making a preliminary measurement. The possible changes in the ratio between M and N gives the bridge a great range of measurement. When M is 1 and N is 1,000 ohms, measurements of resistance as small as .001 ohm may be made. Bridges are usually arranged with a reversing key so that M and N may be interchanged, hence M could be 1,000 and N 1, and measurements of resistance as high as 4,110,000 ohms could be made with the bridge we have considered.

Portable Testing Set. There are many different varieties of bridges and their form always differs from that of the diagrams in Figs. 19 and 21. A portable testing set including Wheatstone's bridge, galvanometer, battery, and keys, is illustrated in Fig. 22. The rheostat of the bridge is made up of coils, 16 in number, of denominations 1, 2, 3, 4, 10, 20, 30, 40, 100, 200, 300, 400, 1,000, 2,000, 3,000, 4,000 ohms—11,110 ohms in all. Bridge coils are 1, 10, and 100 on one side and 10, 100, and 1,000 on the other. A reversing key admits of any ratio being obtained in either direction so that the range of the set is from .001 to 11,110,000 ohms. It is, however, impossible to construct a portable galvanometer of sufficient sensitiveness for these measurements, and the actual limits are from .001 ohm to 300,000 or 400,000 ohms.

Fig. 23. Reversing Keys.

The reversing key, shown in Fig. 23, consists of the blocks M, N, P, and X and two plugs which must both lie on one diagonal or the other. The blocks are connected with the resistances indicated by their letters. In the left-hand figure M is connected with X and N with P, and the bridge arms have the relation

$$\frac{M}{N} = \frac{X}{P}, \text{ or } X = \frac{M}{N} \times P$$

In the right-hand figure M is connected with P and N with X, the bridge arms then having the relation

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P$$

The advantages of having a reversing key in the bridge arms are: the increase in range obtained, six coils being made to do the work of eight, and also that any error in the initial adjustment of the bridge arms can be detected by having the two arms equal, balancing and reversing. Unless the resistance of the coils inserted in M and N are exactly equal, the system will be unbalanced after reversing.

The galvanometer, the needle and scale of which are shown at the left in Fig. 22, is of the D'Arsonval type, and the coil is mounted in jewels. As this galvanometer is not affected by external magnetic fields or electric currents, it is suitable for dynamo or shop testing. The key for the galvanometer circuit is shown in front at the right.

The battery is made up of chloride of silver cells mounted in the bottom of the box. The cells will last a number of months even with daily use. Flexible connecting cords, running from the cells, have their terminal sockets combined with small binding posts so that connection may be made to an extra battery or other source of e. m. f. if desired. The left-hand key controls the battery circuit.

A plan of the connections of this testing set is shown in Fig. 24. The two lower rows of coils (marked 1 to 4,000) are connected beneath the top at the right by a heavy copper rod and constitute the rheostat arm, or what corresponds to P in the formula.

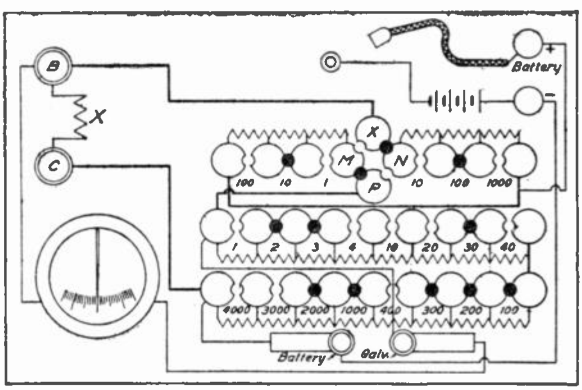


Fig. 24. Diagram of a Testing Set.

By withdrawing the proper plugs in these rows any number of ohms from 1 to 11,110 may be obtained. The upper row of coils consists of the two bridge arms, M at the left and N at the right, with the reversing key between them. The two extremes of the upper row are joined by a heavy copper connection and correspond to the point A in Fig. 19. The upper block X of the reversing key is connected with the binding post B, the block P is joined to the left of the middle row of coils while the other end of the rheostat combination is connected with the binding post C. The resistance to be measured X is connected between the terminals B and C.

Example. Suppose a balance is obtained with an unknown resistance connected between B and C, when the plugs are withdrawn as shown in Fig. 24. What is the value of the unknown resistance?

Solution. The reversing key is arranged so that M is connected with P and N with X, hence

$$\frac{M}{N} = \frac{P}{X}, \text{ or } X = \frac{N}{M} \times P$$

In the figure $N = 100$, $M = 10$, and $P = 2{,}000 + 1{,}000 + 300 + 200 + 100 + 30 + 3 + 2 = 3{,}635$. Therefore

$$X = \frac{100}{10} \times 3{,}635 = 36{,}350 \text{ ohms}$$

Ans. 36,350 ohms.

Use and Care of Bridge. Before beginning a measurement it is essential that each plug be examined to see that it is firmly twisted into place, also in replacing a plug the same care should be used. A slight looseness will considerably increase the contact resistance and so introduce errors in the result. Moderate force only is needed in placing plugs. A strong person may damage the apparatus. For the same reason the plug tapers should be kept clean and the top of the bridge should be free from dust and moisture. Special care should be taken with the surfaces between adjacent blocks. The plugs should be handled only by their vulcanite tops, and care should be taken not to touch the blocks.

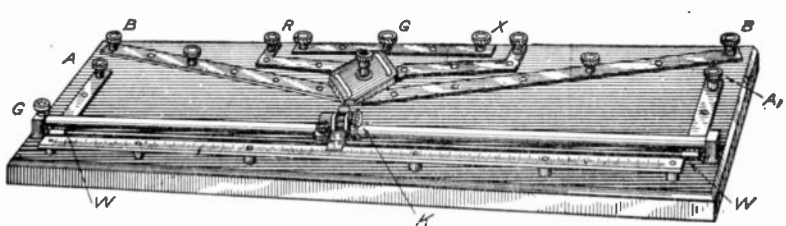


Fig. 25. Slide Wire Wheatstone's Bridge.

The plug tapers may be cleaned with a cloth moistened with alcohol and then rubbed with powdered chalk or whiting.. The powder should be entirely removed with a clean cloth before the plugs are replaced. Sand paper or emery cloth should never be used to clean the plugs or bridge blocks. If there are no idle sockets for the reception of the plugs when they are withdrawn, they should be stood on end or placed on a clean surface.

Slide Wire Bridge. The simplest form of Wheatstone's bridge is the slide wire bridge. Fig. 25 illustrates the apparatus. The foundation of the bridge is a board well braced to avoid warping, which, after being well dried, is saturated with hot paraffin to make it a good insulator. The bridge wire is usually one meter long and stretched between substantial anchorages at the ends. Heavy straps of copper or brass serve as connections of negligible resistance to the other parts of the bridge. The known resistance is inserted at R and the unknown at X. Openings at A and A' are closed by heavy metal straps for the usual method of use, or in more complete methods by resistances which are, in effect, extensions of the bridge wire. The battery and its key are connected between B and B, and the galvanometer between G and G. The heavy rod back of and above the bridge wire is a support for the galvanometer key K and the index which is adjacent to the meter scale shown. The key and the index may be moved along the rod to find the balancing point. A commutator shown at the center of the apparatus serves to exchange the relative position of X and R in the arrangement. The commutator makes connection in four mercury cups. If the portion of the bridge wire to the left of the galvanometer key is a cm. long, the rest of the wire is 100-a long. If the commutator is arranged so that R is connected to the left end and X to the right end of the wire, when a balance is reached we have

$$\frac{R}{X} = \frac{a}{100 - a}, \text{ or } X = R\,\frac{100 - a}{a}$$

If the commutator is reversed and the new reading is a' we get

$$X = R\,\frac{a'}{100 - a'}$$

If the balancing point is near the end of the wire, it is evident that any small error in the reading and the assumption that the connections are of negligible resistance, will result in greater error in the final formula. For this reason it is well to treat the first balance as only approximate and after calculating X to take as known resistance a new value of R as nearly as possible equal to X. In this way the balancing point will be brought near the center of the wire.

For very exact comparison of two nearly equal resistances, we insert auxiliary resistances at A and A'. These are in effect extensions of the bridge wire. Call these resistances equal to A and A' cm. of the wire. When a balance is obtained at the points a and a' for the two positions of the commutator, we have

$$X = R\,\frac{A' + 100 - a}{A + a} \text{ and } X = R\,\frac{A + a'}{A' + 100 - a'}$$

While it is still of advantage under these conditions to have a and a' somewhere near 50 cm. it is no longer necessary, for with the bridge wire extended by A and A' any point of the actual bridge wire is now near the center.

If R is materially larger or smaller than X, the balancing point may be beyond the end of the actual wire, *i. e.*, in one of the extensions, and no balance can be obtained. It is necessary then to adjust R until a balancing point is found on the wire. We may then proceed with the experiment.

A variation of this method, known as the *Carey-Foster method*, is used for the comparison of two standard resistances to discover small differences in adjustment.

Example. If with the openings A and A' closed with straps of negligible resistance and a resistance of 150 ohms for R, the mean balance point comes so that a = 68.4 cm. and b = 31.6 cm., what is the value of X? Ans. 69.3 ohms.

Example. If A and A' are equivalent to 500 cm. each, and R = 150 ohms, and the mean balance point makes a = 68.4 cm., and b = 31.6 cm., what is the value of X? Ans. 140.29 ohms.

Low Resistance Measurement. The bridge methods described above are not suitable to use in the measurement of small resistances, for the *lead* wires (*leading in* wires) used in connecting the unknown resistance to the *bridge* may have more resistance than the unknown. The *ammeter-voltmeter method* is that most generally used. The apparatus is connected as shown in Fig. 26. The current from the battery is led through the ammeter to the unknown low resistance R. An adjustable resistance r of a rheostat may be introduced into the circuit to control the current. The actual resistance r need not be known. The fall of potential V through R is measured by the voltmeter, and the current I by the ammeter. Ohm's law then gives

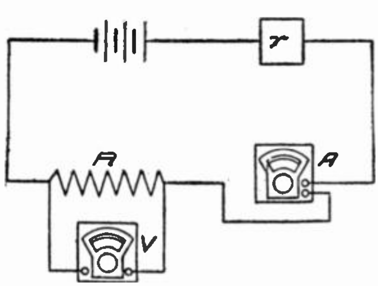


Fig. 26. Ammeter-Voltmeter Method of Low Resistance Measurement.

$$R = \frac{E}{I}$$

Ammeter-Voltmeter Method. It is evident that although the voltmeter is of very high resistance, a small current included in that measured by the ammeter passes through the voltmeter. In strictness this current, equal to $\frac{V}{\text{resistance of the voltmeter}}$, should be subtracted from the ammeter reading to get the value of I to be used in the formula. This correction is easily made, as all makers of voltmeters give the value of the resistance, usually marked on the voltmeter case; but the error resulting from neglecting the correction is generally immaterial. Instruments of suitable range should be used.

Example. The reading of the ammeter is 50 amperes, that of the voltmeter 1.5 volts; what is R? Ans. 0.03 ohm.

In the particular case chosen the ammeter had a range 0 to 75 amperes, and the voltmeter 0 to 3 volts. The resistance of the voltmeter was 300 ohms. The current through the voltmeter was 1.5 ÷ 300 = 0.005 amperes. It is evident that the correction is far smaller than the probable error of reading the ammeter, and any attempt at correction would be absurd.

This method may also be used to measure the resistance of a burning incandescent lamp. In such a case the bridge method is useless as the resistance of a cold lamp is probably double its resistance when hot.

Example. The voltmeter, 0 to 150 volts range and resistance 15,000 ohms, reads 110 volts; the ammeter, 0 to 1 amperes range, reads 0.5 ampere. What is the resistance R? Ans. 220 ohms.

High Resistance Measurement. *Direct Deflection Method.* An excellent method of measuring resistances of one megohm (one million ohms) or more, is the direct deflection method. The main instruments needed are a sensitive galvanometer, usually of high resistance and fitted with appropriate shunts; some standard resistances of 100,000 ohms (0.1 megohm) or more; and a battery of relatively low resistance and constant e. m. f. (a storage battery of many cells, if available). The resistance of the galvanometer both alone and combined with its shunts must be known. That of the battery and the connections is usually neglected. The connections are shown in

Fig. 27. The known resistance R is first connected in series with the galvanometer G and the testing battery B, through a key K. Care should be taken that the insulation of the apparatus be very high. The shunt S is adjusted to give a suitable deflection of the galvanometer and from this deflection what is known as the *constant* is calculated. The value of this constant is the resistance that must be inserted in the circuit to reduce the deflection to one scale division. The value of the constant is therefore equal to the product of the total resistance, assumed to be $R + \frac{G}{m}$, the scale deflection d, and the multiplying power of the shunt m. We thus get

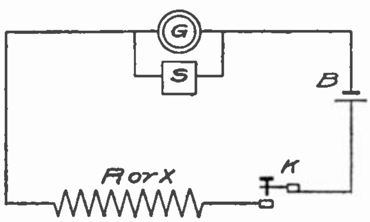


Fig. 27. Direct-Deflection Method of High Resistance Measurement.

$$\text{Constant} = (R + \frac{G}{m})\, d\, m$$

As an illustration, suppose R = 0.1 megohm, G = 20,000 ohms = 0.02 megohm, m = 1,000, and d = 200 divisions; then

$$\text{Constant} = (0.1 + 0.00002) \times 200 \times 1{,}000$$
$$= 20{,}004 \text{ megohms}$$

This means that if the galvanometer were unshunted and the total resistance in the circuit were 20,004 megohms, a deflection of one division would result.

After the constant has been determined the known resistance R is replaced by the unknown resistance X. The galvanometer shunt is readjusted if necessary and the deflection obtained is again noted. The value of the total resistance is then found by dividing the value of the constant by the product of the deflection d_1 and the multiplying power m_1 of the shunt used. To continue our illustration suppose d_1 = 50 divisions, and m_1 = 10. The deflection, if the full current went through the galvanometer, would be 50 × 10 = 500 divisions. A deflection of one division is produced with a resistance of 20,004 megohms; hence a deflection of 500 divisions must correspond to $\frac{1}{500}$ of this, or 40.008 megohms. Subtracting the resistance of the shunted galvanometer 20,000 ÷ 10 = 2,000 ohms, or 0.002 megohm, leaves the unknown resistance 40.006 megohms. The algebraic equation expressing this is

$$X = \frac{(R + \frac{G}{m}) d\, m}{d_1\, m_1} - \frac{G}{m_1} = 40.006 \text{ megohms}$$

Neglecting the resistance of the galvanometer in both cases, a simpler formula would give

$$X = \frac{R\, d\, m}{d_1\, m_1} = 40 \text{ megohms}$$

It may be noted that the difference between these results is an amount corresponding to a difference in deflection of 0.0075 of a single scale division, which is far smaller than the probable error which any observer would make. It is then clearly permissible to use the simpler formula,

$$X = \frac{R\, d\, m}{d_1\, m_1}$$

Example. In a high resistance measurement by the above method the known resistance was .2 megohms, and gave a deflection of 237 divisions, the multiplying power of the shunt being 100. With the unknown resistance inserted, the deflection was 178 divisions with the full current passing through the galvanometer. What was the value of this resistance? Ans. 26.6 megohms.

Voltmeter Method. Another method of measuring high resistance is that in which a sensitive high resistance voltmeter such as the Weston is used. This method, however, is not as accurate as the preceding and is not adapted to measurements of resistance greater than a few megohms. The voltmeter is connected in series with the unknown resistance and a source of constant e. m. f., as shown in Fig. 28.

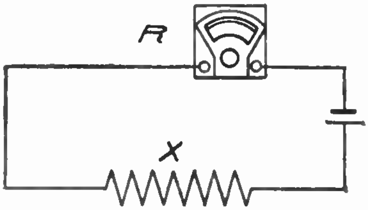


Fig. 28. Voltmeter Method of High Resistance Measurement.

With such an arrangement the resistance X will be to the resistance of the voltmeter R, as the volts drop in X is to that in the voltmeter. The drop v in the voltmeter is given by its reading, and if the applied electromotive force V is known, the drop in X will be $V - v$. We therefore have the proportion,

$$X : R :: V - v : v, \text{ and}$$

$$X = \frac{V - v}{v} \times R$$

The voltage V, which should be at least 100, may be first determined by measurement with the voltmeter.

Example. A voltmeter having a resistance of 15,000 ohms, was connected in series with an unknown resistance. The e. m. f. applied to the circuit was 110 volts and the voltmeter indicated 6 volts. What was the value of the unknown resistance?

Solution. Applying the preceding formula

$$V = 110, \; v = 6, \text{ and } R = 15{,}000,$$

therefore

$$X = \frac{110-6}{6} \times 15{,}000 = 260{,}000 \text{ ohms, or } .26 \text{ megohms}$$

Ans. .26 megohms.

Insulation Resistance. The measurement of insulation resistance is performed by either of the two preceding methods of measuring high resistance. The voltmeter method is the simpler, but since it cannot be used to measure resistances greater than a few megohms, the direct deflection method proves to be the more valuable. The insulation of low potential circuits, however, need not exceed five megohms, and in testing such circuits the voltmeter method may be used. If little or no deflection is obtained it is then evident that the insulation is at least several megohms, which is all that is desired. As the insulation of high potential circuits must be greater than five or ten megohms, the direct deflection method should then be used.

The *connections* in testing the insulation of a circuit by these two methods are similar to those shown in Figs. 27 and 28, the resistance X being replaced by the insulation of the circuit. This is accomplished by connecting one wire to the line and the other to the ground such as, to a gas or water pipe. The insulation of the line from the earth is then included in the testing circuit; the current passing from the battery, or other source, through the voltmeter or galvanometer to the line, from the line through the insulation to the ground, and then to the battery.

The insulation of a dynamo, that is, the resistance between its conductors and its frame, is tested in a similar manner. This resistance should be at least one megohm for a 110-volt machine, but two megohms is to be preferred and is customary. This insulation is measured by connecting one wire to the frame and the other to the binding post, brushes, or commutator. The insulation is then included in the circuit. Insulation resistance decreases with increase of temperature so that this test of a machine should be made after a full load run of several hours.

The e. m. f. used should be constant and of one to two hundred volts value. Secondary batteries are the best for this purpose but silver chloride testing cells are much used. The resistance of dielectrics increases by continued action of the current and this property is known as *electrification*. For this reason the deflection should not be read until after a certain period of electrification—usually one minute. This action is quicker in some materials than in others, and is also greater at low than at high temperatures.

Insulation Resistance of Cables. In the preceding cases of insulation resistance only a part of the insulation is under electric strain. In the case of submarine cables and lead covered cables used on land, the whole of the insulation is subjected to the electric strain. To test the resistance of a waterproof insulation, the insulated wire or cable may be immersed in a tank of water. Care should be taken to leave enough of the cable out of the water so that surface leakage near the ends may not interfere with the test. For short lengths of cable the resistance of the wire inside the insulating material may be ignored. The resistance between the wire and a metal plate immersed in the tank is practically the resistance of the insulation. Fig. 27 shows the arrangement of the apparatus. As a cable takes a certain charge as a condenser when subjected to an e. m. f., it is necessary to protect the galvanometer, by a short-circuiting switch between the galvanometer terminals, during the rush of current on first closing the circuit. The switch box *S*, Fig. 27, has such a short-circuiting switch. This is important as otherwise the galvanometer may be injured. If the insulation resistance is not too high the direct deflection method above described may be used. If the insulation is excellent the deflection produced by the leakage should be very small and some other method must be used.

Charge and Recharge Method. An excellent method in such cases is the charge and recharge method. In this method. Fig. 27, the cable is first charged for several minutes, care being taken to short-circuit the galvanometer. The circuit is then opened for, say, one minute and the circuit closed again, the short-circuiting switch of the galvanometer meanwhile having been opened. While the circuit was open, a certain part of the charge leaked out and this is now replaced by an equal added charge. The galvanometer makes a sudden throw due to this added charge and after many oscillations comes to rest. If the relation between the added charge and the galvanometer throw is known, the quantity added may be computed, and the leakage current is equal to the added charge (equal to that lost) divided by the time in seconds for which the circuit was open. If the steady leakage produces a measurable deflection, account should be taken of this in estimating that part of the sudden throw produced on closing the circuit again. This correction we here suppose to be negligible. To find the relation between charge and throw, a condenser of known capacity (farads) is charged by a known e. m. f. and then discharged through the galvanometer. The charge equals the product of capacity and e. m. f. used. The charge divided by the throw produced, gives the constant of the instrument as a ballistic galvanometer. As condensers are rated in microfarads (millionths of farads) care must be taken to use the value in farads if the value in ohms insulation resistance is required. If the value in microfarads is used, the final result will come out in megohms. If an e. m. f. E_1 volts and capacity C microfarads produces a ballistic throw d_1, and if an e. m. f. of E_2 volts produces a throw of d_2 on closing the circuit through the insulation under test after the circuit has been open for t seconds, ignoring the resistance of other parts of the circuit, the insulation resistance is

$$X = \frac{E_2 \times d_1 \times t}{E_1 \times d_2 \times C} \text{ megohms}$$

Example. If E_1 is 1.44 volts, C is 0.5 microfarad, d_1 is 28.8 cm., E_2 is 100 volts, d_2 is 20 cm., and t_1 is 60 seconds, what is X?

Ans. 12,000 megohms.

As a rule the insulation resistance per mile is required. The longer the cable the more surface is exposed to leakage; consequently it is evident that the insulation resistance per mile is found by multiplying the resistance of the sample by its length in fractions of a mile. That is, a mile of cable would have, say, one-quarter as much insulation resistance as a quarter of a mile of cable.

In the case of lead covered cables, no tank is required, as connection may be made with the lead covering instead of the immersed metal plate before mentioned.

Resistance of Lines. Telegraph, telephone, and power transmission lines may be measured in place to best advantage if one or more additional lines are available between the terminals. If only one wire is available both ends may be connected to ground and the resistance, which involves that of the connections to ground and that of the earth return, may be measured by one of the methods described above. Such a method though unsatisfactory may be the best available. The resistance of the earth return is generally low, but there is always much uncertainty as to the resistance to earth at the ends. Earth currents of electricity, due to many causes, may much complicate the problem. When a second line of resistance X_2 is available, that and the unknown resistance X_1 may be connected together at the distant end and the combined resistance R, which equals $X_1 + X_2$, measured. Next, the distant junction may be grounded and the two wires connected as the proportional arms of a Wheatstone's bridge, as illustrated in Fig. 29. The resistances in the other proportional arms are R_1 and R_2. One terminal of the battery is grounded. When a balance is obtained the proportion of the whole resistance R in X is

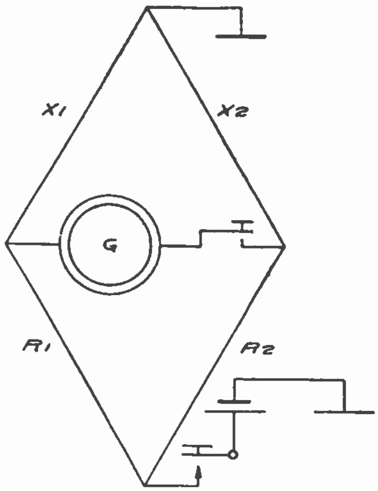


Fig. 29. Bridge Diagram for Line Resistance Measurement.

$$X_1 = R \frac{R_1}{R_1 + R_2}$$

In a similar way, $X_2 = R \frac{R_2}{R_1 + R_2}$

It is well to connect the battery in that branch of the bridge which includes the earth return as there may be a difference of potential due to earth currents, which does not disturb the *bridge* as it simply adds to or subtracts from the battery e. m. f. If a third line is available it may be used in the battery branch in place of the earth return. It will be noted that the resistance to earth at both ends is not in any of the four proportional arms and consequently does not affect the result.

Example. The two wires looped together have a resistance of 248 ohms. When a balance is obtained with them as arms of the bridge, $R_1 = 1{,}000$ ohms and $R_2 = 1{,}127$ ohms, the proportion being $R_1 : R_2 :: X_1 : X_2$. What are X_1 and X_2?

Ans. $X_1 = 116.6$ ohms; $X_2 = 131.4$ ohms.

Locating Grounds. In case a line wire is grounded at some unknown point, the above method may be used in locating the ground. The grounded wire and a second wire free from grounds may be looped together and their combined resistance measured. The loop, as before, is connected as two arms of a bridge, but the junction is left insulated. X_1 is now the resistance from the testing station to the point where the wire is grounded. X_2 is the combined resistance of the rest of that wire and the whole of the other wire. The resistance to the grounded point is then

$$X_1 = R\frac{R_1}{R_1 + R_2}$$

As a rule the resistance of every line is part of the office data, and therefore $R = X_1 + X_2$ is known in advance and need not be remeasured. As the resistance per mile is also usually part of the office data, the actual distance corresponding to X_1 may be computed and a lineman sent to the point to make the repair. If in a severe storm several grounds occur on the same wire, this method, of course, cannot be used to locate the trouble. In the case of ocean cables this method is used with excellent results. The cable repair steamer can be sent to the point of trouble where the cable is raised and repaired.

Locating Faults. This method may be used in the care of a broken submarine cable if both ends are exposed to the water, but it cannot be used for broken land-lines because the ends, even if both on the ground, are too imperfectly grounded. If the conductor of a submarine cable is broken but the insulation left intact, this method cannot be used. A method, however, in which the distributed capacity of the cable is measured in microfarads (see Capacity Measurements later) can be used to determine the location of the break. This latter method may also be used for a broken land-line where the end of the wire hangs free of the ground.

A COMBINATION OF AËRIAL POWER WIRES, OPEN TELEPHONE WIRES, AND AËRIAL TELEPHONE CABLE

MEASUREMENT OF BATTERY RESISTANCE

Voltmeter Method. The following voltmeter method may be used to measure battery resistance. The battery of one or more cells is connected in circuit through a key K, with a known resistance R. The voltmeter of appropriate range is connected, as shown in Fig. 30, to the terminals of the battery. With the key K open, V_1—the e. m. f. of the battery—is measured. The key K is then closed and V_2 —the reading of the voltmeter— is observed. By Ohm's law the current is $\frac{V_2}{R}$. A part of the battery's e. m. f., equal to $V_1 - V_2$, is now lost inside the battery because of the resistance X of the battery. We then have the relation,

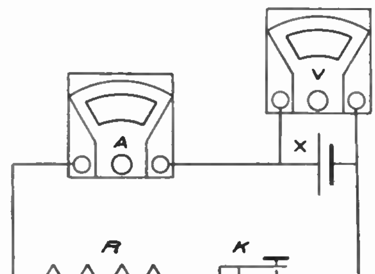


Fig. 30. Voltmeter Method of Measuring Battery Resistance.

$$V_1 - V_2 = X\frac{V_2}{R}, \text{ and}$$

$$X = R\frac{V_1 - V_2}{V_2}$$

If the resistance R is not known, an ammeter may be introduced into the circuit in series with R, and the current I measured directly. Then

$$XI = V_1 - V_2, \text{ and}$$

$$X = \frac{V_1 - V_2}{I}$$

It will be noticed that it is tacitly assumed that when the key K is open, not enough current will pass through the voltmeter to introduce any error. If the battery resistance is large this error is not negligible and a sensitive high resistance galvanometer with considerable additional resistance, perhaps 100,000 ohms besides, may be substituted for the voltmeter. If the deflections of the galvanometer in the two cases (open and closed) are d_1 and d_2, we then have

$$X = R\frac{d_1 - d_2}{d_2}$$

As the battery when furnishing a current begins at once to fall off in e. m. f., that is, *polarize*, a small error due to polarization makes the battery resistance appear too high. Such a value of the resistance R should be chosen as to make the deflections materially different. Otherwise a slight error in V_1 and V_2 or d_1 and d_2 will make their difference $V_1 - V_2$ or $d_1 - d_2$ many per cent in error.

Example. A cell has an e. m. f., $V_1 = 1.47$ volts when S is open and 1.12 when S is closed. R is 5 ohms. What is X?

Ans. $X = 1.56$ ohms.

Mance's Method. Another method is Mance's method, in which the battery, whose resistance X is to be determined, forms one arm of a Wheatstone's bridge, as indicated in Fig. 31. No key is placed in the galvanometer branch and no additional resistance, in the branch which includes the key S. The resistance in R_3 is adjusted until the galvanometer does not change its deflection on closing the key S. It is usually necessary to put considerable additional resistance R in the galvanometer arm to keep the deflection small. If the deflection does not change on closing the key S, it is evident that the decrease in the potential difference at the terminals of the cell due to its increased current when S is closed, must exactly equal the decrease in the potential difference between the terminals of R_3 due to this path being robbed of a part of its current because of the new path. Otherwise the potential difference at the galvanometer terminals, which is the difference of the potential differences over the two arms, would change and the deflection change. Similar reasoning applies to R_1 and R_2, only here the difference over R_2 increases by just the amount that that over R_1 falls, thus keeping the total amount constant for the combination of R_1 and R_2. The arrows show the direction of the currents in the various arms. If no change in the galvanometer current occurs, the changes in R_1 and R_3 must be equal and so also the changes in R_2 and X. It follows then if the galvanometer deflection remains constant whether S is open or closed, that

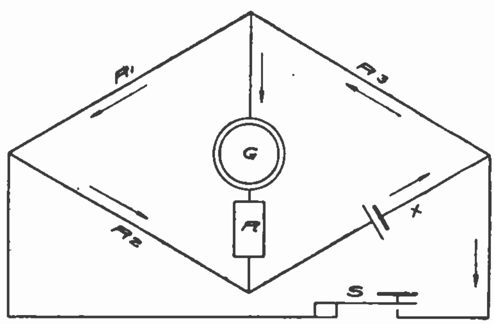


Fig. 31. Bridge Diagram for Mance's Method.

$$R_1 : R_2 :: R_3 : X, \text{ or}$$
$$X = \frac{R_2 \times R_3}{R_1}$$

Should the battery polarization change on closing the key S, the galvanometer deflection will change. For this reason the key S should be closed for an instant only.

Besides these methods there are excellent methods in which alternating currents are used, but they are too advanced to be described in this course. Such alternating-current methods should be used in measurement of the resistance of solutions (so called electrolytes) which are decomposed by a direct current.

MEASUREMENT OF ELECTROMOTIVE FORCE

Voltmeter Method. The simplest method of measuring an electromotive force is by the use of a voltmeter which indicates directly

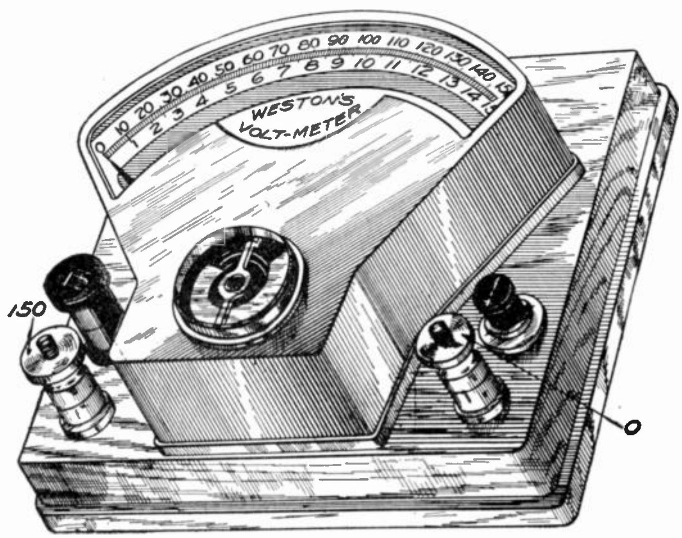


Fig. 32. Commercial Portable Voltmeter.

the number of volts. A voltmeter of the proper range should be chosen. For very small e. m. f.'s the millivoltmeter, usual range 1 to 300 millivolts, *i. e.*, 1 to 0.3 volt, may be used. For higher e. m. f.'s, voltmeters reading to 1.5, 15, 150, and 300 volts respectively, are made by the Weston Electrical Instrument Co. and others. A voltmeter is simply a galvanometer calibrated to be read in volts. It is evident that if an additional resistance equal to that of the voltmeter is placed in series with the latter, twice the voltage will be required to produce the same deflection as before. In general, any resistance in series which makes the total resistance n times that of the voltmeter alone, may be used as a multiplier; and the reading of the voltmeter must be multiplied by n to get the value of the e. m. f. Such a multiplier may be bought with a voltmeter in order to make its effective range greater. For example, if the resistance of a voltmeter of range 0 to 150 volts, is 15,000 ohms, a multiplier having a resistance of 60,000 ohms will bring the total up to 75,000 ohms, and the constant n of the multiplier is 5. With this multiplier in the circuit the upper limit of the voltmeter is extended to 750 volts. If the multiplier is mounted inside the voltmeter, and if on using the binding posts marked 0 and 15 the range is 0 to 15 volts, and using the binding posts marked 0 and 150 the range is 0 to 150 volts, the multiplier evidently must have nine times the resistance of the main part. Such a voltmeter, shown in Fig. 32, is said to be a two-scale voltmeter, and it may be used equally well on either range. As the extra expense of providing the multiplier and extra binding post is slight, a two-scale voltmeter is a very inexpensive substitute for two voltmeters. It is also evident that a low range voltmeter may be used in connection with any resistance box as a multiplier. The Weston voltmeters have approximately 100 ohms resistance per volt of range and, therefore, take a maximum of about 0.01 amperes when used on an e. m. f. which is the maximum of the range. As a rule the current taken by a voltmeter is negligible in comparison with the current in the rest of the circuit.

The voltmeter method may be used equally well with both direct and alternating electromotive forces.

Potentiometer Method. For the comparison of e. m. f.'s, the potentiometer is the most accurate apparatus. When a balance is reached the e. m. f.'s to be compared are not allowed to furnish any current, and consequently no polarization results in their source. The effect of internal resistance is absolutely *nil* also. The arrangement of apparatus is shown in Fig. 33.

Two resistance boxes M and N, each of 10,000 ohms capacity, are arranged to have plugs withdrawn to a total of 10,000 ohms, and are connected in series with a battery B. To avoid injuring B, plugs corresponding to 10,000 ohms should be withdrawn before connecting it in circuit. The circuit has a high resistance and the effect of polarization of the battery B quickly reaches its limit and a steady current I flows through the circuit. If the resistance in box M is R ohms, that in box N is (10,000 − R) ohms; and the fall of potential over M is $R\,I$ volts, and over the box N is (10,000 − R) I volts. One of the cells to be compared, a standard cell of e. m. f. S, is connected in series with some high resistance A, a sensitive galvanometer G, and a key K. In general, on closing the key K the galvanometer will deflect; but if the resistances in M and N are adjusted until the potential difference over M is exactly equal to the e. m. f. of the cell S, the latter is in perfect balance and can neither supply current to the general circuit supplied by B nor can current be forced backward through the cell S. In that case the e. m. f. of S equals the fall of potential through M, and, calling R_1 the resistance in M,

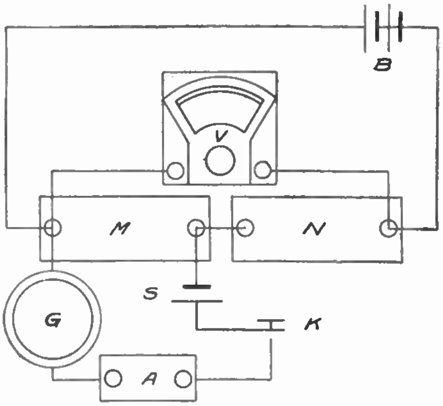


Fig. 33. Potentiometer Method of Measurement of E. M. F.

$$S = I\,R_1$$

If now a second cell of unknown e. m. f. X is substitued for S, and the resistances in M and N readjusted—but their sum kept 10,000—until on closing the key K no deflection results, calling the new value of the resistance in M, R_2, we have the relation

$$X = I\,R_2$$

It follows that

$$X = S\,\frac{R_2}{R_1}$$

If S is known, X may be computed. It is well to repeat the balance with S to be quite sure that no change has meanwhile occurred in the main battery B. Precaution should be taken in setting up the apparatus that B is greater than either S or X and that they are connected into the circuit so that they are in opposition to B. If these conditions are not obeyed, it is evident that no balance can be obtained. If no exact balance can be obtained, but a change of one ohm changes the galvanometer deflection from up to down the scale, the fraction of an ohm needed for an exact balance can be obtained by interpolation. In the next article on the calibration of a voltmeter such an interpolation is made.

Example. With a total resistance in M and N of 10,000 ohms of which the resistance in M was $R_1 = 5{,}267$ ohms, when the standard Clark cell of 1.433 volts was in the galvanometer circuit, and the resistance was $R_2 = 5{,}470$ ohms when the Leclanché cell was in the galvanometer circuit, what is the e. m. f. X of the Leclanché cell?

