INCANDESCENT WIRING

HAND-BOOK

TABLE No. 3.

55 VOLTS.

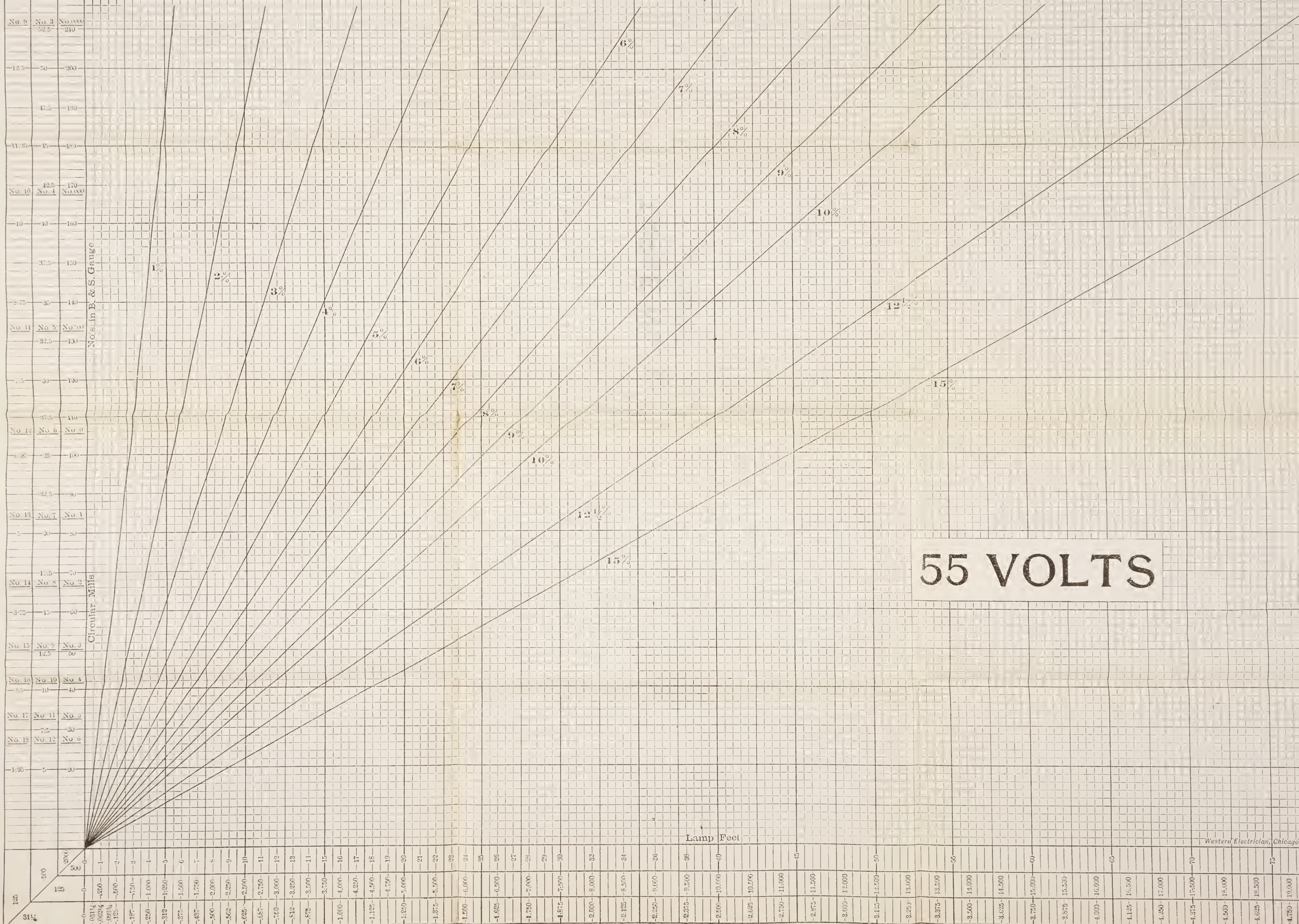
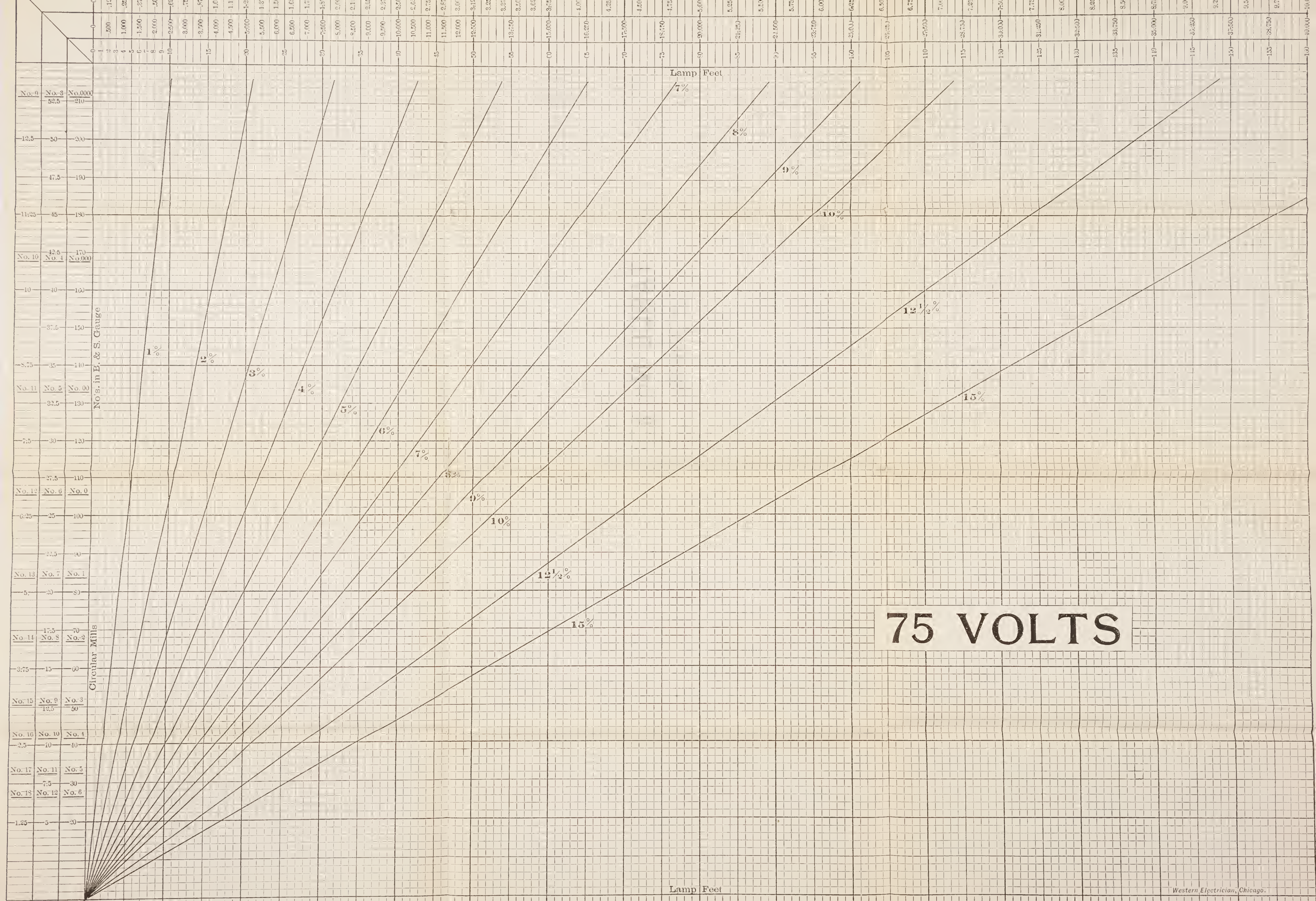

55 VOLTS
No's in B. & S. Gauge
Circular Mills
Lamp Feet
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
12½%
15%
Western Electrician, Chicago

TABLE No. 4.

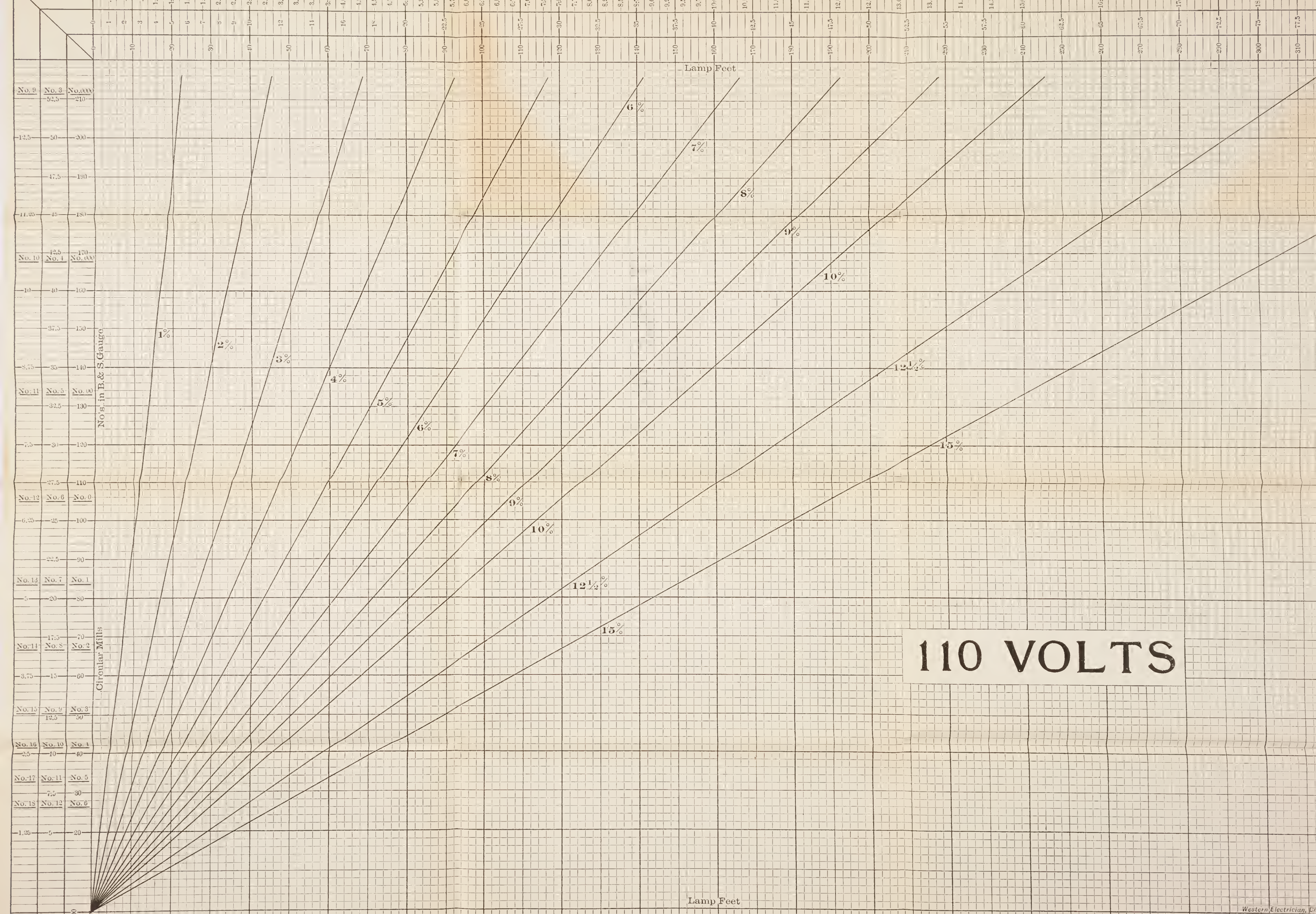
75 VOLTS.



Lamp Feet
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
12½%
15%
Nos. in B. & S. Gauge
Circular Mills
75 VOLTS
Lamp Feet
Western Electrician, Chicago.

TABLE No. 5.

110 VOLTS.



Lamp Feet
1%
2%
3%
4%
5%
6%
7%
8%
9%
10%
12½%
15%
No's. in B. & S. Gauge
Circular Mills
No. 9
No. 3
No. 0000
No. 10
No. 4
No. 000
No. 11
No. 5
No. 00
No. 12
No. 6
No. 0
No. 13
No. 7
No. 1
No. 14
No. 8
No. 2
No. 15
No. 9
No. 3
No. 16
No. 10
No. 4
No. 17
No. 11
No. 5
No. 18
No. 12
No. 6
110 VOLTS
Lamp Feet
Western Electrician

Incandescent Wiring

Hand-Book,

WITH THIRTY-FIVE ILLUSTRATIONS AND FIVE TABLES.

BY

F. B. BADT.

Late First Lieutenant Royal Prussian Artillery.

Author of "Dynamo Tenders' Hand-Book," "Bell-Hangers' Hand-Book."

FIRST EDITION.

ELECTRICIAN PUBLISHING COMPANY,
CHICAGO, ILL.
1889.

PREFACE.

The success which attended the publication of the "Dynamo Tenders' Hand-Book," and the "Bell-Hangers' Hand-Book," induced the author to undertake the preparation of a book of practical instructions for incandescent wiring. That a demand for such a work exists has been amply demonstrated from time to time by numerous letters of inquiry which have been received by author and publisher. It has been the author's object to prepare a hand-book containing practical suggestions for workmen, and tables of exact data from which sizes of wires, distances and percentages of loss in conductors could readily be computed by those unfamiliar with algebraic formulæ. To those who wish to study the principles underlying electric lighting the following works are cordially recommended: "Elementary Lessons in Electricity and Magnetism" and "Dynamo Electric Machinery" by Silvanus P. Thompson; "Electric Light Arithmetic," by R. E Day; "Magneto Electric and Dynamo Electric Machines," by Dr. H. Schellen; Munro & Jamieson's "Pocket-Book of Electrical Rules and Tables;" Badt's "Dynamo Tenders' Hand-Book."

The author desires to acknowledge that he is indebted to the *Manufacturer and Builder* and the *Western Electrician* for several valuable suggestions.

F. B. BADT.

Chicago, June, 1889.

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CONTENTS.

INTRODUCTORY.

The several methods of wiring for electric lighting may be classified as follows:

First—The Multiple Arc System.

Second—The Multiple Series System.

Third—The Three-Wire System, which is really a combination of the first and second systems.

Fourth—The Alternating Transformer System.

These systems are applied according to varying conditions, e. g , for long distances the multiple arc system is not used.

The object of this little book, however, is not to explain these systems of wiring, but merely to give practical rules for wiring buildings.

There are only two reliable systems which may be used for wiring residences, offices and buildings generally for incandescent lights. These are the multiple arc and the three-wire systems. These methods will be explained, and the data necessary for the successful wiring of a building for incandescent electric lights in accordance with these systems will be given. It should be mentioned that in the alternating transformer system which is used for distributing lights over a large area, the high pressure in the mains is converted to low pressure in the transformers. The wiring from transformers to buildings is done on the multiple arc system, so that only a knowledge of the multiple arc and three-wire systems is essential to incandescent wiremen so far at least as the wiring of buildings is concerned.

As the multiple series system and the series multiple system can be used only on a small scale and under certain peculiar circumstances, explanations of the two methods will be omitted. The great disadvantage attaching to these two systems consists in the fact that it is almost impossible where they are employed to insure perfect safety against fire, and their use should therefore be restricted mainly to outdoor lighting or to places in which there is little danger of fire.

There are also systems by which incandescent lamps are run on arc circuits, but the same objection may be be made to them as to the multiple series and series multiple systems.

Chapter I.

The Multiple Arc System.

The multiple arc system of incandescent wiring which is also called the multiple system or the parallel system, will be readily understood by reference to Fig. 1.

Each lamp in the system is independent of all others, and any number of lamps may be switched in or out without interfering with the other lamps, provided the electro-

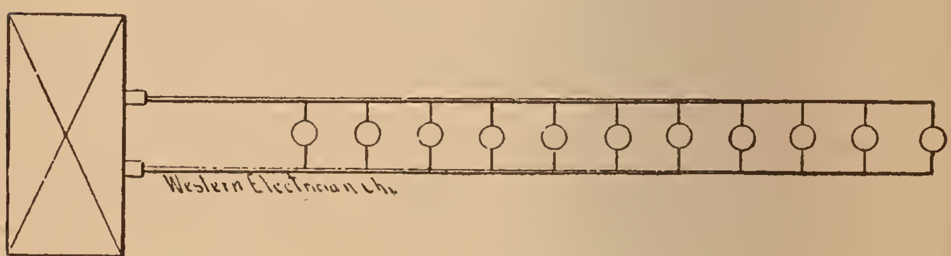


Fig. 1.—Multiple Arc System.

motive force at the dynamo is kept constant. Only lamps intended for a given electromotive force are connected in one system; for instance, in a 50-volt system, only lamps marked fifty volts should be used, and in a 100-volt system only lamps marked 100 volts should be connected, etc.

Chapter II.

The Three-Wire System.

In the three-wire system two dynamos are joined in series, and the lamps are connected between a center or neutral wire and the positive and negative wires of the system. Fig. 2 represents the plan of this system.

The advantage of this method lies in the fact that the electromotive force is double that employed in the multiple arc system, while the current strength is only one-half of that of the latter system. This advantage is evident when it is stated that the mains require practically only three-eighths as much copper as is needed in the mains of a

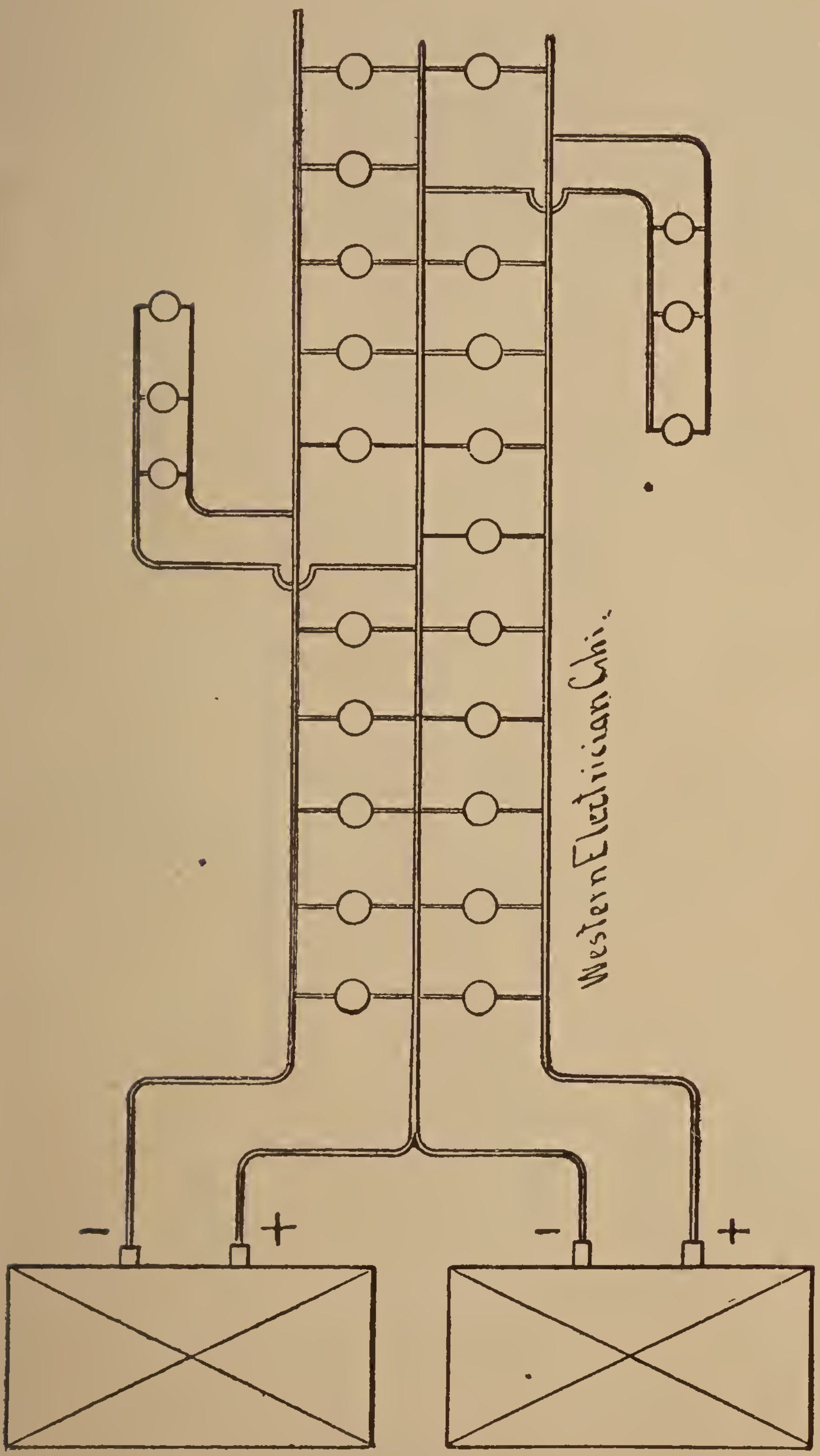


FIG. 2. — THREE-WIRE SYSTEM.

multiple arc system supplying the same territory. For example, if 1,000 pounds of copper were required in a multiple arc system of wiring, for say 200 lamps, only 1,000 x $\frac{3}{8}$ = 375 pounds, would be necessary in the three-wire system. (Compare Chapter XXIX.)

METHODS OF RUNNING WIRES.

After the system of wiring has been decided upon the several modes of running the wires are to be considered

CHAPTER III.

Cleat-Work.

The most common and cheapest method of running wires is by cleat-work. The wires are entirely exposed,

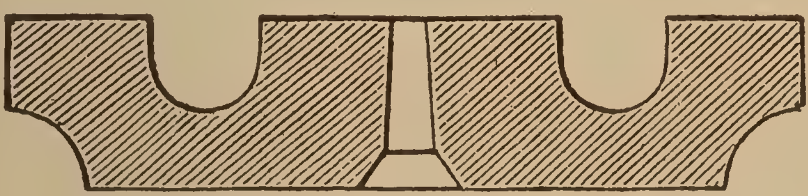


FIG. 3.—TWO-WIRE CLEAT.

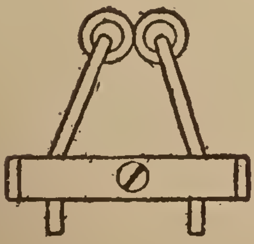
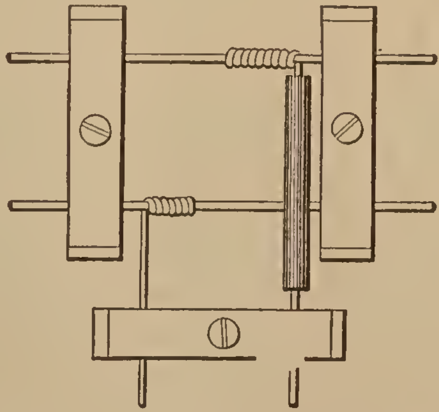


FIG. 4.—WIRES IN SEPARATE HOLES.



Western Electrician, Chi

FIG. 5.—PROTECTION OF WIRES.

being merely secured at short intervals by hard wood cleats. Wires are frequently fastened in this way in stores, where a long straight run is obtained with short branches; waterproof insulation is usually employed. This system is usually followed where the appearance of the wires is of no great consequence; for example in mill and factory

FIG. 6. — THREE-WIRE CLEAT.

wiring, cleat-work is usually the most desirable method of running wires, as it admits of ready access to conductors in case it is necessary to change the location of the lamps.

Figs. 3, 4, 5, 6 and 7 show the use of cleats. Fig. 3 shows a familiar form of cleat. Where the positive wire

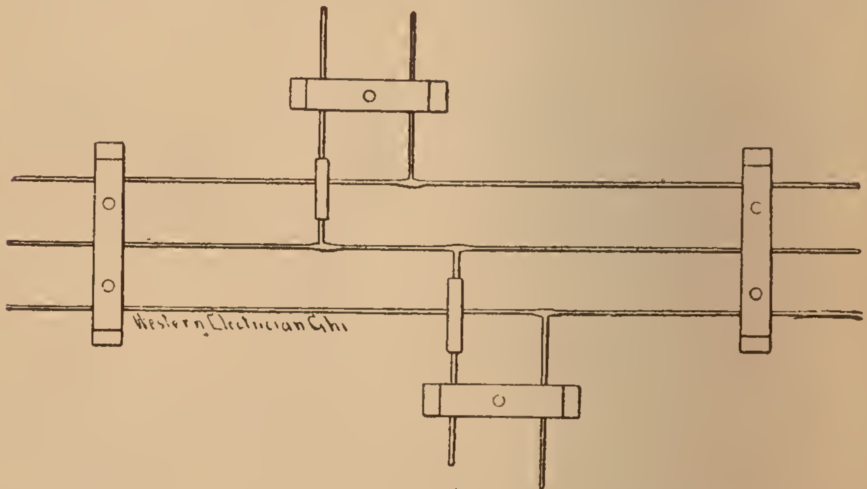


FIG. 7. — USE OF CLEATS ON THREE-WIRE SYSTEM.

crosses the negative, the extra protection of rubber tubing is required to prevent any danger from short circuits, Fig. 5.

In passing through a wall, each wire should be inserted in a separate hole, lined with a hard rubber, glass or porcelain tube, Fig. 4.

Fig. 6 represents a cleat for the three-wire system. Fig. 7 shows the use of three-wire and two-wire cleats in the three-wire system.

CHAPTER IV.

Moulding Work.

Moulding work, so-called because the wires are covered by wooden mouldings, is more expensive, both for material and labor than cleat-work, but is much neater in appearance. It is applicable in all places that are reasonably free from moisture. In damp places the cappings and mouldings are both apt to warp and the appearance of the work will be greatly marred.

It is not usually desirable to attempt to match the woodwork of an ordinary room by using, for example, ash, oak or cherry mouldings. Such mouldings are hard to manage,

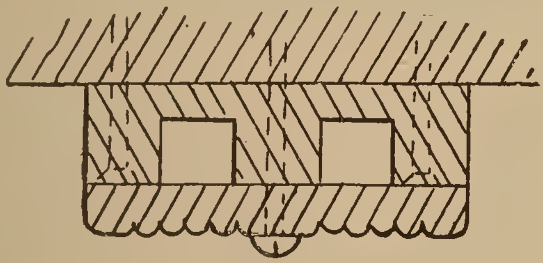


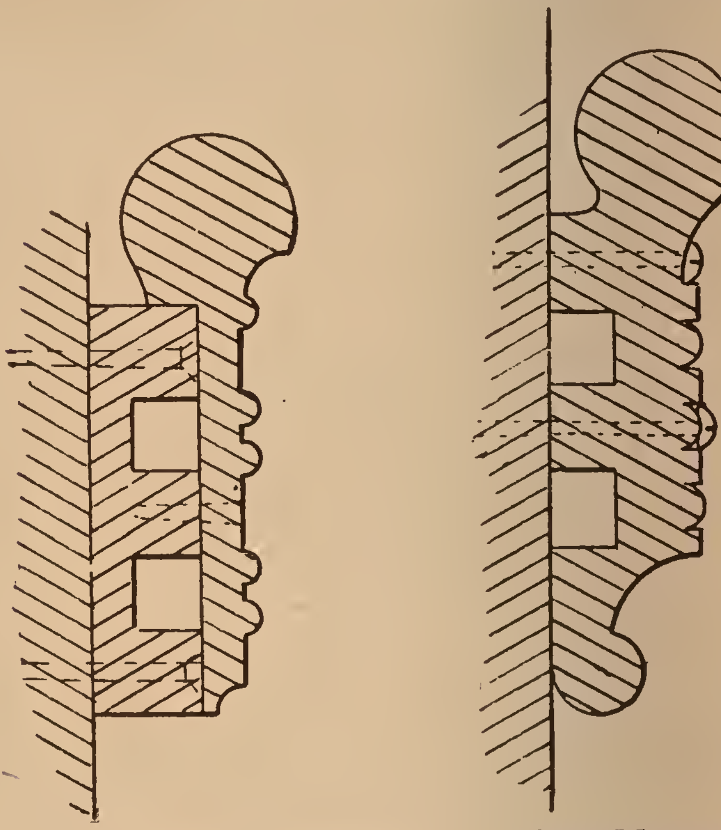
FIG. 8.—PLAIN TWO-WIRE MOULDING.

as they warp and twist badly while seasoning after they have been put in position. They are also hard to cut and fit, and unless the wireman possesses considerable skill as a carpenter, the result will be a piece of work that in the end is more expensive and not as neat as if pine or white wood had been used.

These latter woods do not warp as readily, and when warped are much more easily held in place. As there is a possibility that the location of the lamps may be changed, the cappings should be secured with round head brass screws.

Wires are frequently hidden under strips of moulding that can serve as chair rails, or, under what appears to be an extra row of beading just above the base-board or wainscoting, or below the cornice of a room. A chandelier in the center of a handsomely papered or frescoed ceiling can be reached by dividing the ceiling into panels by mouldings, under one of which the wires can be run, and by the use of rosettes or other ornaments, as the taste of the architect may suggest, often very pleasing effects can be produced by what would at first seem likely to be anything but ornamental.

Fig. 8 represents a cross-section of wood moulding. The lower part is fastened to the wall or ceiling. The positive



FIGS. 9 AND 10. — PICTURE AND WIRE MOULDING.

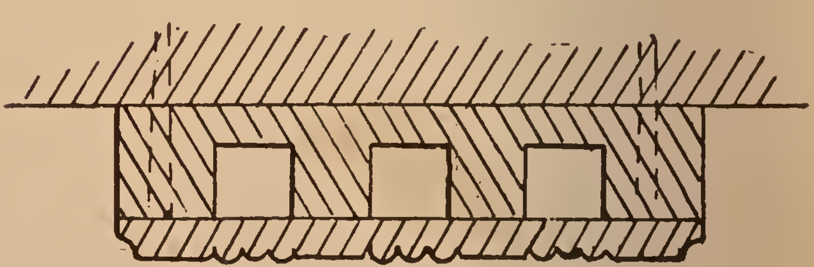


FIG. 11. — THREE-WIRE MOULDING.

wires are put into one groove, the negative wires into the other and the cover is then screwed on. Care must be taken that nails or screws do not touch the wires.

Figs. 9 and 10 represent fancy picture mouldings which are also used as wire mouldings. The use of such moulding in new buildings has recently become very frequent.

Fig. 11 represents moulding as used for the three-wire system.

CHAPTER V.

Concealed Work.

To secure the best results, as far as appearances are concerned, wiring should be concealed. To conceal wires in a building that has already been finished and furnished requires no little skill and care on the part of the workmen. The difficulties which, of necessity, workmen encounter in wiring a finished building are so well known that it is almost superfluous to add that it is very much cheaper to wire a structure while it is building. If this, for any reason, is not desirable the architect should be instructed to leave such openings and holes in the walls and floors as will facilitate the work if done subsequently.

a. Concealed work in a building in course of construction. The best time for doing concealed wiring is when the builders have finished boarding-in and have not yet begun lathing. The cost of wiring at that time is very much less, sometimes not more than one-half as much as in the finished structure. In occupied houses, however, the inconvenience caused by putting in wires can be made slight. Little or no dirt need be made; there need be no hammering or pulling away plaster, laths and floors. The most delicate finishing should in no way be injured by the workmen. When the job is completed, and well done, it should be difficult to discover evidence that the work has been done.

To do concealed work properly requires considerable skill and experience. Such work therefore should be intrusted only to reliable and responsible concerns. Unfortunately, any man who ever fastened a piece of wire for a bell-pull regards himself as an expert also for incandescent wiring. A great number of even important contracts have been executed by men of this kind with the result that, after the expenditure of considerable money by owners of houses it has been necessary to condemn the whole system, as the wires had invariably been improperly placed.

Before work is commenced a building should be thoroughly inspected and plans formed for running the wires.