Ans. $X = 1.4882$ volts.

Calibration of a Voltmeter. If during the previous experiment, a voltmeter had been connected for the whole time between the extreme terminals of M and N, the potential difference V between the terminals of the voltmeter would have been

$$V = 10{,}000\, I = 10{,}000\, \frac{S}{R_1}$$

This gives a convenient method of calibrating a voltmeter by means of a standard cell of known e. m. f. S. The calibration may be extended to various points of the voltmeter by changing the e. m. f. of the main battery B. In such cases the resistance in M, to obtain a balance, will change in the inverse ratio. It is evident that the calibration cannot by this method be extended to points below the e. m. f. of the standard cell. In the case of high e. m. f.'s, it is desirable to increase the total resistance in M and N beyond 10,000 ohms. For example, if the e. m. f. produced by B at the terminals of the voltmeter is 150 volts, a total resistance of 100,000 ohms would be about right. In this case over 99,000 ohms would be in N and less than 1,000 in M. If several standard cells are available, they may be connected in series in the galvanometer branch, thus increasing the resistance for a balance in the box M. As most boxes have one ohm for their smallest resistance, a greater per cent of accuracy is obtained if the resistance in M is large. If an exact balance cannot be obtained and the nearest smaller resistance produces a deflection d_1 one way, and the nearest larger resistance produces a deflection d_2 in the opposite direction, the fraction of an ohm which would have produced a balance is evidently

$$\frac{d_1}{d_1 + d_2}$$

Example. With a total resistance of 100,000 ohms in M and N, and 987 ohms in M producing a deflection of 5 divisions down the scale, and 988 ohms producing a deflection of 15 divisions up the scale, and a standard Clark cell of 1.433 volts e. m. f. in the galvanometer circuit, what is the correction to be added to the voltmeter reading which was 144.9 volts? Ans. Correction = + 0.25 volt.

Suggestion of Solution. The change in deflection by change of one ohm is 5 + 15 scale divisions; therefore, 987 is 0.25 ohm too small and 988 is 0.75 ohm too large. The e. m. f. figures out 145.15 volts; therefore, 0.25 volt will be added to the voltmeter reading to give the correct result.

This method, as will be seen later under the head of "Measurement of Current," can be used with a standard cell to measure a current.

Condenser Method. If a condenser of capacity C is connected by means of a charge and discharge key K, which has an upper and a lower contact, as shown in Fig. 34, alternately to a standard cell of e. m. f. B, and a ballistic galvanometer G, the throw d of the galvanometer will be a measure of the charge of the condenser equal to $B \times C$. If, now, a cell of unknown e. m. f. X is substituted for B, the deflection d_2 will be a measure of the charge of the condenser now equal to $X \times C$. It follows that

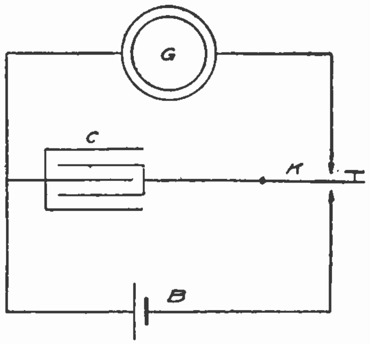


Fig. 34. Condenser Method of Measurement of E. M. F.

$$X = B\frac{d_2}{d_1}$$

This method is free from difficulties due to polarization and internal resistance of the cells; because the very small charge taken by the condenser produces no measurable polarization, and the effect of internal resistance is only to lengthen the time of charging of the condenser, but not to change the total quantity.

The accuracy of the method, however, is limited to that of the reading of the deflections d_1 and d_2, and it is difficult to get results much closer than, say, $\frac{1}{6}$ of 1%. The potentiometer method will give results easily to $\frac{1}{100}$ of 1% if the resistances used are accurate; and in general the accuracy of the potentiometer method is limited only by the accuracy of the resistances. For accurate comparisons the potentiometer method is always used.

VOLTAIC CELLS AND BATTERIES

A *voltaic cell* is usually composed of a pair of electrodes immersed in a liquid or in two liquids separated from one another by a porous partition. The liquid, or liquids, must be what is known as an *electrolyte;* and must undergo a chemical breaking up, called *electrolysis,* with chemical action on one or both electrodes when the circuit is closed and a current flows through the cell.

Some cells fall rapidly in e. m. f. when the circuit is kept closed. This phenomenon is known as *polarization*, and it frequently is due in large part to the deposit of a film of hydrogen gas on the surface of one of the electrodes (the cathode). This gas is one of the products of the electrolysis of the liquid. If the cathode, for example a copper plate, as in the case of the gravity cell, is surrounded by a solution of copper sulphate, the hydrogen does not reach the copper plate but is intercepted by the copper sulphate solution, and copper instead of hydrogen is deposited. Naturally, the deposit of copper on a copper plate produces no polarization. The copper sulphate solution is called a *depolarizer.* The other electrode of the gravity cell is zinc and is immersed in a dilute solution of either zinc sulphate or sulphuric acid.

In the *Grove* and the *Bunsen* cells, the depolarizer is nitric acid in a porous cup in which the cathode is immersed. The nitric acid is rich in oxygen which it gives up to oxidize the hydrogen gas, thus forming water (H_2O) which makes the solution more dilute but causes no polarization. Cells with liquid depolarizers cannot be left on open circuit as the liquids diffuse into one another and the cell is spoiled. Cells for open circuit use must have either a solid or a paste for a depolarizer. The Leclanché cell has manganese dioxide (a solid) packed in a porous cup about its cathode of carbon. The data of various cells can be found in books on cells.

Standard Cells. There have been various cells used as standards of e. m. f. of which the *Clark* and the *Weston* have received most attention. A *standard cell* must be composed of materials which, while the cell is in use, do not change; that is, no new substance may be formed by the action of the cell; the cell should have little or no polarization when used by zero methods like the potentiometer method described above; the cell also must not deteriorate when left on open circuit.

Both the Clark and the Weston cells fulfill these requirements. At the International Electrical Congress, held in Chicago, 1893, the normal Clark cell was recommended for international legalization and its e. m. f. at 15° C. was voted to be considered for practical purposes as 1.434 volts; and a committee, consisting of Professors von Helmholtz, Ayrton, and Carhart, was charged with the duty of drawing up specifications for the precise form of the cell. Von Helmholtz died soon afterward and the other members of the committee could not agree on the specifications, with the result that the principal countries (in electrical matters) have never agreed on a form for the cell.

It has now been displaced by the Weston cell, which, in 1908, was recommended by an International Conference in London as an international standard. It is now known that the Clark cell has an e. m. f. slightly below 1.433 volts, instead of 1.434 volts as thought in 1893. The normal Clark cell uses as materials zinc amalgam in a saturated aqueous solution of zinc sulphate, with an excess of zinc sulphate crystals present, and pure mercury in the presence of mercurous sulphate in the form of a paste which acts as the depolarizer. The action of the cell is to form more zinc sulphate and reduce some of the mercurous sulphate to mercury, or *vice versâ*, when the current flows in the direction of the e. m. f. or is driven in the opposite direction by a greater outside e. m. f. The principal objection to the normal Clark cell is that its e. m. f. changes by a considerable amount with change in temperature, falling about 0.08% for every Centigrade degree rise in temperature.

The Weston normal cell is similar to the Clark cell except that cadmium replaces the zinc, and cadmium sulphate the zinc sulphate The Weston normal cell has a much lower temperature coefficient than the Clark cell, its e. m. f. falling about 0.00406% for each Centigrade degree rise above 20° C. and *vice versâ*. The e. m. f. of the

Weston normal cell at 20° C. was recommended by the London conference of 1908 to be taken provisionally as 1.0184 volts.

Storage Cells. Many voltaic cells when exhausted, may be recharged by forcing current through the cell in the reverse direction by the application of an outside e. m. f. greater than the e. m. f. of the cell. Such cells are called *storage cells.* In general only such cells as form no *new* kind of material when discharging are reversible, and evidently a cell to be charged and discharged repeatedly must be reversible.

All standard cells must be reversible. Reversibility, however, is not the only requirement of storage cells to be used commercially. Other qualities required are low internal resistance, large capacity for charge measured in ampere hours in comparison with size and weight, long life under service, ability to stand without harm in open circuit, moderate cost, etc.

The storage cell most used commercially has both plates of lead with dilute sulphuric acid as electrolyte and lead peroxide as the depolarizer. The lead peroxide is a solid or paste which adheres to the positive pole of the battery. The e. m. f. of a lead cell is about 2.2 volts when fully charged and may safely be discharged until its e. m. f. is reduced to 1.8 volts. When the cell is charged one plate has a deposit of lead peroxide, and the other has a spongy texture, due to its reduction from an oxide or a sulphate of lead in its previous history. When the battery is discharged, the sulphuric acid is electrolyzed; the hydrogen formed reduces some of the lead peroxide of the positive, and the sulphion forms some insoluble lead sulphate from the negative. The sulphuric acid becomes more dilute. On recharging the cell the lead sulphate is reduced to spongy lead at the negative, some additional lead peroxide is formed on the positive, and the density of the sulphuric acid increases. For details as to the manufacture of the various varieties of lead cells and other storage cells, the reader is referred to works on storage cells.

To increase the capacity of a cell the negative consists generally of a number of plates connected together both electrically and mechanically, and the positive consists of one plate less in number and connected together in the same manner. The positive plates are interlarded between the negative plates.

Storage cells are also called *secondary cells* or *accumulators* by some writers.

Batteries. The word battery is technically used to mean a group of cells. In common parlance the word is used sometimes to mean a single cell; but this use is not to be recommended.

MEASUREMENT OF CURRENT

Electrodynamometers. In the choice of a unit of current, it was decided that a unit of current in a straight conductor at right angles to a unit magnetic field, should exert a force (at right angles to both the directions of current and field) of one dyne per unit length of the conductor. As mentioned earlier, this unit of current was thought to be inconveniently large by the committee of the British Association for the Advancement of Science, which had the matter of electrical units in charge, and as a consequence for practical purposes they recommended that one-tenth of this theoretical unit should be taken as the practical unit. The latter unit is called the *ampere*. As the magnetic field due to the flow of an electric current in coils, may be computed from the data of the coils and the current, it is evident that absolute electrodynamometers may be made to measure current without the intervention of other electrical measuring apparatus. These absolute electrodynamometers may take various forms, including that of current balance. By means of an absolute electrodynamometer and a standard resistance, the e. m. f. of standard cells may be determined with a high degree of accuracy according to the principle of Ohm's law.

By comparison either directly with the standard electrodynamometer or indirectly by means of standard resistances and standard cells, other forms of electrodynamometers and all forms of ammeters may be adjusted so as to read amperes. It is evident from the above that as more improved absolute electrodynamometers are constructed, we may expect greater exactness in the determination of the e. m. f. of the Weston normal cell, which for the present is taken as 1.0184 volts at 20° C.

Ammeters. An ammeter is a galvanometer graduated so that it reads current directly in amperes. This graduation is obtained directly by comparison with either an absolute electrodynamometer or indirectly by means of a standard cell and standard resistances.

Ammeters for any desired range of current are on the market, and the accuracy of their readings is in proportion to the care with which they have been constructed and calibrated. Even the best are moderate in price and the poorest should not be one per cent in error.

Ammeters to measure large currents carry the main portion of the current through shunts which differ theoretically in no respect from the shunts used with other forms of galvanometer.

To measure current by means of an ammeter involves introducing the instrument into the circuit, care being taken to connect the terminal marked + to the positive terminal of the source of e. m. f. The exact position of the ammeter in an undivided circuit is not important, as the current is the same throughout the circuit. Care should be taken that the ammeter has a range which the current does not exceed; otherwise the pointer may be bent or even the ammeter may be burned out by the action of excessive current. An ammeter has an exceedingly small resistance, and to connect an ammeter without additional resistance between the terminals of a dynamo or a battery is to produce a short circuit practically. Excessive current will flow through the ammeter and it probably will be destroyed.

Ammeters designed for direct-current circuits cannot be used on alternating-current circuits. Some forms of A. C. ammeters may be used on D. C. circuits; but as a rule ammeters should be used on the type of circuit for which they are designed.

Calibration of Ammeters. An ammeter may be compared directly with another in the same circuit by putting them in series and observing their readings with various values of the current. The current may be varied by changing the resistance in the circuit or the e. m. f. The potentiometer method may be used to calibrate an ammeter.

Potentiometer Method. The most exact method of measuring a current, assuming that the e. m. f. of a standard cell and the resistance of standard coils are known, is the potentiometer method. This is not an *absolute* method. The arrangement of the apparatus is somewhat complicated; but if it is compared with the potentiometer method as used for the comparison of e. m. f.'s (page 41) it will be seen that the commutator C, Fig. 35, is used to insert in the galvanometer branch either the standard cell of known e. m. f. S or a potential difference over a known resistance R due to the current to be measured I. The current I may be passed also through an ammeter A in circuit with R, a rheostat and an auxiliary battery B_2 which causes the current I to flow through the circuit. In the lower part of the diagram the galvanometer G and, if desired, a high resistance to protect the galvanometer, are connected between the left end of the commutator and one terminal of the resistance box L; the right end of the commutator is connected to the other terminal of L. The auxiliary battery B_1 serves to send a constant current through L and M, whose combined resistance is kept constant at, say, 10,000 ohms. In setting up the apparatus, 10,000 ohms should be inserted in L and M before connecting the battery B_1; otherwise the battery will become badly polarized due to an excessive current. This precaution is very important. When a balance is obtained no current passes through the galvanometer on closing the key K.

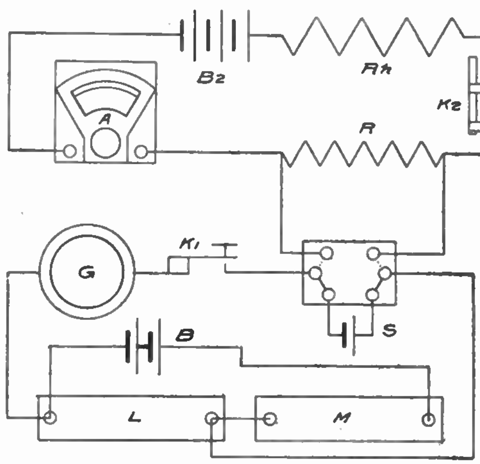


Fig. 35. Potentiometer Method of Current Measurement.

The order of procedure is as follows: first, connect S in circuit by means of the commutator C and shift resistance from L to M, or *vice versâ* until, on closing the key K a balance is reached, as indicated by a zero deflection of the galvanometer. The fall of potential through L, which under these conditions is exactly equal to the e. m. f. of the standard cell S, is then equal to its resistance R_1 multiplied by the current I from the battery B_1, or $S = R_1 I_1$; second, close the upper circuit by K_2, reverse the commutator to the position shown in the figure by dotted lines, which throws the p. d. over R into the galvanometer circuit. Adjust L and M until no current flows through the galvanometer on closing the key K_1. The total resistance in L and M is still kept 10,000 ohms. The resistance in L now has a value R_2, and the potential difference over L is now $R_2 I_1$ and is also in the galvanometer circuit. If no current flows through the galvanometer, $R_2 I_1$ must exactly equal and oppose the fall of potential $R\,I$ over the resistance R. We then have

$$S = R_1 I_1, \quad \text{and } R I = R_2 I_1,$$

or, combining these equations,

$$I = \frac{R_2 \times S}{R \times R_1}$$

By adjusting the rheostat in the upper, or the battery B_2 circuit, the current to be measured I, and consequently the point at which the calibration of the ammeter is desired, may be changed at will. The only limitation is that the battery B_1 must have a higher e. m. f. than the standard cell's e. m. f., and also higher than the largest p. d. over the resistance R.

As the e. m. f. of B_1 may be increased, if necessary, by introducing additional cells into B_1, there is no limit to the current I (in the upper circuit) which may be measured. In the case of very large currents the standard resistance R should be of relatively low resistance. If too much heat is developed in R its temperature may rise with consequent change of resistance.

Standard resistances are made of manganin which will carry any reasonable current without undue heating or change of resistance. These standards are arranged so that the wire may be immersed in an oil bath (pure petroleum) which may be kept stirred so that the heat may be carried away. A thermometer in the oil bath may be used to measure the temperature. Allowance thus may be made for any change in resistance due to change in temperature.

Such standards are made by the best manufacturers for 100, 10, 1, 0.1, 0.01, and 0.001 ohms resistance. Standard resistances calibrated by the Bureau of Standards at Washington are moderately expensive, but the cost is not higher than the cost of manufacture and testing at the Bureau would warrant. The certificate which accompanies each coil states the resistance at 20° C. and the change of resistance per degree change of temperature.

Silver Voltameter Method. If a current is passed through a solution of silver nitrate, each ampere deposits 0.001118 gram of silver from the solution each second. This is closely equal to 4 $\frac{1}{40}$ grams per hour. The silver voltameter is very difficult to handle with the degree of accuracy that is necessary for good results, so it is not recommended for general use.

To set up a voltameter, a platinum bowl is used as a cathode and a plate of pure silver as an anode. The electrolyte, 15 to 20 parts by weight of pure silver nitrate added to 100 parts of distilled water, is placed in the bowl, and the anode immersed in the solution. A current density of $\frac{1}{5}$ ampere or less per sq. cm. is allowed at the anode, and of $\frac{1}{50}$ ampere or less per sq. cm. at the cathode. Care is to be taken that no particles of silver mechanically detached from the anode shall reach the cathode. This may be accomplished by wrapping the anode in clean filter paper.

Before weighing the cathode to determine its increase in weight, any trace of the solution must be removed by careful working with distilled water and the cathode dried. This seems easy, but it is difficult, in fact.

The solution should be made anew for each experiment.

JOINT AERIAL CONSTRUCTION
Telephone and Electric Light Wires.

ELECTRICAL MEASUREMENTS

PART II—ADVANCED

MEASUREMENT OF CAPACITY

Ballistic Galvanometer. In the measurement of the capacity of a condenser by the methods given in the subsequent pages, the charge of electricity from the condenser is allowed to flow as a momentary current through a galvanometer, giving the suspension a sudden *kick*. In order to calculate from this deflection the *quantity of electricity* in the condenser, it is necessary to assume that the galvanometer suspension is so heavy that it will not have moved very far before the charge has completely passed. This requisite, viz, a heavy suspension, is the distinguishing feature of the *ballistic* type of galvanometer. (See Fig. 7, Part I.)

As a rule the methods of measurement involve only a comparison of the deflections produced in the ballistic galvanometer by charged condensers of known and unknown capacity, so that, as long as the capacity of a standard condenser is known, the unknown factors, the galvanometer constant, etc., are unimportant. Nevertheless it may be instructive to know how these unknowns can be determined and the deflections can be made to give the actual quantity of electricity in the given condensers.

Because of the fact that the deflection of the galvanometer is not proportional to the current which produces the deflection, it is necessary to know the factor called the *constant* of the galvanometer before measurements can be taken. This constant is used in various forms but can be briefly stated as *the constant ratio between the current and the deflection produced by it.* When put in more definite form it can be given as follows:

$$K = \frac{2\ I\ D}{d}$$

in which I is the current flowing in the galvanometer, D is the distance from the galvanometer mirror to the scale, and d is the deflection produced on the scale.

With this in mind let us consider *how to find the quantity of electricity Q from the throw θ of the galvanometer, the galvanometer contant K, and the half period of the suspension.*

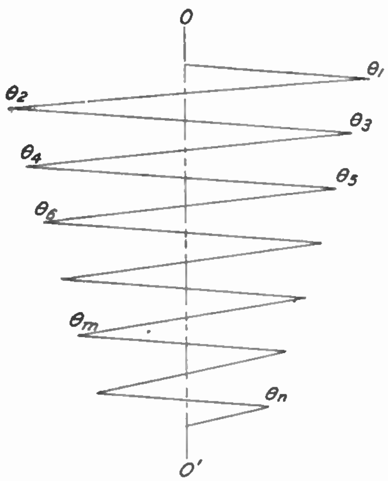


Fig. 36. Damping Diagram.

As has been stated above, while the quantity Q is passing through the galvanometer, short though it may be in duration, it constitutes a current and the magnetic effect of this current exerts a turning moment on the coil.

If I represents the mean value of this current, then the mean moment of force $\overline{Fh}$ acting on the coil while the current is flowing is

$$\overline{Fh} = I \, \mathrm{H} \, A$$

in which H is the strength of the field and A is the area of the galvanometer coil. If τ is the duration of the discharge, then the moment of force times the time can be given by

$$\overline{Fh}\tau = I\tau \mathrm{H} A = Q\mathrm{H}A$$

in which Q is the quantity of electricity, equal to $I\tau$.

If the moment of inertia M of the suspension and the angular velocity, which is given to it by this *kick*, are taken into consideration, the quantity of electricity Q may be obtained from the above equation as follows:

$$Q = K\omega \frac{M}{T_o}$$

in which ω is the angular velocity and T_o is the torsion constant of the suspension. By taking the half period of the suspension, which is easily obtained by counting the time of a given number of swings, and expressing ω in terms of the angle of throw θ, the expression for the quantity of electricity is given by the following equation:

$$Q = \frac{K\theta t}{\pi}$$

in which K is the galvanometer constant, θ the angle of throw (obtained by dividing the deflection d by twice the distance from mirror to scale D), t the half period of the suspension, and π 3.1416.

For accurate work θ must be multiplied by a damping factor $\sqrt{\rho}$, derived as follows: With the suspension swinging freely, Fig. 36, take a deflection θ_m, then after a given number of swings $(n\text{-}m)$ take another deflection, θ_n; ρ is the $(n\text{-}m)$ root of the ratio $\frac{\theta_m}{\theta_n}$.

Condensers. A condenser consists in its simplest form of two metal sheets separated by a nonconducting material, Fig. 37. If an e. m .f. is applied to the two metal sheets, they will take a static charge, one positive and the other negative. The nonconducting material is called a *dielectric,* as the electric force acts through it (*dia* meaning through). The capacity of such a condenser is proportional to the

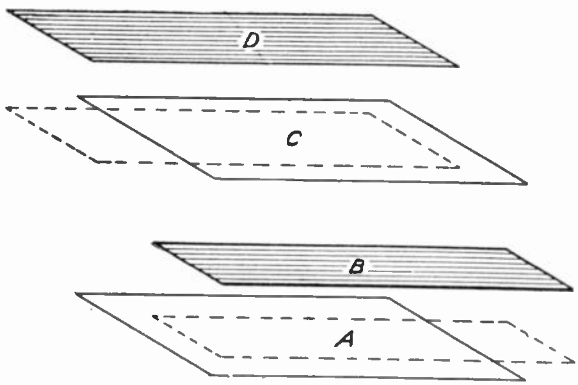


Fig. 37. Condenser Sheets.

area of the sheets and inversely proportional to the thickness of the dielectric. If the condenser is in the form of a glass jar coated outside and inside with tin foil, the arrangement is called a *Leyden jar.* A considerable portion of the surface near the edges of the jar should be free from the tin foil coating in order that the charge may not leak over the surface of the glass. The best condensers are made of many sheets of mica with sheets of tin foil interlarded, every alternate one being connected to one, and the others to the other terminal of the condenser, Fig. 38. By using many sheets of tin foil the capacity is increased in proportion to the total area. Mica is an excellent material for the dielectric as its resistance is extremely high, and very thin sheets have enough strength to withstand the mechanical stress due to the electric charges without breaking down. The mica and tin foil are clamped in place and the whole immersed in melted paraffin and then withdrawn, carrying out a coating of paraffin which protects the condenser from the effects of moisture. Several condensers of assorted capacities are frequently mounted in one box, Fig. 39. A 1 m. f. box will frequently have condensers of 0.5, 0.2, 0.1, 0.1, 0.05

Fig. 38. Simple Condenser.

and 0.05 microfarad, Fig. 40. Cheaper condensers have paraffined paper or other materials in place of mica; but are usually poor since the dielectric, though it does not break down, is apt to yield gradually to the strain of the charge, producing an effect which is known as *absorption of the charge.* It seems as though some of the charge had been lost for when the condenser is discharged, less charge comes out than was put in. It is true that real leakage causes a loss of part of the charge, but we find also that a poor condenser, if set aside after being discharged, will, on a later test, show a small charge which has come from the gradual return of the dielectric to its original state. The Leyden jar (glass dielectric) absorbs a considerable portion of its charge. Standard condensers are sometimes made with massive plates of metal and with air, which has no absorption, as the dielectric. They are very expensive and have small capacity. For practical purposes

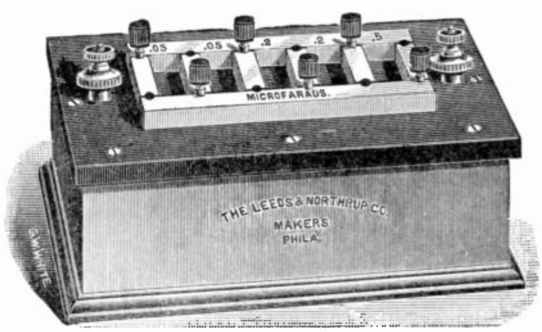


Fig. 39. Variable Condenser.

the best condensers have mica for the dielectric, for mica shows almost no absorption of the charge.

Single conductor submarine and land cables have the properties of condensers, the water acting as the second sheet in the case of the

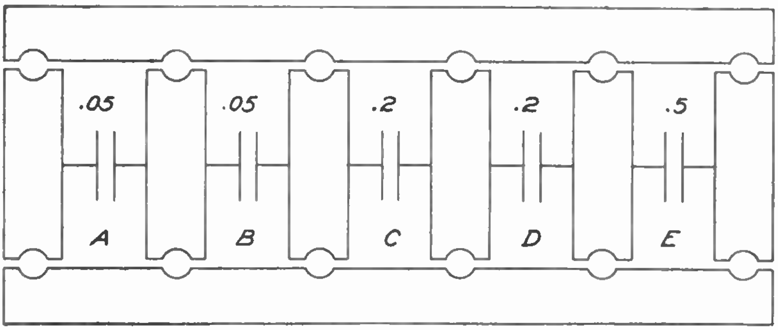


Fig. 40. Plan of Variable Condenser.

former, and the usual lead covering in the case of the latter. In telephone cables, each pair of wires and the insulation between make up a condenser. These cables almost always show considerable absorption of the charge.

Direct Deflection Method. Two condensers may be compared as to their capacity, if first one and then the other is charged by a cell B of known e. m. f., and then discharged through a ballistic galvanometer G, Fig. 41. If the deflection with the standard of capacity C is D_1, and that with the unknown of capacity X is d_2 then

$$X = C\frac{d_2}{d_1}$$

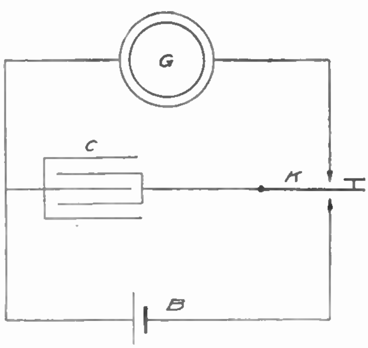


Fig. 41. Diagram for Direct Deflection Method.

A charge and discharge key K, Fig. 42, connects the condenser first to the battery and then to the galvanometer.

This method is convenient, but the accuracy of the results depends on the accuracy with which the throw of the galvanometer can be read. The accuracy is not much better than 1% even if neither condenser shows absorption of charge. If either condenser absorbs charge, the ratio of the deflections will depend on the time of charge and the slowness of clearing out of the charge. There are better methods.

Example. With a condenser of 0.5 microfarads in circuit, the deflection is 46 divisions; with the unknown capacity X in circuit, the deflection is 69 divisions. What is X?

Ans. $X = 0.75$ m. f.

Bridge Methods. The Wheatstone's bridge method of comparing resistances may be adapted to the comparison of two capacities. The apparatus may be arranged as shown in either Fig. 43 or Fig. 44. In the former a charge and discharge key is used to charge and discharge the condensers. If all the charge taken by C_1 passes through R_1 and all taken by C_2 passes through R_2, both in charging and discharging, then the galvanometer will not deflect; otherwise it will deflect in opposite directions for the charge and discharge. As the current divides in parallel circuits in inverse proportion to the resistances; and as the charge, and therefore the current, taken by condensers in parallel is directly proportional to their capacities, it is evident that if no current passes through the galvanometer

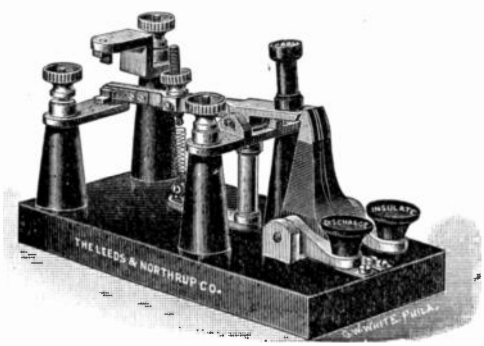


Fig. 42. Kempe Discharge Key.

$$C_1 : C_2 : : R_2 : R_1$$

therefore

$$C_1 = C_2 \frac{R_2}{R_1}$$

In Fig. 44 the battery circuit produces a current through R_1 and R_2, and they take potential differences between their terminals proportional to their resistances when the current becomes steady. The condensers will take a certain charge; and if the galvanometer is open, both condensers must take equal charges regardless of their capacities. If one has a smaller capacity than the other, the former will acquire a smaller potential difference than the latter, as the charge is equal to the product of the capacity and the potential difference. If C_1 and R_1 acquire equal potential differences, and C_2 and R_2 also equal potential differences, then on closing the galvanometer key no deflection will result. If on closing the galvanometer key a deflection results, it is evident that the above relation is not satisfied. If no deflection results

$$C_1 : C_2 : : R_2 : R_1,$$

and

$$C = C_2 \frac{R_2}{R_1}$$

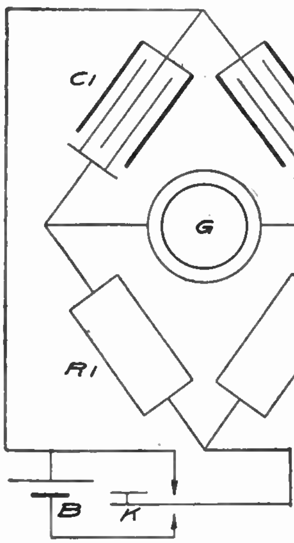


Fig. 43.

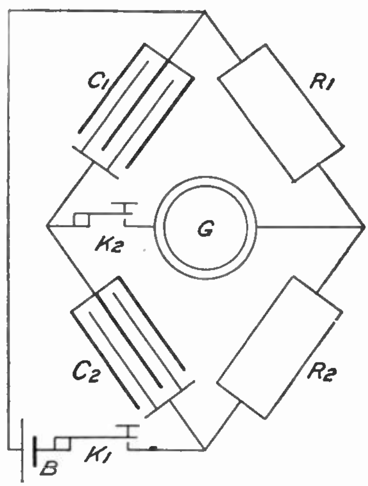


Fig. 44.

Diagrams for Bridge Methods for Measuring Capacities of Condensers.

The order of closing and opening keys is important. It should be as follows: First close K_1, then K_2 and note deflection if any; second, open K_2, then K_1, then close K_2 and note deflection (or discharge) which should be in opposite direction. Then open K_2. It is necessary to discharge the condensers before recharging them, otherwise they will take no new charge beyond what is necessary to make up for leakage or absorption of charge. If the condensers absorb charges it is impossible to get a perfect balance.

Method of Mixtures. In the method of mixtures the positive charge taken by one condenser is mixed with the negative charge of the other, and *vice versâ*, and the remaining difference of charges is discharged through the galvanometer. This method allows the time of charge and the time of mixing the charges to be varied at will, thus allowing the absorbed charge more or less time to make itself felt.

In Fig. 45, the Pohl's commutator P, by bringing the points e and c and f and d into contact as indicated, allows the condenser C_1 to charge until its potential difference is equal to that over R_1 (due to the current from the battery B), and also allows C_2 to charge until its potential difference equals that over R_2. The commutator is then reversed, bringing e into contact with a, and f into contact with d. The points a and b are permanently connected together. The + charge on C_2 can mix with the − charge on C_1, and the other charges on C_1 and C_2—which were previously so-called *bound charges*—now become free and can mix also. The remaining charges are divided between the two condensers in proportion to their capacities. If now the key K is closed, these remaining charges are discharged through the galvanometer. If no deflection occurs the charge remaining must be *nil*. As the charge taken by a condenser is equal to the product of its capacity multiplied by its potential difference, and as the potential differences to which C_1 and C_2 were charged were proportional to R_1 and R_2, then, by Ohm's law, when the charges on C_1 and C_2 are equal we must have the relation that

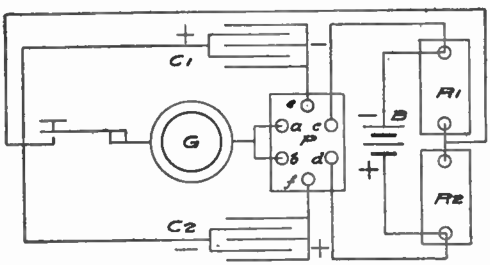


Fig. 45. Diagram for Method of Mixtures.

$$C_1 R_1 = C_2 R_2,$$

or

$$C_1 = C_2 \frac{R_2}{R_1}$$

If condenser C_1 absorbs part of its charge, its total charge will increase on charging for a longer time. If the charges are allowed to mix for a longer time there is more opportunity for the absorbed charge to be given up. It follows that if the time of charging is short, the capacity of the C_1 will appear to be smaller than if a longer time of charging were allowed. With good mica condensers little effect of absorption will be found. With most other dielectrics the absorption is quite marked.

Example. If in the bridge method or in the method of mixtures, $C_1 = 0.5$ microfarads, $R_1 = 2{,}340$ ohms, and $R_2 = 1{,}000$ ohms, what is C_2? Ans. $C_2 = 1.17$ microfarads.

Absolute Method. If a condenser is rapidly charged through a galvanometer and then discharged by short circuiting the condenser, the deflection of the galvanometer will be the same as though an equal charge had passed through the galvanometer in the form of a steady current during the same time. The difficulty with the method is that the galvanometer obstructs the complete charge of the condenser when the charges become very frequent. To get around this difficulty a second circuit to the galvanometer is arranged to carry a steady current equal in value but opposite in direction to the pulsating current due to the charge of the condenser. The result is that the galvanometer carries only the difference of these two currents, and when a balance is obtained, the resultant current is a small alternating current, alternately helped and hindered by the resistance and inductance of the galvanometer. The method then becomes somewhat like the Wheatstone's bridge method.

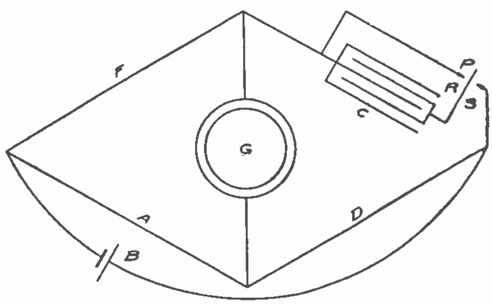


Fig. 46. Diagram for Absolute Method of Capacity Measurement.

To regulate the number of charges to a uniform number per second, a small motor running at a constant known speed or an electrically driven tuning fork of known frequency of vibration, may be used. The apparatus is arranged as in Fig. 46. If the condenser of capacity C is charged when the movable piece P makes contact with S, part of the charge will pass through the galvanometer of resistance G. The condenser is discharged when P makes contact with R. The battery B tends to send a steady current through the divided bridge circuit, part passing through F and G (both of fairly high resistance) and part through A (of low resistance). The resistance in the battery arm must be made very low in comparison with F, D, and G. Let us suppose D a fixed resistance, say, 1,000 ohms, and A, 1 ohm. In this case two proportional arms of a *postoffice* box may be used. Adjust F until a balance is obtained, with no deflection of the galvanometer. Let n be the number of charges of the condenser per second. We then have the closely approximate relation

$$C = \frac{A\ (F + G) \times 10^6}{n\,F\,(DG + DF + AG)}$$

The capacity C is in microfarads. If the factor 10^6 is omitted, the formula will give C in farads.

If the resistances in the battery branch and in A are not small, it is necessary to use a more complicated formula.

Example. When a balance is obtained $A = 1$ ohm, $F = 2{,}340$ ohms, $G = 10{,}000$ ohms, $D = 1{,}000$ ohms, and $n = 32$ periods per second. What is the capacity of C? Ans. $C = 0.01334$ microfarad.

Alternating-Current Method. If a circuit through which an alternating current is flowing includes a condenser, the charge and discharge of the condenser is repeated with every alternation of the current. The quantity of each charge is equal to the capacity multiplied by the p. d. to which the condenser is charged. The rate of charge or discharge is the value of the current at any particular instant. It is proved in treatises on alternating currents that the effective value of a current or an e. m. f. is the square root of the average square of its instantaneous values. Alternating-current ammeters and voltmeters such as those shown in Figs. 47, 52, and 53, calibrated with direct currents, show the effective values of A. C. currents and electromotive forces. The theory of alternating currents shows that the current passing in and out of a condenser, if the e. m. f. follows a sine law, is

$$I = \frac{2\,\pi\,n\,C\,E}{1{,}000{,}000}$$

From this it follows that

$$C = \frac{1{,}000{,}000\,I}{6.2832\,n\,E} = 159{,}155\,\frac{I}{n\,E},$$

when I is the effective value of the current in amperes, E the effective value of the e. m. f. in volts, n the number of cycles per second of the e. m. f. (and consequently of the current too), and C the capacity of the condenser in microfarads. If the capacity is rated in farads, omit the factor 1,000,000. In Fig. 48 the current I flows through the ammeter A, and the condenser of capacity C in series. A high resistance voltmeter V measures the potential difference E at the terminals of the condenser.

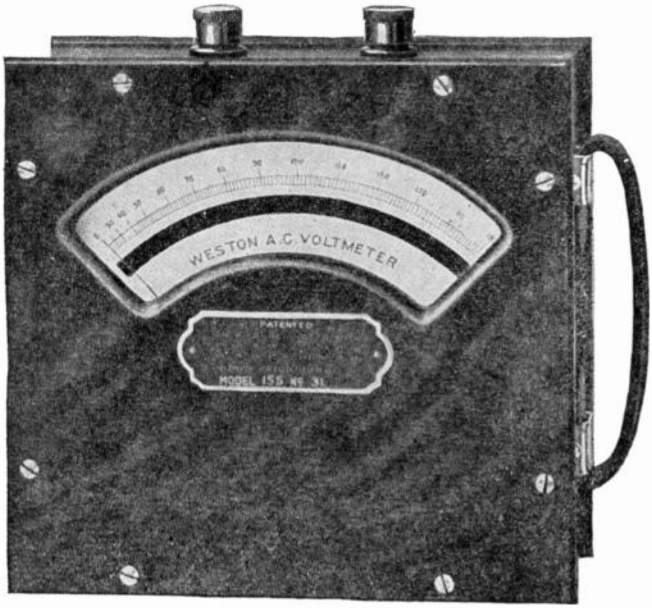


Fig. 47. Commercial Form of Portable A. C. Voltmeter.

Example. The ammeter reads 1 ampere, the voltmeter 220 volts, the frequency n is 60 cycles per second. What is the capacity of the condenser?

Ans. C = 12.06 microfarads.

If the voltmeter takes much current in proportion to the whole, a correction must be made for it. From the theory of alternating currents a condenser takes a current one-quarter of a period in phase *ahead* of its potential difference. A circuit in which there is both resistance and inductance takes a current lagging *behind* the potential difference. As voltmeters have some inductance, which should be small in comparison with the resistance, it will be seen that the current in the voltmeter lags a little over a quarter period in phase behind the condenser current. The relation of the currents with apparatus set up as in the previous figure is shown in Fig. 49, in which I_a, I_c, and I_v, are the currents in the ammeter, condenser, and voltmeter respectively. I_a and I_c are practically of equal length. The directions of the arrows show the phase relations.

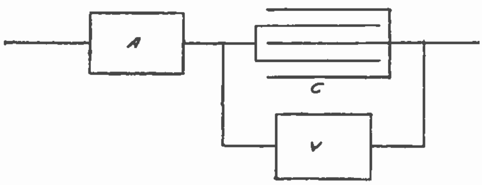


Fig. 48. Diagram for A. C. Method of Capacity Measurement.

If the condenser current is small and the voltmeter current large relatively, it will be seen from Fig. 50 that I_a may be materially larger than I_c, and that the ammeter reading must be corrected. It may be shown by trigonometry that if the voltmeter current lags by an angle a behind its potential difference, we will have

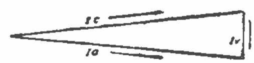


Fig. 49.

$$I_c = I_v \sin a + \sqrt{I_a^2 - (I_v \cos a)^2}$$

By the theory of alternating currents $\tan a = \dfrac{2 \pi n L}{R}$, where n is the frequency of the system, L the self-inductance, and R the resistance of the part of the circuit considered. If n, L, and R are known, a may be found.

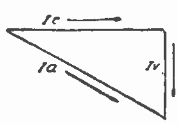


Fig. 50

Example. What correction, if any, should be made in the previous example, $I_a = 1$ amp., $E = 220$ volts, $n = 60$ cycles per second, if the voltmeter takes a current 0.06 amp. lagging 1° behind its potential difference?

Solution.

$$\sin 1° = 0.01745, \cos 1° = 0.99985$$

$$I_c = 0.00105 + \sqrt{0.9964012} = 0.00105 + 0.99820$$
$$= 0.99925 \text{ amp.}$$

As the correction of the current is far below the accuracy with which the ammeter may be read, no correction in the computed capacity of the condenser should be made.

Example. If the current observed was 0.1 amp., the other data remaining the same as in the previous example, what correction, if any, should be made?

Solution.

$$I_c = 0.00105 + \sqrt{0.0064012}$$
$$= 0.00105 + 0.08001 = 0.08106 \text{ amp.}$$

The uncorrected formula gives C = 1.206 microfarads
The corrected formula gives C = 0.978 "
The difference is 0.228 "
which is 19%, a difference much too large to be ignored.

MEASUREMENT OF SELF-INDUCTANCE

Most methods of measuring inductance are too difficult for the readers of this book. The difficulty is due to the fact that a coil of wire which has inductance, has resistance also. During the increase of a current the inductance acts as a false resistance which makes the resistance appear too high. During the current's decrease, however, the inductance acts as a negative resistance, which makes the resistance appear too low. In the case of an alternating current the effect is to make the apparent resistance, called the *impedance*, higher than the real resistance. Algebraically expressed we have

$$\text{Impedance} = \sqrt{R^2 + 4\,\pi^2\,n^2\,L^2} = \frac{E}{I},$$

in which R is the real resistance in ohms, $\pi = 3.1416$, n the frequency in cycles per second, L the inductance in henrys, E the e. m. f. in volts, and I the current in amperes. The impedance of a coil is therefore not a constant quantity if R and L are constant, but depends on the frequency n. For commercial lighting n is usually 60, and for power circuits 25 cycles per second. Coils which have an iron core do not have a constant self-inductance, for the latter, with increase of current, rises slightly to a maximum and then falls off greatly for large values of the current.

Alternating-Current Method. If in a circuit, Fig. 51, the current through a coil of known resistance R and unknown inductance L, is measured by means of an ammeter A (two views of a well-known commercial instrument are shown in Figs. 52 and 53), and the potential difference E over the coil is measured by a voltmeter V, we have the following relation

$$2 \pi n L = \sqrt{\frac{E^2}{I^2} - R^2},$$

or

$$L = \frac{1}{2 \pi n} \sqrt{\frac{E^2}{I^2} - R^2}$$

Example. In a circuit for which the frequency $n = 60$ cycles per second, $R = 0.1$ ohm, $E = 110$ volts, and $I = 10$ amperes, what is the value of the inductance L?

Ans. $L = 0.0292$ henry.

If the resistance or inductance is very high, so that the total current is small, a correction must be made for the portion of the current passing through the voltmeter. The corrected formula is very complicated when expressed directly in terms of L, l, R, r, the inductances and resistances of the coil and the voltmeter respectively, n the frequency, E the potential difference, and I_a the current through the ammeter. If the tangents of the lag of the current in the two branches of the circuit are for the coil

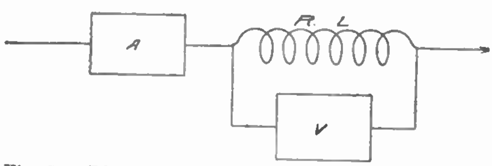


Fig. 51. Diagram for A. C. Method of Self-Inductance Measurement.

$$\tan b = \frac{2 \pi n L}{R},$$

and for the voltmeter circuit

$$\tan a = \frac{2 \pi n l}{r},$$

we get the equation for the cosine of the difference between a and b

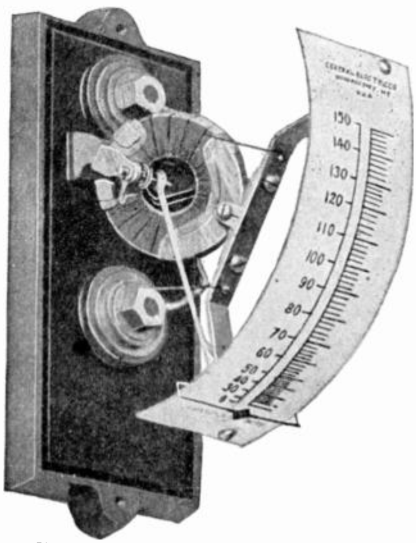


Fig. 52. Thomson Inclined Coil A. C. Ammeter.

$$\cos\left(\pm (a - b)\right) = \frac{rR}{2}\left(\frac{I_a^2}{E^2} - \frac{1}{r^2} - \frac{1}{R^2}\right)$$

Usually b is greater than a, so we write the formula

$$\cos (b - a) = \frac{rR}{2}\left(\frac{I_a^2}{E^2} - \frac{1}{r^2} - \frac{1}{R^2}\right)$$

As the constants of the voltmeter are supposed to be known, the angle a is known; therefore b may be determined and we finally get

$$L = \frac{R \tan b}{2 \pi n}$$

If b is so small that the difference between a and b is not greater than

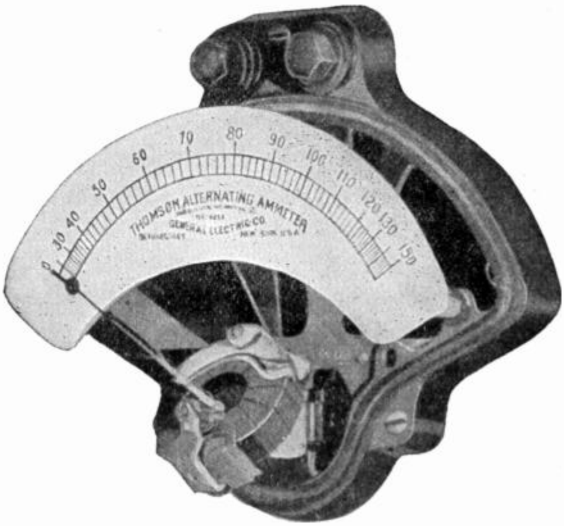


Fig. 53. Thomson Inclined Coil A. C. Ammeter.

a, there is always the possibility that the previous formula is the cosine of $(a - b)$. To determine which result to take, it is necessary to repeat the experiment with additional resistance in one of the two branches, and to take the value of L that equals one of the previous solutions. As a rule, however, the difference between a and b will be greater than a, and the incorrect result will lead to a negative value for b. As b must be positive, the negative result is rejected as impossible.

Bridge Method. Two self-inductances may be compared by a modification of the Wheatstone's bridge method. In the simplest of many bridge methods the coil of unknown inductance X is one arm of the bridge; a double coil, Fig. 54, whose inductance L may be varied by rotating one part to various positions inside the other part, and whose inductance is known for each position and marked by a pointer on a circular scale for each position, is inserted in an adjacent arm. The other arms are non-inductive resistances R_1 and R_2. The arrangement is shown in Fig. 55. The inductive branches have certain resistances R_3 and R_4. A regular Wheatstone's bridge balance is obtained by adjusting the resistances R_1 and R_2, care being taken to close the key K_2 in the galvanometer branch several seconds after closing the key K_1 in the battery branch. This precaution is necessary to insure that the currents are steady when the galvanometer key is closed, as inductive effects are produced only when the current is changing in value. When a balance is obtained $R_1 : R_2 :: R_3 : R_4$. If now the galvanometer key K_2 is closed first, the false resistance due to inductance, will cause the galvanometer to deflect when the battery circuit is closed. After oscillating a number of times the galvanometer finally comes to rest at its zero position. On opening the battery circuit the first deflection is in the opposite direction. If, now, the variable inductance is adjusted until there is no deflection on closing the battery circuit, the galvanometer circuit having been closed in advance, the false resistances due to inductance must increase the apparent resistances in both inductive branches in proportion to their real resistances, from which it follows that

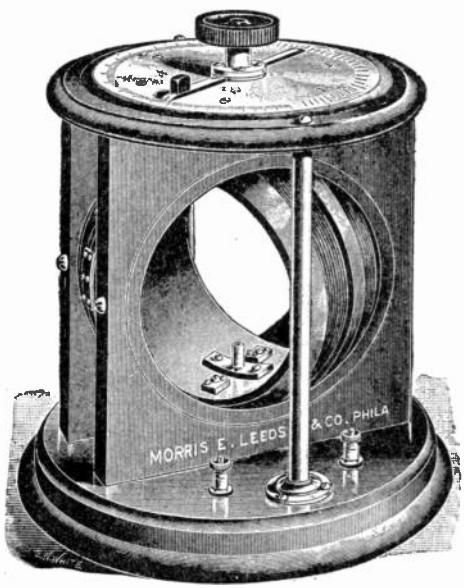
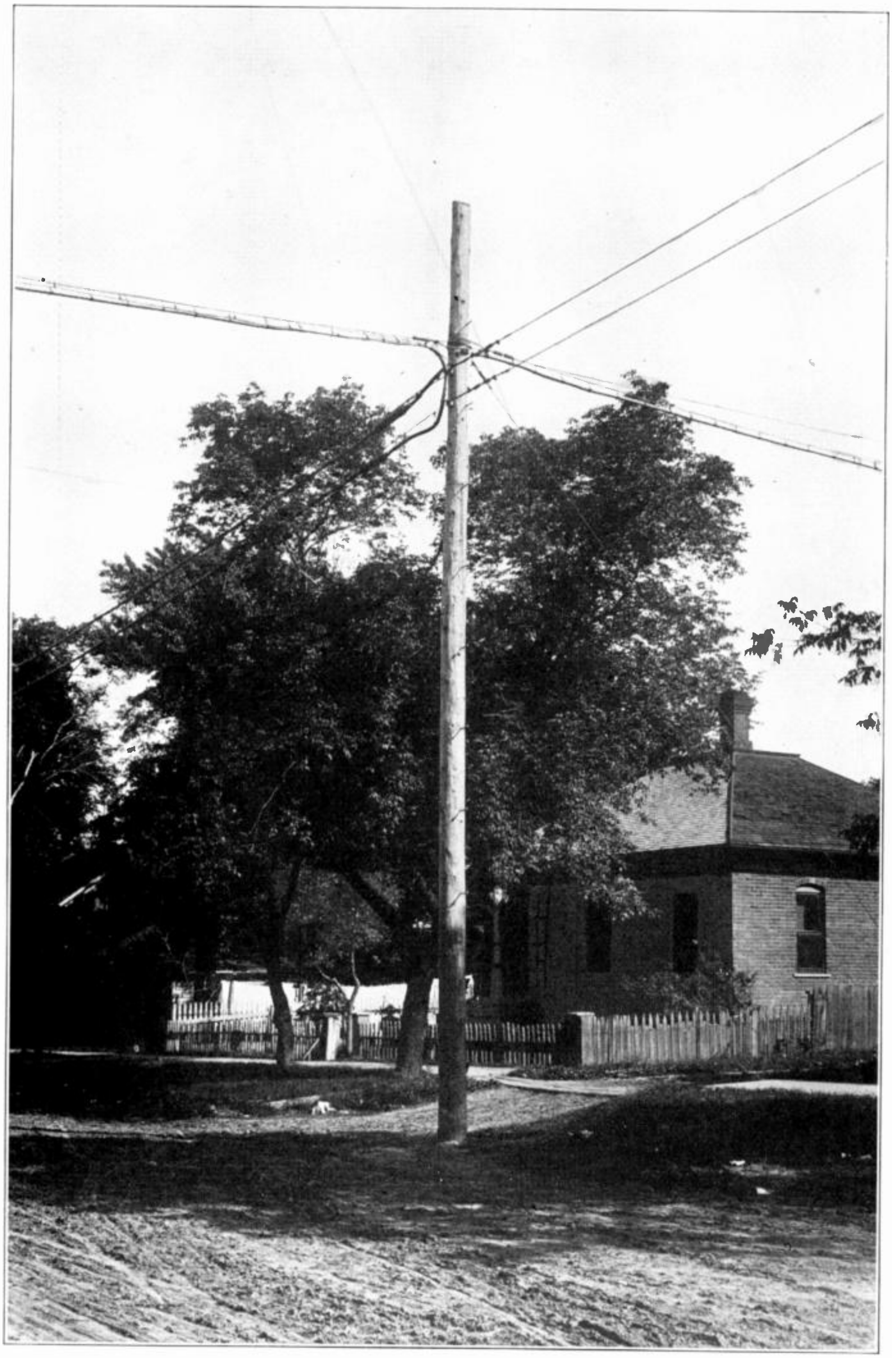


Fig. 54. Variable Self-Inductance.



AN AËRIAL CABLE LEAD DIVIDING INTO TWO SEPARATE LEVELS
Note the Method Employed in Making the Turn at the Pole.

$$X : L :: R_3 : R_4 :: R_1 : R_2,$$

and we get the relation

$$X = L\frac{R_1}{R_2}$$

If no variable standard of inductance is available, there are various modifications of the bridge method which may be used. These methods are as a rule very complicated and consequently beyond the scope of this course.

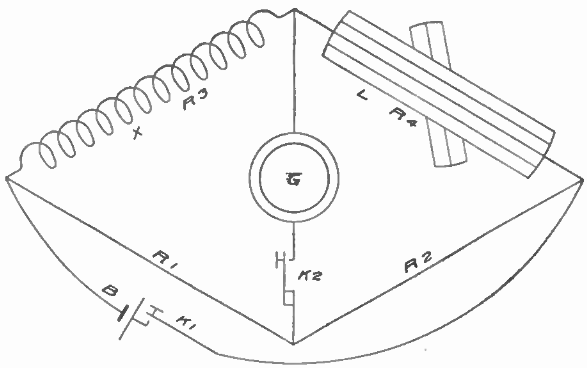


Fig. 55. Diagram of Bridge Method of Self-Inductance Measurement.

Condenser Method. The self-inductance of a coil may be compared with the capacity of a condenser. The bridge is set up as indicated in Fig. 56. The condenser of capacity C is in parallel with M which is one part of a constant resistance R_1. $R_1 = M + N$. R_2 and R_3 are resistances, one or both of which may be varied at will. The coil of resistance R_4, whose inductance L is to be measured, is in the fourth arm of the bridge. The galvanometer G, battery B, and keys K_1 and K_2 are as usual. The resistances are adjusted in R_2 and R_3 until a balance is reached, when K_2 is closed several seconds after closing K_1.

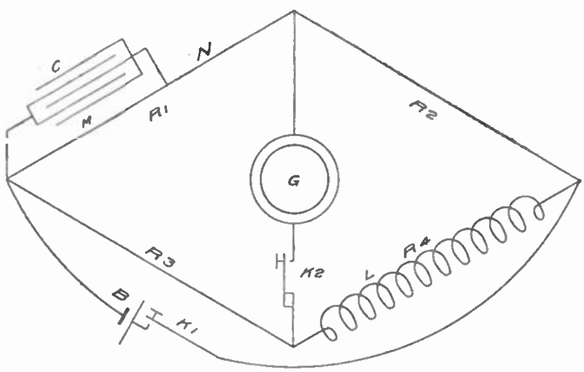


Fig. 56. Diagram of Bridge Method of Self-Inductance Measurement.

Then $R_1 : R_2 :: R_3 : R_4$, the usual Wheatstone's bridge relation. The galvanometer key K_2 is next kept closed and resistance shifted between M and N, care being taken to keep $M + N = R_1$ constant, until no deflection is produced at the instant of closing K_1. The explanation of the method is quite complicated, but leads to the simple result,

$$L = \frac{C\ R_2\ R_3\ M^2}{R_1^2\ 10^6} \text{ henries.}$$

C is in microfarads, R_1, R_2, R_3, and M in ohms, and the result for L in henries.

Example. The resistance R_1 was kept constant at 1,000 ohms, part of which M, when a balance was reached, was 516 ohms. $R_2 = 1{,}000$ ohms, $R_3 = 1{,}260$ ohms, and $C = 1$ m. f., makes up the balance of the data. What was L?

Ans. $L = 0.3355$ henry.

MEASUREMENT OF MUTUAL INDUCTANCE

If two electric circuits are in the neighborhood of one another, the increase or decrease of the current of one will produce a change in the magnetic field which will act to produce an e. m. f., and consequently a current in the second circuit if it is closed. If the current in one circuit varies at the rate of one ampere increase or decrease per second and an e. m. f. of one volt is produced in the second circuit, we say the mutual inductance is one henry. If the mutual inductance is constant, the e. m. f. produced in the second circuit is proportional to the rate of change of current in the first; also larger inductances produce proportionately larger e. m. f.'s in the second circuit with equal rates of change of current in the first. Algebraically expressed, if I_1 and I_2 represent any two values of the current, supposed to be increasing at a uniform rate, and t is the interval of time between these values of the current, and if E is the e. m. f. produced in the second coil whose mutual inductance with respect to the first is M, then

$$M\frac{I_2 - I_1}{t} = E$$

The inductance between the coils is called *mutual* because a certain increase of current in either will produce the same e. m. f. in the other regardless of which circuit has the original current. The relation is therefore *mutual.* If the circuit has an iron core the mutual inductance is not strictly constant, but with increasing current increases to a maximum and then falls again. As it is very difficult, if not impossible, to control the precise rate of change of the current so that it will increase at a uniform rate, either of two methods may be used to obtain the value of M without keeping the rate of change of I constant.

Ballistic Galvanometer Method. In this method the second circuit, called the *secondary* circuit, is of known resistance R_2, and includes a ballistic galvanometer G and sufficient extra non-inductive resistance T_2 to control the deflection within reasonable bounds. The other circuit, called the *primary* circuit, includes a key K, an adjustable resistance r_1, a battery B, and an ammeter A. The arrangement is shown in Fig. 57. The primary coil is P and the secondary S.

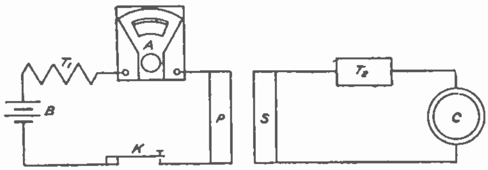


Fig. 57. Diagram of Ballistic Method of Mutual Inductance Measurement.

On closing the key K the current in P begins to increase and the galvanometer G begins to deflect. If we make no allowance for the false resistance due to the self-inductance of the secondary circuit, the current I_2 in the secondary is $I_2 = \frac{E}{R_2}$. As the current I_1 in the primary requires a considerable part of a second nearly to reach its maximum or steady value, it is evident that the secondary current I_2 will require at least an equal time to rise from zero to its maximum and to fall nearly to zero again. Theoretically it takes an infinite time for this to happen, but if the total resistance R_1 in the primary and R_2 in the secondary are reasonably large in comparison with their self-inductance, the time practically necessary is a second or so. The current I_2 in the secondary will, therefore, during the times that it flows, cause a certain quantity Q of electricity to pass through the galvanometer. If the ballistic galvanometer has a long period of swing—a condition required of ballistic galvanometers—practically the whole of the quantity Q will pass before the galvanometer gets far from its zero position. As the e. m. f. of the secondary is proportional to the rate of increase of the primary current I_1, it is evident that the *total* quantity flowing in the secondary will depend on the *total* rise of current in the primary in precisely the same way as the current *at any instant* in the secondary depends on the *rate of increase* of the current in the primary. As before mentioned, we have ignored the false resistance due to the self-inductance of the secondary. We have learned, however, in the chapter on self-inductance, that during the rise of a current the self-inductance increases the apparent resistance, but during its fall the opposite effect is produced. Therefore, during the rise and fall of the current in the secondary, no appreciable error is caused by ignoring the self-inductance of the secondary. The final result is $M I_1 = Q R_2$, or

$$M = \frac{Q R_2}{I_1}$$

To get the value of Q we must know the relation between the throw d_2 of the ballistic galvanometer to the quantity of electricity producing the throw. This may be found by charging a standard condenser of known capacity C by a standard cell of known e. m. f. E_s, and noting the deflection d on discharging the condenser through the ballistic galvanometer. As the charge of the condenser is $E_s C$, we obtain the result

$$Q : d_2 :: E_s C : d,$$

or

$$Q = \frac{d_2 E_s C}{d}$$

Substituting in the earlier equation the value of Q and expressing the capacity of the condenser in microfarads,

$$M = \frac{d_2 E_s C R_2}{d I_1 \times 10^6}$$

Example. The current I_1 in the primary coil rises on closing the circuit to 1 ampere. The total resistance in the secondary circuit is 10,000 ohms. The deflection produced is 21.3 cm. With a Weston normal cell of 1.0184 volts and a condenser of 0.2 microfarads, a deflection of 23.0 cm. was produced on discharging the condenser through the galvanometer. What is the mutual inductance M?

Ans. $M = 0.001886$ henry.

Alternating-Current Method. The previous method may be varied by putting in the secondary an alternating-current voltmeter of high resistance, and in the primary an A. C. ammeter, an e. m. f. source of sine form, and whatever resistance is needed to control the current. From the theory of alternating currents, the e. m. f. produced in the secondary is

$$E_2 = 2 \pi n M I_1,$$

or

$$M = \frac{E_2}{2 \pi n I_1},$$

when n is the frequency in cycles per second, M the mutual inductance, and I_1 the primary current. This relation assumes that the current in the secondary is too small to affect the flux of magnetic lines crossing over from primary to secondary. If the resistance of the secondary coil is small in comparison with that of the voltmeter, the voltmeter reading E_v is taken as E_2. If the coil is of too high resistance to make the last assumption allowable, the reading must be multiplied by $\frac{R_2}{R_v}$, when R_2 is the total resistance of the secondary and R_v the resistance of the voltmeter. We then get

$$E_2 = \frac{R_2}{R_v} E_v = 2 \pi n M I_1,$$

or

$$M = \frac{R_2 E_v}{2 \pi n R_v I_1}$$

If the secondary current I_2 is too large for its magnetic effect to be ignored, or if the current in the primary does not follow a simple sine law, the problem becomes too complex for easy solution.

Example. The current I_1 in the primary is 1.1 amperes, the frequency n is 60 cycles per second, the resistance of the secondary coil is negligible. The reading of the voltmeter E_v is 110 volts. What is the mutual inductance M? Ans. $M = 0.2653$.

Carey-Foster Method. Let a battery of constant e.m.f. be connected in series with one of the two coils P whose mutual inductance is to be determined, a known resistance R_1, and a key K, Fig. 58. Let the ballistic galvanometer G and another resistance R_2 be connected in series with the other coil S. Then if I be the steady current produced by the battery B through P, and M be the mutual inductance, and r be the resistance of the circuit through S, R_2, and the galvanometer, then the quantity of electricity Q, passing through the galvanometer on closing or opening the circuit will be

$$Q_1 = \frac{M\,I}{r}$$

Next, if the galvanometer be removed from this circuit and put in series with a condenser whose capacity is C, which is connected as a *shunt* to the resistance R_1, on opening or closing the battery circuit the quantity of electricity

$$Q_2 = IR_2C$$

By combining these two equations it is possible to find the relative values of C and M. In practice it is much more desirable to combine

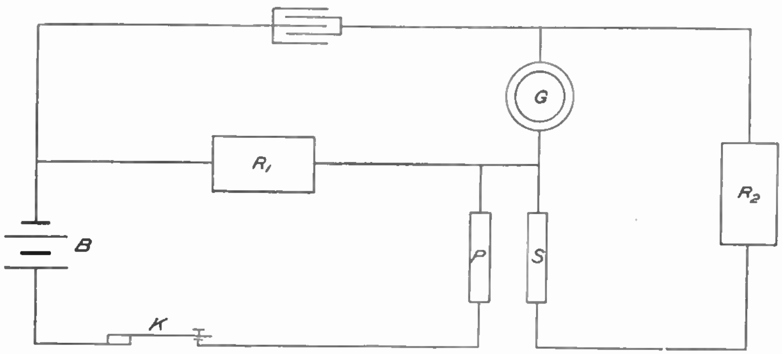


Fig. 58. Diagram of Carey-Foster Method of Measuring Mutual Inductance.

these two circuits, as shown above, so that the charge and discharge of the condenser and the currents produced at the same time in S by mutual induction are in the same direction through C, R_2, and S. Then if the resistance R_1 and R_2 and the capacity C are adjusted until no deflection of the galvanometer is produced, the following may be written:

$$Q_1 r = MI, \text{ but } Q_1 = IR_1C; \text{ hence } M = CR_1 r$$

Attention is called to the fact that in order that the galvanometer current may be 0 at every instant during the establishment of the steady current, it is essential that the coefficient of self induction of the coil S should be equal to the coefficient of mutual induction. Under this condition it is possible to replace the galvanometer by a telephone.

Example. *Small Induction Coil,* no iron core. Resistance of secondary, 194 ohms. Capacity of condenser, 4.9.26 microfarads

The secondary coil could slide endways remaining coaxial with the primary. The following are the results with the centers of the two coils as nearly coincident as possible:

R_1	r	R_1r (C. G. S. UNITS)	R_1	r	R_1r (C. G. S. UNITS)
15	194 + 217	6165×10^{18}	10	194 + 423	6170×10^{18}
14	+ 247	6174	9	+ 490	6156
13	+ 282	6188	8	+ 576	6160
12	+ 322	6192	7	+ 688	6174
11	+ 367	6171	6	+ 835	6174

$$\text{Mean value of } \frac{M}{C} = 6172.4 \times 10^{18}$$

Hence

$$M = 4.926 \times 10^{-15} \times 6172 \times 10^{18} = 3.04 \times 10^{7} \text{ or } .0304 \text{ henrys.}$$

MAGNETIC MEASUREMENTS

Certain materials, notably iron (or steel), nickel, and cobalt, have a property known as *magnetism*. These materials when magnetized have the property of attracting soft iron. The modern view of magnetism is that it is a property of the individual molecules of a body. A body which seems to be unmagnetized probably has its molecules arranged in more or less irregularly formed closed chains, Fig. 59, which produce no outside effect. To magnetize a body, it is, according to this theory, necessary to break the chains and to rearrange the connections of the molecules so that the ends of the chains of molecules come out at points on the surface where so-called magnetic charges appear, Fig. 60. The centers of action of these chain ends are called *poles*. In the simplest magnets there are two poles, and if the magnet is free to turn in a horizontal plane, one of the poles is turned toward the north and the other toward the south approximately. In general, the magnetic meridian, determined by the line joining the poles when at equilibrium in the horizontal plane, does not agree exactly with the geographical meridian. The line of no

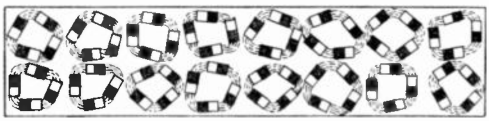


Fig. 59. Supposed Molecular Condition of a Piece of Unmagnetized Steel.

variation at present is located near the eastern shore of Lake Michigan and is moving westward. A century ago it was near the eastern end of Lake Erie. For points to the east of the line of no variation, the magnetic compass points west of north; and for points west of this line of no variation, it points east of north. The north seeking pole of a magnet is commonly called the *north pole* and the other the *south pole* of the magnet. If the magnet is free to turn in all directions, the north pole will dip downward and the south pole rise upward for points in the northern hemisphere and *vice versâ* for points in the southern hemisphere. The dip in Chicago is in the neighborhood of 70°.

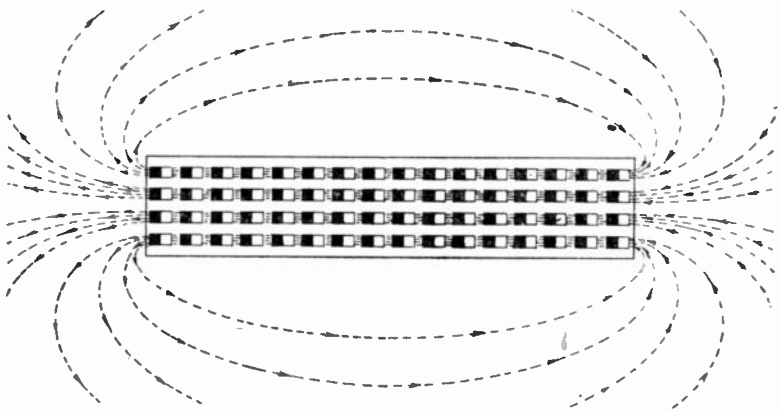


Fig. 60. Supposed Molecular Condition of a Magnetized Piece of Steel.

From the above it appears that the earth has a magnetic field, meaning by magnetic field an extent of space where magnetic forces are to be found. If a magnet with poles 1 cm. apart and of unit strength is in a unit magnetic field, it will act on each pole with a force of one dyne; and if the poles are turned so that the directions of the forces are at right angles to the line connecting the poles, a unit turning moment, or torque, is exerted on the magnet. In the first chapter of this book, unit magnetic pole was defined as a pole which, at a distance of one centimeter in air from a like pole, produces a repulsion of one dyne of force. It appears then that a magnetic field has both direction and magnitude, and is what is called a *vector* quantity. To define a vector quantity both magnitude and direction must be known.

Methods of Magnetizing. Besides natural magnets, composed of the magnetic oxide of iron and known as *loadstones,* artificial magnets may be made by subjecting hard steel to a magnetic field. The magnetic field used may be due to a loadstone, or an artificial magnet previously made, or a magnetic field due to an electric current in a coil of wire. Before 1819, when Oersted discovered the magnetic field produced by a current, the source of all artificial magnets was directly or indirectly the loadstone. Permanent magnets nowadays are practically all magnetized by means of electric currents.

Lines of Force and Permeability. To Michael Faraday we owe the notion of lines of force to express the vector quantity defining the magnetization. The direction of the lines is used to indicate the direction of magnetization, and the number of lines per square centimeter indicates the magnitude of the magnetization. The numbers of lines per square centimeter is commonly called the *flux density* or *flux of force* per square centimeter. The unit value occurs when there is one line per square centimeter, and is called the *gauss.* The symbol B is used to express this quantity algebraically. As different materials when put in equal fields take different degrees of magnetization, the relation of field strength to flux, known as the *permeability,* must be known. If H indicates the field strength, B the flux per sq. cm., and μ the permeability, we have the relation

$$B = \mu H$$

When the section considered has an area A sq. cms. and the average flux intensity is B, the total flux designated by Φ is algebraically expressed as

$$\Phi = B A = \mu H A$$

The unit in which Φ is measured is the Maxwell and is equal to one line of force.

If the lines of force pass from one material into another of different permeability μ, the lines representing B and Φ will usually suddenly change direction at the surface of separation between the materials, commonly called *media,* except in the case that the lines are normal to the surface. If the permeabilities of two media are μ_1 and

μ_2, and the angles between the normal and the lines in the two media are a_1 and a_2, we have the relation

$$\frac{\tan a_1}{\tan a_2} = \frac{\mu_1}{\mu_2}$$

Lines of force follow by preference paths of high permeability, though, other things being equal, they tend to follow the shorter paths. Consequently it rarely happens that the lines are straight, as they converge toward spaces filled with bodies of high permeability and there diverge again in spaces of low permeability. In general the total flux Φ distributes itself so that, length of path and permeability considered, it takes the easiest course. A line of force never ends, but always returns on itself. Many writers carelessly confuse and use the same unit (the gauss) for measuring B and H, for both are vector quantities and may be represented by lines. To avoid confusion we shall not represent H by lines. For highly magnetic materials, B is much greater than H. In the case of iron the ratio may be as high as $\mu = 3{,}000$ for moderate values of B. The value of μ is not constant for the same material for different values of B. In the case of soft iron the permeability for low values of B may be about $\mu = 120$, rising to $\mu = 2{,}000$, or in good samples $\mu = 3{,}000$, when B reaches a value between $B = 5{,}000$ to $B = 8{,}500$. For nickel and cobalt the highest value of the permeability is about $\mu = 200$. As a standard of comparison the permeability of air is taken as $\mu = 1$ and is believed to remain sensibly constant for all values of B. It follows that in air $H = B$ (numerically). Materials more magnetic than air, for which $\mu > 1$, are called *paramagnetic*. Materials less magnetic than air, for which $\mu < 1$, are called *diamagnetic*. No magnetic material is without permeability, that is $\mu = 0$; in fact, even the most diamagnetic material, bismuth, is within a fraction of one per cent as permeable as air. Magnetic insulation is therefore impossible and to avoid magnetic leakage of lines of force from a prearranged path, it is necessary to distribute the *magnetomotive force* over the whole path.