If the building is in process of construction the wiring contractor must of course use every argument to induce the architect to make provision for the electric light wires. The following will serve as a suggestion:

Whether the plaster is laid directly on the bricks or the wall is furred and lathed, passages should be left by the builders along its surface where necessary, by recessing a course of brick, say three-fourths to one inch. Vertical openings are less easily left; still, by making use of the space between a door casing and an adjacent wall and by making an opening to the floor above or below, the wires can be readily run. The passage of wires from one room to another ought to be provided for by leaving openings through the partitions at suitable places between ceiling and

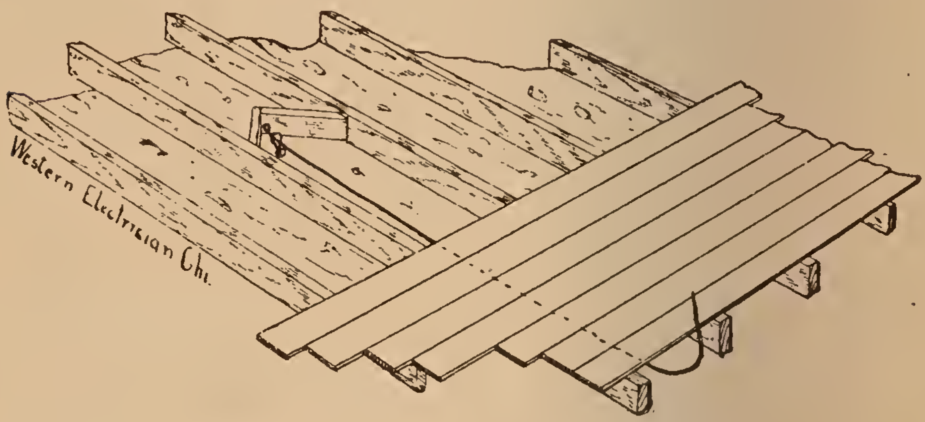


FIG. 12.—USE OF FISHING HOOK.

floor. Wires can be easily secured to the floor timbers after passing from the walls to positions over the chandeliers.

If the building is fire-proof a space of an inch or two will generally be found between the floor boards and the brick or concrete beneath. If wires are not put in at once, one of the spaces between the nailing strips to which the floor is secured, over the chandelier in the room below, should be carefully kept free from dirt and closed with pieces of wood placed in the form of a "V," with the apex near the place for the opening in the ceiling to be made in the future. If the little device shown in Fig. 12 is used when building, at the cost of a few cents, and one of the spaces is reserved for the wires instead of all being made receptacles for rubbish and blocks of wood, hours of labor would be saved in the future when the tedious process of "fishing" wires through the openings is undertaken. Such precautions, too, will often save the cutting or removal of parts of handsome floors which may prove insuperable obstacles to the wiremen.

Mouldings of the types shown in Figs. 9 and 10 facilitate greatly the running and distribution of wires and will prove very convenient in making auxiliary branches for concealed wiring.

It is frequently convenient to use chases about four inches square, purposely left in the walls, to carry wires for room or floor distribution. The location of such chases should be carefully considered with reference to lateral openings. Each section of the building can in this way be provided with "risers," which, with the methods already described, form a perfect system of distribution applicable to almost any building. "Pockets" or openings of sufficient size, say 18x12 inches, must be left in the flooring opposite the wall chases to allow connection with "cut-outs" and "branches," and also for convenience in "fishing." A proper "cut-out" box should be placed in the wall near the chase, to which the wires are run before passing under the floor.

From the foregoing it would seem plain that, in order to secure the best results for the least money, it is necessary the architect should make ample provision for electric wiring. With proper preparation, made at an almost insignificant cost, the difficulty of electric light wiring can not only be greatly diminished, but the cost of the work to the owner can also be greatly reduced. If a wiring contractor is assured that intelligent provision has been made for his work; that convenient openings have been left through walls and floors with as much care as for steam or gas pipes; that he will not have to devote days to drilling brick or stone walls, or taking up and relaying floors, it is hardly necessary to say that he can afford to charge much less for his work.

The importance of this too often neglected matter to architects, owners and builders, is too obvious to require further comment.

b. Concealed work in a completed building. In old buildings, especially those which are not fire-proof, the "fishing" of wires will proceed with few obstacles. The following instructions may give beginners some valuable hints:

HOW TO FISH WIRES.

Punch a hole through the plastering at the required position, being careful that there is no studding at that place.

Use a brad-awl and cut the hole large enough to permit the running of the wires. With a short length of small brass spring wire, push through the opening a few inches of number 19 double jack-chain such as is used for general fishing purposes, first having connected the end of the chain with a piece of heavy linen thread. Run out the thread between the laths and the outside wall until the chain touches the floor beneath; move the thread and locate the chain by the sound; bore a hole through the base-board or floor, as the case may be, toward the chain. Use a two or three-foot German twist gimlet With a small brass spring wire bent at the end in the shape of a hook, fish for the chain and draw it out. At the other end of the thread attach the wire and draw it through with the thread. Passing under the floor bore a second hole through the floor as near the other as possible. Run into this a piece of snake or fishing wire which is ⅛x1-64 inch steel wire, with a hook at the end, until it comes to an obstruction. Locate the obstruction by sound. In running wires under the flooring first carefully examine all parts and find the direction in which the beams and timbers run, and run the wires parallel with these. After locating the end of the fishing wire see if the obstruction is a timber; if so find the center and bore from the middle diagonally through it in the direction of the fishing wire. Drop the jack-chain and thread through the hole; fish for it and draw it through hole number 2; attach the insulated wire and draw it back. Starting hole number 3, bore hole number 4 diagonally through the timber in the direction in which the wire is to be run, making holes 3 and 4 form an inverted "V" through the timber. Run the fishing wire through hole number 4 until it meets an obstruction. If at the end of the room bore through the floor, drop the chain, fish it out, attach wire and draw it home. Putty up holes after having done with them, or, in case of hard finish, plug them up with wood.

In lightly built houses it is often found easier to take off the moulding above the base-board and run the wire under it. In such cases care should be taken to break off the old nails, as any attempt to drive them out would cause a bad break. In closets and around chimneys it is usually found easy to work. A "mouse" or lead weight attached to a string may often be dropped from the attic to the cellar ceiling through the space outside the chimney. It is well before starting on a job to examine carefully the whole house and find the easiest places to run in. When it is necessary to take up carpets be sure and put them down again as quickly as possible, in order to reduce to a minimum the inconvenience to residents.

LOCATION OF SAFETY DEVICES AND SWITCHES.

Having determined which of the three methods of wiring, "Cleat," "Moulding" or "Concealed Work," shall be followed in the different parts of the building, the wire contractor must decide on what general plan the work shall be done.

Ordinarily one of two plans is adopted, either what may be termed the "Tree System," or the "Closet System."

Both systems are applicable to all cleat, moulding and concealed work, and to either the multiple arc or the three-wire system.

Usually, however, cleat-work and moulding-work are done on the tree system and concealed work on the closet system.

CHAPTER VI.

The Tree System.

Fig. 13 represents the tree system of multiple arc wiring.

The system is easily understood. All branch lines connect to the main wires as branches to the trunk of a tree. Whenever the size of a wire changes, or a branch is run from a main, a safety device is inserted. Switches are located in a branch wherever necessary or especially convenient. These safety devices and switches will be further considered in a subsequent chapter.

CHAPTER VII.

The Closet System.

Often in concealed work and sometimes in cleat and moulding-work it is not desirable to have the cut-outs and switches scattered over the ceilings and walls of the several rooms and halls as would be the case if the tree sys-

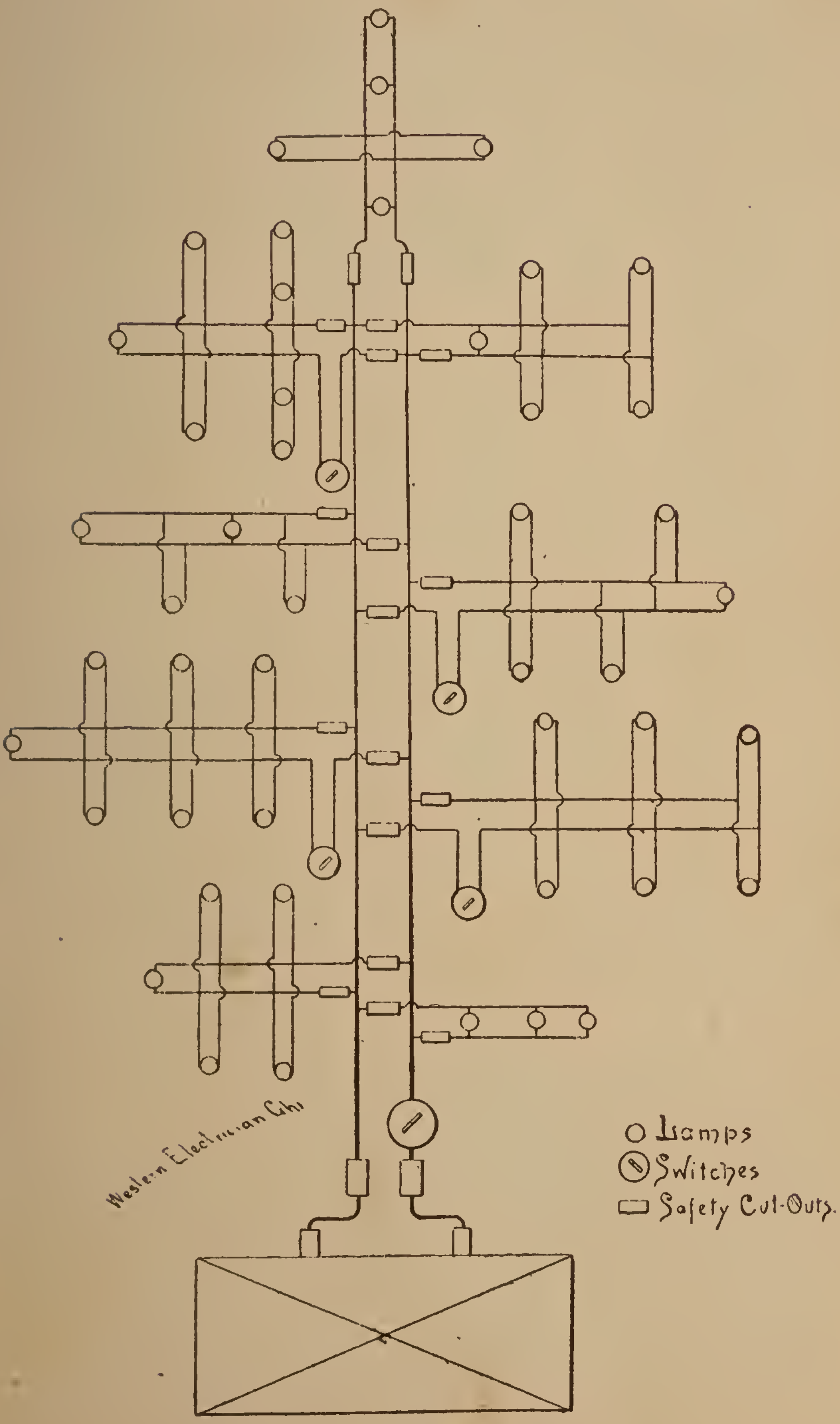


FIG. 13 — TREE SYSTEM.

tem were adopted. It is, therefore, preferable whenever practical to group the cut-outs and switches in dry and easily accessible places. An excellent way, for example, is to place a neat box in the wainscoting. All branch wires lead to this box, and nothing appears except groups of cut-outs and switches. This box should be provided with lock and key. If the building is in course of construction recesses should be left in partition walls for branch wires and boxes.

Fig. 14 represents the closet system.

Fig. 15 shows a box with cut-outs and switches located in a partition wall with several branch wires fished under the floor and through a recess in the partition wall.

The boxes containing the cut-outs and switches should be lined with some non-combustible material such as asbestos cloth of a thickness of at least one-sixteenth of an inch. The outside of the boxes should be painted with asphaltum or other insulating paint.

It is not necessary of course that each room and passage should have its own switch as is sometimes required. Key sockets can generally be used to advantage for brackets and small chandeliers, except where the lamps are inaccessible. Each floor can be controlled by a switch conveniently placed in a hallway, the lights in which should be on a separate circuit. Long passages, cellars seldom used, etc., should have switches placed at their entrances so that they may always be lighted when a person enters or leaves them. The number of modifications which may be made in the location of switches is unlimited, and special arrangements can always be devised to suit the convenience or whims of owners of houses. With the exception of these special switches it is generally advisable to locate the switches and cut-outs in closets as described.

Chapter VIII.

Safety Devices.

Strips of an alloy which fuses at a low temperature are used as safety devices, or plugs, in incandescent wiring. The cross-section of the plug must be of such size that it will melt before the wire it protects becomes dangerously warm. Hence, the sectional area of the safety plug depends upon the cross-section of the wire to be protected and not upon the number of the lamps. Safety plugs are not supposed to protect incandescent lamps from an excess

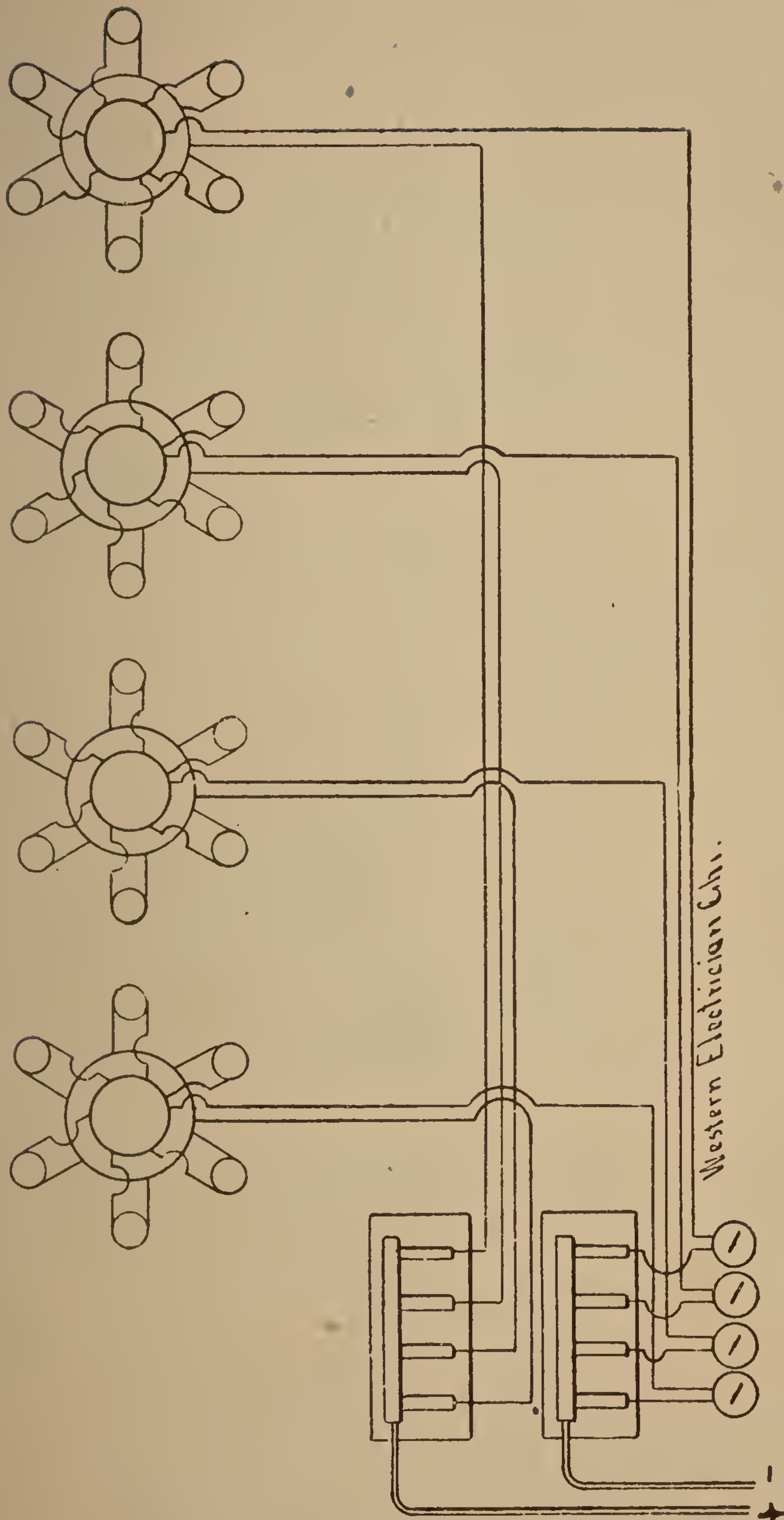


FIG. 14. — CLOSET SYSTEM.