Magnetomotive Force. By analogy with electric circuits, where the potential difference over each unit length of the circuit is found by multiplying the current by the resistance of that unit length, or dividing the current by the conductivity (the reciprocal of resistance) for the unit length, we see that in a part of a magnetic circuit, one centimeter long and one square centimeter in section, μ is analogous to the conductivity per cm. cube of an electric circuit. B is analogous to the current per sq. cm. of section of the conductor and H is analogous to the potential difference per centimeter length. H is called the magnetomotive force per unit length, and the total magnetomotive force is the average value of H multiplied by the length of the circuit l. It follows that the magnetomotive force (m. m. f.) is

$$\text{m. m. f.} = \mathrm{H}\, l$$

If the magnetic field is produced by a current in a wire, the intensity of the field is greatest at the surface of the wire and falls in value to zero at the middle of the wire, and outside the wire falls in value according to the law of the reciprocal of the distance from the center. If, however, the wire is coiled into a long, straight coil of uniform section, called a *solenoid,* the magnetic field for the portion far from the ends is practically zero outside the solenoid and of uniform value inside the solenoid. If there are n turns of wire per centimeter and a current of I amperes, the inside magnetic field is

$$\mathrm{H} = 0.4\ \pi\ n\ I = 1.2566\ n\ I$$

If the whole number of turns of wire is N, the magnetomotive force is

$$\text{m. m. f.} = 1.2566\ N\ I$$

The unit of m. m. f. is the *gilbert,* or that value of magnetic force which will establish one line or one maxwell per centimeter cube of air. Many practical authorities prefer to express the m. m. f. in *ampere turns* $N\ I$ omitting the factor 1.2566. This leads to some confusion if the fact is not made clear by stating that the m. m. f. is in ampere turns. If a long solenoid is bent into the form of a ring, it is called a *ring* solenoid. If the width of the ring is small in comparison with its diameter, it is assumed that the average value of H is equal to its value along the central line of the ring.

Reluctance. If a circuit is l centimeters long and averages A sq. cm. in section, the reluctance R of the whole circuit is

$$\mathrm{R} = \frac{l}{A\ \mu}$$

The unit in which reluctance is measured is the *oersted.*

By analogy with Ohm's law the magnetic flux Φ is

$$\Phi = \frac{\text{m. m. f.}}{\text{reluctance}} = \frac{\text{m. m. f. } A\,\mu}{l} = B\,A = \mu\,H\,A$$

Hysteresis. When iron or steel has been magnetized and the magnetizing force removed, a portion of the magnetization will still remain as more or less *permanent* magnetization. If next the magnetizing force is applied in the reverse direction, the magnetization will not be reversed until the m. m. f. has reached a certain value, *i. e.*, until H reaches a certain value. The residual value of B when the field is reduced to zero is called the *remanence* or *retentiveness* by some writers. The reverse field, m. m. f., necessary to reduce B to zero is called by the barbarous term (as Professor Mascart puts it) of *coercive force*. Further increase of the reverse m. m. f. will cause a rapid rise of B. With repeated cycles of change between positive and negative m. m. f.'s the values of H and B go through cycles. The tendency of B to lag behind H is called *magnetic lag* or *magnetic hysteresis*, hysteresis being the Greek word for lagging behind. A certain amount of energy is expended in the cycle and appears in the form of heat generated in the iron. This loss of energy per cycle is repeated n times per second, and the power used is known as the *hysteresis loss*, and is measured in watts per cubic centimeter. Sometimes the energy lost per cycle is measured in joules. One joule equals 10,000,000 ergs. The relation of H and B during the hysteresis cycle may be expressed in the form of a curve plotted in terms of H (horizontally) and B (vertically). The curve shown in Fig.

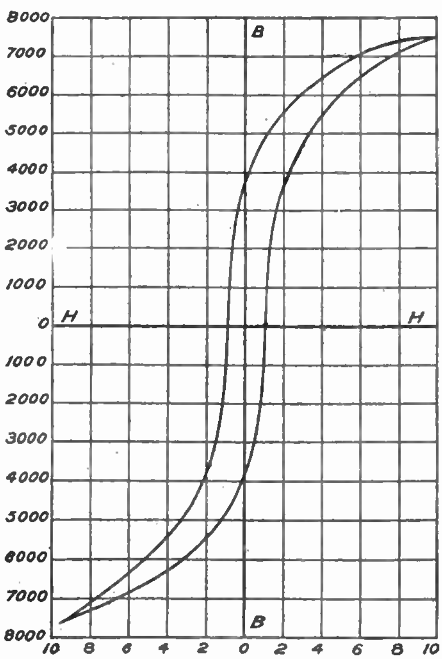


Fig. 61. Hysteresis Diagram.

61 is known as a *hysteresis curve*. If H and B are plotted to scale, the area of the curve divided by 40,000,000 π, or 125,660,000, gives the energy lost per cycle in joules. For measurements of hysteretic losses the sample may be made into the form of a ring with small difference between its largest and smallest radius. The ring may then be wound with a coil of wire in the form of a ring solenoid and the current and turns in the coil will determine the m. m. f. and consequently H in the core.

Magnetic Dip. *By Dip Needle.* If a long and slender magnetic needle, Fig. 62, with pointed ends is mounted on an axis passing precisely through its center of gravity, at the middle of an accurately graduated circle standing vertically in the magnetic meridian, the north pole of the needle will point downward from the horizontal by an angle equal to the magnetic dip. The angle of dip may then be read directly from the circle. As, however, it is difficult to magnetize the needle with exact uniformity, the bearing should be made reversible so that the needle may be turned over. Any irregularity of magnetization may be eliminated by taking the mean of the two readings of the magnet in the two positions. In case the bearing fails to pass exactly through the center of gravity, the error may be compensated by reversing the magnetization of the needle, care being taken to use the same magnetic field as before, and then repeat the observations of the dip with the magnet in both positions. The mean of the four

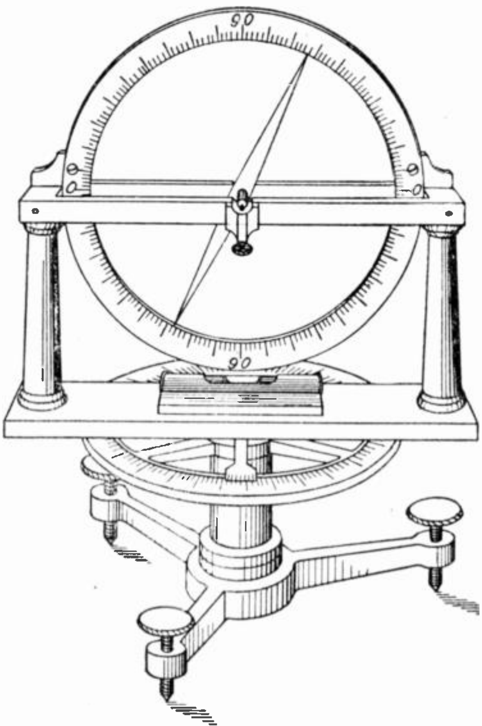


Fig. 62. Magnetic Dip Needle.

readings will give the value of the dip. If the divided circle is not in the magnetic meridian, an error will be caused which is slight for slight deviations from the meridian. A compass needle mounted over the divided circle will locate the magnetic meridian well enough for practical purposes.

Earth Inductor Method. Another method is by use of the earth inductor which is a coil of wire mounted in a frame and which may be turned about an axis in the plane of the coil. No iron or other magnetic material should be used in the apparatus. The frame is carried on a support by which the axis of rotation may be made vertical or horizontal. The apparatus is shown in Fig. 63. All heavy parts are made of brass which is practically non-magnetic.

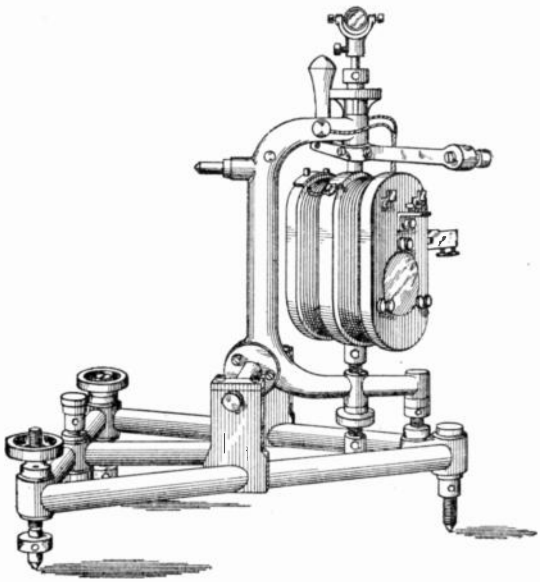


Fig. 63. Earth Inductor.

If the coil is turned about a vertical axis, as shown in the figure, from an east and west plane through 180° to the reverse position in the same plane, the number of lines = B A cos δ of the earth's magnetic field passing through the coil, will be cut by the coil, and if a ballistic galvanometer is in the circuit, its deflection d_1 will be proportional to the flux cut. If now the axis of rotation be made horizontal and the coil horizontal, a reversal in position will cut the number of lines = B A sin δ of the earth's magnetic field passing through the coil. The resulting deflection d_2 of the ballistic galvanometer is proportional to the flux cut. We then have the relation

$$\tan \delta = \frac{d_2}{d_1}$$

If the deflections are small they may be increased by reversing the position of the coil on the return swing of the galvanometer, and continuing until the amplitude of swing becomes constant. The deflections in two positions of the axis of the coil are proportional to the *horizontal* and the *vertical* components respectively of the magnetic field, and the ratio of the second to the first gives the tangent of the dip of the earth's field.

The angle of dip varies from + 90° at the earth's north magnetic pole to − 90° at the south magnetic pole. It is zero at the magnetic equator.

The Earth's Magnetic Field. If in the previous method, the data of the earth inductor and of the ballistic galvanometer are known, the value of B may be determined. As the experiment is performed with air as the medium, the value of μ is 1, and H is numerically equal to B. The horizontal component of the earth's magnetic field is frequently spoken of as H, meaning thereby the *horizontal* component. In the same way V is the vertical component. The tangent of the angle of dip is the ratio

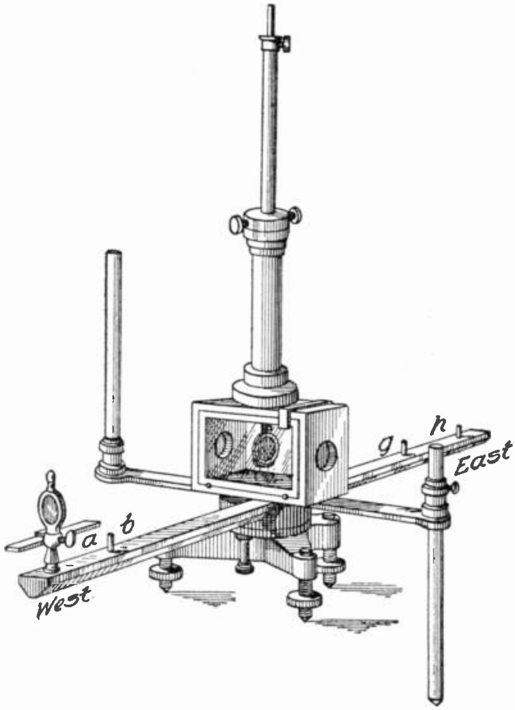


Fig. 64. Magnetometer.

$$\frac{V}{H}$$

Magnetometer Method. The horizontal component may be measured by means of two magnets, one of which is of light weight and the other relatively large and heavy, both carrying mirrors. The little magnet and mirror may be suspended at the center of an instrument called a *magnetometer*, Fig. 64. The second magnet, of considerable size, is mounted on a support at its center at a fixed distance to the east of the little magnet and in an east and west position (point *g* of the figure). The small magnet takes up a position parallel to the resultant of the horizontal component of the earth's field and that of the large magnet. By means of a telescope and scale at a known distance, the angle of the deflection is measured. The other pole of the large magnet is now turned toward the small magnet by turning the large magnet end for end. The deflection measured by the telescope and scale should be as before, only in the opposite direction. The large magnet is now transferred to a support *b* at an equal distance to the west of the small magnet, and the observations repeated, obtaining two more deflections. All four deflections should be equal. If they differ slightly the mean is taken; if they differ much, something is wrong with the arrangement and the apparatus should be examined and the trouble corrected. The observations are now repeated at a larger distance (points *a* and *h*), and four more observations taken. From the data, assuming that the magnetic field falls off according to the inverse square of the distance from the poles of the magnet, a pair of equations may be formed from which the strength of the magnet's poles in terms of the horizontal component of the earth's field and their distance apart may be calculated. This distance apart of the poles will be found to be somewhat less than the length of the large magnet. The product of the pole strength and length between poles is called the *magnetic moment* of the magnet, represented by M. If r_2 = the larger distance, r_1 the smaller distance, and Φ_1 and Φ_2 the deflections, we get

$$\mathrm{M} = \frac{\mathrm{H}}{2}\,\frac{r_2^5 \tan\Phi_2 - r_1^5 \tan\Phi_1}{r_2^2 - r_1^2}$$

The large magnet is now hung up by a fine wire and set to vibrating. The period of vibration T_1 is determined by measuring with a stop watch the time of a considerable number of vibrations and finding the time of a single swing. If K_1 is the moment of inertia and θ the correction for the rigidity of the wire, we have

$$T_1 = \pi\sqrt{\frac{K_1}{\mathrm{M\,H}(1+\theta)}}$$

As there may be some difficulty in computing the moment of inertia

AN EXAMPLE OF CLEAN-CUT AËRIAL CABLE WORK

K_1, it is usual to add a brass ring of rectangular section and easily computed moment of inertia K_2. This ring must be placed on top of the magnet so that its center lies on the prolongation of the suspending wire. The moments of inertia are then added to get the total moment. There are reference marks on opposite ends of a diameter of the ring and corresponding marks on portions of a circle of the same radius of the ring marked on the top surface of the magnet to ensure precise centering. With the ring in position, the new time T_2 of vibration is determined.

$$T_2 = \pi \sqrt{\frac{K_1 + K_2}{M H (1 + \theta)}}$$

θ is determined by turning the torsion head, from which the magnet is hung by the wire, through a considerable angle and determining by the telescope and scale the angle through which the magnet follows. This enables one to compute how much effect the rigidity of the wire has on the restoring force which is due principally to the earth's field. If on turning the torsion head an angle α, the magnet follows an angle β, there is obtained, $\theta = \frac{\beta}{\alpha - \beta}$. Combining the earlier equations gives

$$M H = \frac{\pi^2 K_2}{(1 + \theta)(T_2^2 - T_1^2)}$$

Substituting the value of M previously obtained we get on solving for H

$$H = \pi \sqrt{\frac{2 K_2 (r_2^2 - r_1^2)}{(1 + \theta)(T_2^2 - T_1^2)(r_2^5 \tan \Phi_2 - r_1^5 \tan \Phi_1)}}$$

The value of H in the southern part of Michigan is about 0.18 and the vertical component is about three times as strong or about 0.54. As the presence of masses of iron in the neighborhood has a considerable effect on the dip of the magnetic field and also on the value of the field, a measurement made in any place with iron masses near by, cannot be assumed as valid for even other parts of the same building. Laboratories for the study of the earth's magnetic field should have all iron excluded from the building materials and from the apparatus except the magnets.

If the angle of dip δ has been found by one of the previous methods, the total value of the earth's magnetic field F is

$$F = \frac{H}{\cos \delta}$$

The bars N and L shown in Fig. 51 are not used in this experiment.

Magnetic Flux and Permeability. There are a number of excellent methods of determining flux and permeability, of which the following will suffice for the purposes of this work.

Divided Bar Method. The divided bar method assumes that the material under test is in the form of two long iron bars or rods with the ends ground and polished into accurately plane surfaces. One bar, with the polished end upward, is mounted in a long solenoid, the polished end being at the middle of the solenoid. The other bar is placed on top of the first with the polished ends resting one on the other and accurately centered. The upper piece is attached to a spring balance which is used to measure the tension necessary to separate the bars. If the weight of the upper piece is subtracted, the remainder gives the pull. The bars and the solenoid must be long enough to have the magnetic field H at the surfaces in contact practically equal to what it would be in an infinitely long solenoid, for which I is the current in amperes and n the number of turns of wire per centimeter length, otherwise a correction must be made for the ends.

$$H = 0.4 \pi n I = 1.2566 n I$$

If the area of the ends of the bar is S sq. cm., and the force in grams (weight) F, the value of gravity g (= 980 about), we get for the flux density B,

$$B = \sqrt{\frac{8 \pi g F}{S}} = 156.9 \sqrt{\frac{F \text{ (grams)}}{S \text{ (sq.cm.)}}}$$

If the pull F is measured in pounds and the area S in square inches, we must allow for the ratio of the units. We then obtain

$$B = 1316 \sqrt{\frac{F \text{ (pounds)}}{S \text{ (sq. in.)}}}$$

In using the method, the spring balance should be supported in guides and drawn upward gradually by means of a turn-buckle or analogous means. The last reading before the bars separate is the one to be taken. If the bars are rounded at the corners an error will be made because the value of B will be increased at the smaller section to a greater value than back in the rod, as the total flux Φ is spread over a smaller area. The pull will be increased because from the above formula it appears that the pull is proportional to the product SB^2. Therefore avoid rounding the edges. If the surfaces do not fit one another, the air where they do not touch will have a lower permeability and there will be a tendency for some of the flux to escape at the side, thus reducing B and consequently the pull.

To obtain the permeability μ divide B by H. As mentioned earlier the permeability increases as B increases, reaching a maximum for moderate values of B and then falls off rapidly for further increase of B.

A magnetization curve (B, H curve) or a permeability curve (B, μ curve) may be plotted from values obtained for different values of B, H, and μ. A bar of iron which has never previously been magnetized, will behave for small values of H differently from what it will again. For this reason the values of H used should increase gradually from lower to higher values. A bar once magnetized cannot be brought back to its original condition by any process except heating it to the temperature at which it becomes practically unmagnetic and then cooling it again, retempering it if necessary. If it is demagnetized by reversing the direction of the field and reducing the latter to lower values gradually on each reversal, most of the magnetism may be removed. This is supposed to reduce the magnetization of the bar to a set of concentric magnetizations in opposite directions in successive concentric layers. This is not quite equivalent to the irregular chains of molecules in a bar which has never been magnetized. A bar which has been demagnetized by a simple reversal of the field to a value apparently reducing B to zero, results in reversing the outer layer only, making the total flux zero *algebraically* as the sum of two *equal* and *opposite* fluxes in concentric layers.

Divided Ring Method. The divided ring method has the material in the form of a ring which has been cut in two and the opposite surfaces polished. The surfaces should be exactly in the same plane to insure a close fit when the ring is put together again. The pull necessary to separate the ring is twice as much as for one surface; so the total pull, after allowing for the weight of the upper part, should be divided by two before applying the previous formula. The ring is magnetized by a ring solenoid surrounding it. The solenoid is in two parts which separate with the parts of the ring.

Ballistic Method. If the material to be tested is in the form of a very long rod, say, 50 diameters in length, or better in the form of a ring, Fig. 65, with little difference between the outer and the inner radius, surrounded by a solenoid of n turns per cm. length through which the current I amp. passes, the field is $\text{H} = 1.2566\ n\ I$. A secondary coil of a small number of turns (of which all or a part only may be used) is wound about the ring and is connected to a ballistic galvanometer whose throw for a known quantity passing is known. The ratio K of quantity to throw may be found by charging a condenser of known capacity C microfarads by a standard cell of e. m. f. E volts, and discharging it through a ballistic galvanometer, producing a deflection d. The constant K is then $K = \frac{E\ C}{d \times 10^6}$. Or the galvanometer constant may be determined by winding a solenoid of n_1 turns per cm. on a core of wood or other material of the same permeability as air, for which μ equals 1. H then equals B, and the flux passing through the core whose area is A_1, the current being I_1, is

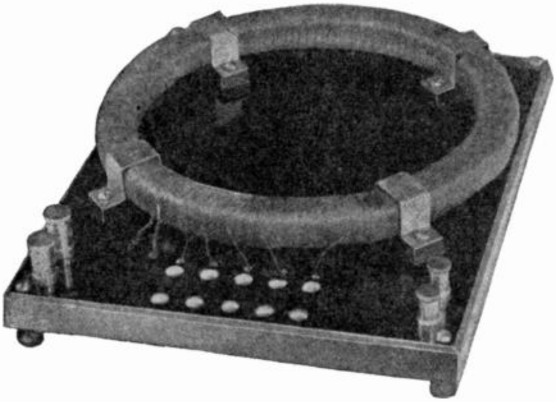


Fig. 65. Iron in Ring Form for Ballistic Measurement.

$$\Phi_1 = 1.2566\ n_1\ A_1\ I_1$$

The total quantity of electricity Q_1 passing through a ballistic galvanometer in series with a secondary circuit of m_1 turns and in a circuit of total resistance R_1, on making or breaking the primary circuit I_1, is

$$Q_1 = \frac{m_1\ \Phi_1}{R_1} = \frac{1.2566\ n_1\ m_1\ A_1\ I_1}{R_1}$$

If the deflection is d_1, the quantity per unit deflection is

$$\frac{Q}{d_1} = \frac{1.2566\ n_1\ m_1\ A_1\ I_1}{R\ d_1} = K$$

K is called the *constant* of the ballistic galvanometer.

If the primary circuit, the solenoid, has n turns per centimeter length, and the secondary circuit a total number m of turns, and the area of the section of the ring is A, and the resistance of the secondary circuit is R, and the deflection is D on reversing the primary circuit of I amperes, we have the flux

$$\Phi = \frac{R\ D\ K}{2\ m}$$

and

$$\mathsf{B} = \frac{\Phi}{A} = \frac{R\ D\ K}{2\ A\ m}$$

The current must be reversed suddenly, some form of commutator being used, otherwise the galvanometer may not feel the full effect. We had previously

$$\mathsf{H} = 1.2566\ n\ I$$

The value of the permeability for any value of H is

$$\mu = \frac{\mathsf{B}}{\mathsf{H}}$$

In using the method the current in the primary is *reversed* because otherwise the residual magnetism will produce a disturbance. If in the experiment the current starts at small values, the disturbing effects of previous magnetization is a minimum. We then insert a high resistance in the circuit at first and note the deflection of the galva·nometer on reversing the current. Then increasing the current, the process is repeated. Several reversals should be made at each value of the current until enough observations have been made to ensure an accurate result. The deflection on the first reversal is apt to be different from those following. The B, H curve obtained by this method starts from the origin.

Hysteresis Curves. If instead of reversing the current it is simply changed by a sudden change in the resistance, the deflection will measure the change in B. Starting with no current in the primary and the ring unmagnetized, the circuit is suddenly closed with auxiliary resistance in circuit and the throw of the galvanometer noted as well as the current in the primary. The values of B and H are determined. Next the current is suddenly increased by cutting out part of the resistance and the deflection noted and the ammeter read. The deflection of the galvanometer measures the *increase* of B. The value of B is found by adding the *increase* to the previous value. The current is again increased and the deflection of the galvanometer will measure the increase of B. This is added to the previous total, and so on until the value of B is found for the highest value of H which is to be used. The current, and consequently H, is now reduced by steps, and the deflections of the galvanometer in the opposite direction will measure the decrease of B. To obtain the value of B, these decreases in B are subtracted from the previous value. When the zero value of the current, and consequently of H, is reached, the value of B will still be a considerable amount. The current is now reversed and built up by steps and the deflections will measure the continued decrease of B to zero and its reversal and building up in the reverse direction. This is continued until the maximum reverse value H is reached, equal, we will say, to its previous positive maximum. The current is reduced by steps to zero, reversed, and built up again in the first direction. The deflections measuring changes in B are noted and the total computed by the algebraic sum of all that precede. The sum of all the deflections corresponding to all the steps from the positive maximum to the negative maximum, should equal the sum in the reverse direction. The B, H curve will then make a closed curve for each cycle after the first quarter cycle. The curve for the first quarter cycle starts from the origin and never returns there again. As explained before, the magnetization lags behind the field H, producing the magnetization.

If the curve of B and H, as obtained by this method, is plotted, it is called a *hysteresis curve*, Fig. 61. The curve plotted to scale has an area to 4π times the energy in ergs expended per cubic centimeter per cycle. Dividing the area by $4 \times \pi \times 10^7$ gives the energy in joules per cycle. If the cycle were run through n times per second, the power in watts would be equal to $\frac{\text{area of curve} \times n}{40{,}000{,}000\ \pi}$ watts expended in each cubic centimeter. This is what happens when an alternating current is used.

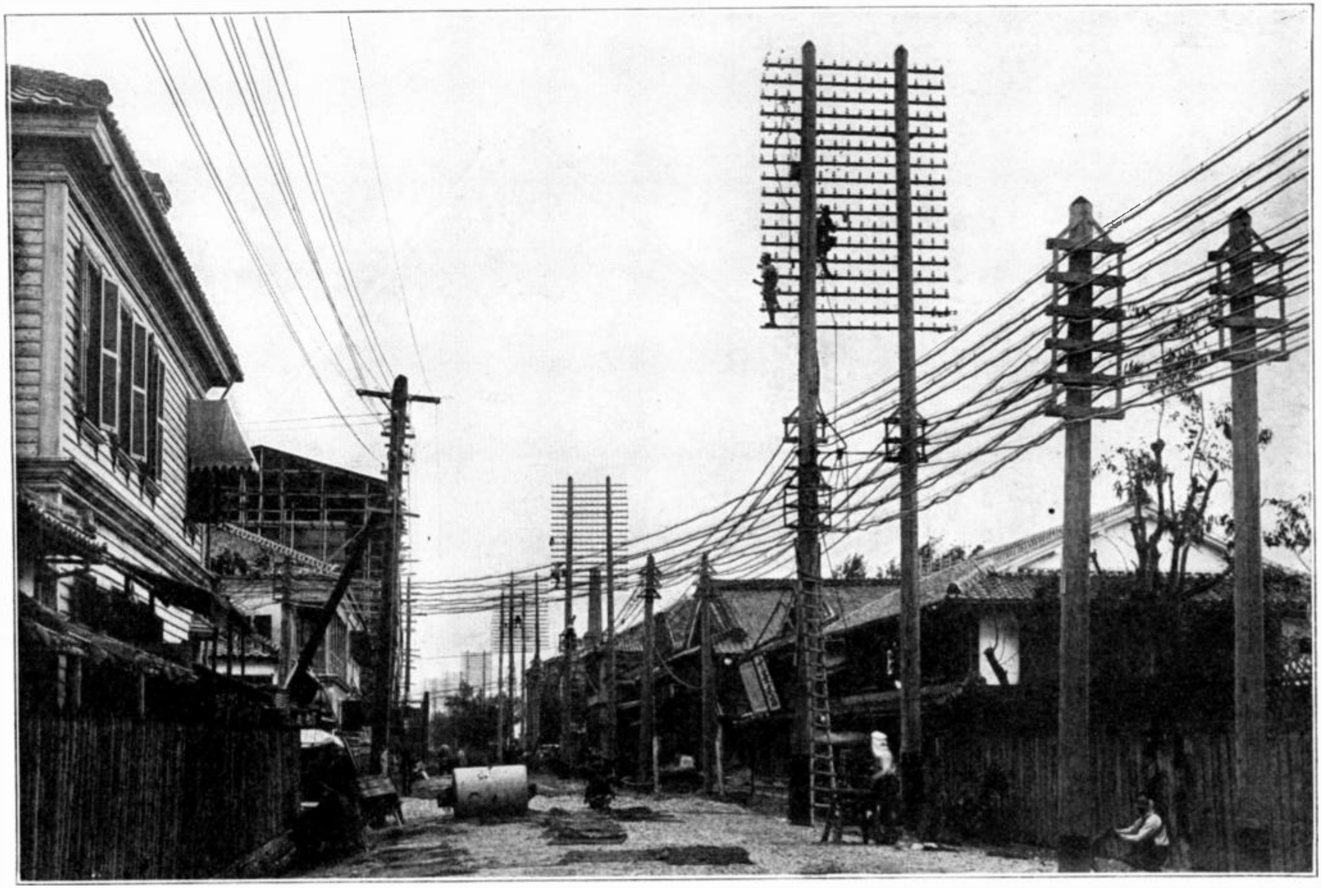
There are two sources of error which may cause trouble in this experiment and which have not been mentioned above. The first is the effect of the current in the primary producing eddy currents in the material of the ring, just as currents are produced in the secondary circuit. In fact, the material of the ring is in itself a secondary circuit of a single turn, and currents in the material of the ring will be parallel to the current in the secondary outside. These eddy currents produce a magnetic field in the ring which opposes the rise of H and B in the ring. Therefore, H in the ring rises slower than the current in the primary coil; and unless the period of the galvanometer is high, some of the effect of the increase of B, which may be slow in increasing, will come too late to be measured by the galvanometer deflection. The other trouble is that if there is any vibration the magnetization may change by small steps one for each shock. This causes the magnetization to creep up or down, depending on whether the field has last been increased or decreased. To avoid the first error it is well to have the material in the form of thin sheets which give little chance for eddy currents, and to avoid the second the ring should rest on a pad of felt or other material which will absorb the vibrations.

Hysteresis Tester. A method of comparing the hysteresis loss of different samples of iron is to compare their effect in dragging the magnetic field when samples are rotated in a constant magnetic field. Suppose the sample takes the form of a disk between a pair of field magnet poles. If the disk is at rest the field will produce a flux density B in the disk parallel to H. If the disk is now rotated the residual magnetization will cause the flux to rotate with the disk until the tangential component arrests further rotation of the flux. H and B then make a small angle with one another for very soft iron in the disk, and a proportionately larger angle for harder iron which shows more hysteresis. The turning moment required to rotate the disk will be proportional to the energy expended per cycle. If the poles are free to turn, they will follow the disk. If the poles are kept from rotating by some counter moment due to springs or gravitational action, the displacement of the poles in the direction of rotation of the disk will measure the relative hysteresis loss. If with one sample disk the displacement is twice that produced by another sample, the hysteresis loss is about double. If the hysteresis loss is known for one disk that of the other may be computed.

As the relative twist of B with respect to H is the same for all moderate speeds of rotation, it is not necessary to be careful about the exact speed of rotation. Also it is not necessary that the sample be in the form of a disk. The same relation for samples in the form of bundles of equal size strips will be found to hold true. The absolute angles of twist will be different, but they will have a ratio of equal value.

Professor Ewing has devised a hysteresis tester in which the sample, in the form of a bundle of strips, is rotated by means of a crank and gear train between the poles of a permanent magnet which is mounted on knife edges at a point above its center of gravity. The magnet follows the rotating bundle until the gravitational force gives an equal torque in the opposite direction.

If the sample is in the form of a solid bar, eddy currents of considerable magnitude may be produced which will complicate the results and introduce more or less uncertainty. Moreover, the eddy currents will be greater at higher than at lower rates of rotation, thus introducing different corrections at different speeds. For these reasons the bundle must be well laminated to obtain reliable results.



AËRIAL TELEPHONE CONSTRUCTION IN JAPAN

TWENTY-TWO DUCT RUN OF FIBER CONDUIT IN ALLEY
Sioux City, Iowa.

STORAGE BATTERIES

Storage or secondary batteries, also called *accumulators*, consist of cells in which a chemical change is brought about by passing an electric current through them, thereby rendering them capable of giving back electrical energy, or *discharging*, until they return to their original chemical condition.

Ordinarily a storage battery consists essentially of two sets of plates suspended in a chemical solution. The plates are of metal or metallic oxide, and the solution is incapable of acting upon them until an electric current is passed from one set of plates to the other. This current decomposes the electrolyte, one of its ions or constituents going to one set of plates and the remaining ion or constituent to the other. Thus two chemical elements or compounds are formed, having a tendency to combine or react; and when combination or reaction occurs on closing the circuit, the energy evolved appears as an electric current, which flows in a direction opposite to that of the charging current. This flow of current continues until the cell is restored to its original condition; when this occurs, the cell is said to be *discharged*.

A *Primary Cell* is one in which electrical energy is produced by the chemical action of one or two solutions on the plates of the cell. When the solutions or plates are exhausted, they are not restored to their original condition by the passage of an electric current in the same cell; but it is possible to regenerate or recover the solutions and metal by treating them electrolytically or chemically in other vessels.

An *Electrolyte* is a chemical compound capable of acting as an electrical conductor, and while so acting, undergoes chemical decomposition. This phenomenon is called *electrolysis*.

For example, when hydrochloric acid is decomposed by electrical energy, it is decomposed into the elementary gases hydrogen (H) and chlorine (Cl). The chemical formula for this action is,

$$2H\,Cl + \text{Electrical energy} = Cl_2 + H_2.$$

When sulphuric acid is electrolyzed, it is at first split up into hydrogen (H_2) and the radical sulphion (SO_4); the latter combines with the water of solution present and reforms sulphuric acid (H_2SO_4), oxygen being liberated. The chemical equations for the above primary and secondary reactions are:

$$2H_2O + 2H_2SO_4 + \text{Electrical energy} = 2H_2 + 2SO_4 + 2H_2O$$
$$2H_2 + 2SO_4 + 2H_2O = 2H_2 + 2H_2SO_4 + O_2$$

The modern theory of electrolysis is based upon the existence of free ions in every electrolyte. For example, a metallic salt dissolved in water is partially ionized; that is, a certain percentage is dissociated into the metal constituent and the other component part of the salt. These carry respectively positive and negative electrical charges, which are neutralized when the ions reach the negative and the positive plates of the battery. The various ions have definite velocities at which they travel or migrate through the electrolyte. The conductivity of electrolytes is entirely due to the presence of these ions, as the non-ionized portion does not conduct.

In 1802, soon after the invention of the primary cell by Volta, Gautherot demonstrated the fact that platinum wires, after being used to electrolyze saline solutions, were able to produce secondary currents. Volta, Ritter, Davy, and others noted similar effects, the phenomenon being what is commonly called *polarization*. In 1859, Planté undertook a series of experiments with the object of studying and magnifying this effect, and finally developed the Planté type of storage battery. Many of the most successful types of storage batteries of the present day are based upon Planté's invention.

Types of Storage Batteries:

Planté;
Faure;
Combination of Planté and Faure;
Non-lead.

PLANTE TYPES OF BATTERY

The Planté cell was originally made by placing two plates of metallic lead in a vessel containing dilute sulphuric acid. These plates were connected to an electric generator, and a current sent through the cell, which decomposed the electrolyte and oxidized the positive plate. The cell was then discharged; but the energy obtained was very small, since the action was confined to the immediate surface of the plates. By repeated charging and discharging, first in one direction and then in the other, the oxidation penetrated deeper and deeper into both plates, thus increasing the storage capacity of the cell.

The chief difficulty with the original Planté battery was the great length of time and consumption of energy required for *forming* the plates, which process, as just explained, consists in converting the surface of the plates into active materials, by repeated charging and discharging. Planté found that he could hasten this forming process by pickling the plates in dilute nitric acid, then washing them in a 10 per cent sulphuric acid solution, after which they were electrically formed. Other methods of facilitating the forming process, or increasing the active surface, are given later.

In 1881, Faure devised the method of *pasting* the lead oxide or active material directly upon the plates. This largely avoids the tedious forming process; but the plates thus produced are not so durable as the Planté elements, being more likely to disintegrate, because the paste is not an integral part of the plate.

General Principles of the Storage Battery. Any primary battery will act as a storage battery provided its chemical action is reversible. The ordinary gravity cell, for example, may be regenerated by sending a current through it in the direction opposite to that produced by it. The zinc sulphate and the metallic copper are thus reconverted into metallic zinc and sulphate of copper respectively, the chemical action being

$$ZnSO_4 + Cu + \text{Electricity} = Zn + CuSO_4,$$

which is exactly the reverse of the action in the primary cell. There are, however, practical difficulties in the continued recharging of a spent gravity cell, due to the ultimate mixture of the sulphate solutions so that the copper salt will reach the negative electrode, where it is deposited and sets up destructive local action. In some forms of primary cells, the chemical action liberates a gas that escapes, so that the action in these cases is obviously irreversible.

Chemical Action in Lead Storage Batteries. The exact nature of the chemical changes which occur in lead batteries, is not yet fully established. Planté believed the charging action to consist in the formation of peroxide of lead (PbO_2) on the positive plate, and metallic lead on the negative, which were converted into lead oxide (PbO) on both plates by the discharge. It was shown later by Gladstone and Tribe, and corroborated by subsequent investigations, that the formation of lead sulphate plays an important part.