of current, but to protect buildings from fire by preventing any part of the electric light conductors from carrying an excess of current, and thus becoming too hot. The marking of safety plugs with the number of lamps they can carry has led many a wireman to conclude that the plugs

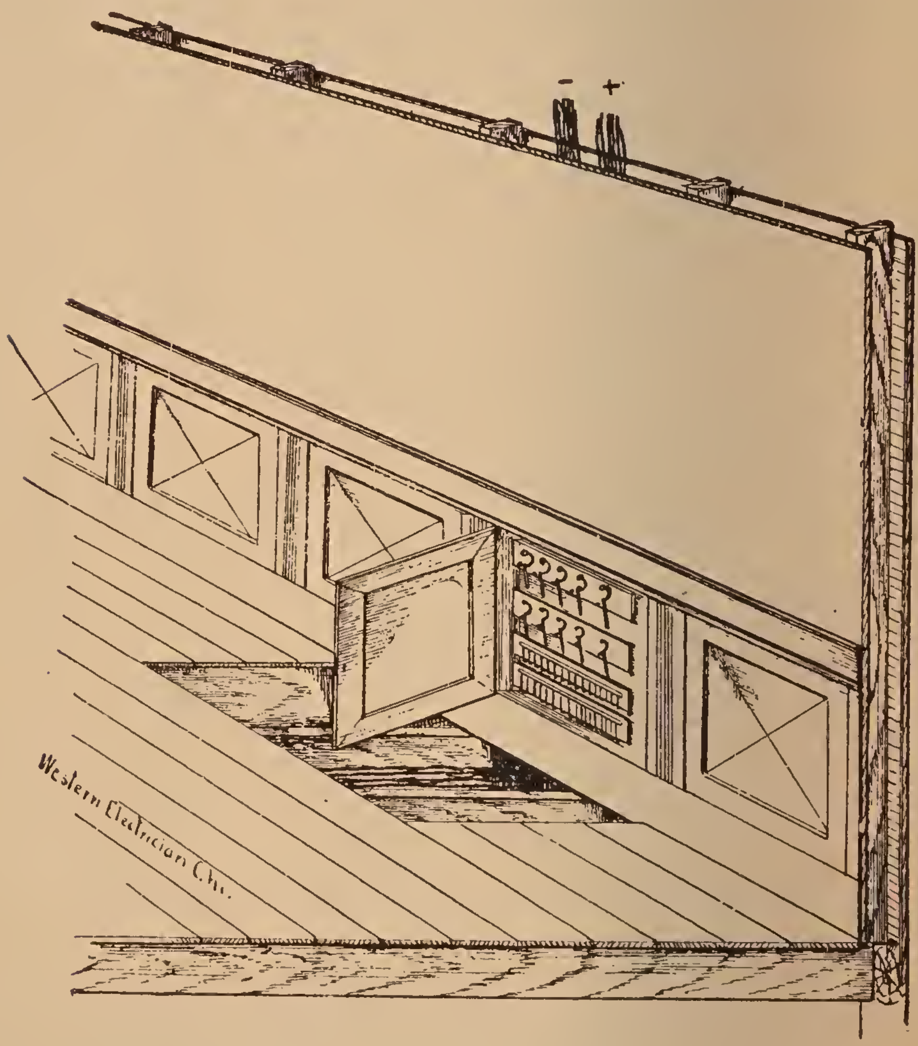


FIG. 15.—DISTRIBUTING CLOSET.

are put in for the protection of a certain number of lamps. The marking of the plugs simply expresses their carrying capacity in 16 candle power lamps instead of in amperes.

The blowing-out of safety plugs is very often caused, not by an excess of current, but by poor contact between the safety plug and the safety plug-holder. A poor contact, of course, will cause heating, which will gradually fuse the metal at one end.

A multitude of safety devices or "cut-outs" has been invented. They entirely eliminate the element of danger if a sufficient number is used, and if work is properly done, when a building is first wired.

Wherever the size of a wire changes, or a branch is run from a main to supply a smaller conductor, fusible plugs or "cut-outs" are employed. These protect the small wires from a dangerous amount of current that would tend to pass through them in the event of a "cross" caused by the accidental contact of bare wires of opposite polarity. Too strong a current will, of course, fuse the cut-out and break the circuit. Large or small clusters of lights in chandeliers are protected in the same way by a small device often called a "bug." This is a small fusible wire secured to an insulating block of wood or porcelain, and concealed under the canopy of the fixture or chandelier. Only double-pole safety cut-outs should be used, *i. e.*, each branch, etc., should be provided with a cut-out in both the out-going and the return wires.

Chapter IX.

Switches.

A switch is a device used to break or make circuit, or, in other words, to cut off the current in certain convenient places from a number of lamps or cut them in again. The switches should be so constructed that they will open and close the circuit very quickly and spark but little. This is accomplished by having the switch so arranged that the hand will start it,—while a powerful spring throws the switch open or closes it immediately. The contact should be sufficient to prevent heating at these points.

Switches are either of the single or double-pole break type. Double-pole switches are preferable as they allow both the cutting-out of a faulty circuit and the testing for faults in the shortest time.

Chapter X.

Splices.

When a splice in a wire is necessary, it should be made after the fashion of the American telegraph splice, Fig. 16.

It should be perfectly cleaned, firmly soldered, and afterward well taped with insulating tape.

This splice can easily be made in wires not larger than No. 3 B. & S. gauge. In larger wires splices are made in the manner shown in Fig. 17.

Fig. 18 shows the method of attaching a small branch wire to a larger wire.

Joints must always be soldered. Use acid for soldering and not resin. The reason is best given in the following

FIG. 16.—AMERICAN TELEGRAPH SPLICE.

abstract from a letter written by an inspector of the Boston Fire Underwriters' Union: "I am often asked why I prefer acid to resin to solder joints in electric light wires. I do not prefer it, but think that we get better results from acid than resin. It is safe to say that only one out of ten

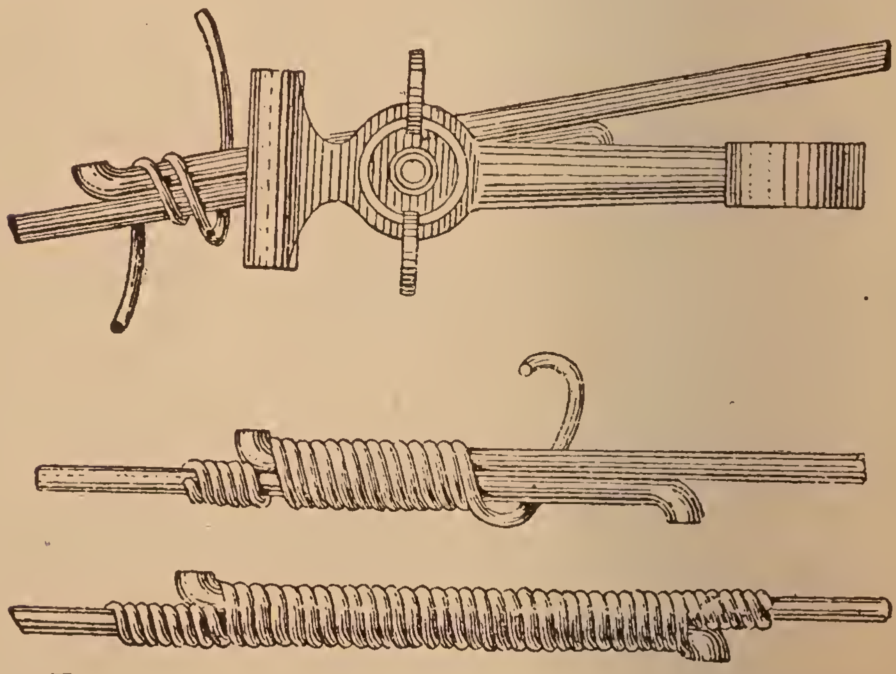


FIG. 17.—METHOD OF SPLICING HEAVY WIRES.

knows how to make a good joint with resin, or, if they do know, they will not take the trouble. The secret of joints made from resin is a perfectly clean surface. This, of course, requires some care, while with acid, if the wire has any oil or grease, or any of the insulation which the linemen have failed to scrape off, the acid will do the work which the workmen (by name, but not by nature) have failed to do. I have learned from experience that the wires eaten off by acid are so few that the danger from fire from such cases is less than those from poor joints with resin. I hope that some time in the future we shall have men that we can depend on to make joints with resin."

Never apply tape to unsoldered wire splices; the rubber on the tape will cause corrosion and so make poor a contact which at first was good.

The joints or connections in waterproof wires should be made waterproof also. This is done in the following way: After having cleaned, spliced and soldered the wires properly, cover the joint with hot Chatterton's compound, holding it between the fingers, to almost the total thickness of the insulated wire. Cover it with kerite tape and give

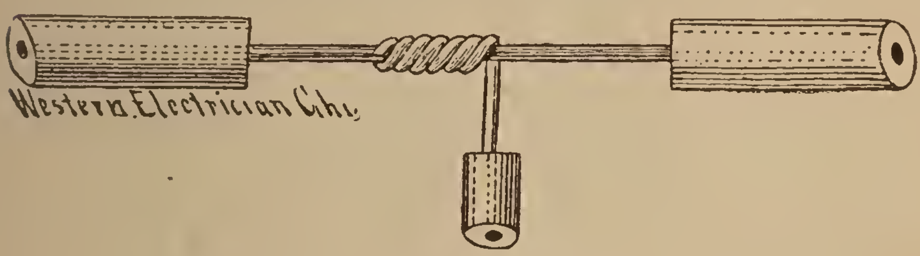


FIG. 18. -- METHOD OF TAPPING.

it a second thin coating of hot compound, or hot asphaltum, and then give it a second coat of kerite tape. Hot liquid asphaltum should be used instead of compound, where there is danger from sewer or illuminating gas, which often permeates the soil and basements of houses in large cities. Frequently waterproof wires with an outside braiding or taping are used. This outside cover is intended simply as a protection for the real insulation or dielectric from abrasion. When joints are made or branches are taken off the mains, this braiding or taping must not reach into the insulating material of the splice, as it would practically form a path for the moisture to penetrate the insulation to the wire. This point, although of the greatest importance, is very often overlooked, and its neglect causes frequent break-downs of the insulation of joints.

Chapter XI.

Safety Rules.

1. Whenever wires pass through walls, roofs, floors or partitions, or there is liability to moisture, abrasion, or exposure to rats and mice, the insulation must be protected with rubber, stoneware or some other satisfactory material.

2. Wires entering buildings must be wrapped with tape, and bent in such a manner that water will be prevented from entering the building.

3. All wires passing over or under steam, gas or water pipes, must have good insulation between them. Blocks of wood are the most desirable. This rule also applies to foreign wires; they should be treated the same as pipes.

4. Soft rubber tubing is not desirable as an insulator.

5. Wires should go over water pipes, where it is possible, so that the moisture will not settle on them.

6. Where incandescent wires enter buildings, they must have double-pole safety catches as near the entrance as possible.

7. Main wires must not be less than two and a half inches apart, except where they are in grooves.

8. All wires that are fished over the ceiling or in the walls, must have waterproof insulation. This rule also applies to wires covered with moulding, or concealed in any manner.

9. Where underwriters' wire is used, it must be in plain sight on the walls or ceilings.

10. Care must be taken to avoid placing wires above each other in such a manner that water could make a cross connection.

11. Wires located in damp places, for instance in packing houses or breweries, must be run on glass or porcelain insulators of suitable form.

12. Conducting wires leading to each important branch circuit, must be provided with an automatic safety device, capable of protecting the system from any injury due to an excessive current of electricity. These devices must be proportioned to protect the smallest wires in the loop to which they are attached.

13. On all loops of incandescent circuits, safety catches must be used on both sides of the loop, and switches on such loops should be double-poled.

14. Ceiling blocks that are used on pendant drops must have safety fuses in them where flexible cord is used;

cord should have a knot tied in it with the knot on the top side of the block, so that the strain will come on the knot instead of on the connection; and where it is possible, a knot should be inside of the socket, the same as the block.

15 The small wires leading to each lamp from the main wires must be thoroughly insulated, and if they are separated or broken, no attempt must be made to join them while the current is in the main wires.

16. When wires are put on gas fixtures, the fixture must be insulated from the main pipe, and the insulating joint used for this purpose must be made so that the sediment in the gas will not form a connection over the insulating material.

17. Chandeliers or brackets attached to any ground connection must have insulating yokes or couplings on them. Individual insulation of lamps at the sockets is not allowable except on brackets in special cases.

18. The use of metal staples for fastening wires is not permissible under any circumstances.

19. In rooms where explosive gases may develop, or where the atmosphere is very damp, the incandescent lamps should be inclosed in vapor-tight globes. Switches are not permitted in places filled with explosive gases (breweries, distilleries), as the spark at make or break might cause an explosion. Fusible safety plugs must be inclosed in air-tight non-combustible cases.

ALTERNATING TRANSFORMER SYSTEMS.

20. Transformers or converters on alternating circuits must be outside of buildings, and must be placed high enough from the roof to prevent possible injury to firemen. Inside wires should be treated as any other incandescent circuits.

ABSTRACT OF CHICAGO SAFETY RULES.

No plant shall be run without a certificate of inspection from the superintendent of city telegraph.

The insulation resistance of each circuit supplied by separate feeders or mains, must measure at least 100,000 ohms.

.The use of underwriters' or similar wire, is not permitted.

The inspector's fee is one dollar for each horse power, ten sixteen candle power lamps being allowed for one horse power.

The plant cannot be legally altered after inspection, without first notifying the city electrician. While the plant remains in the same condition as at the date of the certificate, that document is valid.

Violation of any of the above requirements subjects the party so transgressing to a fine of from $50 to $100 for each day the infraction is continued.

Chapter XII.

Insulation and Testing for Faults.

When wires are being put up they should from time to time be tested for short circuits and grounds. If the building is being constructed, close watch must be kept on other artisans, especially on carpenters, plumbers and gas fitters These workmen usually have no idea of the meaning of insulation, and seem to delight in cutting wires, injuring costly insulation and perpetrating other malicious mischief generally.

It has been shown in the foregoing pages how wires should be put up, and the abstracts of the safety rules clearly indicate the required standard of insulation. On this subject Prof. J. D. F. Andrews very pertinently says in a paper recently published:

"The conductor is copper, and the most widely adopted insulation is India rubber in many modified forms. The insulated conductors are usually protected and held in position by wooden casing. We need hardly question the object of the conductor, but what is the object of the insulation? The conductors, if held in good, dry, wood casing only, would be protected from interference. Its object is to meet one of the worst contingencies—moisture or water, which is an ever-working evil on electric light wires. If you place a copper wire in water with electricity passing along it, the copper will be removed electrolytically from the part of the wire where the electricity enters, and deposited where it leaves. The same process goes on where uninsulated or badly insulated electric light wires lie in water, or surrounded by moisture. Even though no electricity is flowing through a copper wire exposed to moisture and the atmosphere, it is acted upon chemically. The result of the electrolytic and chemical actions on electric light wires is to thin them and make them insufficient for carrying the current, and consequently they become heated. Or the result may be that when the wire is eaten through an electric arc is produced. This effect or fault is called an opening circuit, and is about the most difficult and dangerous fault to contend with. It is usual to lay the electric light leading wire in a groove in the casing neighboring and parallel to the return wire. Water often saturates the casing between them, and when the insulation is poor the electricity will pass through the moistened wood and char it, often setting it in flames. Faults such as this where a great leak is taking place between the wires are called partial short circuits, and are equally difficult to avoid and as dangerous as opening circuits. The study of the insulation of the wires is therefore obviously of great importance. The next contingency that has to be contended with is mechanical damage. The wires being more or less flexible and the covering soft, they are easily damaged. This difficulty is usually met by casing the wires in wood, and, it being necessary to employ two conductors for electric lighting, the casing has two grooves, one for each conductor, a cover being fixed over them. Wood casing has the disadvantage of harboring moisture. Another method of protecting the wires is that of sheathing them with an outer covering of wire. This method protects the wires much more effectually than casing, and does not harbor moisture. Iron pipes have been used in many cases, and are an excellent protection; but moisture collects in them, and if there should be a fault in the insulation it is sure to find it. There is another fault besides the opening circuit and partial short circuit not yet touched upon, namely, a dead short circuit, or a direct contact between the opposite conductors. This is the most frequent fault, and if it were not that there is a simple appliance called a fuse to meet it, it would also be the most dangerous fault. Short circuits usually happen in the fittings where the opposite conductors are necessarily brought nearer each other, and at these points the insulation is generally much thinner and poorer. Short circuits also often happen where the wires cross, and frequently by contact with gas and water pipes, which make very complicated faults because the two wires usually touch the pipes a distance apart."

The insulation resistance between wires and earth must be as high as possible, and each branch should be tested separately, while the work is in progress.

The wireman of course, can not as a rule afford to buy an expensive testing set and measure the actual insulation resistance. He can however, easily obtain a magneto or a detector galvanometer, and by means of it, test through a resistance of even more than 15,000 ohms and thus locate the worst faults in the insulation.

A testing set designed especially for incandescent wiremen, linemen, dynamo tenders and bell-hangers consists of a highly-polished wood box containing a small *dry* galvanic cell, a detector galvanometer of 500 ohms' resistance, a contact key, and two binding posts. The box is so arranged that by detaching two hooks the connection between the cell, galvanometer and key can be easily inspected. There is in the upper part of the box space enough to carry wires to be attached to the binding posts and the object to be tested. The galvanometer, key and

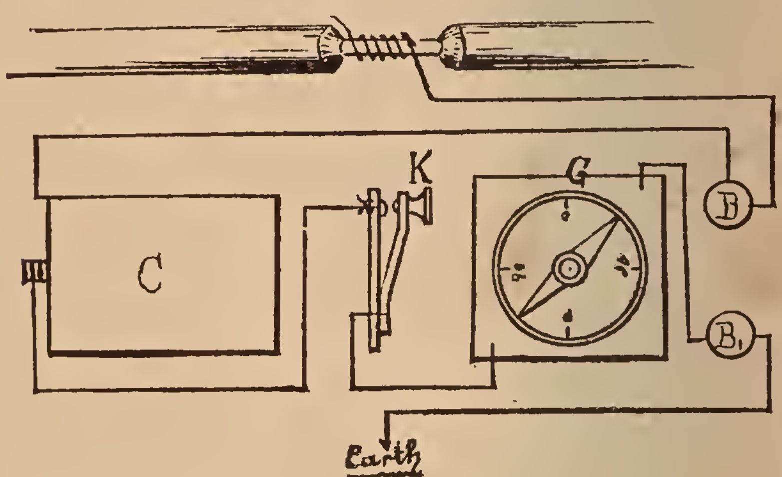


FIG. 19 — CONNECTIONS OF A TESTING SET.

binding posts are mounted on the upper surface of a little shelf which divides the box into two parts. The lower part contains the dry cell. The center shelf slides in notches so that by opening the box entirely the whole centerboard with galvanometer and cell may be pulled out for inspection or repairs. As the battery is dry the box may be handled and carried in any position without the least danger of damaging it.

Fig. 19 explains the connection of the little instrument. *C* is the dry cell. *K* is the contact key. *X* is the contact point below the key. *G* is the galvanometer. *B B* are the binding posts of the instrument.

The object to be tested is connected to the two binding posts *B* and *B*, and then the contact key is pressed down.

If the needle deflects, there is a current passing through the circuit; if the needle does not deflect, there is no current passing.

Before testing, the instrument should be put on a level, and be turned until the needle points to 0. The greater the deflection the greater the current which passes through the galvanometer. The resistance of the coils of the standard galvanometer in this set is 500 ohms. They are made of any resistance, however. One cell will deflect the needle even through a resistance of 15,000 ohms. If, for instance, the insulation resistance of a wire should be tested, one binding post is connected by means of a wire to the bare copper wire, while the other binding post is connected to "earth." Any gas pipe or water pipe, which runs into the ground may be used as "earth." Care should be taken not to use a waste pipe, or any pipe which does not run into the ground as "earth."

WIRING FIXTURES AND ELEVATORS.

CHAPTER XIII.

Wiring of Fixtures.

When a building is equipped with incandescent lights, it is frequently desirable to attach the lamps to chandeliers or other metal fixtures which may be provided.

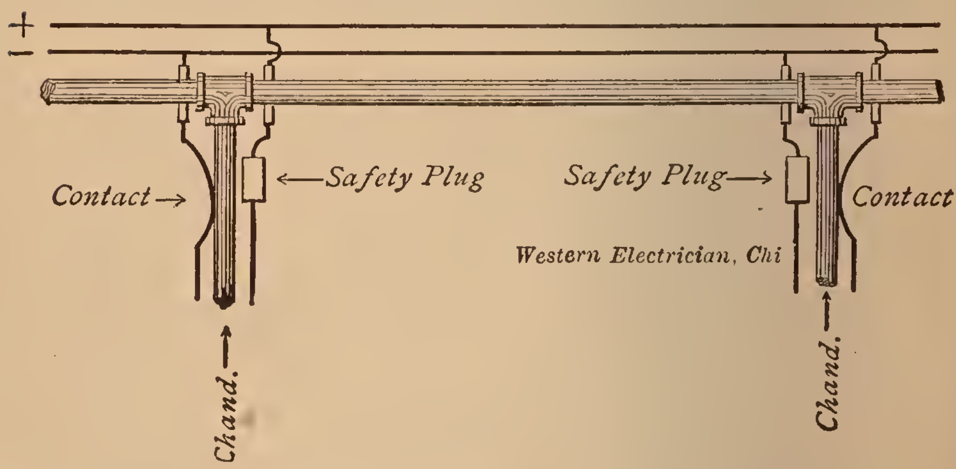


FIG. 20.—GROUNDING ON GAS FIXTURES.

The fixtures may be of three kinds, viz., those designed for electric lights only; those designed for gas only; and those which may be used for either or both gas and electricity, and are called combination fixtures.

When the incandescent light is introduced in old buildings, it will be frequently necessary to adapt the gas fixtures to the new method of lighting. Special pains must then be taken to keep up a good insulation.

The wires having been brought to all gas outlets, it is next necessary to insulate all fixtures from each other and from ground by means of insulating joints. If the fixtures were not insulated, the grounding of a wire on one fixture would necessarily ground the whole system; furthermore, if a positive wire on one fixture and a negative wire on another fixture should become grounded, the gas pipe connecting the two fixtures would constitute a short circuit between the two poles of the dynamo. Fig. 20 explains this clearly. The diagram also shows that in such a case, *single* pole safety fuses would constitute no protection. *Double* pole safety fuses should always be used. The use of single pole safety fuses without insulating joints at the base of the fixtures may result in the burning of holes in the gas pipes, followed by the escape of gas, and ultimately by the ignition and explosion of a dangerous mixture of gas and air. The wires must be kept as far from gas pipes as possible. The combination of escaping gas and grounded wires is very undesirable.

Insulating joints are of many sizes and various patterns, the design of each being determined by the special use to which it is to be put. All insulating joints, however, consist of two pieces of iron or brass fastened together in some way, but entirely insulated one from the other. The metal parts are threaded. Both threads are female usually, one to receive the gas pipe outlet, the other the iron chandelier stem. The insulating material consists of either vulcanite or compressed paper fiber; the latter is superior, as it makes excellent and durable gas-tight joints, the fiber shrinking but little when tested by time. The construction of the joint should be such that no sediment formed by condensation, or chemical combination of the elements composing the gas, can collect and form a short circuit across the insulating material. In ordering insulating joints the purchaser should state the diameters of gas outlets and fixture stem, and should explain whether gas, combination or electric light fixtures are to be used; whether the joints are to be attached to the gas outlet or are to be provided with tripods; and whether the joints are intended for a chandelier or a wall bracket.

Gas attachments for incandescent lamps are used for fastening lamps to the arms of a gas fixture. This attachment generally consists of a narrow strip of metal, commonly brass, provided at one end with a small nipple for attaching the lamp socket; the other end is flat and through it a hole is punched to permit clamping directly under the gas pillar when it is screwed down, thus making a very simple but nevertheless a very neat looking fixture.

Insulating each lamp socket separately from its attachment by means of a small rubber thimble has of late also become customary, and is considered an excellent precaution as too much care can not be taken in maintaining good insulation throughout. The insulating thimble alone, should, however, never be considered sufficient, without an insulating joint, and in every case where lamps are attached to any metal supports the fixtures should be insulated from the latter.

Brass rings are often fastened around iron posts or columns to hold a circle of incandescent lights. They should always be thoroughly insulated from the columns. Fixtures attached or fastened to iron girders should be insulated. Insulating joints should be examined occasionally, and the clamping screws tightened, to prevent any possible leakage of gas on account of shrinkage of the insulating material.

A gas fixture to be properly wired must be taken down from its support, a cap being temporarily screwed on the pipe to prevent the escape of gas. All the wires on a fixture should, if possible, be concealed between the iron body and the metal covering or shell which is generally made of brass or bronze If sufficient space cannot be found there, it is often possible to make room for the wires by substituting smaller iron stems in the chandelier body, or by increasing the size of the shell. The wire in the fixture should be left slack so that at any small turn or twist the fixture will not break the wire or cut or injure its insulating covering. Care must be taken, too, where the wire passes over any sharp bends or burred edges. File away as much as possible of the rough metal and use soft rubber tubing or wrap the wire well with tape to prevent injury to the insulation.

To pass the rings and other sections where there is not sufficient space, bore through with a small monkey drill, or punch a hole with the brad-awl, and file off sufficient metal to allow an exit; if necessary run the wire through and over the obstruction. The wire employed must always be of the best insulation, and must not be too thick, as the space is usually very limited. When it is utterly impossible to conceal the wires, or when the job is to be done very cheaply, outside wiring must be resorted to. Here duplex wire can be very advantageously employed, the color of the covering matching as nearly as possible that of the fixture.

The wire should be held in place by means of a few turns of small insulated wire of similar color around the arms of the fixture, and these as well as the wire itself should be glued to the fixture by a little shellac varnish. In this way the wire will be held firmly in place and if the work is well done it will often be quite difficult to find any indication that the fixture has been wired on the outside of its shell. The joints or hinges of a swing bracket must be bridged over with a wire loop in the shape of a spiral of a size sufficient to prevent interference with the action of the bracket.

A canopy which slides over the outside shell and is provided with a set screw to hold it in any desired position on the chandelier, will hide from view both the insulating joint and the "bug" or chandelier safety plug with which each fixture should be provided. (Compare Chapter VIII.) It will also catch any molten fuse metal, and will always form an ornamental finish to the entire fixture.

Fixtures intended for electric lights only are the easiest and most simple to wire, as special provisions are always made for this purpose. If the fixtures are not attached to any system of gas piping or other metal supports, the matter of suspending them is very simple; iron tripods only are required to fasten them to walls or ceilings. If they are to be attached to such a system of piping, whether connected to the gas mains and containing gas or not, the precautions already noted must be taken to insulate each fixture. A special insulating joint is made for this class of fixtures which serves also as a cap for the gas pipe.

Combination fixtures are arranged to allow the use of either gas or electric light, as there are two separate sets of arms or piping, one for gas, the other for electric lights. They are usually wired by the manufacturers and sold complete with insulating joints. All that remains for the wireman to do is to attach and connect the lamp holders. The insulating joints in this case are of the same general type as those used for the fixtures designed for gas only.

Old brass gas fixtures can very often be easily remodeled to form combination fixtures by attaching additional arms for incandescent lamps, and by providing the necessary channels for the wires. Such work is best done in a gas fitter's or brass finisher's work shop.

In general, every fixture should be well tested for gas leaks and grounds or short circuits before being used. Very often it will be found cheaper and safer to use independent electric light fixtures than to attach the incandescent lamps to gas fixtures. This is especially true in factories and similar places. The fixtures there are often in a deplorable condition, and should not be used as supports for incandescent lamps unless first entirely overhauled and put in good order.

Chapter XIV.

Wiring of Elevators.

The usual method of wiring for elevators is to suspend one end of a two-conductor cable midway between the top and bottom of the elevator well, and to run the other end to the top of the cab, fastening each end securely. Care must be taken to allow the cable to swing freely, so that the cab will not interfere with it. Some slack must be left, so that when the elevator is at the top or bottom of the well the cable will not be pulled tight.

At the end of the cable which is fastened in the well a double-pole safety plug must be placed, so that in case of accident to the cable it will be cut off from the feeding circuit. The other end of the cable connects with the wires of the fixture inside the cab.

An extra heavily insulated flexible twin cable should be used. The common twin flexible cable used for portable lamps and for suspending lights from ceiling cut-outs is not suitable for this purpose. Each strand of wire should be at least equal to No. 14 B. & S. gauge, and each strand should have thick insulation of good quality. Both conductors should be covered and braided with cotton until the cable has at least an outside diameter of ⅝ inch. A cable manufactured in this way will be cheaper in the end, as it will last much longer than the common twin cable drawn through a soft rubber tubing, which is so often used. Several wire manufacturers make a special electric light elevator cable similar to that described.

WIRE GAUGES.

CHAPTER XV.

Wire Gauges.

There is a multiplicity of wire gauges. For incandescent wiring, however, only three are used, viz.: The Brown & Sharpe or American gauge, the Birmingham gauge, and the Edison standard gauge.

Wires are generally "gauged" by measuring their diameters. What we really want to know, however, is the sectional area of wires, which varies in the ratio of the square of the diameter. A thousandth part of an inch called a "mil" is usually taken as the unit of measure of the diameter of a wire.

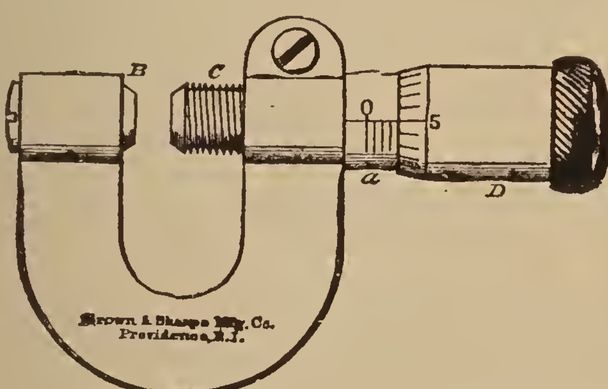


FIG. 21. — MICROMETER GAUGE.

Since wires are round, and the areas of circles increase as the squares of the diameters, we may regard the "mil" as circular wire.

By squaring the diameter in "mils" of any wire, we obtain at once its area in "circular mils," that is to say, the number of unit wires to which it is equivalent.

In Table I are given the circular mils for the three wire gauges named. In ordering special sizes of wire, it is always advisab!e to give the cross-section of the wire in circular mils, not the gauge.

One mistake often made is to call, for instance, "0000" wire 'four o" wire. This is entirely wrong.

Table I shows that in the B. & S. gauge a "0000" wire is equal to 211,600 circular mils, while the term "four o"

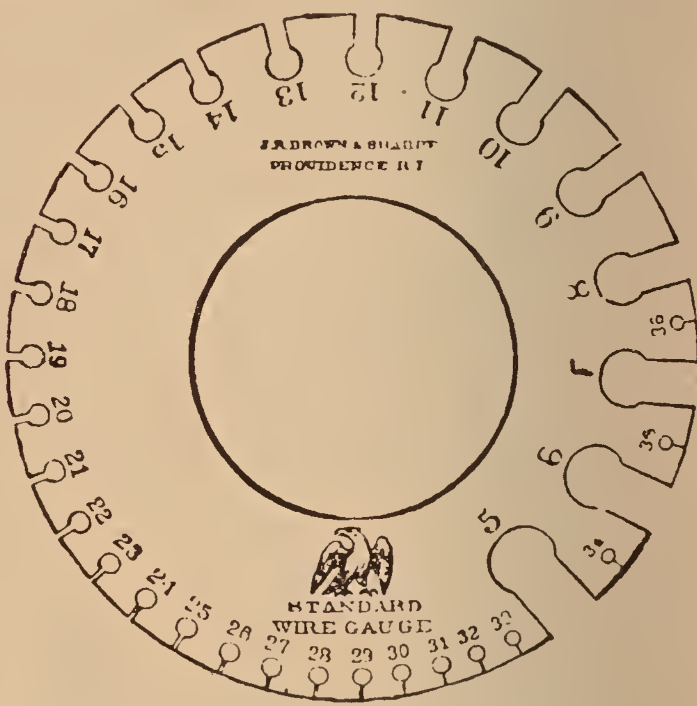


FIG. 22. — AMERICAN GAUGE.

wire indicates a conductor made up of four single "o" wires equal to 105,592×4=422,368 circular mils.