This reaction may be represented as follows:

	Positive Plate		Electrolyte		Negative Plate
Charged Condition	PbO_2	+	$2H_2SO_4$	+	Pb
Discharged "	$PbSO_4$	+	$2H_2O$	+	$PbSO_4$
Charging Current			$\longrightarrow$		
Discharging Current			$\longleftarrow$		

According to the above equations, the active material on both plates is converted into lead sulphate when the battery is discharged. The reasons for believing this to occur are: *first,* chemical analysis shows that lead sulphate exists in the discharged plate; *second,* the density of the electrolyte decreases during the discharge of the cell, corresponding to the consumption of sulphuric acid and the formation of water, as shown in the above reactions; *third,* on thermochemical grounds, the combination of lead and oxygen as lead oxide (PbO) does not evolve sufficient energy to account for the E. M. F. produced.

Storage Batteries of the Planté Type. It was noted that the first difficulty met with in the making of Planté plates was the inordinate length of time and cost of current necessary to form them; and it was also shown how Planté treated them with nitric acid to hasten this action. Other methods are used to facilitate the formation; these are tabulated as follows:

1. *Mechanical Action:* Laminated plates, made up of lead ribbons. The surface of the plate is grooved with some forming tool. Built up of lead wires, etc.
2. *Chemical:* Treating the plates in some pickling bath, to produce initial oxidation.
3. *Electrolytic:* Forming a plate of some compound of lead or an alloy, and either reducing the compound or eating the foreign matter away, leaving a porous lead plate.

Gould Storage Battery. This battery is made by the Gould Storage Battery Company, of New York, and the plates are produced by a combination of the first and third methods. The plates or blanks are placed in steel frames and given a reciprocating motion between two revolving shafts which carry grooving discs, giving the plates a surface as shown in Fig. 1. No lead is removed by this process; but the surface is ploughed up. It is then subjected to electro-chemical treatment to form the active material. The types manufactured range in size from a cell of three plates 3 inches by 3

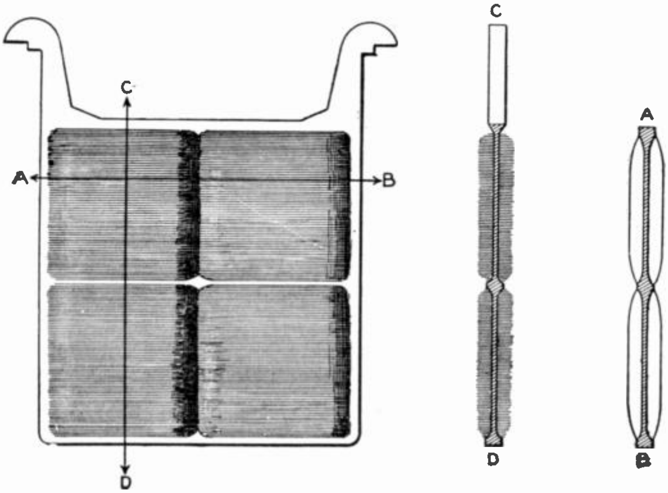


Fig. 1. Gould Storage-Battery Plate.

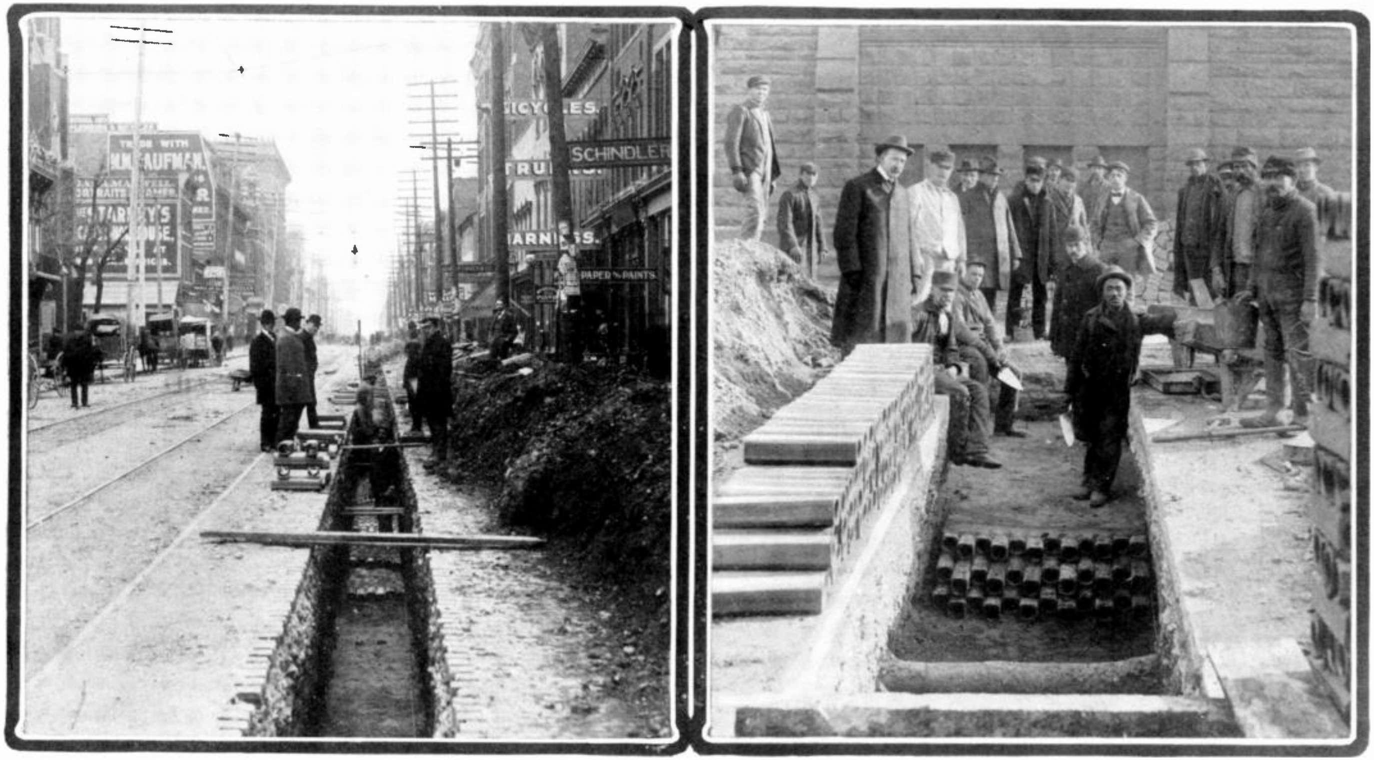
inches, to one of 105 plates, each 15.5 inches by 31 inches; and in capacity from 5 ampere-hours in the smallest size to 17,000 ampere-hours in the largest.

Bijur "High-Duty" Battery. Batteries of this type are manufactured by the General Storage Battery Company, of New York. They are made in standard sizes ranging from 6 ampere-hours to 12,688 ampere-hours, the smallest cell being made up of two plates, one positive and one negative, each 3 inches by 3 inches, suspended in a small glass jar. The largest type comprises 67 plates, each 15¾ inches by 31¾ inches, suspended in a lead-lined tank. Some of the standard sizes manufactured are shown in Table I.

Both positive and negative plates are of the Planté type, and are of the same general design, Fig. 2. Each plate consists of the grid or supporting frame, made up of pure lead containing a small percentage of refined antimony, producing a rigid inoxidizable supporting and conducting member for the active lead. In the openings of this rigid framework are welded gratings or *grills* of pure lead. Each grill consists of vertical strips supported by heavier horizontal

TABLE I
Data, Bijur High-Duty Battery

Type		BB	DDS	C	D		E		F		G		K		L	
Size of Plate (inches)		3x3	4⅛x8¼	3x5½	5½x5⅝		8⅛x8		10⅝x11		15¾x16		18¼x18⅝		15¾x31¾	
No. of Plates		2	2	7	5	11	5	15	7	19	11	57	21	71	19	67
Discharge Rate (in Amperes)	8 hrs.	¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
	5 "	1	4.2	6.5	8	21	17	59	50	151	168	942	504	1,760	605	2,218
	3 "	1½	6	9	12	30	24	84	72	216	240	1,344	720	2,520	864	3,168
	1 "	3	12	18	24	60	48	168	144	432	480	2,688	1,440	5,040	1,728	6,336
Normal Charge Rate		¾	3	4.5	6	15	12	42	36	108	120	672	360	1,260	432	1,584
Outside Dimensions of Glass Jar	Width	2⅜	3⅛	6¼	4¾	9⅛	5¼	13½	7⅜	....	....	....	....	....	....	....
	Length	3⅞	6⅛	6¼	7⅞	8⅛	9	9½	12¾	....	....	....	....	....	....	....
	Height	5⅜	12	10	10	10	12	12	16	....	....	....	....	....	....	....
Outside Dimensions of Lead-Lined Tank	Width	....	....	....	....	....	....	....	....	21¾	15⅛	54⅞	25	66½	23½	63¼
	Length	....	....	....	....	....	....	....	....	15	19¾	21½	24½	24½	22	22
	Height	....	....	....	....	....	....	....	....	17⅝	26	27½	31½	31½	48⅞	49⅞
Outside Dimensions of Glass Tanks	Width	....	....	....	....	....	....	....	....	20¼	....	....	....	....	....	....
	Length	....	....	....	....	....	....	....	....	13	....	....	....	....	....	....
	Height	....	....	....	....	....	....	....	....	18¼	....	....	....	....	....	....
Weight of Complete Cell, Incl. Acid and Containing Vessel (Pounds)		5⅝	19	25½	36	75	61	161	152	516 466	603	2,670	1,486	4,706	1,947	6,070



INSTALLATION OF TELEPHONE CONDUIT EMPLOYING SINGLE-DUCT VITRIFIED-CLAY TILE
Note the Staggering of the Joints Shown in Thirty-six Duct Run at Right.

members which act as I-beams to stiffen it laterally, and which, with the vertical ribs, form the oxide cells. The active material is formed from the grill expanding as it grows in each of the minute oxide cells, thus locking itself in place.

The grills have no central web; and, being open structures, a through - and - through circulation of electrolyte is obtained. The grills are held on both sides by the alloy frame to which they are welded.

A suitable space is provided between each end of the grill and grid to allow for vertical elongation, while the spacing of the strips accommodates the lateral expansion. The grills are therefore free to expand in every direction, thus avoiding the tendency to set up strains in the plates, which might cause them to buckle.

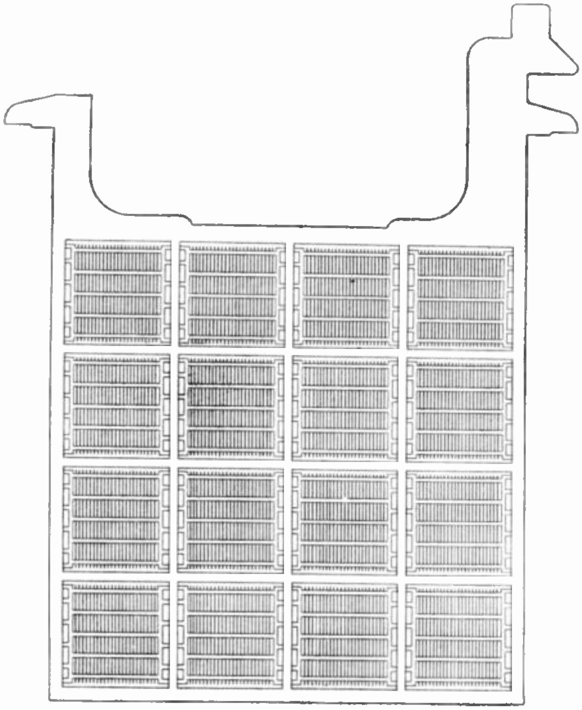


Fig. 2. Bijur High-Duty Battery Plate.

In welding the grills to the grid or frame, a heat process only is employed; no solder, flux, or foreign substance of any kind is used. Since the grill is an open structure, grown from which is a very thin layer of active material, and as this active material does not entirely close the small oxide cell, the gases evolved at high rates of charge have ready means of escape. This results in lower E. M. F.'s required for charging, and the acid diffusion thus obtained also maintains the E. M. F. when discharging at excessive rates.

With the closely adherent layers of active material in intimate contact with the metallic lead, and the absence of concentration of the electrolyte in the pores of the active mass, due to the diffusion, excessive sulphating does not occur.

The loss of negative capacity, due to shrinkage of the active material into a metallic mass, is avoided in this particular plate, by a special treatment which the plates undergo.

FAURE TYPES OF BATTERY

The difficulty with this type is the tendency to disintegrate or buckle. Various means intended to increase the permanency of adhesion of the active material have been suggested, of which the most important are as follows:

1. Plates are grooved, roughened, or *pocketed*.
2. Plates are entirely perforated, the holes being circular, or rectangular, and varying in cross-section; some have a uniform section through the grid

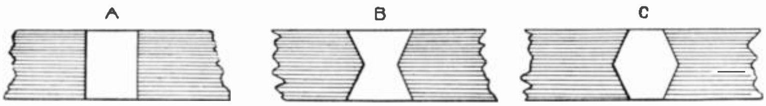


Fig. 3. Different Cross-Sections of Faure Plate Perforations.

(*A*, Fig. 3); others are contracted at the center (*B*); and again they have been expanded at the center of the grid (*C*).

3. The active materials may be enclosed in either a conducting or a non-conducting cage.
4. The plates may be made up entirely of active material.

Faure cells usually have a greater weight efficiency than those of the Planté type, because the proportion of active material may be made greater.

E. P. S. Battery. This is one of the most important of the Faure type, its name being the initials of the Electric Power Storage Company by which it is manufactured in England. It is sometimes called the "Faure-Sellon-Volckmar" cell, being based upon the work of these and several other inventors.

The plates consist of lead grids cast in an iron mould, and have the cross-section shown in Fig. 4. The later types have a thin perforated strip of lead running across each opening midway between the edges. The holes *A* in the grid are completely filled with a paste of red lead or minium (Pb_3O_4) and dilute sulphuric acid, for the positive;

while the paste for the negative consists of minium, or litharge (PbO), and dilute sulphuric acid, or a magnesium sulphate solution. These pastes are pressed into the grids and dried.

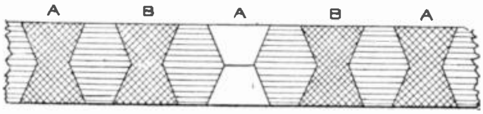


Fig. 4. Section of E. P. S. Battery Plate.

The plates are hardened in dilute sulphuric acid, after which they are ready for forming. A strong current of 48 hours' duration is required for the positive plate, and twenty-four hours is required for the formation of the negative plate. To prevent short-circuiting after the cells are set up, the plates have glass rod separators placed between them.

The E. P. S. batteries are made in many different sizes and forms, of which the L type is a good example, being used extensively in isolated plants. Data of this type are given in Table II.

TABLE II

Data, E. P. S. Accumulator, L Type

No. of Plates	Maximum Normal Charge or Discharge Rate	Capacity (Ampere-Hours)	Approximate External Dimensions			Weight Complete with Acid (Wooden Cell)
			Length	Width	Height	
7	13 amperes	130	5½ in.	13½ in. for wooden and 12 in. for glass cell	18 in. for wooden and 13½ in. for glass cell	74 lbs.
11	22 "	220	8 "			107 "
15	30 "	330	9½ "			143 "
23	46 '	500	14½ "			228 "
31	60 "	660	19 "			286 "

One of the smaller types of the E. P. S. battery is used extensively in England in electric vehicle work.

Exide Battery. This type is manufactured by the Electric Storage Battery Company, of Philadelphia, Pa., chiefly for electric vehicle duty. The plates are of the Faure type, and consist of lead-antimony grids (about 5 per cent antimony) pasted with oxides of lead.

The grid for the positive plate is of the cage type, consisting of thin vertical ribs the edges of which are flush with the faces of the plate and connected by small bars of a triangular cross-section; the bars on one face are staggered with respect to those on the other side. This finished form is then pasted up with red lead (Pb_3O_4), and formed in the usual way; the thickness of the finished plate is about $\frac{7}{32}$ inch. From this description it is evident that the plate is made up in accordance with method 3 described on page 8, the enclosing cage being of conducting material. The active material is in the form of rectangular pencils extending from the top of the plate to the bottom. The thin, flat ribs are on two sides of these pencils; and the triangular cross-pieces are imbedded in the other two sides which constitute the faces of the plates. The Exide cell is shown in Fig. 5.

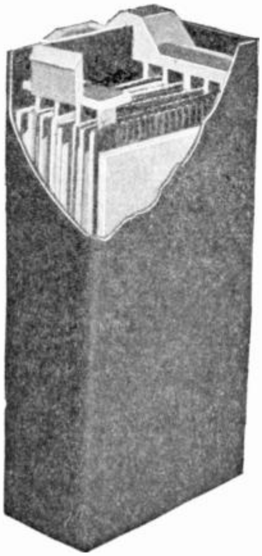


Fig. 5. Exide Battery.

The negative plate consists of a thin antimony-lead sheet, with a comparatively heavy frame of cast lead. The body of the sheet is perforated at regular points, about half an inch apart. These perforations, being made by a tool which does not remove the material, are not actual punchings; but are simply holes torn in the plate, leaving the surrounding material in ragged projections which curve back towards the sheet, forming, as it were, a series of hooks. These projections are formed on both sides of the plates.

The grid is then pasted with litharge (PbO) on both faces; it is held to the plate by the "hooks," as well as being riveted by passing through the holes which the projections surround. The thickness of this finished plate is about $\frac{3}{16}$ inch.

When assembled, the plates are placed in rubber jars of dimensions shown in Table III, and separated from one another by wooden partitions. In addition, a perforated rubber sheet is placed against the faces of the positive plates.

TABLE III
Data, Exide Cells*

Type	M. V.							P. V.			
No. of Plates	7	9	11	13	15	17	19	5	7	9	11
Discharge 4 Hours. (Amperes)	21	28	35	42	49	56	63	12	18	24	30
Size of Plates—											
Length (inches)	5¾	same	same	same	same	same	same	4 13/16	same	same	same
Height (inches)	8⅝	same	same	same	same	same	same	8⅝	same	same	same
Outside Measures of Rubber Jars—											
Width (inches)	2 7/16	3¼	4¼	4 11/16	5 3/16	6¼	7 3/16	1 13/16	2 3/16	3¼	4¼
Length (inches)	6 3/16	same	same	same	same	same	same	5 5/16	same	same	same
Height (inches)	11½	same	same	same	same	same	same	11½	same	same	same
Weight (lbs.)—											
Elements	15¾	20¾	25½	30¼	35	40	44¾	9¼	13¼	17¼	21⅛
Electrolyte	2½	3½	4½	6¼	7	8	8¾	1½	2¼	3	4½
Complete Cell	19½	25½	31½	38½	44½	50	56	11½	17½	21½	27½

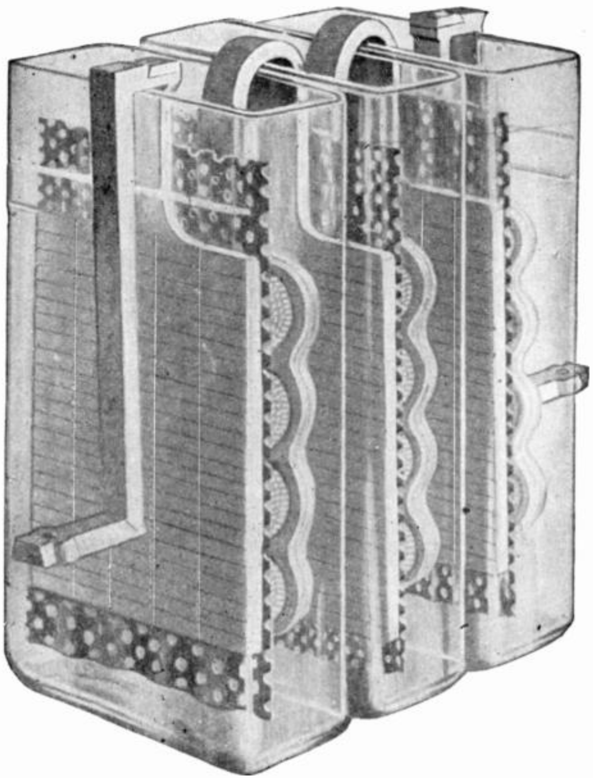
*Note.—For data on the "Express Type" of Exide cell, see literature of the Electric Storage Battery Company, Philadelphia, Pa.

The *brougham* or *hansom* battery of this type of cells consists of 44 cells of TV-9 size, having four positive and five negative plates. The weight of this outfit complete with tray is about 1,659 pounds; the capacity, 156 ampere-hours (4 hour, 39 ampere rate); the average voltage during discharge, about 1.98 volts per cell, or 87 volts for 44 in series; the total watt-hour output being therefore 13,572, or 8.18 per pound of battery complete including trays.

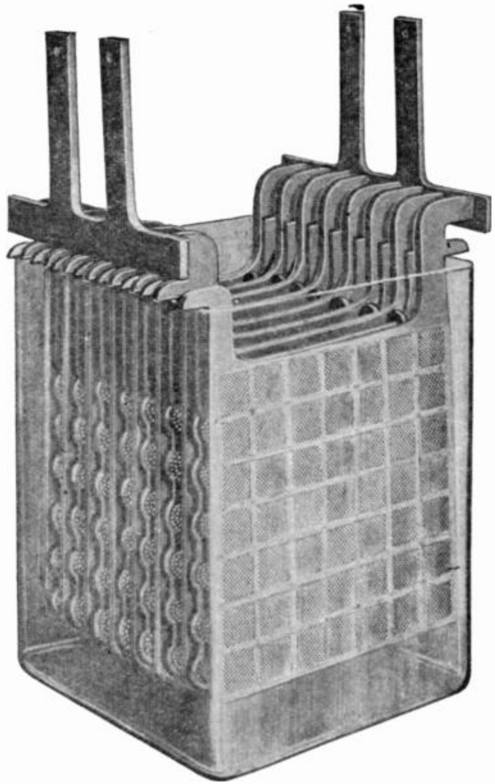
COMBINATIONS OF PLANTE AND FAURE TYPES

Chloride Battery. In the form which was manufactured until recently by the Electric Storage Battery Company and allied companies in England, France, and Germany, the Chloride Battery is a compromise between the Plante and Faure types, the positive being a Plante type and the negative of practically the Faure type.

The principal features in the manufacture of this battery are as follows: The first step is the production of finely divided lead, which is made by directing a blast of air against a stream of the molten metal, producing a spray of lead which, upon cooling, falls as a powder. The powder is dissolved in nitric acid (HNO_3) and precipitated as lead chloride ($PbCl_2$) on the addition of hydro-



B. T.—Couples in Glass Jars.



Type F—15 Plates in Glass Jar.

Fig. 6. The Chloride Battery.

chloric acid (HCl). This chloride, washed and dried, forms the basis of the material which afterwards becomes active in the negative plate. The lead chloride is mixed with zinc chloride and melted in crucibles, then cast into small pastiles or tablets about $\frac{3}{4}$ inch square and of the thickness of the negative plate, which, according to the size of the battery, varies from $\frac{1}{4}$ inch to $\frac{5}{16}$ inch. These tablets are then put in moulds and held in place by recesses, so that they clear each other by .2 inch and are at the same distance from the edges of the mould. Molten antimonious lead is then forced into the mould under about 75 pounds pressure, completely filling the space between the tablets. The result is a solid lead grid, holding small squares of active material. The lead chloride is then reduced by stacking the plates in a tank containing a dilute solution of zinc chloride, slabs of zinc being alternated with them. This assemblage of plates constitutes a short-circuited cell, the lead chloride being reduced to metallic lead. The plates are then thoroughly washed to remove all traces of zinc chloride.

In the new form of negative plate which has replaced the chloride type just discussed, the negative consists of a pocketed grid, the openings being filled with a litharge paste; it is then covered with perforated lead sheets, which are cast integral with the grid.

The positive plate is a firm grid, composed of lead, alloyed with about 5 per cent of antimony, about $\frac{7}{16}$ inch thick, with circular holes $\frac{25}{32}$ inch in diameter, staggered so that the nearest points are .2 inch apart. Corrugated lead ribbons $\frac{7}{16}$ inch wide are then rolled up into close spirals $\frac{25}{32}$ inch in diameter, which are forced into the circular holes of the plate. These spirals are electrochemically formed into active material. The process requires about thirty hours; at the same time, the spirals expand so that they tend to fit still more closely in the grids. This form of positive is that known as the *Manchester Plate.*

Recent types of "Chloride accumulator" are shown in Fig. 6. In setting up the cells, the plates are separated from one another by thin wood partitions having vertical grooves to facilitate the rising of the gases. These separators are stiffened by split wooden pins slipped over them. Sometimes glass tubes are used as separators.

Table IV gives data of the various types and sizes of cells. To save space, only the smallest and largest sizes of each type are given;

TABLE IV
Data, Chloride Battery

Types		B	C		BT	CT	PT	D		E		F		G		R*		H	
Size of Plate, inches		3x3	4⅜x4		3x4	5x5	8¾x5	6x6		7¾x7¾		11x10½		15½x15½		18⅝x18⅝		15½x31	
No. of Plates		3	3	7	2	2	2	3	13	5	15	9	27	11	75	25	75	21	75
Discharge in Amperes	For 8 hrs.	⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
	5	⅞	1¾	5¼	1	2	4¼	3½	21	14	49	56	182	140	1,036	510	1,550	560	2,072
	3	1¼	2½	7½	1½	3	6	5	30	20	70	80	260	200	1,480	720	2,220	800	2,960
	1	....	....	....	....	....	....	10	60	40	140	160	520	400	2,960	1,440	4,440	1,600	5,920
Normal Charge Rate		⅝	1¼	3¾	¾	1½	3	2½	15	10	35	40	130	100	740	360	1,110	400	1,480
Outside Dim. of Glass Jars (inches)	Width	2½	3½	5¼	1¾	2¼	2½	3¼	11	5½	11	9	No glass jars for these large sizes.						
	Length	4	5¼	5¼	3¾	6¼	6	7⅞	8¼	9⅛	9⅛	12⅝							
	Height	6½	7¼	7¼	6¾	8	12	9½	9½	11⅜	11⅜	17							
Outside Dim. of Lead-Lined Wooden Tanks	Width	....	....	....	....	....	....	....	....	....	....	13⅜	28⅜	15⅛	69⅞	24¾	24¾	25⅛	69⅞
	Length	....	....	....	....	....	....	....	....	....	....	15	15	19¾	21½	28⅜	69⅞	21½	21½
	Height	....	....	....	....	....	....	....	....	....	....	20¼	20¼	26	27⅞	31½	32½	48¾	49¼
Weight of Cell Complete (lbs.)		5½	10½	19	3½	7½	13½	19½	64	48¾	112	175	....	....	....	....	....	....	...
Ditto. Lead-Lined Tanks		....	....	....	....	....	....	....	....	....	....	250	615	561	3,260	1,641	4,616	1,885	5,986

* This size of cell is listed by its manufacturers on the 6, 2 and 1 hour rates; but for purposes of comparison it is brought to the same basis as the other sizes.

but in all cases intermediate sizes are made with every odd number of plates. The capacities, weights, etc., are of course nearly proportional to the number of plates.

The smaller sizes are provided with either rubber or glass jars, and the larger ones, from F up, with lead-lined tanks.

Tudor Cell. This type is very extensively used in Europe, and to some extent in this country, although it is no longer manufactured here. The American patent rights are controlled by the Electric Storage Battery Company.

The plates consist of rolled, grooved sheets as shown in Fig. 7, *A* being the hollows or grooves into which the paste is set, and *B* the lead frame. The thickness of the plate between opposite grooves is about .12 inch for the positive and about .06 inch for the negative. The width of grooves on the positive plate is also about .12 inch, while on the negative it is about .08 inch. The grooves are first coated with a thin layer of peroxide of lead (PbO_2) by electrolysis, and then packed with the oxides as required; the plates are then rolled to *fix* the paste. This treatment of the grid with an electrolytic bath before applying the active material, is covered by United States patent No. 413,112.

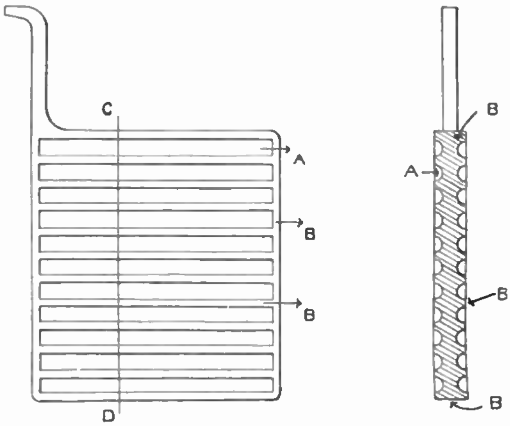


Fig. 7. The Tudor Battery Plate.

TABLE V

Tudor Cells

Type	Available Capacity	Maximum Current (in amperes)		Dimensions of Cells (in centimeters)			Total Weight
	Amp.-Hours	Charge	Discharge	Length	Width	Height	Kgms.
I	26	6	8	12	21	35	10
V	91	21	28	30	21	35	30
X	270	54	72	42	42	55	110
XIV	630	126	168	74	42	55	230

In addition to the sizes given in this table, all the intermediate sizes are made.

Lithanode. Mr. Desmond Fitzgerald has made storage batteries with a positive plate consisting entirely of active materials made up of litharge (PbO) mixed with ammonium sulphate $(NH_4)_2 SO_4$ which he pressed into the required shapes. This plate is converted into peroxide by chemical treatment. The negative consists of the ordinary lead plate. While this cell has an exceedingly high weight efficiency, it is not of much commercial importance, though used considerably in laboratory work.

It is the tendency in Europe to make the positive plate of the Planté form, and the negative of the Faure or pasted type. The reason for this is that the Planté form is hard to make; and as the activity is small on the negative, the pasted plate is good enough.

The practice in lead batteries is to make the negative plate of greater capacity than the positive, as the charging and discharging of a cell in service tends to produce or form more active material on the positive plate, whereas the negative plate is made to decrease, so that allowance for this is made as above stated. A still further allowance is made to cover this action, by always having one more negative than positive plate in a cell.

Storage Batteries Containing Metals Other than Lead. It has already been stated that almost any primary cell will act more or less as a secondary cell; as, for example, the common gravity battery. A great many have been devised in which the lead in one or both of the plates has been replaced by some other metal. For example, Reynier made the negative plate of zinc instead of lead, this zinc in discharging being converted into zinc sulphate, which dissolved in the electrolyte. The substitution of zinc for lead secures an increase in initial E. M. F. from 2.2 to 2.5 volts, and also allows of a considerable reduction in weight, since for the storage of a given amount of energy the weight of the zinc required is much less than that of the equivalent lead. A difficulty with this type of cell is the formation of *trees* of zinc on the negative plate during the charging process, which are likely to fall off or extend across to the positive plate, thus short-circuiting the cell.

Another difficulty is the difference in density of the solution between the top and bottom of the plates, the tendency being to exhaust the zinc sulphate from the upper portion of the liquid during charging. In order to avoid this trouble, the plates have been arranged horizontally, so that the density would be uniform for each plate; but the difficulty then arises that the gases which form to a certain extent in almost all batteries collect between the plates and interfere with the chemical action and the passage of the current.

A similar type of cell has been manufactured by the Union Electric Company of New York, in which the negative plates consist of thin sheet copper covered with an amalgam of zinc, and the positive plates are made up of laminæ of lead held together by leaden rivets and perforated with numerous small holes, these positives being formed by the Planté process.

Waddell-Entz Accumulator. The copper alkali-zinc primary battery of Lalande, Chaperon and Edison being reversible in action, can be used as a storage battery. Waddell and Entz have constructed accumulators on this principle. When discharged, the positive plate consists of porous copper; on charging, the electrolyte is decomposed, metallic zinc being deposited on the negative plate; the porous copper of the positive plate is oxidized, and the liquid becomes converted into a solution of caustic potash (potassium hydrate).

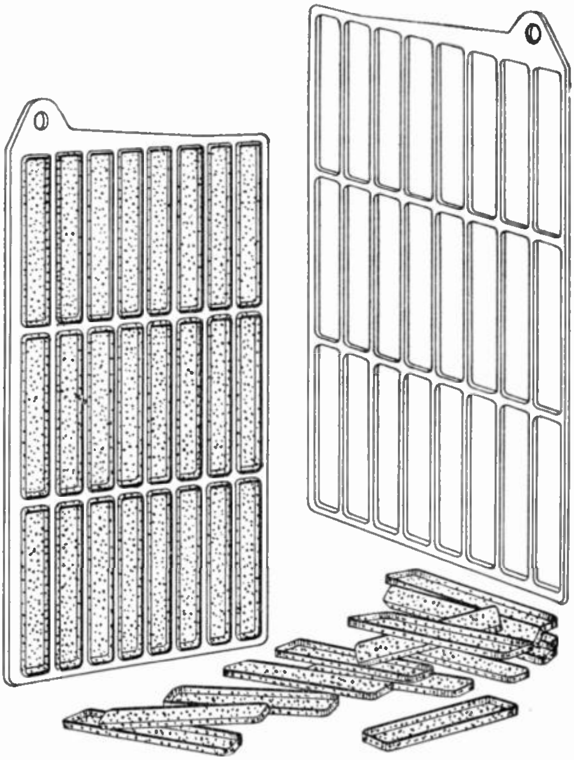


Fig. 8. Plates and Receptacles of the Edison Cell.

This storage battery was formerly used with considerable success for traction purposes; but its E. M. F. is so low, being only about .7 volt, that it would require 170–180 cells for the ordinary 110-volt electric-lighting circuit, allowing for loss of potential in the battery and conductors. This number is three times as great as is required with the lead battery. This is a serious objection to this or any other low-voltage cell.

Edison Storage Battery. The standard cells of this type are 13 inches high, 5.1 inches wide, and vary in length according to their rating, the various capacities being obtained by simply increasing the number of plates. The positive and negative plates are alike in appearance, and consist of rectangular grids, of nickel-plated iron, each about 9½ by 5 inches by .025 inch, punched with three rows of rectangular holes, eight holes to the row (Fig. 8), each hole being filled by a shallow perforated box of nickel-plated steel, the perforations being very fine, about 2,500 per square inch.

The difference between the positive and negative plates is entirely in the contents of the perforated receptacles; those for the positive plate containing a mixture of oxide of nickel and pulverized carbon, the latter being employed to increase the conductivity of the active material. The compartments of the negative plates contain a finely divided oxide of iron and pulverized carbon. When filled, these receptacles are secured to the grid by placing them in the openings of the same, and subjecting the assembled plate to a pressure of about 100 tons, which expands the pockets and fixes them firmly in the grid. A set of assembled plates as employed in a complete battery, is shown in Fig. 9.

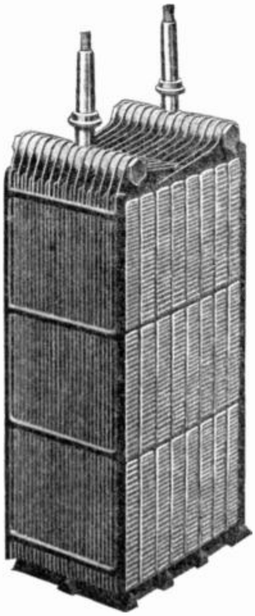


Fig. 9.
Complete Edison Cell.

The electrolyte consists of a 20 per cent solution of caustic potash, which, however, undergoes no chemical change during the process of charge or discharge, acting simply as a conveyor of oxygen between the plates. The charging current, entering at the positive plates, oxidizes the nickel compound to the peroxide state, and reduces the iron compound in the negative plates to a spongy iron mass. The containing vessel consists of nickel-plated steel; and the plates are strong individually and close together, being separated by thin strips of vulcanized rubber, thus forming a compact mass. The terminals of the plate pass through the cover of the cell, from which they are insulated by vulcanized rubber bushings.

The electrical features of the Edison cell are as follows:

Average voltage of charge at normal rate, 1.68.
Average voltage of discharge at normal rate, 1.24.

A set of charge and discharge curves of a 180-ampere-hour cell is shown in Fig. 10. This battery is rated at 30 amperes for a period of six hours. The various cells have a weight efficiency of 11.5 to

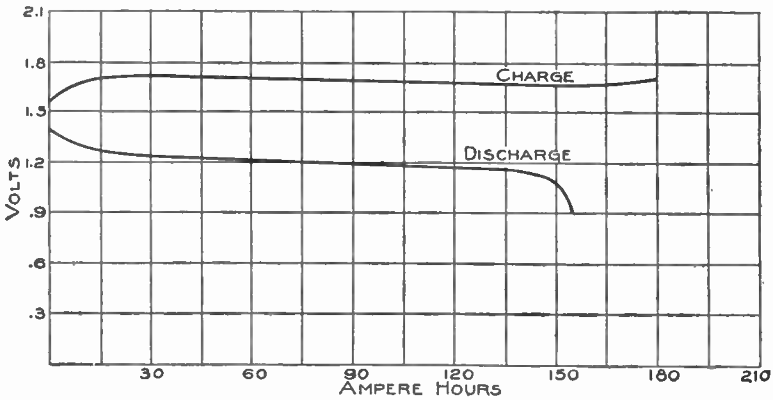


Fig. 10. Charge and Discharge Curves of Edison Cell.

13.2 watt-hours per pound, depending upon the size. The watt efficiency under normal working conditions is about 60 per cent. The charging and discharging rates are alike, and cover wide ranges. A cell may be charged at a high rate in one hour, without apparent detriment except lowering the efficiency slightly. It is not appreciably influenced by temperature changes, and may be fully discharged to the zero-point of E. M. F., or even charged in the reverse direction, and then recharged to normal conditions, without suffering loss in storage capacity or other injury. The best results are obtained when twice as many positive as negative plates are employed; and the standard cells are made up on this basis. This type is intended especially for electric automobile service, by virtue of its high weight efficiency and its ability to endure rough mechanical as well as electrical treatment. The same qualities would also adapt it to portable electric-lighting purposes.

MANAGEMENT OF STORAGE BATTERIES

In describing the handling of storage batteries, the various types of lead cells will be considered, as they constitute a very large majority of the cells in commercial use.

Battery Room. In the installation of a battery, the first point to be considered is its location. The room for this purpose should be dry, well ventilated, and of a moderate temperature; otherwise, not only will the evaporation of the electrolyte be excessive, but if the temperature be very high, the plates themselves will be affected and their life shortened. The floor, walls, and ceiling must be of some acid-proof material, brick or tile being preferable, and the floor so made as to drain readily, an outlet being provided to the drainage system. If the room should be an old one, and have a wooden floor, the floor should be coated with asphaltum paint, and lead trays placed below the batteries; any woodwork or ironwork in the room should be likewise treated.

The room should be sealed from the rest of the building, and located near the generating machinery and distribution switchboard, so that the copper cables may be low in cost. The windows in the battery room should be of either ground or painted glass, so that no direct rays of the sun may strike the cells, as the heat might crack the cells (glass) or increase the activity of the acid, which is not desirable.

In case the battery installation is in a cold climate, some device for keeping the electrolyte at a moderate temperature must be used.

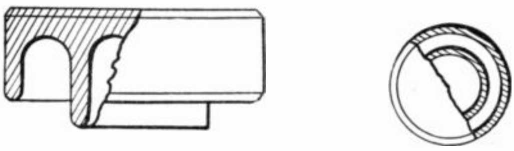


Fig. 11. Glass Insulator for Battery Support.

Setting Up the Cells. The battery is usually placed on the floor, or upon strong wooden shelves; Fig. 11 shows a form (made of glass or porcelain) adapted to cells of medium size. Iron stands are sometimes used for large and heavy cells, but they must be protected from acid fumes and drip by several coats of an acid-proof paint. Wooden stands should be varnished, painted, or soaked in paraffin for the same reason. It is important to have every cell accessible for inspection, cleaning, and removal, it being desirable to reach both sides of the cell. There should also be sufficient head-room between shelves so that the elements may be lifted out.

It is highly important that the cells be thoroughly insulated from one another, to avoid leakage of current. This is accomplished by standing each cell on four insulators of porcelain or glass of the design shown in Fig. 11. Glass is now almost universally employed because porcelain is frequently found to deteriorate gradually as a result of the action of the acid fumes.

Lead-lined tanks for 500-volt installations are usually set as follows: The floor is covered with a layer of glazed tile or brick; on this are placed two wooden stringers about 3 by 4 inches, carefully painted with asphaltum varnish or some acid-proof paint. Under each tank are set four or more insulators held in place by wooden pegs which are kept in position by pouring melted sulphur around them. Sometimes the insulators have short, threaded projections on the top, which are screwed into the bottoms of the tanks. On top of these are placed the battery tray and battery as indicated in Fig. 11.

In the case of 125-volt installations, the insulators are sometimes set directly on the tile flooring, which has been leveled by running molten sulphur under the tiling.

Oil insulators were at first used; but oil collects and holds dust, and, as dust is likely to cause leakage, they are no longer employed. For very large lead tank outfits, a double system of the supporting construction shown in Fig. 12 is used, but with individual stringers for each cell.

Glass cells are often set on wooden trays, which are filled with sand to distribute the strains and absorb the drip. Sawdust was formerly also used; but it becomes carbonized by the acid drip, and, as this is likely to cause leakage, it has been abandoned.

In connecting the cells, which are usually put in series, great care should be taken to join the positive terminal of one cell to the negative of the next, and so on. The color of the plate is the best indication of its polarity, the positive plate being a light brown when discharged and a chocolate color when charged, while the negative varies from a light to a dark slate color.

It may be noted at this point, that the nomenclature concerning storage batteries is different from that of primary cells. The positive

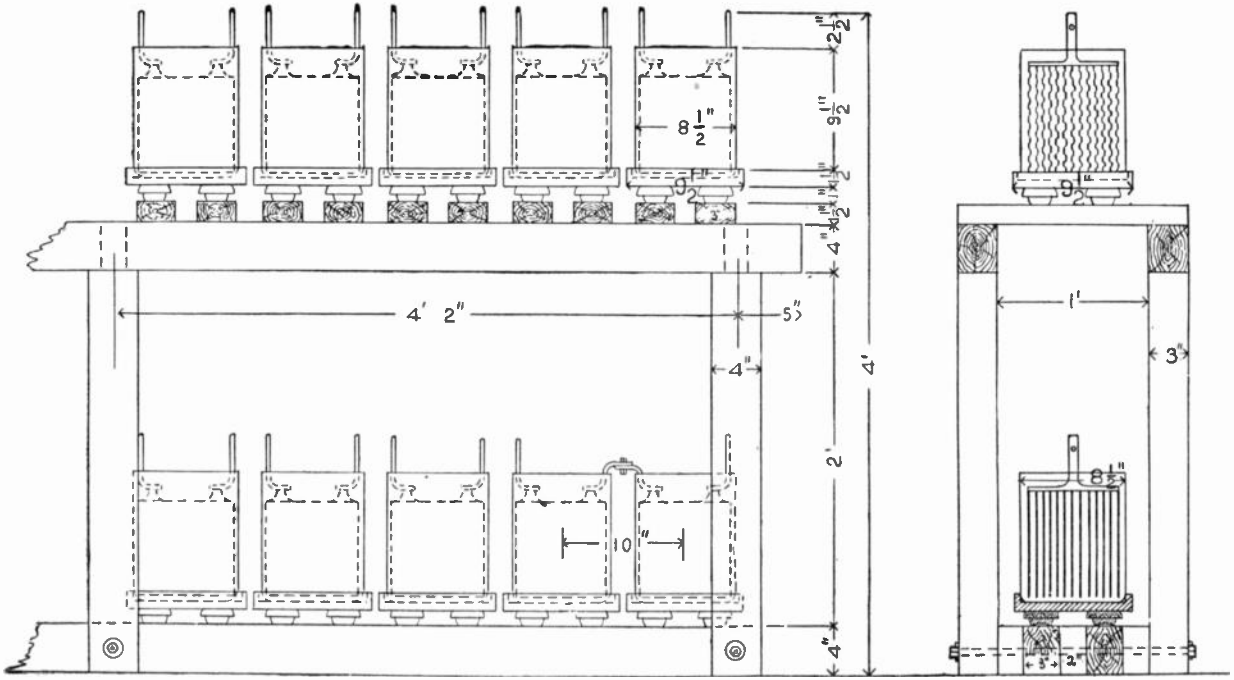


Fig. 12. Shelf Construction for Battery Support.

INSTALLATION OF TELEPHONE CONDUIT EMPLOYING MULTIPLE-DUCT TILE
Note the Wrapping for Joints.

plate in the former is the peroxide plate (brown), and is that one from which the current flows out in discharging; whereas that would be the negative plate of a primary battery.

The positive pole or terminal in a storage battery is an extension of the positive plate, and is connected to the positive terminal of the dynamo in charging; consequently there is much less cause for confusion of terms than there is in the primary cell.

It is well to test the polarity of each cell and of the circuit, before making connections. This may be done with any form of pole-tester, or by the positive expedient of dipping the two terminals in dilute sulphuric acid, the one from which the most bubbles arise being negative. The connections should be scraped clean and screwed up very tight, then coated with acid-proof paint to avoid corrosion. The most satisfactory way to connect up a cell is to weld or *burn* the positive terminal to the negative terminal of the next cell, though soldered connections are good.

This soldering is done as follows: Two strips of lead and the terminals to be connected are very carefully cleansed; the lead strips are then clamped to the terminals, a mould placed around the joints, and molten lead poured into it.

The Electrolyte. Practice varies considerably as to the strength of solution to use. Chemically pure sulphuric acid is poured into water until its density becomes about 1.2, and then the mixture is allowed to cool before pouring it into the cells. The electrolyte *should completely cover* the plates. Cells for vehicle work use an electrolyte with density as high as 1.3. It is important to use perfectly pure acid and water, as impurities will cause local actions and ultimately destroy the plates.

It is well to remember that *water should never be poured into sulphuric acid,* as it is likely to cause the liquid to be thrown out violently.

The advantage of a strong solution is its lower resistance; but it is likely to produce the very objectionable effect of *sulphating.*

The density of the electrolyte falls immediately after filling a cell, since some of the acid is taken up by the plates; but it rises again in charging—for example, from 1.17 to 1.2. It is convenient to keep a hydrometer in several cells to observe the density of the electrolyte, not only at the beginning, but as a permanent indicator of the amount of charge and general working conditions.

The hydrometer is an instrument for determining the specific gravity of a liquid, and consists of a weighted bulb and an upright glass rod, bearing a scale, the unit point being fixed by the distance to which it sinks in pure water at 4°C. Readings above this point are for solutions of lower specific gravity than water, and those below it are for solutions of a higher specific gravity. For storage battery work, the specific gravity of the electrolyte is always between 1.1 and 1.3; hence we require only a certain portion of the scale as represented in Fig. 13.

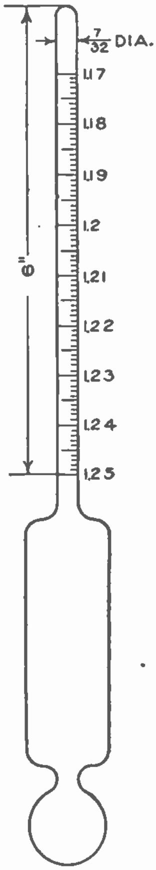


Fig. 13.
Hydrometer.

Charging. The charging should begin immediately after a new cell is filled with the electrolyte; otherwise the plates are likely to become sulphated. The first charge differs from subsequent regular charges in that it should be at a rate (lower than normal) that will not cause the temperature of the cell to reach 100°F.; but in all other respects it is the same.

Indications of Amount of Charge in a Storage Battery. There are various methods of ascertaining the amount of charge in a storage battery. The following are the indications that will serve the purpose:

1. The E. M. F. rises from 2.1 volts, at the beginning of the charging of a lead cell, after it has been discharged, to approximately 2.5 volts when fully charged, although this value may be made a trifle higher or lower, depending upon the rate of charge and temperature of cell. The rise is quite gradual, but more rapid near the beginning and end of the charge, as indicated in Fig. 14. When the cell is fully charged, the E. M. F. becomes constant, and the curve approaches a horizontal line as shown. The charging should then be stopped, as any more energy passed through the cell is simply wasted in producing gases. The external voltage is higher in charging than in discharging, because of the internal resistance of the cell and resulting IR drop, which must be overcome in charging.

The measurements of voltage should always be made when the current is flowing either in charging or discharging.

The E. M. F. on open circuit has little practical significance, since a cell, no matter how low it may have been discharged, will show about 2.1 volts after standing on open circuit a short while.

2. *If a record is kept* of the exact number of ampere-hours of charge and discharge, the actual amount of energy in the battery at any time is known, due allowance being made for leakage and other losses. For this purpose any integrating instrument, such as the Thompson recording wattmeter, may be used.

3. *The density of the electrolyte* gradually rises during the charging operation (Fig. 14), the density when charged being about .025 higher than when discharged. There is a lag in the change

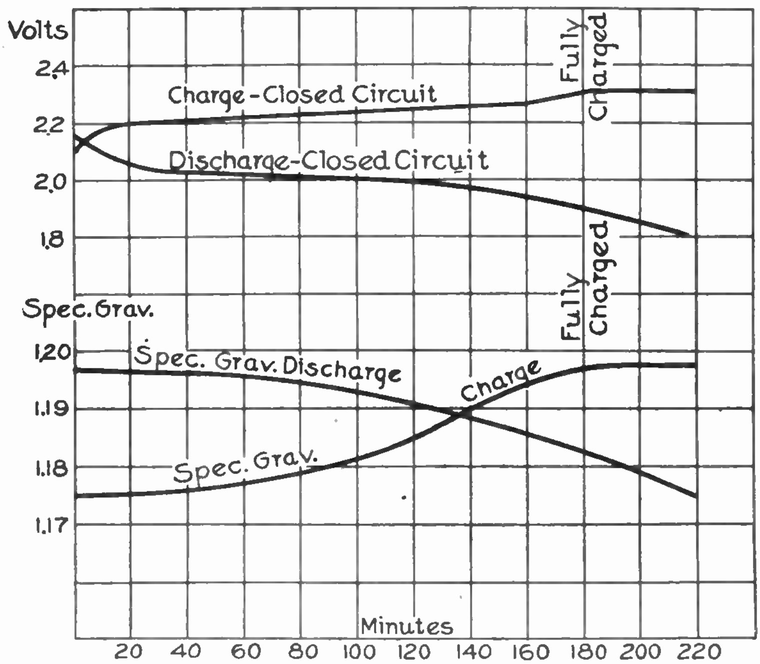


Fig. 14. Curves Showing Variations in Specific Gravity and Voltage in a Storage Battery during Charge.

of the density of the electrolyte, the acid not being absorbed or given off at once by the plates; hence a little time should be allowed before taking any hydrometer reading as final. It is also advisable to agitate the electrolyte to insure complete diffusion, as the electrolyte at the bottom of the cell is otherwise denser than at the top.

4. *Bubbles of gas are given off* freely when the battery is fully charged, since the material of the plates is then no longer able to take up the oxygen and hydrogen which tend to be set free by the electrolysis; these bubbles give the electrolyte the appearance of boiling, and often they are so fine that the liquid looks almost milky white, particularly in a cell which has not been very long in use.

5. *The color of the positive plates* varies from a light brown on active parts to a chocolate color when fully charged, and to nearly black when overcharged. The negatives vary from pale to dark slate color, but they always differ in color from the positives. This indication of the amount of charge is acquired by experience, but is quite definite after one becomes familiar with a particular battery.

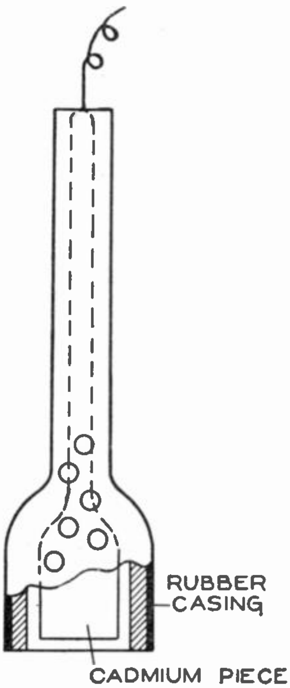


Fig. 15. Cadmium Test-Piece.

6. *Cadmium Test.* The apparatus for making this test consists of a small piece of cadmium, say $\frac{5}{8}$ by $\frac{5}{8}$ by $\frac{1}{32}$ inch, contained in a perforated hard rubber casing (shown in Fig. 15), the rubber covering being employed to prevent short-circuiting of the cell during the test (see Fig. 15). A rubber sleeve contains the conducting wire, wax being used to protect the soldered joint of copper and cadmium. Cadmium is used because it will give reliable readings of the E. M. F. of the positive and the negative plates, with respect to itself. In this way a relative condition of the battery and also of each plate can be determined.

With normal conditions of cell, when fully charged and in open circuit, the difference of potential between the positive and the cadmium piece immersed in the liquid is 2.5 volts or nearly so, and between the cadmium and the negative plates is zero or nearly so. In fact it is sufficient if the sum of the readings is about 2.5 volts.

To avoid false conclusions in making a cadmium test, hydrometer, temperature, and charge data should be noted. The cadmium test is usually made by inserting the tester at the center of the cell to get a uniform current distribution. This test gives readings the sum of which is less than 2.50 volts, when hydrometer tests, temperature, and charge data show that the cell is not fully charged. If the hydrometer, temperature, and other data show the charge to be completed, and the cadmium test gives .1 volt or more below 2.5 volts, one or more plates are defective and may be found by individual cadmium readings. For example, suppose we have a cell in which all the other conditions tend to show full charge, but the potential difference is low. A cadmium test is made; and the set of plates which shows the falling off from normal reading is the defective one, and should be examined for some of the troubles that will be discussed later.

In some cases the cadmium reading with respect to both positive and negative plates may approach zero; this is caused by a short circuit in the cell, which should be found and removed immediately.

In practice it is advisable to have the cadmium wet before the test is made, as the readings increase when cadmium is first placed in the electrolyte. The simplest way to accomplish this is to keep the cadmium tester in a beaker of distilled water when not in use. All foreign matter should be carefully removed from the cadmium, as it might affect the results. If gas bubbles collect on the cadmium, they should be taken off, as they tend to lower the readings.

The proper rate of charge depends upon the size and type of cell, and is usually specified by the manufacturer in each case, since it is merely an empirical fact, being determined by the construction of the plates.

The current for charging is ordinarily obtained from a direct-current dynamo, but any other direct-current source may be employed. The potential required for charging must exceed that of the battery, which, during the operation, acts as a counter-E. M. F., the expression being $I = \frac{P-e}{R}$, in which I is the current, P the potential applied to battery terminals, e the counter-E. M. F., and R the internal resistance of the cell. Usually P is 5 to 10 per cent greater than e, in order to cause the necessary charging current to flow through the resistance R of the cell.

In practice, P is regulated until the required charging current I is obtained.

The above equation, put into form of $R = \frac{P-e}{I}$, enables the internal resistance R to be calculated; but, as this varies considerably with the temperature and with different states of charge, its exact value is not often considered.

Another form of the above equation, $e = P - IR$, shows that the true E. M. F. of the battery is less than the charging voltage by an amount equal to the product of the charging current and the internal resistance. Conversely, in discharging, the total E. M. F. of cell is greater than the difference of potential P between its terminals, by the same amount; that is, $e = P - IR$. Hence it is necessary to know I and R, in order to find the real E. M. F. of cell. This applies to each individual cell, as well as to the entire battery, and is important in determining the amount of charge or working condition of a particular cell.

If the charging voltage P be kept constant, it is evident from the above equations that the current I will gradually decrease, since the C. E. M. F. or e of the cell steadily rises as shown in Fig. 16. This effect is counteracted somewhat by the fact that the inter-

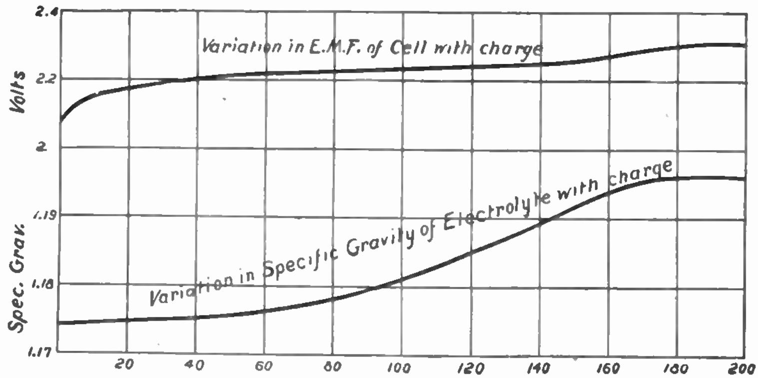


Fig. 16. Curve Showing Increase of E. M. F. in a Charging Cell.

nal resistance R also diminishes, owing to the density of the electrolyte increasing. This gradual reduction in the strength of the charging current is considered desirable by some authorities, since it enables the cell to take a greater charge than if the current were maintained at full strength. On the other hand, this diminishing charge makes it difficult to keep account of the exact number of ampere-hours supplied to the cell; hence, in ordinary commercial work, it is considered simpler to charge with a constant current, and if it is desired to keep the cell temperature down, the current is decreased near the end of the charge. The charging operation may be continued until the battery is fully charged as shown by the indications already stated. Since most types of cells are not injured by a slight overcharging at a moderate rate, it may even be carried a little beyond the charged point, as it tends to remove sulphating. A considerable overcharge should be avoided, as it causes excessive formation of gas bubbles in the active materials and is likely to heat the cell and even to cause disintegration and buckling of the plates.

Discharging. A storage battery is in most cases discharged within a few hours after being charged, as, for example, in electric lighting, when the engine and dynamo are run during the day for charging the battery which supplies current to the lamps during the night. But a portable battery for feeding lamps or a vehicle battery might be required to retain its charge for several days. The loss of charge in any battery standing on open circuit is about 25 per cent in one week, but for one day or less it is quite small.

Even when the discharge occurs immediately, the average voltage and the ampere-hours obtained are less than for the charge, as explained under "Efficiency." The loss referred to is additional, depending upon the time.

The operation of discharging is naturally the converse of charging, the changes which have been described as occurring in the latter take place also in the former, but in the reverse order. The normal rate of discharging is usually equal to that of charging, but may be somewhat greater. In some cases it is necessary to discharge at higher rates; but, by so doing, a percentage of the capacity in ampere-hours is sacrificed.

For example, a cell whose normal or eight-hour discharge rate is 100 amperes, can easily be discharged at 400 amperes for one hour, but only 50 per cent of the cell's capacity in ampere-hours is obtained at the latter rate. Under these latter conditions, there is not a large loss of energy, as is shown by the fact that to recharge a cell thus discharged requires only about 50 per cent of the normal charge.

TABLE VI

Percentage of Capacity Variation at Different Discharge Rates

Rate in Hours	Percentage of Capacity at 8-Hour Rate		
	Planté	Planté (+) Faure (−)	Faure
8	100	100	100
7	99	97	96
6	96½	93½	92
5	93	89	86
4	88	83	80
3	80	75	72
2	70	65	61
1	55	50	40

An excessive discharge rate is injurious to most types of storage-battery plates, since it tends to disintegrate the plates, and abnormally heats the electrolyte, which hastens the disintegration. It is therefore advisable to protect the battery with fuses or a circuit-breaker.

A storage battery *should never be discharged completely*, as it is very likely to become sulphated or otherwise injured; and moreover the voltage falls so rapidly towards the end of discharge that the current would be of no practical value. The limit of discharge is usually considered to be the point at which the voltage drops to 1.75, though when cells are used at the one-hour rate the limit of discharge is 1.6 volts.

A battery should never be allowed to stand in a discharged condition, but should be recharged immediately.

The charge usually left in a storage battery is from 10 to 30 per cent of the total capacity, depending on the rate of discharge; but this involves no considerable loss of energy or efficiency, since it remains in the battery each time, and the charging begins at that point.

Efficiency of Storage Batteries. The efficiency of any apparatus is the ratio between output and input. In a storage battery it is the ratio of the amount of discharge to what is required to bring the battery back to its original condition after a discharge.

The *ampere efficiency*—or, more properly, the *ampere-hour efficiency*—which is the ratio of current in ampere-hours drawn from the battery to current in ampere-hours put into the battery, is quite different from the *watt-hour efficiency*. The latter is the *real efficiency* since it considers the energy, and includes the voltage as well as the ampere-hours. The former may be used either through ignorance or intention to give a false idea, since the ampere efficiency is often 15 per cent higher than the watt efficiency.

Another difficulty is the fact that it is possible to obtain an apparent efficiency of over 100 per cent from a storage battery. Since a certain amount (about 25 per cent) of charge is always left in the cell, it is possible to draw more ampere-hours than were put in during the last charge, by simply discharging the cell more than usual.

This matter has been investigated by Ayrton, who says:

> "If an E. P. S. accumulator be over and over again carried around the cycle of being charged up to 2.4 volts, and discharged down to 1.8 per cell, the charging and discharging currents being the maximum allowed by the makers—namely, .026 ampere per square inch of surface in charging, and .029 ampere per square inch in discharging—the working efficiency thus obtained may be 97 per cent for the ampere-hours, and 87 per cent for the watt-hours. If, on the contrary, the cell be constantly charged up before being tested, then for the first few charges and discharges between the above limits, and with the same current density in charging and discharging, even the energy efficiency may be as high as 93 per cent; whereas, if the accumulator has been left for some weeks, then, although it was left charged, the energy efficiency for the first few charges and discharges will be as low as 70 per cent."

In general practice it has been found that the watt-hour efficiency of storage-battery plants, when in good condition, varies from 75 to 80 per cent. For instance, referring to the battery plant at the Edison Electric Company station in Boston, a series of tests made there show the battery installation to have an efficiency of 75 per cent.

Depreciation of Accumulators. The depreciation is claimed to be as low as 4 or 5 per cent per annum; but 7 per cent is a safer allowance to cover depreciation and renewals extending over long periods of time. During the first few years the depreciation may be practically nothing; but after five or ten years it will be considerable. These statements apply to *stationary* batteries in central stations or isolated plants. For *traction* or *automobile* service, which is much more severe, the life of storage batteries in some instances has not exceeded six months; and 3,000 to 5,000 miles total run is considered a good result in actual practice. For either stationary or vehicle storage batteries, the life of the positive plates is only half as great as that of the negatives. The figures given are based upon an average of the two.

It has been the practice of several storage battery manufacturers to insure their stationary battery equipments for 6 per cent per annum of their first total cost. This insurance is a maintenance contract calling for inspection and any repairs necessitated through normal use of cells.

TROUBLES AND REMEDIES

The most serious troubles which occur in storage batteries are *sulphating, buckling, disintegrating,* and *short-circuiting* of the plates. These can usually be avoided, or cured by proper treatment if they have not gone too far.

Sulphating. The normal chemical reaction which takes place in storage batteries is supposed to produce lead sulphate ($PbSO_4$) on both plates when they are discharged, their color being usually brown and gray, as already stated. But under certain circumstances a whitish scale forms on the plates, probably consisting of $Pb_2 SO_5$. Plates thus coated are said to be *sulphated.* This term is therefore somewhat ambiguous, since the formation of a certain proportion of ordinary lead sulphate ($PbSO_4$) is perfectly legitimate; but the word has acquired a special significance in this connection.

A plate is inactive, and practically incapable of being charged, when it is covered with this white coating or sulphate, which is a non-conductor.

The conditions under which this objectionable sulphating is likely to occur are as follows:

(*a*) A storage battery may be overdischarged—that is, run below the limits of voltage specified—and left in that condition for several hours.

(*b*) A storage battery may be left discharged for some time, even though these limits have not been exceeded.

(*c*) The electrolyte may be too strong.

(*d*) The electrolyte may be too hot (above 125° F.).

(*e*) A short circuit may cause sulphating, because the cell becomes discharged (on open circuit), and, when charging, it receives only a low charge compared with the other cells of the series. A battery may become overdischarged or remain discharged a long time, on account of leakage of current due to defective insulation of the cells or circuit; or the plates may become short-circuited by particles of the active material or foreign substances falling between them.

Sulphating may be removed by carefully scraping the plates. The faulty cells should then be charged at a low rate (about one-half normal) for a long period. In this way, by fully charging and only partially discharging the cells for a number of times, the unhealthy sulphate is gradually eliminated. When the cells are only slightly sulphated, the latter treatment is sufficient without scraping; when the cells are very badly sulphated, the charge should be at about one-quarter the normal rate for three days.

Adding to the electrolyte a small quantity of sodium sulphate, or carbonate, which latter is immediately converted into sodium sulphate, tends to hasten the cure of sulphated plates by decomposing or dissolving the unhealthy sulphate. This is not often used in practice, as a cell must be emptied and thoroughly washed, and fresh electrolyte added after the plates have been restored to their proper condition, before the cell can be used to advantage.

Sulphating not only reduces the capacity of lead storage batteries, but also uses up the active material by forming a scale which falls off or has to be removed. It also produces the following troubles:

Buckling. Buckling or warping of a plate, is caused by uneven action on the two surfaces; for example, a patch of white sulphate on one side of a plate will prevent the action from taking place there, so that the expansion and contraction of the active material on the other side, which occurs in normal working, will cause the plate to buckle. This might be so serious that it would be impossible to straighten the plate without breaking or cracking it; but, if taken in time, this may be accomplished by placing the warped plate between boards, and subjecting it to pressure in a screw or lever press. Striking the plate is objectionable, because it cracks or loosens the active material; but, if it should be necessary to straighten a plate in this way, a wooden mallet should be used very carefully, with flat boards laid under and over the plate. Buckling may be caused by an excessive rate of charging or discharging, as well as by sulphating.

Disintegration. Some of the material may become loosened or entirely separated from the plates, as a result of various causes.

The chief of these is sulphating, which forms scales or blisters that are likely to fall off, thus gradually reducing the amount of active material and the capacity of the cell. Buckling also tends to disintegrate the plates. Contraction and expansion of the active material take place in normal working, and are increased by excessive rates or limits of charging and discharging. This constitutes another cause of disintegration, particularly in plates of the Faure type containing plugs or pellets of lead or lead oxide paste.

The fragments which fall from the plates not only involve a loss of material, but are also likely to extend across or gather between the plates, and cause a short circuit.

The positive plates are far more susceptible to and injured by these troubles than the negatives. The former are also more expensive to make; therefore it is to them that special attention should be directed in the management of storage batteries.

Short-Circuiting. Short-circuiting of a cell may be caused by conditions previously stated, and also by the collection of sediment at the bottom of the containing cell. The short-circuiting caused by the dropping in of foreign matter, or the bridging of the active materials, is prevented by the use of glass, rubber, or wooden separators.

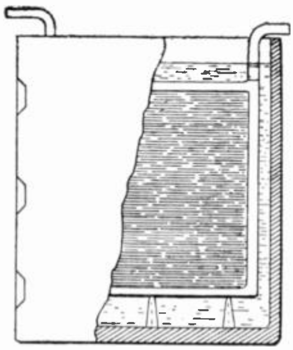


Fig. 17. Glass Frame Support Used to Prevent Short-Circuiting by Sediment.

The short-circuiting of plates by the formation of sediment is prevented, or the chances of it are decreased, by raising the plates so that they clear the bottom of the containing cell. In small batteries this clearance is about an inch; in very large cells it is considerable, being about 6 inches; and large-sized plates, on account of their weight, are supported at the bottom by glass frames running lengthwise through the cell, as shown in Fig. 17.

This sediment should be watched carefully; and when it reaches a depth of 1 inch or more at the center of the cells, it should be removed. The usual method is to take out the plates, siphon the electrolyte off carefully, and then flush out the tanks until all the sediment is removed. If siphoning cannot be resorted to because of the absence of drop, a pump may be used, either of glass or of the bronze rotary type.

Troubles from Acid Spray. A storage battery gives off occasional bubbles of gas at almost any time or condition; but when nearly charged, the evolution becomes more rapid. These bubbles, as they break at the surface, throw minute particles of acid into the air, forming a fine spray which floats about. This spray not only corrodes the metallic connections and fittings in the battery room, but is also very irritating to the throat and lungs, causing an extremely disagreeable cough.

Glass covers are sometimes placed over cells to prevent the escape of fumes; but this is not advisable, as the glass becomes moist and will collect dust, thus forming a conducting surface over the cell.

Attempts have been made to do away with this spraying by placing an oil film (thin layer of oil) over the electrolyte; but this has the objection of interfering with hydrometers; in addition, it sticks to the surface of the plates when they are removed, and interferes with their conductivity on replacing them.

Another plan consists in spreading a layer of finely granulated cork over the surface of the liquid; but while this does not interfere with the hydrometer, it makes the cell look dirty.

The general practice is to depend almost entirely upon ventilation to get rid of the acid fumes; in fact, even forced ventilation is used. A blower forces fresh air into the room, which is provided with a free exhaust.

In connecting up the cells, it is advisable to use lead-covered copper cables, and to paint all connections with an acid-resisting paint, as these coverings protect the copper and prevent the formation and the dropping of copper salts into the cell.

Purity of the Electrolyte. This is very important, and great care should be taken to insure it. The electrolyte may have nitric acid present when formed (Planté) plates are used; and some chlorine, when Chloride negatives are used. In addition, iron may be present, due to the water or acid if the sulphuric acid is made from iron pyrites; it may also be present owing to the corrosion of iron fittings near the cells, some of the scale falling into the electrolyte. Similarly, some of the copper salt formed from the connections by this corrosive action may fall into the cell. Mercury may also be present as a result of the breakage of hydrometers or thermometers.

Other foreign substances might be present, but those named are the most harmful. Nitric acid, even in exceedingly small quantities, will cause disintegration of plates, as the supporting material is destroyed. Chlorine has a similar effect. Iron, mercury, and copper produce local action, and thus decrease the efficiency and ultimately the life of the cells. The electrolyte should be tested about once a week for these impurities; and if any of them are present, it should be drawn off and renewed. If nitric acid is present, it is even advisable to flush the cell with pure water.

TESTS

1. **Test for Chlorine.** Take a sample of the electrolyte, acidulate with nitric acid, and add a few drops of silver nitrate solution. If a curdy white precipitate forms, which is soluble in ammonium hydrate, chlorine is present in some of its compounds.

2. **Test for Iron.** Iron may appear in one of two forms, namely, ferrous or ferric salts. A small sample is taken, and some concentrated hydrochloric acid added, and then some potassium ferric cyanide; if a heavy blue precipitate forms, ferrous iron is present; if in very minute quantities, a deep blue-green discoloration results.

3. **Test for Ferric Salts.** To a sample of the electrolyte, add some hydrochloric acid and a few drops of ammonium thiocyanite; if a blood-red solution or precipitate is the result, ferric salts are present.

4. **Test for Copper.** To a sample of electrolyte, an excess of ammonium hydrate is added; if a rich blue solution is the result, copper is present. It is advisable to check the test by taking another sample and adding some potassium hydrate to it; if a blue precipitate is found which turns black upon boiling, it is additional proof of the presence of copper.

5. **Nitric Acid or its Compounds.** As these are injurious, even in very small quantities, it is advisable to make the following test, which is very sensitive: Some diphenylamine in concentrated sulphuric acid is added to the sample; if a deep blue color is the result, nitrates or nitrites are present.

6. **Test for Mercury.** Mercury may be present in two forms, mercurous or mercuric compounds. The *mercurous* compounds give a black precipitate with lime water, and a greenish precipitate with potassium iodide. The *mercuric* compounds give a yellow precipitate with lime water, and a red or scarlet precipitate with potassium iodide.

On account of possible difficulties with these various impurities, the following are recommended:

1. Test every carboy of sulphuric acid before using.
2. Concentrated sulphuric acid should not be kept around, as it may be used by mistake, which would ruin the plates.
3. Only distilled water from carboys should be used, and not from barrels, as in the latter case it may be contaminated by organic matter.
4. Water from the city mains is never to be used unless the amount of impurities which it contains is very small.
5. When testing with hydrometer for specific gravity, the battery should be fully charged, and tests *always made at the same temperature, or temperature changes should be corrected for,* because the specific gravity of the electrolyte falls with increase of temperature. The specific gravity changes due to temperature are given in Table VII.

TABLE VII

Specific Gravity of Dilute Sulphuric Acid at Various Temperatures

Temperatures	30° F.	40° F.	50° F.	60° F.	70° F.	80° F.	90° F.	100° F.	110° F.
Sp. gr.	1.1593	1.1562	1.1531	1.1500	1.1469	1.1438	1.1407	1.1376	1.1345
"	1.2096	1.2064	1.2032	1.2000	1.1968	1.1936	1.1904	1.1872	1.1840
"	1.2620	1.2590	1.2530	1.2500	1.2470	1.2440	1.2410	1.2380	1.2350
"	1.3090	1.3060	1.3030	1.3000	1.2990	1.2940	1.2910	1.2880	1.2850
"	1.3620	1.3580	1.3540	1.3500	1.3460	1.3420	1.3380	1.3340	1.3300
"	1.4144	1.4076	1.4048	1.4000	1.3952	1.3904	1.3856	1.3808	1.3768

Putting the Battery out of Commission. If, for any reason, the battery is to be but occasionally used, or the discharge is to be at a very low rate, a weekly freshening charge to full capacity at normal rate should be given.