In Table II are given other valuable data covering electric light conductors.

Figs. 21 and 22 show two familiar types of wire gauges. The micrometer gauge is preferable as it measures the diameter of a wire in mils, and will answer in every case, no matter which gauge may be used by the manufacturer.

GENERAL ELECTRICAL DATA.

Preliminary to the explanation of the methods employed in calculating sizes of wires and percentages of loss in conductors a few electrical data will be given which may help the beginner to understand the underlying principles.

The ordinary statement that an electric current is flowing along a wire is only a conventional way of expressing the fact that the wire and the space around the wire are in a different state from that in which they are when no electric current is said to be flowing.

To illustrate the action of this so-called current, it is generally compared with the flow of water. In comparing hydraulics and electricity, it must be borne in mind, however, that there is really no such thing as an "electric fluid," and that water in pipes has mass and weight, while electricity has none. Whatever electricity may be, it is *not* matter, and it is *not* energy. We do not speak of water as energy, but we mean by a water power a quantity of water under a head or pressure; so a quantity of electricity under a pressure is stored energy, and can do work. All our electrical machines or batteries are merely instruments for moving electricity from one place to another, or for causing electricity when accumulated in one place, to do work in returning to its former level distribution.

The head or pressure of a standpipe is what causes water to move through the pipes which offer resistance to the flow. We might call this head or pressure the *water-motive* force; so in electricity, the head or pressure, or as it is called the *electromotive* force, will make the electricity move through the wires.

CHAPTER XVI.

Coulomb.

The unit quantity of electricity is called the coulomb.

CHAPTER XVII.

Ampere.

A current of water is the *rate of flow*, or the intensity or the strength at which the water flows. We say, for instance, the water flows through a pipe at the rate of one gallon per second. Similarly the unit of electric current is *one coulomb per second. This is the ampere* or unit rate of flow, or unit of current strength, or simply the unit of current of electricity.

In the case of the water flow, we have no single word to express the strength of the current. but have to speak of quantity and time.

CHAPTER XVIII.

Volt.

The unit of electric pressure, or electromotive force or difference of potential, is called the volt. We speak of an electromotive force of so many volts as we might speak of a head of water of so many feet, or of a steam pressure of so many pounds to the square inch. Water may fall from a higher to a lower level, a certain vertical distance, say of ten feet, so of electricity it is said to fall through a difference of potential, of say ten volts.

There is a difference in the meaning of the terms "difference of potential" and "electromotive force," although in most cases these two terms are equivalent. In the case of a water standpipe, the height or head of the fluid would be the "potential," and the difference between head and lower level the "difference of potential," while the tendency to flow produced by the potential would be the "electromotive force."

CHAPTER XIX.

Ohm.

A pipe of small diameter offers a greater resistance to the flow of water than a pipe of larger diameter. So a wire of small diameter offers more resistance to an electric current than a wire of large diameter. If we double the cross-section of a wire we halve its resistance. If we double the length of a wire, we double its resistance. If we double the cross section and double the length of a wire, the resistance remains the same. This law may be expressed thus:

For a wire of a given substance the resistance is directly proportional to the length, and inversely proportional to the cross-section. The unit of electrical resistance is called an *ohm*.

CHAPTER XX.

Conductors and Insulators.

Bodies in which the electric current moves freely are called conductors, and those in which it does not move freely are called insulators. There is, however, no substance so good a conductor as to be devoid of resistance, and there is no substance of so high a resistance as to be strictly a non-conductor.

In the following list the substances named are placed in order, each conducting better than those below it in the list:

Best Conductor	
Silver	
Copper	
Gold	
Zinc	
Platinum	
Iron	Good Conductors.
Tin	
Lead	
Mercury	
Charcoal	
Acids	
Water	
The body	
Cotton	
Dry Wood	Partial Conductors.
Marble	
Paper	
Oils	
Porcelain	
Wool	
Silk	
Resin	
Gutta-Percha	Non-Conductors or Insulators.
Shellac	
Ebonite	
Paraffine	
Glass	
Dry Air	
Worst Conductor	

CHAPTER XXI.

Ohm's Law.

Ohm's law expresses the relation of the three units, ampere, volt and ohm to each other. The law states that the current strength in any circuit is directly proportional to the electromotive force, and inversely proportional to the resistance. This law may be expressed in an equation, viz.:

$$\text{Current in amperes} = \frac{\text{Electromotive Force in Volts.}}{\text{Resistance in Ohms.}}$$

This equation is generally written in symbols thus:

$$C = \frac{E}{R},$$

C denoting current strength; E, electromotive force; and R resistance.

This law may also be written:

$$E = C \times R \quad \text{or}$$

$$R = \frac{E}{C}.$$

CHAPTER XXII.

Conductivity.

Conductivity is the inverse of resistance. The term expresses the capability of a substance to conduct the electric current. If Co is the conductivity of a substance, $\frac{1}{Co}$ is its resistance, and if R is the resistance of a body, $\frac{1}{R}$ is its conductivity. Good conductors of heat are also good conductors of electricity.

The figure which indicates the relation between one substance and another as to their capacity to conduct electricity is called, "relative conductivity." Taking the relative conductivity of silver as 100, that of pure copper is 96. The "specific resistance" of a substance is the reverse of its relative conductivity. The specific resistance of a substance is generally expressed as the resistance of a centimeter cube of that substance in thousand-millionths of an ohm. The following table gives the data for a few metals:

Substance.	Specific Resistance.	Relative Conductivity.
Silver	1,609	100
Copper	1,642	96
Gold	2,154	74
Iron (soft)	9,827	16
Lead	19,847	8
German Silver	21,170	7.5
Mercury (liquid)	96,146	1.6

The specific resistance of copper is therefore: $\frac{1642}{1000000000}$ ohms, or 1.642 microhms. *

CHAPTER XXIII.

Divided Circuits.

If a circuit divides, as in Fig. 23, into two branches at A, uniting again at B, the current will also be divided, part flowing through one branch and part through the other.

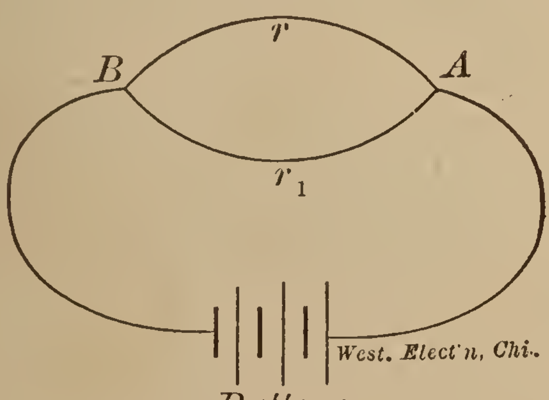


FIG. 23. — DIVIDED CIRCUITS.

The relative strength of current in the two branches will be proportional to their conductivities.

In fact, this law will hold good for any number of branch resistances connected between A and B. Conductivity is, as shown before, the reciprocal of resistance. If, for in-

* The prefixes "meg" and "micro" denote million and millionth. For example, a megohm equals 1,000,000 ohms, a microhm equals $\frac{1}{1000000}$ of an ohm.

stance, we assume that the resistance of r=10 ohms and r_1 =20 ohms, the current through r will be to the current through r_1 as $\frac{1}{10}$ to $\frac{1}{20}$. This may be written in the form of a proportion:

$$\frac{1}{10} : \frac{1}{20} :: = \frac{2}{20} : \frac{1}{20}$$

or as 2 : 1,

or, in other words, $\frac{2}{3}$ of the total current will pass through r and $\frac{1}{3}$ through r_1. The *joint resistance* of the two branches between *A* and *B* will be *less* than the resistance of either branch singly, because the current has increased facilities for travel. In fact, the joint conductivity will be the sum of the two separate conductivities. Taking again the resistance of r=10 ohms and r_1=20 ohms; we have the joint conductivity $\frac{1}{10}+\frac{1}{20}=\frac{3}{20}$, and taking the reciprocal of $\frac{3}{20}$ we get $\frac{20}{3}=6\frac{2}{3}$ ohms as the joint resistance. In most of the cases we have to deal with, the resistances of the different branches will be alike; this simplifies the calculations considerably Take, for instance, two branches of 100 ohms' resistance each and find the joint resistance.

DEMONSTRATION: $\frac{1}{100}+\frac{1}{100}=\frac{2}{100}$; the reciprocal is $\frac{100}{2}$=50 ohms, or in words, the joint resistance is one-half of the resistance of a single branch, and each branch, of course, will carry one-half of the total current in amperes.

With three branches of equal resistance the joint resistance will be $\frac{1}{3}$; with 4 branches $\frac{1}{4}$; with 100 branches $\frac{1}{100}$ of the resistance of a single branch.

If, for instance, the resistance of an incandescent lamp hot is 180 ohms, the joint resistance of 100 such lamps, connected in multiple arc, is $\frac{180}{100}$=1.8 ohms.

If we assume the electromotive force of the system to be 110 volts we find according to Ohm's law the current for 100 lamps to be $\frac{110}{1.8}$=61.11 amperes, or the current passing through each lamp would equal $\frac{110}{180}$=.61 ampere.

CHAPTER XXIV.

Work, Energy, Power.

As a quantity of water moving from a higher to a lower level will do work, so also will a quantity of electricity falling through a difference of potential. The mechanical unit of work is the foot-pound. If we raise one pound one foot, we do one foot-pound work. It makes no difference whether we perform this work in one minute or in one year; we may do our work at different speeds. So in electricity, one coulomb falling one volt in *any length of time* is the unit of electrical work, and is called the *volt-coulomb* or *the joule*. As the energy of a body is measured by the work it can do and heat is only another form of energy, the same unit is used for work, energy and heat.

In practice we want to know at what rate we can do a certain amount of work The rate of doing work is called power. In mechanics we use the horse power as the unit, which is the work done by raising 33,000 pounds one foot in one minute, or 550 pounds one foot in one second, or one pound 550 feet in one second, etc. The electrical unit of rate of doing work is when a coulomb of electricity falls through one volt in one second, or as one coulomb per second is one ampere, we may say the electrical unit of power is when electricity falls through one volt at the rate of one ampere.

This unit of power is called the volt-ampere, or the watt One watt equals $\frac{1}{746}$ of a horse power, or one horse power equals 746 watts. Hence we may express electrical work thus:

$$\text{Horse power} = \frac{\text{watts}}{746} \text{ or Watts} = \text{H. P.} \times 746.$$

As one watt is the product of one ampere and one volt, it can easily be seen that we can do work at the same rate with great current strength and low electromotive force, or with small current strength and high electromotive force, for instance: 100 amperes $\times$ 10 volts=1,000 watts, 10 ampere $\times$ 100 volts=1,000 watts.

CALCULATING SIZES OF WIRES.

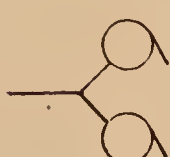
CHAPTER XXV.

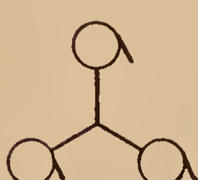
Plans and Symbols.

When the wire contractor has decided upon the general system to be followed in running wires and in locating switches and cut-outs, he should make a general plan. This plan should show the location of each incandescent outlet with the number of lamps, and give in each case the distance from the dynamo or main distributing point. The following symbols are generally used in such a plan:


Sixteen candle power lamp without key.


Sixteen candle power lamp with key.


Two-arm bracket with key-holders.

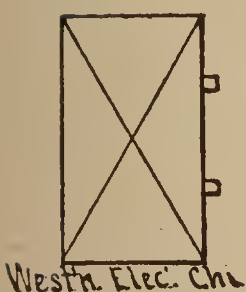

Three-light chandelier with key-holder.


Ten candle power lamp.

Thirty-two candle power lamp.

Wall switch.

Safety plug.



Dynamo.

Chapter XXVI.

Drop of Potential and Loss of Energy.

If a current of constant strength is passing through a circuit of uniform resistance, the potential will fall uniformly.

A B, Fig. 24, represents a wire of uniform thickness, marked off into 10 equal parts. If the potential or e. m. f.

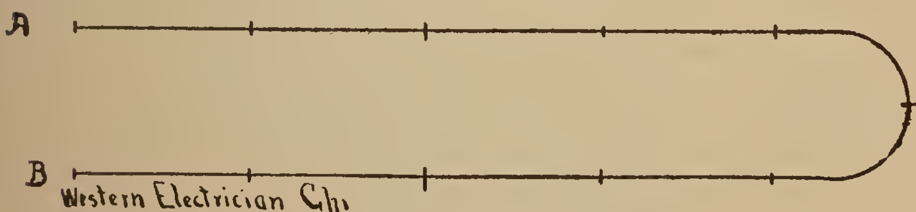


Fig. 24. — Fall of Potential along a Circuit.

between *A* and *B* measures 100 volts, the e. m. f. measured at the terminals of each of the equal divisions will be $\frac{100}{10}=$ 10 volts.

If the circuit offers uneven resistances to the passage of the current the potential will fall unevenly; and it will be found it will fall most rapidly through that part of the circuit which offers the greatest resistance. In fact the fall of potential in any part of a circuit is in every case proportional to the resistance of that part of the circuit.

A C and *B D*, Fig. 25, are conductors of 10 ohms' resistance each. *C D* is an incandescent filament of 180 ohms resistance hot.*

The total resistance of the circuit would be 10+180+10 =200 ohms, or in other words 20 ohms or 10 per cent is represented in the conductor and 90 per cent. in the lamp.

Assuming the e m. f. between *A* and *B* to be 100 volts, 10 per cent. or 10 volts will be lost in overcoming the resistance of the conductors and 90 per cent. or 90 volts will be expended in the lamp. The loss in the wire of course is not desired but is a necessary evil, hence the resistance of the wire conductors might be termed the

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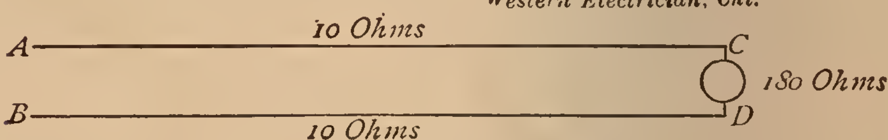

FIG. 25.—DISTRIBUTION OF RESISTANCES AND POTENTIALS.

wasteful resistance, and the resistance offered by the lamp as the useful resistance.

The percentage of the total potential which is wasted in the conductors is called the "Drop of Potential," or briefly the "drop."

As the loss of energy for the same current strength in any particular case is proportional to the "drop" it is correct to speak of the "percentage of energy" lost in the conductors. In the last example we may therefore say either that there is a 10 per cent. drop, or that 10 per cent. of the energy is lost in the conductors.

Electrical energy, as explained in Chapter XXIV, may be found by multiplying the current in amperes by the e. m. f. in volts. According to Ohm's law

*NOTE.—In these calculations the resistance of an incandescent lamp is assumed as that of the carbon filament when hot. Carbon filaments when cold are of much higher resistance than when hot.

$C=\frac{E}{R}$ or using the figures of the last example, $C=\frac{100}{200}=$ ½ ampere. If we now multiply ½ by the e. m. f. we get the energy in watts: ½×90=45 watts, the energy expended in the lamp; ½×10=5 watts, the energy lost in the conductors. We see that 5 watts form 10 per cent. of the total energy of 50 watts, and that therefore 10 per cent. of the energy is lost in the conductors.

It may now be readily understood how the sizes of wires for certain percentages of loss may be determined. Let us take 100 lamps of 180 ohms' resistance each. The total resistance of these lamps, joined in multiple, is $\frac{180}{100}$, or 1.8 ohms. (Compare Chapter XXIII.)

The problem is to lose 10 per cent. of energy in the conductors; in Fig. 26, 1.8 ohms represent then 90 per cent. of the *total* resistance which includes lamps and conductors. The total resistance of lamps + conductors is therefore $=\frac{1.8\times 100}{90}=$ 2 ohms and the resistance of the conductors $=\frac{2}{10}$ or .2 ohm. Suppose the distance from dynamo to lamps is 500 feet, the whole length of the circuit is 1,000 feet. The problem is now to determine the size of a copper wire whose resistance for 1,000 feet of length is .2 ohm. We may use Table II. In Column No. 11 the resistances of copper wire per 1,000 feet are given. The nearest number to .2 in that column is found to be .205,

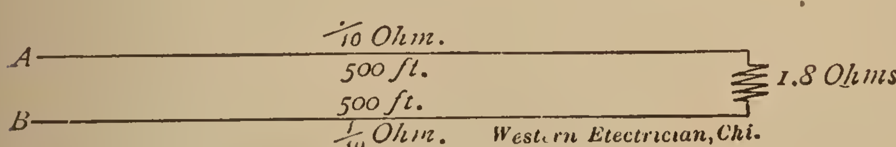

FIG. 26. — DISTRIBUTION OF RESISTANCES AND POTENTIALS.

which corresponds to No. 3 B. & S. wire. This is the required size of the wire.

CHAPTER XXVII.

Practical Rules for Determining Proper Sizes of Wires.

Although a *general* explanation of the principles underlying the calculation of the sizes of wire was given in the previous chapter, it is necessary to have *practical* rules for this purpose—rules which will enable us to determine the size of wire without the aid of a table.

The resistance of a unit wire, *i. e.*, a pure copper wire 1 foot long and 1 circular mil in cross-section, measured at 75° Fahrenheit, is 10.79 ohms.

Suppose in Fig. 27 *a* represents the unit wire; *b* a wire of the same cross-section (one circular mil) but 2 feet long. If the resistance of *a* is 10.79 ohms, it is obvious that the resistance of *b* will be twice that of *a*. Let us assume farther that *c* is a cable 1 foot long and of two circular mils cross-section. Its resistance naturally will be ½ that of *a*. (Compare Chapter XXIII on Divided Circuits.) Suppose *d* is a cable 2 feet long and of two circular mils

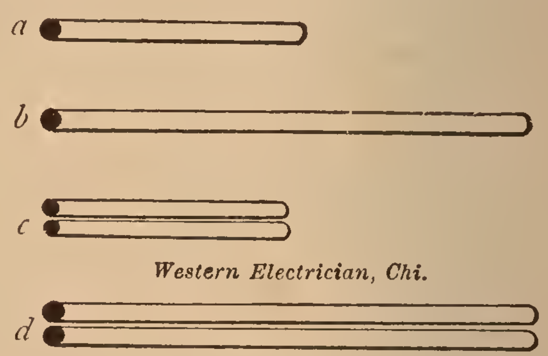

FIG. 27. — RESISTANCES OF WIRES.

cross-section, its resistance will then be equal to *a*. This demonstration leads us to the first rule:

RULE I. The resistance of a copper wire is equal to its length in feet multiplied by 10.79 and divided by its cross-section in circular mils.

We may write this rule in symbols thus:

$$R = \frac{10.79 \times L}{d^2}.$$

in which R is the resistance in ohms, L the length of wire in feet, and d^2 the square of the diameter in mils.

We can also write the formula thus: $d^2 = \frac{10.79 \times L}{R}$

from which we may deduce:

RULE II. The cross-section of a copper wire in circular mils is found by multiplying 10.79 by its length in feet and dividing the result by its resistance in ohms.

EXAMPLE.—Find the cross-section of a wire 1,000 feet long and of a resistance of 100 ohms.

$$d^2=\frac{10.79\times 1000}{100}=107.9 \text{ circular mils.}$$

In incandescent wiring, however, the resistance of this wire is a certain percentage of the total resistance of conductors and lamps.

The total resistance of a certain number of lamps joined in multiple arc is found by:

RULE III. The total resistance of lamps in multiple arc is found by dividing the resistance of one lamp when hot by the number of lamps.

We may also write this as a formula thus:

$$\text{Total } R=\frac{r \text{ of lamp hot}}{\text{number of lamps}}.$$

It may be mentioned that the resistance of a lamp when hot may be found by dividing the e.m.f. by the current. (Compare Ohm's law.)

EXAMPLE.—Find resistance of a lamp hot of 110 volts e.m.f. and .55 amperes of current:

$$r=\frac{110\times 100}{55}=200 \text{ ohms.}$$

EXAMPLE.—Find the total resistance of 50 110 volt lamps connected in multiple. $R=\frac{200}{50}=4$ ohms.

It will be remembered that the joint resistance of the lamps is only a part of the total resistance of the circuit, which includes wires and lamps. (See Fig. 26.)

RULE IV. The resistance of the conductor is found by multiplying the total resistance of the lamps by the percentage to be lost, and by dividing the product by 100 minus the percentage of loss.

Written as a formula, this rule becomes:

$$R=\frac{r\times\%}{100-\%}$$

If we combine Rules III and IV we obtain:

$$R=\frac{r \text{ hot}}{N}\times\frac{\%}{100-\%}, \text{ or in words:}$$

RULE V. The resistance of the conductor is found by dividing the resistance of one lamp hot by the number of lamps (N) joined in multiple arc, and multiplying the quotient by the percentage of loss, divided by 100, minus the percentage.

EXAMPLE —Find the resistance of a conductor for 50 lamps, each of 200 ohms' resistance hot, with 10% loss.

$$R=\frac{200}{50}\times\frac{10}{100-10}=4\times\frac{10}{90}=\frac{40}{90}=\frac{4}{9}\text{ or .44 ohm.}$$

It is not sufficient, however, to find the resistance of the copper conductor. It is also necessary to determine its cross-section in circular mils.

It is stated under Rule I that $d^2=\frac{10.79\times L.}{R}$ The explanation of the symbols is repeated: 10.79 ohms represent the resistance of a unit wire, L is the length of a circuit which is twice the distance, R is the resistance of conductors.

If for L in the formula we substitute twice the distance, 2 D, we have $d^2=\frac{10.79\times 2D}{R}$ and if we now insert for R the value as given in Rule V and multiply 2 by 10.79 we find that

$$d^2=\frac{21.58\times D}{\frac{r\text{ hot}}{N}\times\frac{\%}{(100-\%)}}$$

We can simplify this and obtain the general important wiring rule:

RULE VI. $d^2=\frac{21.58\times D\times N}{r\text{ hot}}\times\frac{(100-\%)}{\%}$ **in which** $d^2=$ **circular mils: D=distance in feet; the distance is ½ the full length of the circuit; N=number of lamps; r=resistance of one lamp hot; %=desired percentage of loss in conductor given as a whole number and not as decimal fraction.**

EXAMPLE.—150 lamps are to be run 400 feet with 5 per cent. loss. The voltage of the lamp is 110 volts, and the current per lamp is ½ ampere.

Demonstration: We must first find the resistance hot of one lamp: resistance hot $=\frac{\text{volts}}{\text{amperes}}=\frac{110}{\frac{1}{2}}=$ 220 ohms.

Working by Rule VI we obtain:

$$d^2=\frac{21.58\times 400\times 150}{220}\times\frac{(100-5)}{5}$$

$$d^2=\frac{21.58\times 400\times 150}{220}\times\frac{95}{5}=111{,}823\text{ circular mils.}$$

By referring to Table I we find that this wire is a little larger than No. 0 B. & S. gauge.

RULE VI will hold good for all lamps and for every percentage of loss. The cross-section of the wire is found in circular mils, and no table is necessary.

RULE VII. Where lamps or groups of lamps are placed at different distances from the dynamo, determine first the proper wire for each lamp or group of lamps if placed on independent circuits starting from the dynamo, then combine all wires running in the same direction.*

Fig. 28 shows three groups, 1, 2 and 3, of 50 lamps each. D is the dynamo, and + and — its positive and negative binding posts. The first group is 100 feet from the dynamo, the second 250 feet, and the third group 350 feet. We figure on lamps of 220 ohms resistance hot and 5 per cent. loss. Take the most distant group first. Proceeding by Rule VI we find

$$d^2 = \frac{21.58 \times D \times N}{220} \times \frac{100-5}{5}$$

As we desire to figure on the same kind of lamps and same percentage of loss we may simplify our calculations by first figuring out the constant part of our formula or "a constant" and subsequently multiplying D × N × constant.

$$K \text{ (constant)} = \frac{21.58}{220} \times \frac{100-5}{5} = 1.86$$

$d^2 = D \times N \times 1.86$. $d^2 = 350 \times 50 \times 1.86 = 32{,}550$ circular mils for Group 3. Taking Group 2 we find:

$d^2 = 250 \times 50 \times 1.86 = 23{,}250$, circular mils.

Adding to this total 32,550 we have a wire of 55,800 circular mils to be used for Section 2.

Proceeding in the same way with Group 1 we find:

$d^2 = 100 \times 50 \times 1.86 = 9{,}300$ circular mils, which added to the total in the last case gives 65,100 circular mils.

From these data we conclude that we must use a wire of 65,100 circular mils between the dynamo and Group 1; a

*By groups of lamps is meant a number of lamps comparatively near each other, as for instance, lamps in a room of a building or on a chandelier, or, in station lighting the lamps in one store. Up to the first group, the mains must be of sufficient size to carry all the lamps or groups of lamps in circuit. Beyond the first lamp or group the mains may diminish as the number of lamps or groups diminish.

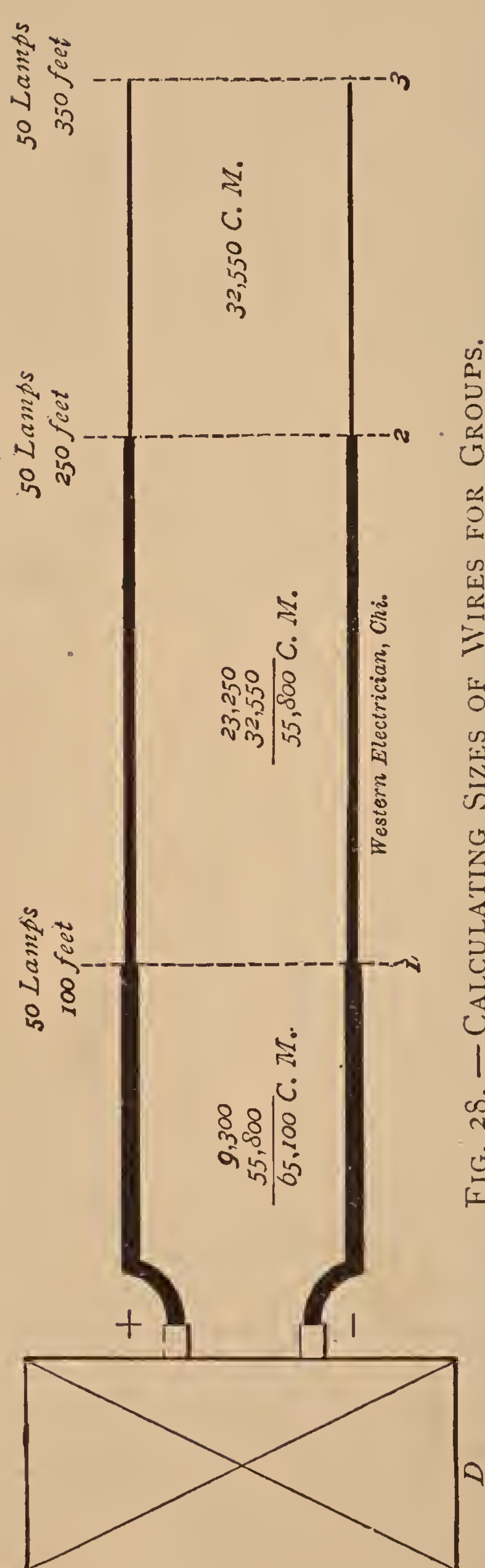

Fig. 28.—Calculating Sizes of Wires for Groups.

wire of 55,800 circular mils between Group 1 and Group 2, and a wire of 32,550 circular mils between Group 2 and Group 3.

RULE VIII.—First calculate the sizes of mains and feeders; then determine the sizes of branches. Not more than 5 per cent. loss must be allowed between the main distributing point and lamp outlets.

In the closet system, for instance, 3 per cent. loss may be allowed from the dynamo or main distributing point to the closets and 2 per cent. from the closets to the lamp outlets.

The percentage of loss in the wires should be made as small as possible, for two reasons: In the first place, a large drop in the wires involves considerable waste of energy, and secondly the system will not admit of automatic regulation of the pressure. Complaints are often made that an incandescent dynamo does not regulate very closely, i. e., when a number of lamps are thrown on or off, the remainder of the lamps become dimmer or brighter as the case may be. It is obvious that, no matter how efficient the dynamo or the transformer may be, a considerable loss in the wires will interfere with the maintenance of even pressure throughout an entire system.

Suppose we have figured mains for 100 lights on a basis of 20 per cent. loss; lamps to be of the 112 volt class. In this case the dynamo must run at 140 volts, with 100 lamps in the circuit;

20 per cent. of 140=28 volts, which is the drop in the wires. If 50 lamps are switched out, and the potential of 140 volts at the dynamo remains unchanged, the voltage at the lamps will increase 50 per cent. of 28 volts, or to 112+14=126 volts.

This condition of course would be fatal to the life of the lamps. Again it may happen that while on one branch all the lamps are running, on another, only a small fraction of the total number of lamps is switched on. The lamps on

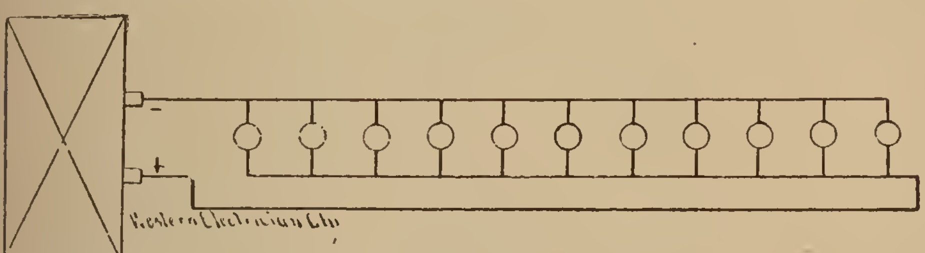

FIG. 29.—LOOP CIRCUIT FOR EQUAL POTENTIALS.

one circuit would thus burn at nominal pressure or candle power, while on another circuit they would be far above the nominal candle power. If only a small percentage of loss has been allowed in the wires, this condition cannot ensue, as the maximum difference in the potentials of the different circuits must necessarily be within the percentage of loss allowed in the wires.

The foregoing considerations lead us to:

RULE IX.—Calculations should be so made that substantially the same potential (within two or three volts), may be maintained at every point in the circuit, no matter how many or how few lamps be burning at different points.

It can easily be seen that that would be an ideal system, where each lamp was provided with a separate circuit direct to the dynamo. No matter how many lamps were switched on or off, the percentage of loss in the other circuits would not be altered. Of course such a system is impracticable. The next best thing is the subdivision of the system of wiring into as many independent circuits as possible. The adoption of this plan will result

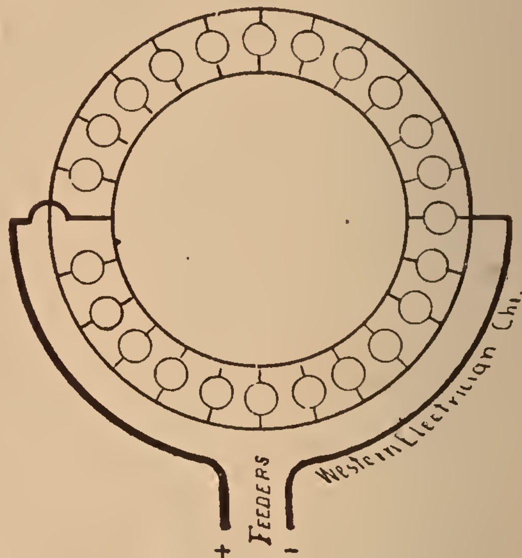

FIG. 30.—CLOSED LOOP CIRCUIT.

in many advantages, for example, faults in the insulation will be more readily located and the use of large fusible safety plugs, which act very sluggishly when of large cross-sec-

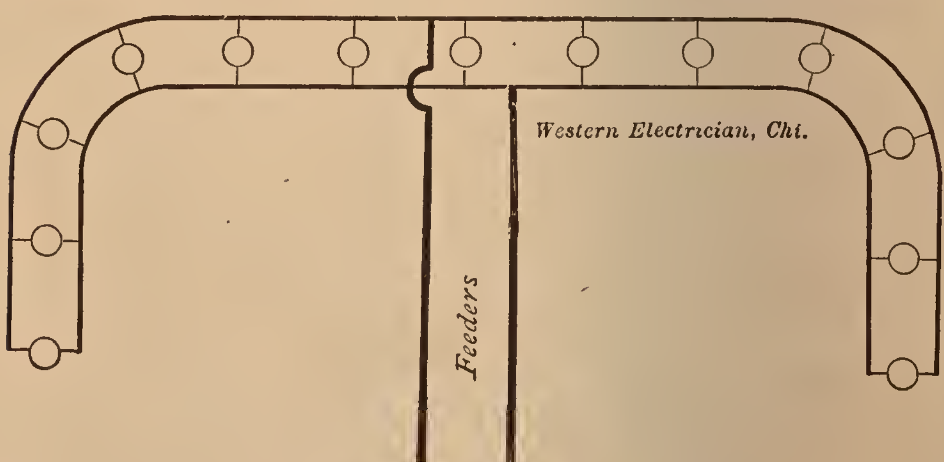

FIG. 31.—LOCATION OF FEEDERS.

tion, will be avoided. Fifty lamps should be the maximum number on a single circuit within a building.