It frequently happens in practice that a storage battery equipment is put out of commission for a lengthy period (for instance, in most summer or winter resorts, the battery may be used for one-half of the year only). In such cases the procedure is as follows: First give the battery a complete charge at normal rate, then siphon off the electrolyte into carefully cleaned carboys (as it may be used again); and, as each cell is emptied, *immediately* refill it with pure water, to prevent the charged negative from heating in the air, as this would result in loss of capacity. When the acid has been drawn from all cells and replaced with water, begin discharging the battery, and continue until the voltage falls to or below one volt per cell at normal load (rate); when this point has been reached, the water should be drawn off. In this condition the battery may stand without further attention until it is to be put again into service; and to do this, proceed in the same manner as when the battery was originally put into use.

If, during discharge, when water has replaced electrolyte, the battery shows a tendency to get hot (100°F.), add colder water.

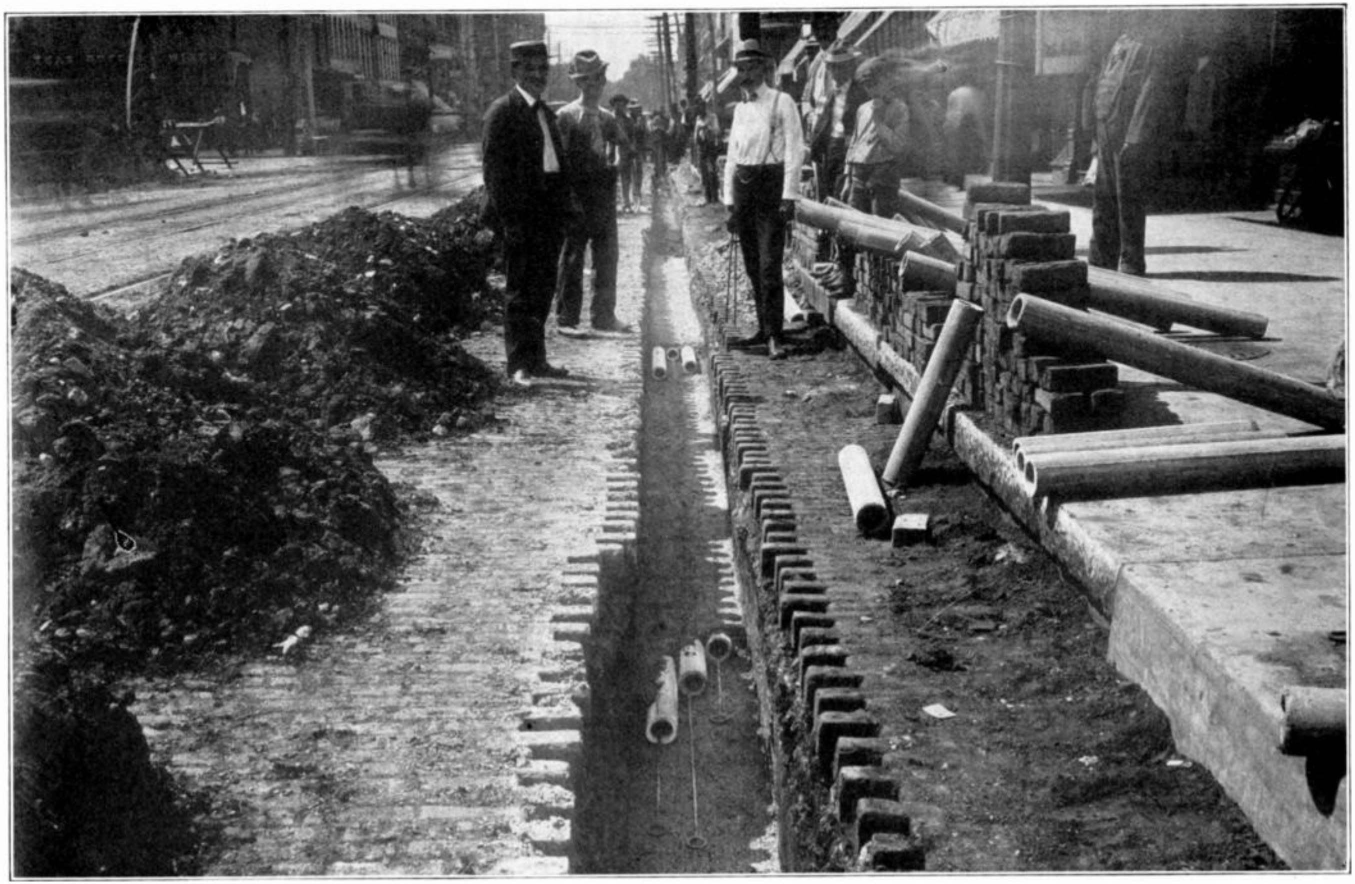
COMMERCIAL APPLICATIONS

The function of a storage battery is to receive electrical energy at one time or place, and to give it out at some other time or place. The principal uses are the following:

1. To furnish portable electrical apparatus with power.
2. To make up for fluctuations, and thus steady the voltage and load on the generator.
3. To furnish energy during certain hours of the day or night, and enable the generating machinery to be stopped.
4. To aid the generating plant in carrying the maximum load (peak), which usually exists for only an hour or two.
5. To make the load on engines or prime movers more uniform, by charging the battery when the load is light.
6. To transform from a higher to a lower potential by charging the cells in series, and discharging them in parallel, or *vice-versa*.
7. To subdivide the voltage, and enable a three- or a five-wire system to be operated from a single generator.
8. To supply current from local centers or substations.
9. To supply current to electrically-driven vehicles.
10. As sources of current in telephone and telegraph systems.
11. For car-lighting purposes.
12. As sources of constant potential and current in electrical laboratories.

Portable Storage Batteries. The storage or the primary battery is practically the only means of supply for portable electric lamps or for those not connected to a dynamo even when they are not portable.

The various manufacturers furnish portable forms of storage batteries. The Gould Storage Battery Company's portable battery



CONSTRUCTION OF TELEPHONE CONDUIT USING CEMENT PIPE FOR DUCT MATERIAL

(Fig. 18) is arranged in a case made as a hard rubber jar, lead-lined box, or glazed earthenware jar, over which is placed a rubber gasket, and then a wooden cover clamped in place by U-shaped straps passing around the containing vessel. For ventilation in charging, the cover has threaded holes, which, when the battery is in use, are closed with hard rubber stoppers. The usual number of cells in a case is from one to five, although they are made up in larger numbers if desired. The batteries are rated at 2 volts per cell.

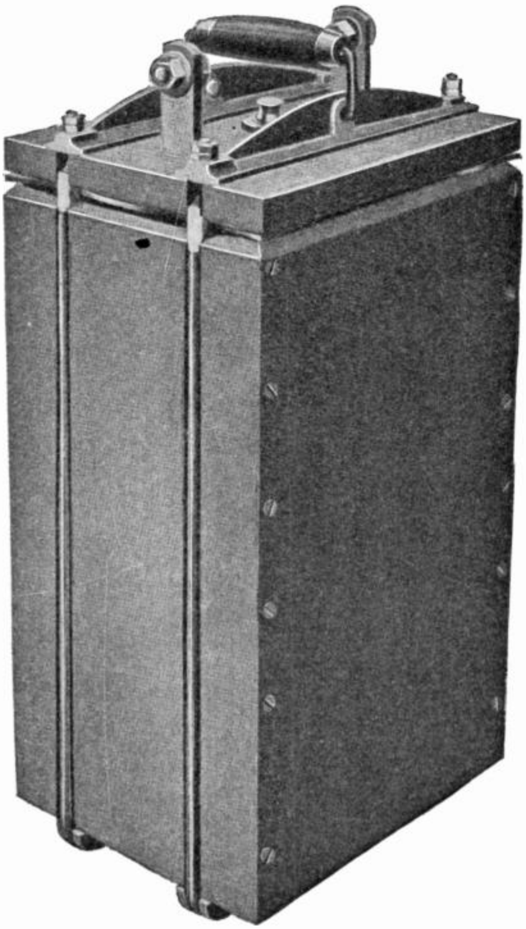


Fig. 18. Gould Portable Storage Battery.

A serious objection to portable storage batteries is their great weight. For example, a standard size weighing 100 lbs. yields 5 amperes at ten volts, or fifty watts, for ten hours—just enough to feed a 16-candle-power lamp. The total discharge is 500 watt-hours or two-thirds of one horse-power-hour. The special forms of battery used in automobiles give about twice this output for the same weight.

This weight is almost prohibitive to portability, except for automobiles, railway train lighting, and special purposes.

Portable batteries, for example, are used for feeding small motors, lamps, etc., for medical or dental purposes, in which cases their weight is not a serious difficulty, in view of the importance of the work and the small amount of energy required. Another special field for very small batteries is the theatrical application, for which they are carried by performers. Storage batteries are also extensively used as sources of power to drive small fan and kinetoscope motors.

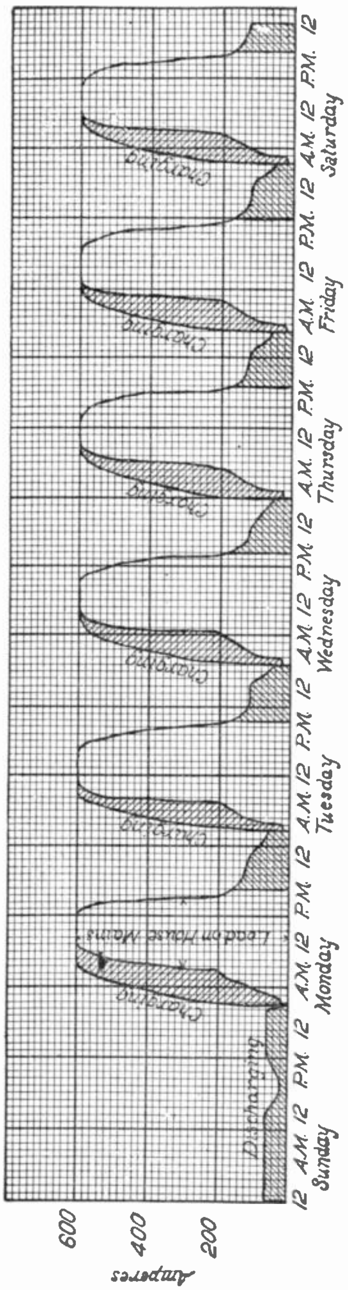


Fig. 19. Load Curve of Astor Building, New York City.

Storage Batteries for Preventing Fluctuations due to unsteadiness in the driving power or in the load, as with elevators, are often applied successfully. A dynamo driven by a gas engine for example, may vary periodically in speed because of the explosive action of the gas in the cylinder; and a battery connected in parallel with the dynamo will have the effect of steadying the voltage. A storage battery is generally installed in connection with a small gas-engine or steam-engine lighting plant, to enable the engine to be stopped for a considerable portion of the time, and thus save labor and attention, in which case the battery may also act to prevent fluctuations. A windmill electric-lighting plant must have an accumulator or some other means of storing energy, not only to eliminate fluctuations in speed, which are continually occurring, but also to bridge over the considerable periods of calm weather.

To Furnish Energy during Certain Portions of the Day or Night. In almost every electric-lighting plant, there are long periods during the day and late at night when the number of lamps lighted is so small that it may not pay to run the generating machinery.

For example, Fig. 19 is a load diagram showing the weekly output of the electric plant of the Astor Building in New York City. The generator plant runs from 3 a.m. to 8 p.m. each day, the battery being charged from 3 a.m. to 11 a.m.; and when the generating plant is shut down at 8 p.m. the battery carries the entire load from then until 3 a.m., when the plant is started up again. Saturday nights the plant is shut down at eight o'clock, and the battery furnishes all the power required from then until Monday morning at 3. This enables the plant to be operated by two gangs or shifts, practically no labor being required for the remaining seven hours, as the battery carries the load, and the machinery is stopped entirely all day Sunday, giving a stretch of thirty-one hours once a week, and seven hours each night for cleaning and repairs. In a hotel or residence, or on board

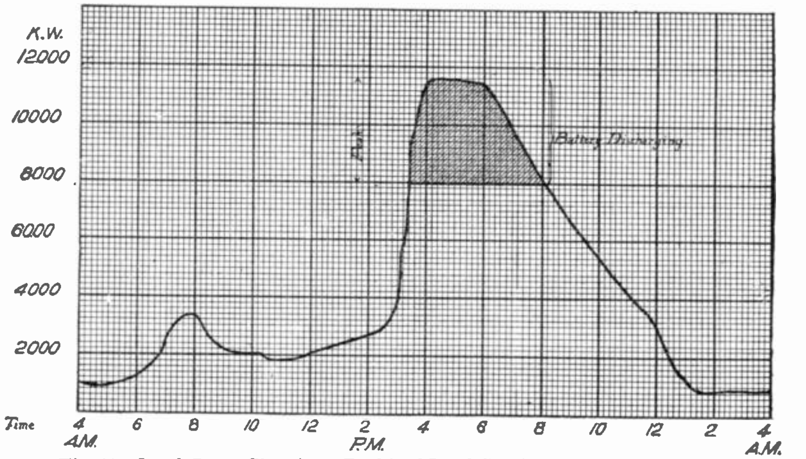


Fig. 20. Load Curve Showing "Peak" of Load Carried by Storage Battery.

a yacht, it may be desirable to stop the machinery and avoid the vibration and noise during the night.

Storage Batteries to Aid in Carrying the Maximum Load. Assume, in the case of the load diagram shown in Fig. 20, that the generating machinery is capable of supplying 8,000 kilowatts, and that a storage battery is used to furnish the remaining 3,600 kilowatts at the time of maximum load—that is, the *peak* of the load diagram. This simply means that batteries are substituted for a certain portion of the machinery plant, and the question is whether or not the substitution is of any advantage.

The first cost of a battery for a given rate of output depends simply upon the time of discharge. Batteries usually have a normal period of discharge of about 8 hours, at which rate the price of accumulators to furnish a given number of watts would be 3 to 5 times as great as that of the equivalent boilers, engines, and dynamos combined; but if the time of discharge is reduced to about 2 or 3 hours, the costs are about equal; and with a still higher rate, the cost of batteries would be less.

As a matter of fact, the storage battery secures other advantages, so that the total gain may be very important. For example, there is a reserve supply in case of accident; and the load may be made more uniform, as will now be explained.

Storage Batteries to Maintain Uniform Loads on Engines. Steam engines are very inefficient at light loads, and this fact often causes serious losses, especially in electric-lighting plants. Judicious selection of the number and sizes of the engines enables them to be worked in most cases at a considerable fraction of their full capacity nearly all the time. Nevertheless the storage battery gives greater flexibility to the plant, and renders it easy to increase the economy of the engines by making their loads still more uniform and nearer to their full capacities while they are running. The engines can be made to have a uniform full load, the battery being charged when the external load is light, and the battery taking the peak of the load when it is heavy.

Storage Batteries Used as Transformers. If the cells of a battery are arranged in series while being charged, and in parallel for discharging, a high voltage will be required for charging, and a low voltage will be given out. The amounts of energy measured in watt-hours are the same, less the loss of about 25 per cent which always occurs in accumulators; the result is similar to that obtained by an alternating-current transformer or motor-dynamo, but is less efficient. As an example, the equipment used at the Brooklyn Navy

Yard may be mentioned. It consists of about 250 small cells connected up in series parallel of 5 sets of 50 cells each and charged on a 110-volt circuit. When discharged, they are connected up all in series, and give about 500 volts, but with very small current. This equipment is used to furnish 500 volts for the *insulation test* of cables, and therefore requires little or no current.

Storage Batteries Used for Subdividing Voltage. The most important practical case is that in which a dynamo of 220 volts charges a battery of corresponding potential, a three-wire system being supplied from the battery, the neutral wire of which is connected to the middle point of the battery, as represented in Fig. 21.

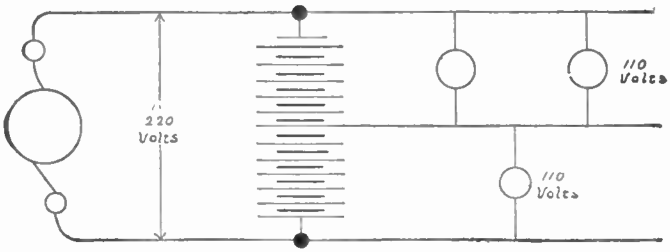


Fig. 21. Battery Used to Subdivide Voltage.

This arrangement avoids the necessity of running two dynamos, and allows the battery to be placed in a substation near the district to be supplied, so that it is necessary to run only two conductors to that point instead of three. The same principle may be applied to the five-wire system. When used in this manner, each side of the system requires its individual end cells and regulators.

The Hartford Electric Light Company was one of the first in this country to introduce the modern method of high-tension transmission, with low-tension 3-wire distribution.

The auxiliary battery used in connection with this equipment consists of 130 Chloride accumulators (65 on a side), each cell containing 31 negatives and 30 positive plates, each 15½ by 31 inches, placed in lead-lined tanks measuring 58¼ by 21½ by 43⅞ inches. Fig. 22 is a diagram showing the general plan of the system. The power is transmitted 10.8 miles from the Farmington River Power Station to the Pearl Street Station, in Hartford, by means of step-up transformers, a 10,000-volt transmission line, and step-down transformers for distribution. From Pearl Street Station to State

Street, a distance of 3,000 feet, the current is transmitted at 2,400 volts, at which latter point, by means of step-down transformers and rotary converter, the storage battery is charged and the current distributed over a low-tension three-wire system.

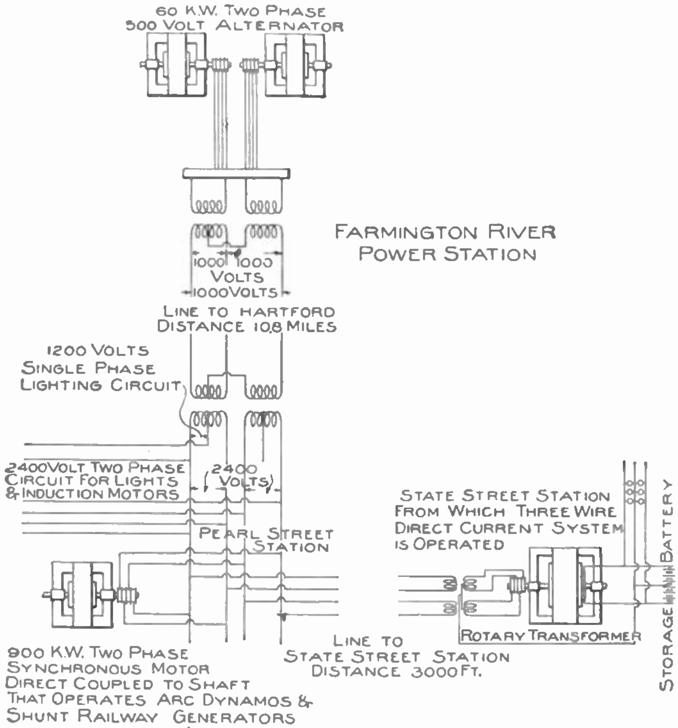


Fig. 22. Plan of Farmington River-Hartford Distribution System.

Storage Battery for Substations. The plan of installing battery plants at local centers, which are charged from the main station, enables some of the conductors to be saved in a three- or five-wire system, as already stated. It also makes it possible to reduce the size of these conductors, because the current which flows over them can be kept practically constant, so that it is not necessary to have them large enough to carry the maximum current consumed by the lamps, etc., which may be several times its average value. The generating machinery has the same steady load as if the battery were located near it.

The batteries at the various substations may be connected and charged in series or in parallel. The former plan would require far less copper in the conductors, since the voltage is multiplied by the number of batteries in series, and the current is the same as for a single battery. On the other hand, this great difference of potential would exist between the first and the last batteries of the series; and if either of these became grounded any person connected to the earth and touching a wire supplied by the other battery would receive a shock due to the total voltage.

An excellent example of a storage battery substation is the Bowling Green Plant of the New York Edison Company. The Bowling Green Station furnishes an auxiliary supply of current directly from the battery, enabling the feeders, extended as tie-feeders into the Bowling Green building, to be used as distributing feeders to the system from both the Duane Street and Bowling Green Stations. While acting as an auxiliary supply to the general system, the battery also takes care of the distribution of current to the extensive installation in the Bowling Green building itself. The supply of current to charge the battery is taken from the Duane Street Station, about a mile distant, over four tie-feeders equipped with controllable disconnective switchboxes on the Bowker-Van Vleck system. This enables them to be used as tie-feeders by disconnecting them from the general system during the hours of light load, and as distributing feeders during the hours of maximum load, when they feed current into the system from each end. A considerable saving is thus effected in the investment, because costly feeders are not required to supply the maximum load to a distant part of the system.

This installation of an auxiliary source of current supply in the lower district makes it possible to shut down the generators in the Duane Street Station during the hours of minimum load, the supply of current to the district below 8th Street being derived from the battery plants at Bowling Green and 12th Street Stations, supplemented, if desired, by the supply of current from the 26th Street Station, over the tie-lines to 12th Street Station, whence the current is distributed through boosters raising it to the required potential, over the tie-feeders to the Duane Street Station switchboard. The battery and operating rooms of the Bowling Green

Station are located in the sub-basement of the Bowling Green Office Building. Vitrified hollow tile for conducting the feeder cables are laid under the battery-room floor, which consists of glazed white tile. Drains to carry off the water or acid run in the aisles between the cells, and lead to small cesspools which discharge into a lead drain-pipe.

The battery consists of 150 Chloride cells, 75 in series on each side of the three-wire system. The cells consist of wooden tanks, 40¾ by 21½ by 30½ inches, treated with an acid-proof paint and lead-lined, each containing 14 positive and 15 negative plates 15½ inches wide by 31 inches high. Each tank is supported on four petticoat porcelain insulators resting upon 6-inch glazed tiles.

The plates are suspended in the tanks by shoulders resting upon sheets of heavy glass, which stand upon lead saddles in the bottoms of the tanks. The cells are connected by welding the plate terminals to lead bus-bars, no mechanical connections being used.

Twenty of the end cells on each side of the system are used for regulating, being separately connected to contact points on the regulating switches, which carry movable contacts operated by a screw. The potential is raised or lowered by cutting in or cutting out the regulating cells. Two regulating switches are connected in multiple on the positive, and two on the negative, side, to permit of discharging at two potentials, or to enable the battery to be charged and discharged simultaneously. The conductors between each series of cells, and between the regulating cells and the regulating switches, consist of copper bars 3 inches wide by ½ inch thick. These bars are supported on porcelain insulators resting in hangers. The connections of this equipment are shown in Fig. 23.

The capacities of the battery at various rates of discharge are:

2,000 amperes per side for 1 hour.
1,000 amperes per side for 3 hours.
400 amperes per side for 8 hours.

Provision has been made in the battery-room, for the installation of a duplicate battery, which can be placed over the present plant. The booster is used to raise the voltage from that of the system to that required for charging the battery. The booster can be used also to raise the voltage of discharge for feeding some distant point of the system at a higher potential than would normally be required. The machine consists of one positive and one negative dynamo at each end of a common shaft driven by two motors. Each dynamo

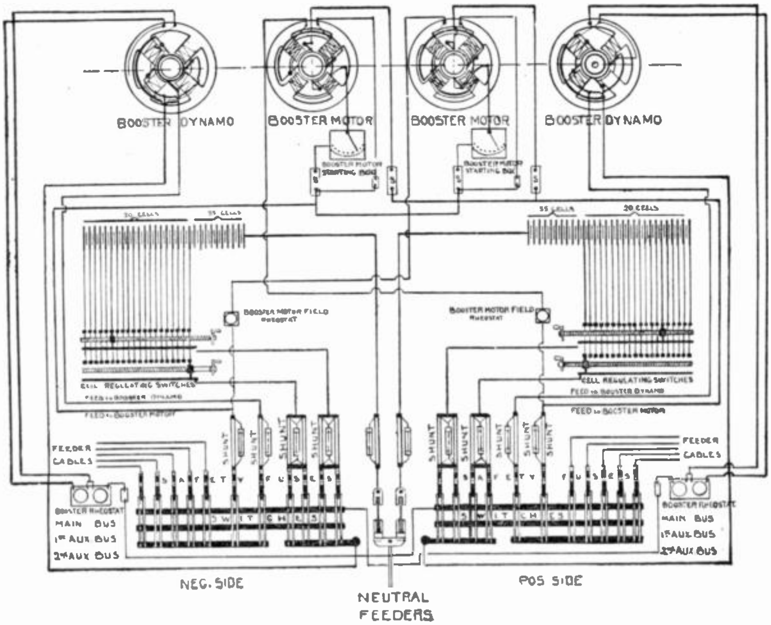


Fig. 23. Connections of the Bowling Green Storage Battery Substation.

has a capacity of 1,200 amperes, and a range of pressure up to 60 volts.

Storage Batteries Used for Two or More of the Above-Named Purposes. Each of the different uses has been considered separately to avoid confusion, but in most cases the storage battery is adopted in order to secure several advantages. By thus combining different applications, the plant is rendered not only more economical, but also more flexible. For example, the battery may be utilized to help out the generating machinery at times of heavy load, or when the latter is partially or wholly disabled. It often happens that it is difficult to produce or maintain sufficient steam pressure, owing to poor draft or other conditions, in which event a battery enables the boilers to be temporarily relieved of some or all of the drain upon them while the pressure is being raised to the proper point. It may also be necessary or desirable to shut down the machinery or a portion of it, temporarily, in order to make some repair or adjustment. It is also possible to feed some of the circuits from the battery while the others may be supplied at a higher or lower voltage by the machinery. In these and many other ways the storage battery may be a convenient adjunct to an electrical system. The fact that it is so radically different from the machinery in its nature and action, makes it very unlikely that the entire plant will be crippled at any one time, since the two sources of current are not exposed to the same dangers. An accident to the steam piping, for instance, might shut down all the machinery, but probably it would not affect the battery; and, *vice-versa,* an accident to the latter is not likely to extend to the former.

As an example of this application of the storage battery to several purposes, the following case may be cited:

The installation of storage batteries at the power house of the Woronoco Street Railway Company, in Westfield, Mass., presents features of special interest. After considering various methods of increasing the power-house capacity, rendered necessary by the construction of an extension of the line, it was decided that the storage battery offered the greatest advantages.

The station equipment consists of two 75-kilowatt multipolar generators belted to two 120-horse-power, high-speed, simple, non-condensing engines, steam being furnished by two 90-horse-power return tubular boilers.

The battery consists of 264 Chloride Accumulator cells, Type F–11, in glass jars of Type F–13, permitting an increase of 20 per cent by the addition of one pair of plates in each cell, and is installed in a small brick extension to the power house. The cells are located in one tier, each cell being supported on a sand tray resting on four glass insulators. The foundation for each row of cells consists of two stringers of wood suitably braced and supported on brick piers. This battery was not installed as a voltage regulator, the feeder system being so designed that the drop on the line is only a small amount.

By means of the battery, the load on the machinery is reduced within the capacity of one unit, leaving the second one as a reserve in case of an accident or an unusually heavy load. Without the battery, both machines would be needed nearly all the time.

The economy of operation due to using one unit instead of two, is clearly shown by the following station records:

	Date, 1899.	Lbs. coal.	Output kw.-hrs.	Lbs. coal. per kw.-hr.
With battery	Oct. 25–27	16,250	3,032	5.36
Without battery	Oct. 28	6,250	981	6.37

This shows an increase in the coal consumption, of 19 per cent, on the day when the operation of the battery was discontinued. The plant is also noteworthy from the fact that the station attendance is reduced to one man per shift, the engineer doing his own firing. This arrangement could not have been continued under the conditions of increased load, had it not been for the improved regulation and reduction of coal handling, and especially the increased reliability of operation secured by the battery.

On several occasions the battery has been called upon to carry the entire load of the system for an hour or so, during a temporary shut-down of the rest of the plant, as well as early in the morning or late at night, when only one or two cars are in operation.

Storage Batteries for Propelling Vehicles and Boats. The storage battery is usually about 35 per cent of the total weight in the modern electric automobile; and even with this great proportion, the distance run on one charge is seldom more than from 20 to 40 miles at a speed of about ten miles per hour, and that only on comparatively smooth roads. The ordinary battery equipment consists of about 44 cells of 108 ampere-hours capacity with an average discharge voltage of about 1.9.

In cities or where the roads are good, with charging stations close at hand, the electric automobile is superior to the gasoline types on account of the absence of explosive vapors, with the accompanying odor and noise. But for general touring they are not so handy, on account of the limited capacity of the battery.

The application of the storage battery to the street-car, while presenting such great advantages as the entire absence of poles and overhead wires, has not been a commercial success, mainly on account of the mechanical weakness of the plates, which are not able to stand the jolting and jarring or the rush of current due to frequent starts and stops. Another objectionable feature is the escape of acid fumes into the car, producing throat irritations and coughs among the passengers, although this is overcome by the use of fans.

The storage battery has been comparatively successful as a source of power in submarine boats, being charged while the vessel is on the surface, and discharged to run electric motors and lights when the vessel is manœuvering under the surface.

Storage Batteries in Telephone and Telegraph Systems. Since the adoption of the central battery systems by telephone companies, the use of the storage battery for this purpose has become very common, its advantages over the primary cell being as follows: Lower first cost; smaller space required (about $\frac{1}{4}$ of that occupied by an equivalent primary battery); greater constancy of E. M. F. and lower internal resistance; absence of the annoying *creeping salts;* and rapidity of recharge. The cost of storage-battery maintenance is about $\frac{1}{8}$ that of the primary cell.

In telephone work, the battery is installed in the district station, and charged when the line is not in use, from either a street connection or a generator in the station. When the line is in use for conversation, the charging current is automatically cut off, and the battery alone switched into service.

The storage battery in telephone work has become so important that the following description of a typical installation is given.

In the Filbert Street Exchange of the Philadelphia Bell Telephone Company, there are two generating units, forming a duplicate plant, each consisting of one engine, directly connected to a 30-kilowatt, 110-volt dynamo. These machines are run on alternate days, and are used for lighting the building and for furnishing power at 110 volts to various motor-generators. The latter comprise two 1.5-kilowatt machines for charging a 20-volt battery, one 1.5-kilowatt machine for charging an 8-volt battery; one 500-watt machine for charging a 4-volt battery; and two $\frac{1}{4}$-horse-power 75-volt alternating-current motor-dynamos for ringing call bells. Only one machine is installed for the 8-volt battery, and one for the 4-volt battery. Both batteries are in duplicate. To avoid a possible breakdown, a rheostat is furnished, so that the batteries of lower voltage can be charged from batteries or motor-generators of higher voltage. All machines are protected by automatic cut-outs.

The 20-volt battery consists of ten Chloride Accumulators having a capacity of about 1,000 ampere-hours, which furnish all the current needed by the subscribers for talking and for calling up the central office. The 8-volt batteries, in duplicate, consist of four cells, each having a capacity of 2,400 ampere-hours. This battery furnishes current for the "disconnect" signals on the operator's cords, and for the relays which cut out the subscriber's lamp signal when the operator answers his call, by plugging into the jack corresponding to the lamp signal.

Half the drop in potential of the 8-volt battery is in the 4-volt lamp, and the other half in the cut-out relay. This battery is in duplicate, so that one can be charged while the other is being discharged. This avoids danger of burning out the lamps, as the voltage of the battery is raised from 8 to 10 volts during charging.

Each of the duplicate 4-volt batteries comprises six 13-cells arranged in two sets. One of these sets consists of four cells, two in series, two in multiple; the other of two cells. The two extra cells are needed on one of the batteries to supply current for the operator's transmitters. The latter is arranged to furnish a current of four volts or two volts as desired. The 4-volt battery also furnishes all current for the lamp signals, which light when a subscriber takes his telephone off the hook. This lamp is put out when the operator answers the call. This battery also is made in duplicate, one being charged while the other is discharged, to avoid burning out the lamp from the higher voltage during charge.

Storage Batteries for Train Illumination. When cars are lighted by oil or gas lamps, these, owing to their size, and the heat produced by them, can be installed only in certain places, so that the distribution of light is not general, besides which, the heat and odor given off by the lamps are objectionable. The inflammable character of the illuminants involves great danger of explosion or fire in case of a train wreck. The absence of these disagreeable and dangerous features in electric lighting, is what has made its application so desirable in traction work.

Several methods of electric illumination have been tried on railroad trains. In one of the simplest of these, a small dynamo on the locomotive truck, or one perched above the boiler, is driven by a small steam turbine. While this is an economical method, it has the objection, that when the locomotive is uncoupled, the cars must be illuminated by some other means.

For this reason, the storage-battery system of supply has been adopted. One of the most successful methods is the "Axle Light" system. This, as its name implies, derives the motive power for its dynamo from the car axle. The mechanism is suspended from the bottom of the car, and is completely encased, so as to be dust-proof and waterproof. It comprises a small dynamo driven from a pulley on the axle of the car by means of a friction coupling.

The dynamo and driving mechanism are shown in Fig. 24. The former generates from 32 to 40 volts, depending upon the speed

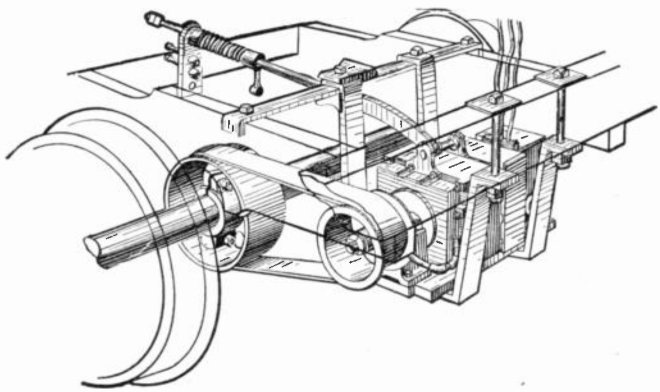


Fig. 24. Method of Suspension Used by the "Axle Light" System.

of the train, provided that it exceeds 15 miles per hour, the dynamo being then automatically connected to the battery and lamp circuit. An automatic device rectifies the direction of current, so that even though the direction of rotation is reversed, the battery is always charged in the proper direction. A variable resistance in series with the field coils is automatically adjusted by a small motor, so that even at high speed the normal limit of voltage is not exceeded.

The lamps are 16-candle-power at 30 volts, the filaments being short and heavy so that they are not injured by vibration.

After the storage battery has been charged, it acts in parallel with the dynamo, and avoids fluctuations in voltage. When the car stops, the dynamo is automatically cut out, and the full supply of current is furnished by the battery, which is large enough for a ten-hour supply at full load.

Storage Batteries for Electrical Laboratories. The great advantage of this source of power in electrical laboratories, is the fact that any variation in the voltage is very gradual, and by the simple regulation of a rheostat in series with the battery, the operator can keep his voltage and current absolutely constant while a test or calibration is being made. When a large current is wanted, as in the case of ammeter calibration, the cells may be connected in parallel and discharged through a low resistance, thus cutting down the energy required for the test. A storage battery may also be used to step up the voltage, the cells being connected in parallel groups for charging, and in series for discharging.

The special arrangement shown in Fig. 25 consists of a storage battery *S.B.*, the charging current for which is regulated by a bank of incandescent lamps *L*. Where a large-capacity battery is employed, a rheostat or motor-dynamo can be substituted for the lamps. In the instance shown, four distinct operations may be carried on simul-

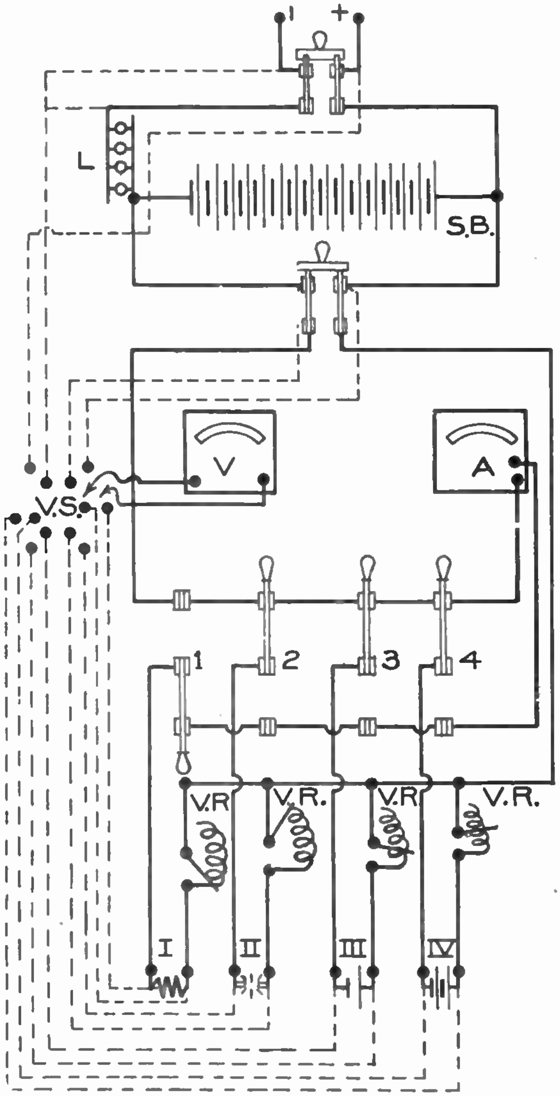


Fig. 25. Diagram of Connections of a Laboratory Equipment Arranged to Supply Current for Four Independent Operations.

taneously, without having one interfere with the other. Each one of the circuits is supplied with a regulating device *V. R.*, so that any desired current density is obtainable at the electrodes of the experimental devices I, II, III, and IV. The arrangement of the voltmeter circuits is such that the voltage of each individual circuit can be readily obtained through the use of the twelve-point voltmeter switch at *V. S.* The switching arrangement is such that by means

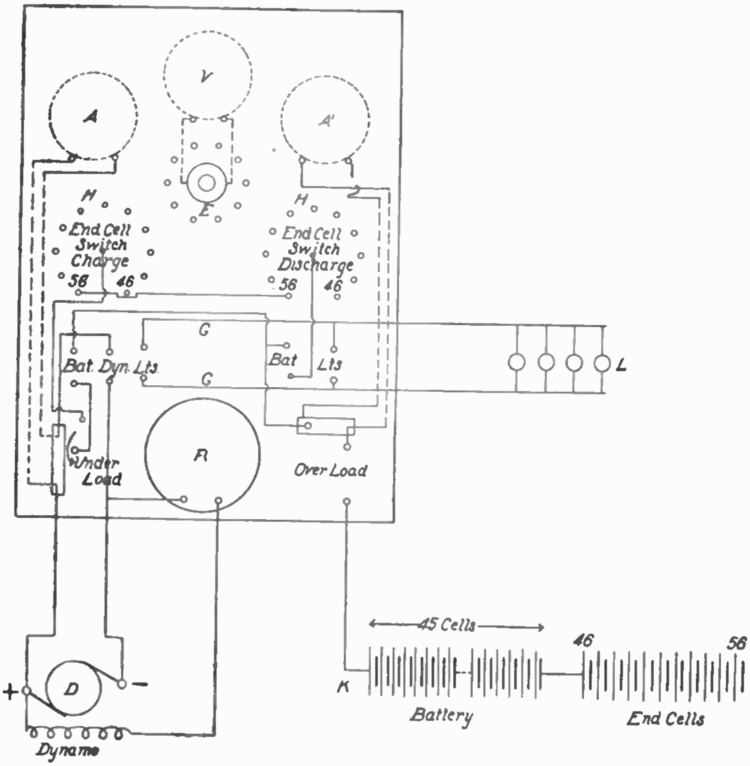
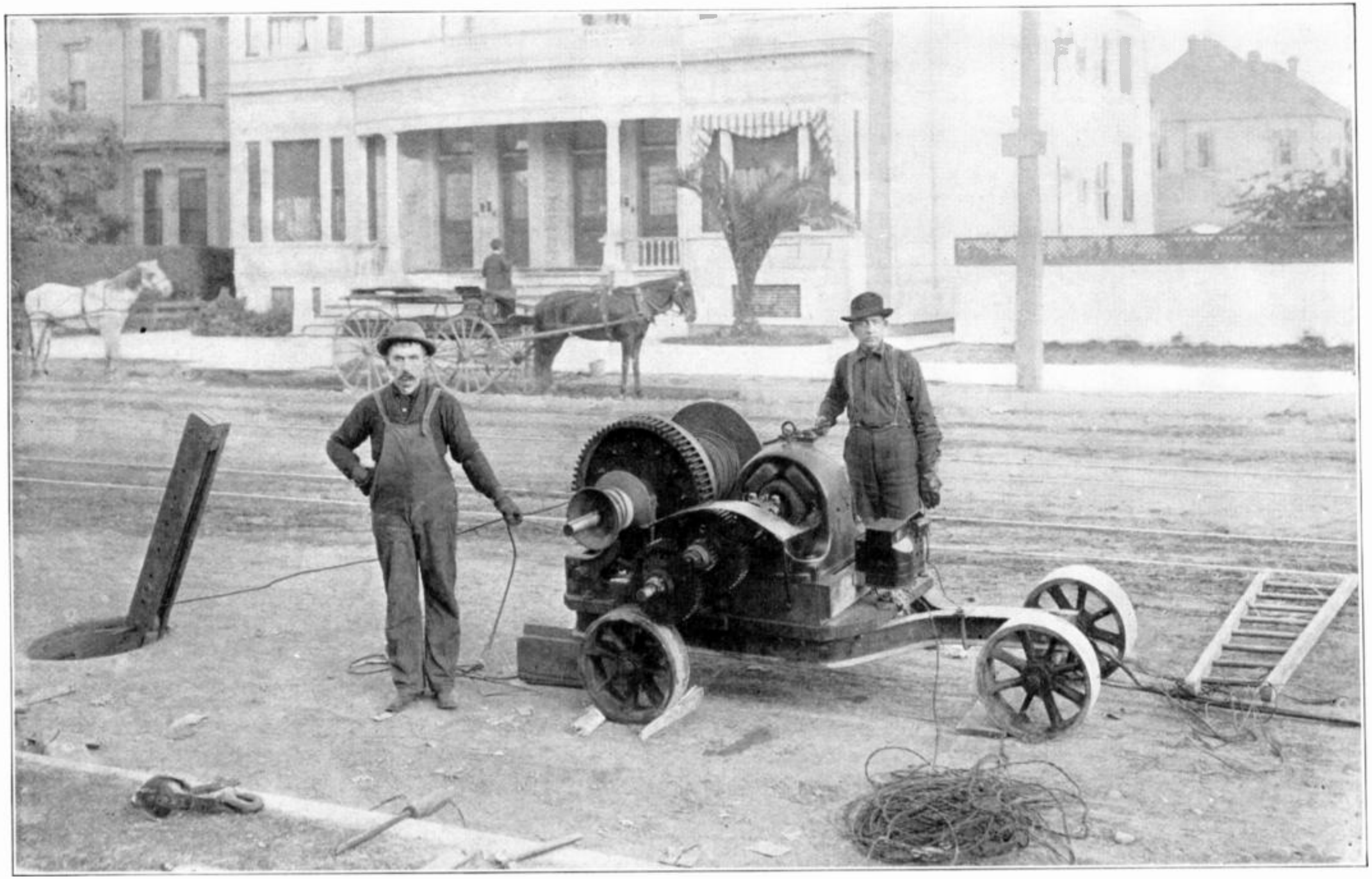


Fig. 26. Switchboard, Dynamo, and Battery Connections.

of one ammeter *A*, separate readings of the current in each branch circuit may be made, or the total current read. For example, with the switches as shown in the figure, the current flowing through the first apparatus consisting of a resistance furnace is being measured. If switch 1 were thrown in the opposite direction, and switch 2 had its position reversed, the current of group II would be shown by the ammeter. If all the switches were placed in the same position as



ELECTRIC WINCH FOR DRAWING CABLES INTO UNDERGROUND DUCTS switch 1, the ammeter would indicate the total current drawn by the four pieces of experimental apparatus.

Connection and Regulation of Storage Batteries. The complete control of a battery in an electric-lighting plant requires provision to be made for feeding the lamps, etc., from either the dynamo or battery separately, or from the two working in parallel; and it should be possible to charge the battery at the same time that lamps

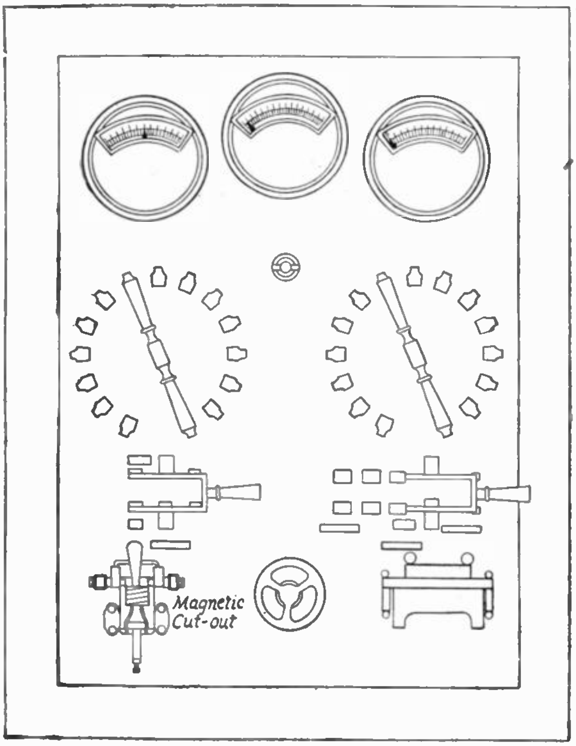


Fig. 27. Face of Switchboard.

are being supplied. To accomplish these results requires three switches—one to connect the battery to the dynamo, one to connect the lamps to the dynamo, and one to connect the lamps to the battery. In some plants the second switch is omitted, because the lamps are always fed by the battery alone, the latter being charged during the day, when no lamps are in use. However, it would seem desirable to have all three switches in every plant in order to be able at least to supply lamps and charge the battery at any time. In the battery circuit, there should be an ampere-meter having a scale on both sides of zero, so that it shows whether the battery is being charged or discharged, as well as the value of the current. Another similar ampere-meter is required in the circuit between the dynamo and the battery, to show the direction and amount of current. A third ampere-meter is desirable in the lamp circuit, to show the total current supplied to the lamps; but it need indicate only on one side of zero, since the current there always flows in the same direction. A voltmeter is required with a three-way switch, which enables it to be connected to the dynamo, battery, or lamps respectively.

An automatic overload switch must be inserted in the battery circuit so as to open or introduce resistance into the circuit when the current becomes excessive. An automatic cut-out is required between the dynamo and the battery to open the circuit when the charging current falls below a certain value, and thus avoid any danger of the battery discharging through the dynamo, if from any cause the E. M. F. of the latter drops below that of the former. This completes the ordinary measuring and circuit-controlling apparatus employed in connection with storage batteries. The arrangement is shown diagrammatically in Fig. 26, in which *A* and A^1 are the two ampere-meters, the third one being omitted in this case; *V* is the voltmeter; *E* the voltmeter switch to connect to the dynamo, battery, or lamps as desired; *G* the bus-bars; *L*, lamps; *D*, dynamo; *R*, rheostat in field-circuit of dynamo.

The regulating device consists of eleven end-cells, which are connected to corresponding contacts on the end-cell switches (Fig. 26). But as the drawing of these connections would complicate the figure, they have been omitted. Fig. 27 shows the switchboard with these devices mounted upon it.

Parallel Charge, Series Discharge. With batteries of small capacity, where it is not advisable or convenient to raise the generator voltage in order to charge all the cells in a single series, it is usual to divide the battery into two parts and charge each half of the battery individually, through a resistance from the main lines. This method is inefficient, however, and should be employed only with small equipments. Fig. 28 shows a diagram of connection for charging in this manner, and coupling the two halves of the battery in series during discharge, the discharge voltage being also regulated by resistance, there being no end cells employed.

Regulation of Storage Batteries. This is one of the most troublesome problems involved in the practical use of storage batteries. It arises from the fact that the voltage falls continually from the begin-

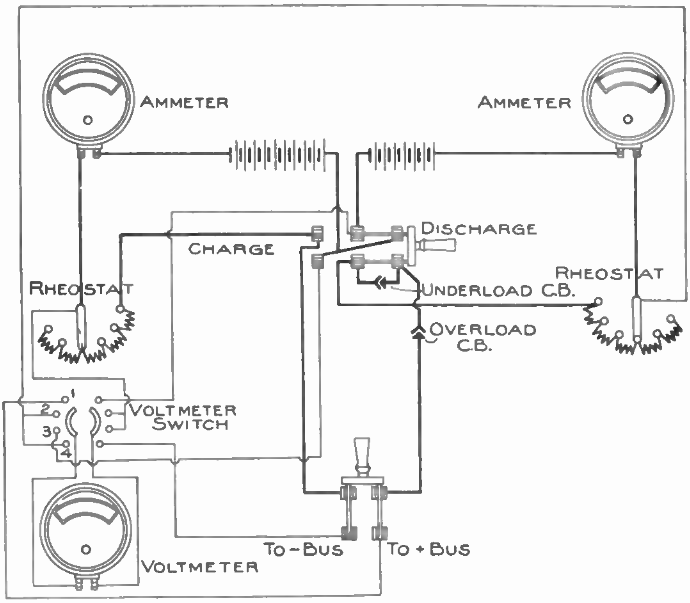


Fig. 28. Connections for Parallel Charge, Series Discharge.

ning to the end of discharge. To be sure, this decline is gradual; but its total value is large, being from about 2.2 to about 1.8 volts, which is a decrease of nearly 18 per cent.

In order to maintain a constant voltage, the usual plan is to have a number of extra cells, which are successively switched into circuit as the potential falls. These reserve cells and the switches which control them are represented in Fig. 26.

The contact-pieces of these switches must be made in such a way that they do not short-circuit the cells as they pass from one point to the next. This is accomplished by splitting the movable contact arm into two parts, between which a certain amount of resistance is introduced, so that when the two parts happen to rest on two adjacent contact-points, the resistance prevents the cell which is connected to these two points from being short-circuited, and also avoids breaking the circuit.

The number of extra cells depends upon conditions; for 110-volt lamps, it would require 51 cells to obtain 112.2 volts when fully charged and giving 2.2 volts each, assuming the drop on the conductors at 2 per cent. When the battery becomes discharged. and its potential falls to 1.8 volts per element, 10 additional cells, or 61 in all, would be needed. These would yield 111.8 volts, assuming the average potential of the reserve cells to be 2 volts, since they have not been discharged to the same extent as the original battery. If the drop on the conductors is 10 per cent of the lamp voltage, the potential at the battery will have to be 110 + 11 = 121. This will necessitate 4 more elements, or a total of 65, when the 51 original cells are fully discharged to 1.8 volts, and the 14 extra cells give 2 volts each.

For a three-wire system, the above figures should, of course, be doubled. This switching of extra cells into and out of the circuit obviously results in discharging them unequally; hence they require to be charged to a corresponding extent. This is accomplished by successively cutting the cells out of circuit as soon as they become fully charged, the last cell which was put into the circuit being fully charged in the shortest time, and so on. The amount of charge is determined by the methods already given. If the cells employed are not injured by overcharging, they may be left in circuit until the entire battery is fully charged. This saves the trouble of operating the switch; but it is wasteful of energy, since the full counter-E. M. F. and resistance of the charged cells must be overcome, which requires about 2.5 volts more per element. The switches might be operated automatically by a voltage regulator or by clockwork.

REGULATION OF GENERATOR IN CHARGING STORAGE BATTERIES

The variation in E. M. F. which occurs in accumulators renders it somewhat difficult to regulate the generators employed to charge them. A constant potential will give a decreasing rate of charge, owing to the gradual rise in counter-E. M. F. This is advantageous in that it enables the cells to receive a larger charge; but the increase in their voltage is so great that it is practicallv necessary to regulate the charging potential. In practice it is customary to maintain the charging current approximately constant for considerable periods of time; otherwise it would be difficult to determine the quantity of energy put into the battery, and its efficiency. When extra cells are used, they facilitate the regulation of the generator, since they are gradually cut out as the E. M. F. rises.

If the lamps are supplied at the same time that the battery is being charged, some provision must be made for the fact that it may be necessary for the voltage of the dynamo to be considerably higher than that required by the lamps. One plan is to have two separate switches connected to the reserve cells, as shown in Fig. 26, the charging current from the dynamo being led in through one, and the current for the lamps passing out through the other, so that the potential can be independently controlled in the two circuits. Another method is to insert counter-E. M. F. cells (without active material) in the circuit between the dynamo and the lamps, in order to bring down the voltage of the former to suit the latter. The number of these cells is varied in accordance with the excess of the potential of the dynamo.

Simple resistance coils may be used in place of the counter-E. M. F. cells to reduce the pressure; but the cells have the great advantage, that they have an effect practically independent of variations in the current. All these methods, however, involve a waste of power, the value of which in watts is the product of the current in amperes and the number of volts by which the potential is cut down. In small plants this loss is not serious, but in large plants or central stations it may become very considerable.

Booster Methods of Regulation. The best plan is to make use of a *booster*, in which case the main dynamos are run at the proper voltage to supply the lamps directly, and the additional pressure required to charge the battery is furnished by the booster. This is connected in series with the dynamo, being inserted in the circuit between the latter and the battery.

When a battery is placed at the end of a long feeder to compensate for line drop, and at light loads to act as a storage reservoir, it is not usual to equip this *floating battery* with any regulating device. In such cases the battery is simply connected across the line, and the charge and discharge are determined by the feeder drop. For instance, when a small load is on the line, the drop is small, and the potential applied across the battery terminals is high enough to send a charging current into the battery; if the load on the line increases, the drop naturally increases, the pressure at the end of the line falls, and, if it falls below the battery voltage, the battery discharges in parallel with the generator, carrying a certain portion of the load. The floating battery has the advantages of simplicity, and acts immediately, as it has no time lag, which is always present in any apparatus depending upon changes in magnetization. Usually the variations in voltage and the fluctuations in load are too great for successful operation of a floating battery on any but an electric railway or power circuit, and a booster is required if incandescent lighting is a part of the load.

The duty of a booster is to vary the voltage at the battery terminals with variation in load, causing charging or discharging of current as conditions may require. The booster is an auxiliary dynamo, the E. M. F. of which is used to raise or lower the voltage in the battery circuit. These machines are classified as *series, shunt, compound, differential,* and *constant-current* boosters.

Shunt Booster. This is a shunt dynamo, driven by any source of power, having its armature circuit in series with the line from generator to battery. This form is used in plants where the bat-

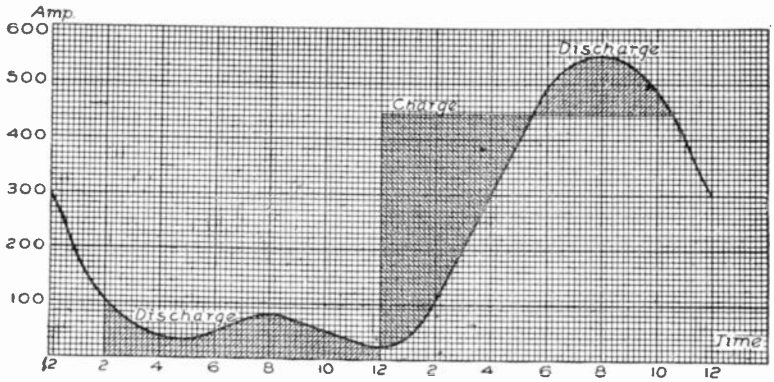


Fig. 29. Load Diagram of Case in which a Shunt Booster is Applicable.

tery is not designed to take up load fluctuations, but is in service only to carry the peak of the load, being charged during periods of light load, and discharged in parallel with the generator. It acts to increase the voltage applied to the battery so that the charging current will flow into the latter. As a rule, the battery used in conjunction with a shunt booster is made large enough to carry the entire load during the light-load period. As the battery discharges and its voltage drops, the end-cells (regulation cells) are cut in and the proper voltage maintained. Fig. 29 shows a load diagram to which this system is applicable, and Fig. 30 shows diagrammatically

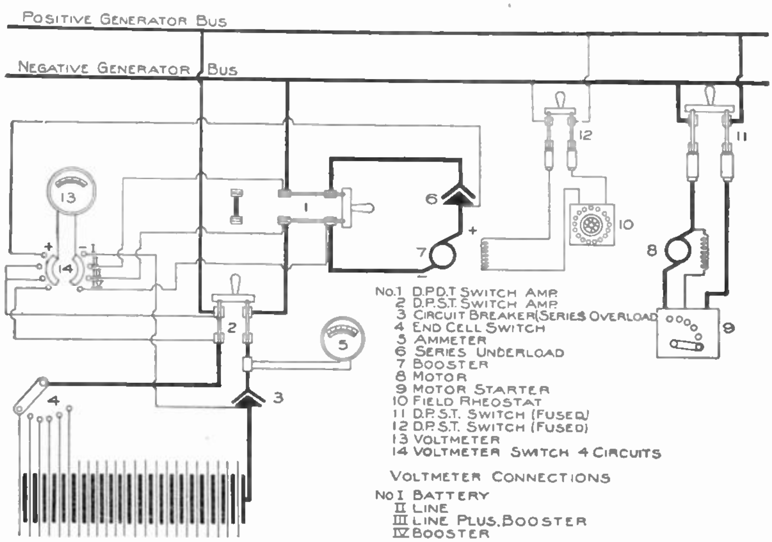


Fig. 30. Shunt Booster Connections.

the connections of this system. The booster (7) is direct-connected to and driven by a shunt-covered motor (8), which takes current from the main bus-bars. The field of the booster is provided with a single winding excited from the generator circuit. This winding has a rheostat (10) in series with it so as to be able to regulate to booster E. M. F. It is to be noted that the shunt booster is not applicable where there are sudden fluctuations which are great compared with the capacity of the generator, and that it is not automatic in changing from charge to discharge, the switching being performed by hand.

Series Booster. The connections are like those of the shunt booster with the battery and booster in series across the line; but the field of booster being in series with the battery circuit, its E. M. F. is zero when no current is flowing in or out of the battery. Should the voltage of the line rise, due to a decrease of load, and a charging current flow into the battery, the E. M. F. of the booster would increase, and thus tend to increase the rate of charge. The reverse occurs when the battery discharges, as an increase of load on the line increases the current through the series field of the booster, thus raising the voltage of discharge so that the battery carries a larger part of the load.

This booster acts to compound the battery on discharge, and tends to maintain a constant voltage on the line. It depends on the fact that the generator voltage falls when the load increases; hence it is used with a shunt generator or equivalent source of supply.

This system is applicable to power, but not to lighting purposes, and is similar in its operation to a floating battery. It is not so extensively used as the compound and differential booster arrangements, which give better regulation under similar conditions.

Compound Booster. This system is used on railway and power circuits with great fluctuations in load, the battery action to prevent excessive drop and to assist the generating machinery in carrying the load, relieving it from the strain of sudden rushes of current. The connections of this system are indicated in Fig. 31, and the operation

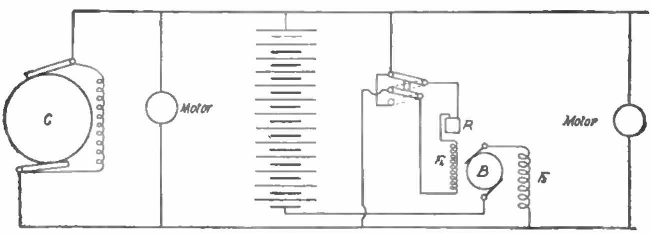


Fig. 31. Compound Booster Connections.

is as follows: Under normal load conditions the shunt field F_h of the booster creates an E. M. F. in the same direction as the battery, tending to discharge it. Calling E_g the generator E. M. F.; E_a the booster E. M. F.; and E_b the battery E. M. F., we have $E_g - E_a = E_b$ when no current is flowing into or out of the battery. In this case the generator carries the whole external load.

If the load increases, E_g decreases, so that $E_b - E_a$ is greater than E_g, and the battery begins to discharge. In discharging, the current passes through the series field F_s of the booster and produces a proportional E. M. F., acting with the shunt field to raise E_a, thus increasing the battery discharge and shifting more of the load from the generator, until the system becomes balanced.

If the load on the external circuit be light, the generator voltage E_g rises and current flows into the battery. In this case the series field acts against the shunt field and decreases E_a, so that the generator voltage is greater than booster and battery voltage combined, thus increasing the rate of charge of the battery, until the load causes the generator voltage to drop to normal and the system is again balanced. The battery and booster can be placed at the power house or at the point at which the greatest drop is likely to occur.

A battery can also be used to help out the generators at the peak of the load, by increasing the shunt-field current and thus causing E_a–E_b to be greater than E_g.

Since this system also depends for its action upon the drop of voltage with increase of load, it is only applicable to shunt-wound generators or equivalent source.

Differential Boosters. The differential booster system most commonly used is shown in Fig. 32. The compensating field S_1

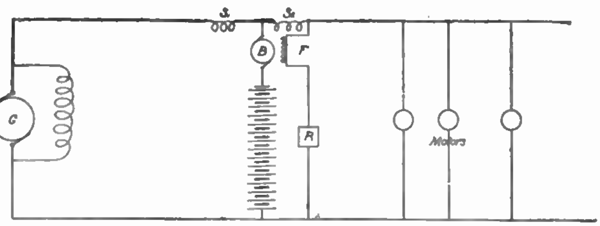


Fig. 32. Differential Booster Connections.

prevents the variation of the battery E. M. F. from disturbing the equilibrium of the system. If the battery E. M. F. be lower than normal, it will not discharge rapidly enough to relieve the generator from overload fluctuations, unless the booster E. M. F. be increased; and the generator will therefore have to supply a current of greater than its normal value. If, however, a current of greater value than the normal flows through S_1, the value of f–S_1 is decreased, and S_2 still further overpowers the resultant of f–S_1 and causes a higher booster E. M. F., tending to discharge the battery, thus bringing down the generator load to normal. Should the battery E. M. F. be above its normal value, the battery would discharge too rapidly and carry more than its share of the load; in this case f–S_1 is greater than it should be, and the booster E. M. F. causes the load to become evenly distributed between the battery and generator.

In operating this system, the varying load must be beyond the booster equipment. If desired, the coils S_1 and S_2 may be short-circuited so that the battery may be charged more rapidly.

Constant-Current Booster. In systems having short lines and small drop, it is often desirable to have the voltage fall on sudden application of an overload, so that the rush of excessive current is prevented. This rush of current occurs in buildings where elevator and power motors constitute a large percentage of the load; and to prevent it, the *constant-current booster* system is used.

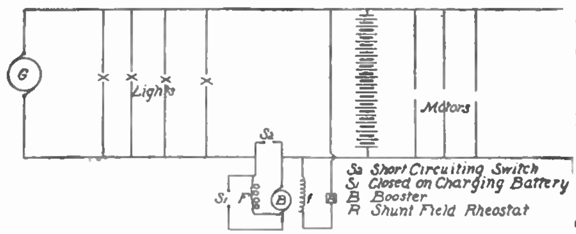


Fig. 33. Constant-Current Booster Connections.

Fig. 33 represents a constant-current booster system, in which the main current passes through the armature and series field of the booster; and this current does not reverse.

The voltage impressed on a fluctuating load of motors, on the right, is greater than that impressed on a non-fluctuating load of lamps on the left, by the amount of the booster voltage.

The shunt-coil f creates an E. M. F. in the same direction as that of the generator; while the series-coil F opposes it.

Should a load come in the motor portion of the circuit, the generator sends a greater current through the series coil S, the action of which reduces the booster E. M. F. in direct proportion to this rush of current, and causes the booster E. M. F. to vary inversely as the motor load, thus tending to maintain an almost constant current delivery from generator. If it is desired to have the battery furnish power to both lights and motors, at periods of light load, and not to use the generator, this can be done by simply opening the generator switch and short-circuiting the booster by closing switch S_2.

The switch S_1 is closed in charging the battery, as the rate of charge can be controlled by varying the shunt-field resistance R.

This is often done, when the battery has been carrying a heavy load for some time and the recharging must be hurried.

In the automatic booster systems already described, the regulation is obtained by two or more field windings acting differentially or cumulatively.

Systems of External Control. In the following systems of booster control, only a single field winding is provided, and this winding is excited from the main bus-bars through an automatic field regulator which varies the field current to produce the necessary booster E.M.F. as the load on the line changes. The booster armature is connected

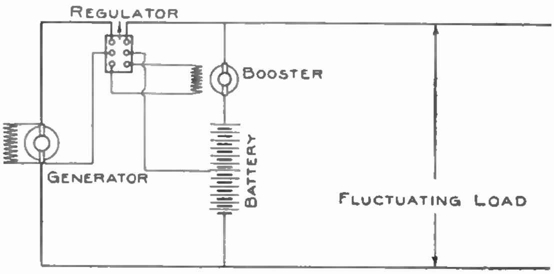


Fig. 34. External Control Differential Booster System.

in series with the battery and generator as heretofore. Figs. 34 and 35 show diagrammatically the connections of the differential and constant-current systems arranged on this plan.

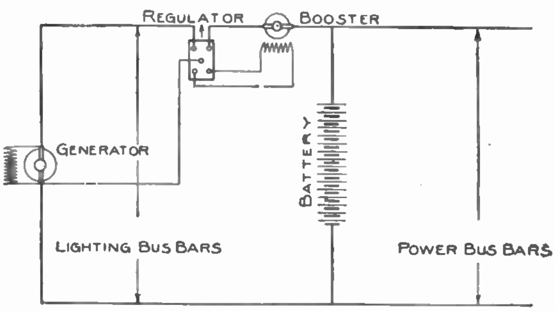


Fig. 35. External Control Constant-Current System.

These externally controlled booster equipments are the system employed by the General Storage Battery Company, and in one of these constant-current systems the following excellent regulation was obtained: The load across the power bus-bars was a rapidly fluctuating one, varying instantly from zero to 2,500 amperes, while the average current required amounted to only 150 amperes. With no load across the power bus-bars, the booster passed 150 amperes from the generator to the battery, tending to charge the latter; with a sudden increase of power demands from zero to 2,500 amperes, the generator current rose to a value of only 159 amperes. This example brings out the definition of a constant-current booster—that is, it should be one which maintains a practically constant power load on the generator.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY

PAGES 11—84

1. Explain under what conditions cabled wires are more favorable than open wires and why.

2. For what reason are cables laid under water?

3. Give the characteristics of copper-clad wire.

4. What insulating material is used in cables and for what reason?

5 What are mutual and "regular" capacity and explain the difference?

6. Describe the two ways of loading cables.

7. Name the timbers commonly used for telephone poles.

8. What is the object of roofing a telephone pole?

9. Describe a fully equipped telephone pole.

10. What is the most important governing factor in the construction of a toll line?

11. How is an anchor constructed and what purpose does it serve?

12. Why does the telephone wire run alongside the insulator, and why is it tied to it rather than passed around it?

13. Sketch a Western Union wire joint.

14. Draw a diagram showing the best method of making a running transposition.

15. About how many poles are there to the mile in rural districts?

16. Draw a diagram showing the method of placing pole lines for cables when crossing from one side of a street to the other.

17. What is a *messenger* wire? Of what material is it usually made?

18. Is it advisable to allow much sag in cable supporting *messengers?*

19. Compute the sag for a 200-foot span to give the same tension as a 6-foot sag gives a 100-foot span.

20. How are the ends of *messenger* wire joined when necessary?

21. Describe the method of erecting aërial cables.

22. Show by diagram the method of turning a corner at an intermediate point between poles of a wire cable without splicing.

23. What is meant by *pot-heading* cables in terminals?

24. What special advantage has the wooden terminal box?

25. Show by sketch the details of the most common method of inserting protection between aërial and underground cables.

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY

PAGES 85—172

1. Give the reasons for placing wires under ground.
2. Describe the different duct materials.
3. What is a dowel pin? For what is it used?
4. Draw a diagram of a 16-duct conduit and give a short description of its construction.
5. Describe fiber pipe conduit.
6. What is the use of manholes and what should be their distance from each other?
7. Give description and sketch of a concrete manhole.
8. When is it necessary to make test holes?
9. Why are curves in a conduit line undesirable?
10. What is a lateral run?
11. Give sketch and description of a lateral riser.
12. Describe the operation of rodding.
13. Describe a cable grip. Give sketch of the general arrangement of the cable reel and of the apparatus employed in pulling in cables.
14. Is it advisable to use lubricants in drawing in cables?
15. Show by sketch a systematic arrangement of cables in a manhole.
16. Describe the general method of splicing.
17. Describe the pot-head.
18. What is a central-office pot-head?
19. Describe the manner in which aërial cables enter a central office.

20. Describe the underground entrances for larger plants.

21. Who has to decide as to the location of cable runs in a central office?

22. What important fundamental difference is there between a telephone line and other electric light and power distributing systems?

23. State the three different kinds of connections from cable lines?

24. Give a short description with sketch of a rear wall or fence distribution.

25. What is a circle top distribution?

26. How is a connection established between underground cables and large office buildings?

27. What principal points are to be considered in wiring of office buildings for telephone service?

28. Sketch a race-way moulding.

29. Give diagram of a ceiling conduit.

30. For what purpose are riser cable shafts provided?

31. Give a short description of the best method for wiring an average hotel.

32. What points are to be considered in wiring an apartment house?

33. What do you understand by electrolysis?

34. Give a short description of some remedies against electrolysis.

REVIEW QUESTIONS

ON THE SUBJECT OF

TELEPHONY

PAGES 173—215

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1. What do you understand by development study?

2. What points are to be considered in an exchange development study?

3. What determines the location of central offices?

4. What is meant by maintenance expenses?

5. What are the fundamental rules of maintenance?

6. Why are maintenance methods and costs very important?

7. Enumerate some of the general troubles and their remedies in the outside plant.

8. What is the cause when the operator cannot ring?

9. What is the most important handicraft of the telephone repair man?

10. What is the reason for electrical tests?

11. Describe and make diagram of test for continuity.

12. Describe the sounder test for insulation.

13. Describe the telephone test for capacity.

14. Make diagram and describe the method of testing for resistance.

15. Describe the method of locating grounds by means of the exploring device called a *jigger*.

16. Describe an identification test for conductors.

17. Describe the D'Arsonval galvanometer.

18. Describe a test for insulation resistance, giving diagram of the arrangement of the different parts used.

19. Describe the megger and give its advantages.

20. Describe and sketch the insulation testing set of Nalder Brothers, London.

21. Describe the Varley loop test for grounds.

22. Describe the Murray loop test for grounds.

23. How would you determine the location of a break by means of the capacity test?

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRICAL MEASUREMENTS

PART I.

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1. What is the distinction to be made between fundamental and derived units? Give examples of each.

2. Describe briefly the different types of galvanometers and explain wherein they differ and the advantages of each.

3. Voltmeters and ammeters are really *galvanometers.* Why do they fall into this class and to which type do they belong?

4. Explain the *lamp and scale* and the *telescope and scale* methods of reading galvanometer deflections.

5. Describe the control magnet as used with needle galvanometers and explain its function.

6. Describe and explain the electrodynamometer and the wattmeter. How do they differ?

7. Describe the rheostat. What materials may be used for the resistance?

8. How do resistance coils differ from the rheostat mentioned in Question 6? What material is generally used for accurate resistance units and why?

9. Describe and explain the use of shunts for galvanometers.

10. Explain the Wheatstone's bridge. Describe the two usual forms of the bridge.

11. Make the usual "diamond" diagram of the connections of a bridge and find the value of X when $M = 1{,}000$, $N = 10$, and $P = 3{,}247$.

12. Describe a good method for measurement of a low resistance.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRICAL MEASUREMENTS

PART II.

1. Describe the ballistic galvanometer and explain why its period of swing should be long.

2. Describe a condenser, mentioning materials used, method of connection, etc. What is the *unit of capacity* in which condensers are rated?

3. Make a diagram of connections for the direct-deflection method of comparison of capacities of condensers.

4. Describe and explain either the bridge method or the method of mixtures for comparison of capacities of two condensers.

5. If in question 4, $R_1 = 2{,}100$, $R_2 = 1{,}000$, $C_1 = 0.2$, what is C_2?

6. Describe the alternating-current method of determination of the capacity of a condenser.

7. What is *self induction?* What is *impedance* and how is it expressed in terms of resistance and inductance?

8. Describe the alternating-current method of measuring an inductance.

9. What is a *variable standard of self inductance* and how is its inductance varied?

10. Describe the bridge method of comparison of two self inductances, one being variable.

11. Show how a capacity is compared with a self inductance by the condenser method.

12. What is *mutual induction* and why is it so called?

13. Describe the ballistic galvanometer method of measuring mutual inductance.

REVIEW QUESTIONS

ON THE SUBJECT OF

STORAGE BATTERIES.

1. What is the lowest voltage to which a lead battery should be discharged?

2. What means may be employed to make up for the drop in potential of storage batteries during discharge?

3. What causes sulphating?

4. What plate of a storage battery is the positive?

5. Describe the several indications by which the amount of charge in a storage battery can be determined.

6. How is the capacity of a storage battery usually expressed?

7. What is an electrolyte?

8. What is meant by a floating battery, and when is it applicable?

9. How must a storage battery room be arranged?

10. What causes buckling?

11. Why are there always more negative plates than positive plates in a storage battery?

12. Give several applications of storage batteries.

13. When a storage battery is charged, what is found on the positive plate? What is found on the negative plate? What occurs when the cell is discharged?

14. What is the maximum voltage obtainable from a lead storage cell?

15. How may sulphating and buckling be prevented?

16. How would you put a battery out of commission for a long period, and how would you place it in service again?

17. What is the difference in construction between Faure and Planté plates?

18. What is the essential difference between a primary and a storage battery?

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