Many plans have been proposed for the maintenance of an even potential, but the best made is to keep the percentage of loss in the wires very low. The only objection to the plan is that it involves additional cost for large copper wires. This expense, however, is small in the wiring of a building in comparison with labor and other items of expense. There is another reason why the loss within a building should be kept very small, which will be taken up in the chapter treating of "Safe Carrying Capacity"

Fig. 29 represents a plan on which equal potentials must necessarily be obtained at all lamps.

Fig. 30 represents the so-called closed loop plan, with feeders diametrically opposite each other.

It might be stated that as a general rule in order to secure an equal potential, it is advisable to cross-connect the mains whenever possible, and attach separate feeders at the centers of distribution.

Fig. 31 shows the proper location of feeders.

Chapter XXVIII.

Safe Carrying Capacity.

The National Board of Fire Underwriters specifies that the carrying capacity of a conductor is safe when the wire will conduct a certain current without becoming painfully warm when grasped by the closed hand.

All wires will heat when a current of electricity passes through them. The loss of energy which was referred to in the previous chapter is a loss only in the sense that it is lost for *useful* work.

Nothing is lost in nature; electrical energy may be transformed into heat, light, motion, etc., but energy cannot be lost. This so-called lost energy in the wires will therefore re-appear as heat, although not wanted in the wire.

The greater the current in amperes and the smaller the wire, the greater the heating effect.

Larger wires will be heated comparatively more than smaller wires as the latter have comparatively more radiating surface.

It is approximately true that the heat increases directly as the square of the current, and inversely as the cube of the diameter of the wire. This statement may be written thus:

Heating effect $=\frac{c^2}{d^3}$ where c is the current and d the diameter of the wire.

In Table I are given the carrying capacities in amperes, and lamps of different sizes of wire. A wire is here assumed to have a safe carrying capacity when its temperature, is not increased over 30° F. above that of the surrounding air, when conducting current. In many tables a much higher temperature is adopted as a standard. It is safe to fix upon 30° F. as a maximum, however, as many circumstances, such as may be found in hot engine rooms, proximity to steam pipes, in twists or sharp bends in the wire, may cause a considerably higher rise of temperature than anticipated. The following empirical formula is used for calculating the carrying capacity:

$$c = \sqrt{\frac{d^3}{2500}}$$ for an increase of 30° F. in temperature,

where c stands for current, d for diameter in mils, and 2,500 is a constant.

RULE X. Ascertain the proper size of wire according to Chapter XXVI for permissible loss, number of lamps and distance. Then determine by Table I whether the wire has the necessary carrying capacity. If not, assume smaller percentages of loss, until a wire is found that will be large enough to carry the current safely.

It may tend to make certain phenomena more easily understood to state that the electric current passing through a wire is frequently compared to water flowing through a pipe. Prof. Ayrton says in "Practical Electricity," this analogy, however, like many other analogies, must not be strained too much; for example a bend in the pipe, even with a steady flow of water, is found to cause a falling off in the water pressure; whereas, a bend in a wire has no effect on the electric potential if a steady current is flowing; or, again, if there be a sudden expansion or contraction in a pipe, there is a sudden alteration of the water pressure, which has no analogy in any sudden alteration of the electrical potential at a point in a circuit where the sectional area of the conductor changes abruptly. In fact, the flow of water or of gas in a pipe can be diminished to any extent by a contraction of one point *only*, which may be practically effected by partially closing a tap or cock; whereas, if an electric circuit consist of many yards of wire, no appreciable alteration of the current will be produced by making only half an inch of the wire, say one-tenth of its previous sectional area. The carrying capacity of any part of a wire, however, is materially reduced by making it of a smaller cross-section, and such a reduction in sectional area may cause a considerable heating of that portion of the wire.

A sharp bend in a wire is therefore only dangerous as it reduces the sectional area, and not because it introduces a resistance.

Fig. 32 explains how a sharp bend may cause a wire to be partially torn asunder, and thus decrease the sectional area and cause undue heating at this point.

It may be stated as a general rule, that when a large percentage of loss is allowed with lamps at short distances, the size of wire calculated simply in accordance with

FIG. 32. — SHARP BEND IN A WIRE.

resistance rules will be found too small to carry the current safely.

This simple fact is often overlooked, and even though wires may have been correctly calculated for a uniform percentage of loss, they will become painfully hot simply because the table of carrying capacity was not consulted.

The cross-connection of mains wherever possible, as recommended in the previous chapter, for the purpose of maintaining equal potentials, will also often reduce the heating effects of the current. A case came under the author's observation which will well illustrate this fact. A circle of about 50 lights was wired, Fig. 33. After the current had been turned on the wires of the circle became hot, and there was quite a perceptible difference of candle power between the lights near A and those near B. Investigation disclosed the fact that the loop, contrary to instructions, had been left open. A few inches of wire connecting A and B and C and D remedied the fault; the

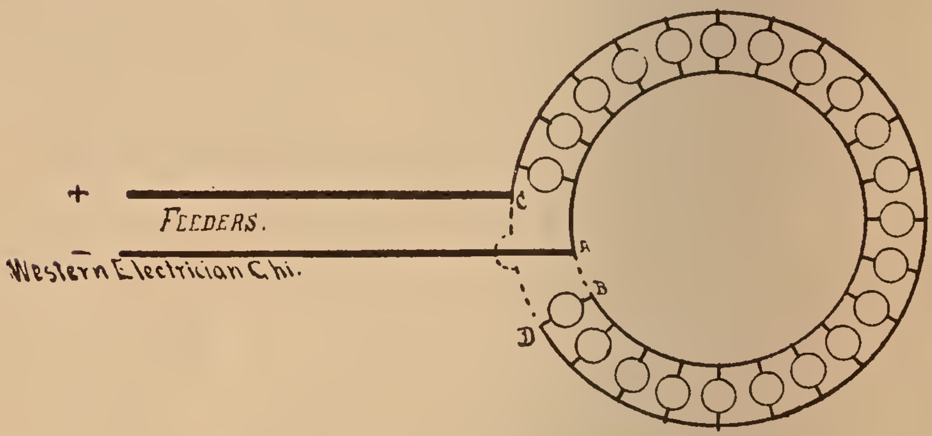

FIG. 33.—FAULTY LOOP CIRCUIT.

wires remained cool and the candle power was practically the same all around the circle.

The smallest wire used for incandescent wiring should be at least of 250 circular mils cross-section. Smaller wire will break too easily when handled, and thus cause endless trouble.

CHAPTER XXIX.

The Three-Wire System.

Chapters XXVI and XXVIII which treat of "Drop of Potential" and "Safe Carrying Capacity" have reference only to conditions met with in a multiple arc system of distribution.

It was explained briefly in Chapter II that in the three-wire system the electromotive force is double and the current is one-half that required for the same number of lamps on the multiple arc system.

All the rules given in the previous chapters may readily be applied to the three wire-system.

Let us again compare these two systems.

EXAMPLE: Find the electrical data for four lamps of 100 volts and 200 ohms' resistance each for both systems, *Demonstration*: The current for one lamp according to Ohm's law $=\frac{100}{200}=\frac{1}{2}$ ampere

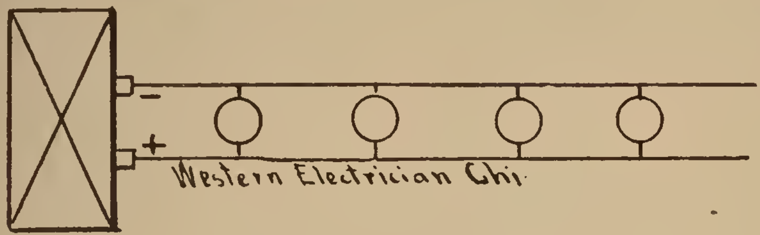

FIG. 34. — MULTIPLE ARC SYSTEM.

a. Multiple Arc System. (Fig. 34.) Joint resistance $=\frac{200}{4}=50$ ohms; total electromotive force $=100$ volts; total current $=$

$\frac{1}{2}\times 4=2$ amperes or $\frac{\text{electromotive force}}{\text{total resistance.}}=\frac{100}{50}=2$ amperes.

b. Three-Wire System. (Fig. 35.) The joint resistance may easily be found by omitting from the calculation the

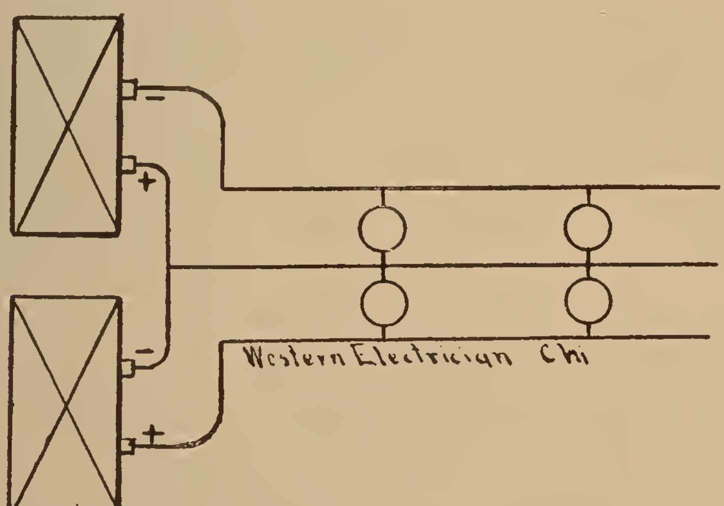

FIG. 35. — THREE-WIRE SYSTEM.

third or neutral wire. We will then have two series of two lamps each. The resistance of two lamps joined in series will be of course twice that of one lamp, or 400 ohms.

The joint resistance of two series will therefore be $\frac{400}{2}=200$ ohms. (Compare Fig. 2, Chap. II), or in other words the joint resistance of the lamps in the three-wire system will be four times the joint resistance of the same number of lamps in multiple arc.

The total electromotive force in the three-wire system of course will be twice that of the electromotive force in the multiple arc system.

Again, the total current will equal $\frac{\text{total electromotive force}}{\text{total resistance}}$ or, $C=\frac{200}{200}=1$ ampere, or in other words, the total current required for the lamps in the three-wire system, will be ½ of the total current required for the same number of lamps in the multiple arc system.

With this demonstration in mind we are ready to form

RULE XI. For the same kind and same number of lamps the joint resistance of the lamps in the three-wire system is four times that of the multiple system; the total electromotive force of the lamps in the three-wire system is twice that of the multiple arc system, and the total current strength of the lamps in the three-wire system is one-half the corresponding unit in the multiple arc system.

It can easily be seen that as the joint resistance of the lamps is four times greater in the three-wire system than in the multiple arc system, the resistance of the positive and negative conductors will be four times greater for the same percentage of loss. In other words, the cross-section of the wires in the three-wire system is ¼ that of the wires in the multiple arc system for the same percentage of loss. This gives us:

RULE. XII. In order to find the proper size of wire for the three-wire system, first find the size of wire for the same number and kind of lamps on the multiple system in accordance with Rules VI and VII, then divide the number of circular mils by four.

The sum of the lengths of the positive and negative wires is the entire length of the circuit in the three-wire system, and the amount of copper required for the circuit is equal to one-fourth the amount of copper required in a multiple arc circuit; the length of the center or neutral wire, if of the same size as the positive and negative leads will be only one-half the length of the total circuit; hence the total amount of copper in the three-wire system will be $\frac{1}{4}+\frac{1}{8}=\frac{3}{8}$ of the amount necessary in the case of the multiple system.

As a matter of fact the neutral wire may be made smaller than the positive and negative wires, as it seldom will be called upon to carry more than a fraction of the maximum current. For practical reasons, however, it is advisable to make all three wires of the same size.

It will be seen that as the number of circular mils per wire in the three-wire system is ¼ the cross-section per wire in the multiple system, the carrying capacity in amperes of course is also reduced to ¼.

When Table I for the three-wire system is used it should be borne in mind that *only twice* the number of lamps may be carried by the wires, as the current is reduced to ½ for the same number of lamps.

The three-wire system in a building is generally followed throughout the whole network of feeders, mains, branches and sub-branches, down to circuits of from three to six lights; smaller numbers would then be connected in simple multiple arc.

Chapter XXX.

Explanation of Tables.

Wiring Tables 3, 4 and 5 may be used by any one who does not care to study the principles underlying the calculations of the sizes of wires as explained in Chapters XXVI and XXVII; but even to those who thoroughly understand the demonstrations, the tables will be found of great convenience.

The first thing to do is to select the table for the lamps which are to be used. Let us consult the table for data relating to the 1 0 volt lamps.

We find in the horizontal columns at the top and bottom, numbers which correspond to "lamp-feet." (Lamp-feet is a brief expression used to denote the product obtained by multiplying the number of lamps by the distance in feet.) At the left of the table we find three vertical columns filled with figures representing circular mils; and also underlined figures giving the numbers of the Brown & Sharpe gauge. Each horizontal column corresponds to a vertical column.

The radial lines starting near the left hand corner represent percentages of loss. Each small space in the inside columns represents 2000, in the middle columns, 500 and in the outside columns, 125; that is to say in the horizontal columns the numbers represent lamp-feet; in the vertical columns the numbers represent circular mils, except where underscored, when they represent the number of the wire according to Brown & Sharpe gauge.

Although the difference would be very slight in any case, it is necessary to note, for those who may desire absolute accuracy in determining the circular mils, that the short heavy lines beneath the Brown & Sharpe gauge figures in the vertical column, are the correct gauge lines and may be understood as extending the full width of the table.

The figures given in the columns represent thousands. For instance, 100 denotes 100,000; 4.25=4250; 2.5=2500, etc.

EXAMPLE: Find the size of wire for 100 110 volt lamps at 1000 feet distance, at 10 per cent. loss.

Demonstration: 100 × 1000 = 100,000 lamp-feet. We find 100 in the *inside* horizontal column; we follow the vertical 100 line until it intersects the 10 per cent. line. We take a ruler and lay it horizontally through this point and find it strikes about 88 in the *inside* vertical column. The proper size of wire has a sectional area of 88,000 circular mils. If we wish to wire on 5 per cent. loss we follow the vertical 100 line until it intersects with the 5 per cent. line and obtain by laying a horizontal line through this point about 186,000 circular mils.

From this demonstration we deduct the following general rule for computing from wire tables:

RULE XIII.—Find the number of lamp-feet (lamp × feet), in one of the horizontal columns, follow the vertical line until it intersects the desired percentage line. A horizontal line laid through this point will show in the corresponding vertical column the cross-section of the wire in circular mils.

In consulting the table, always use corresponding columns, If the lamp-feet are found in the middle column, the circular mils must be read from the middle column; if the lamp-feet are found in the outside column, the circular mils must be read from the outside column, etc.

EXAMPLE: Find the size of wire for 20 110 volt lamps, at 900 feet distance at 5 per cent. loss.

Demonstration: 20 × 900=18,000. We find 18 in the *middle* horizontal column; we follow the vertical 18 line until it intersects with the 5 per cent. line, and following the horizontal line we find in the middle column 33,500 circular mils.

EXAMPLE: Find the size of wire for 50 110 volt lamps at 100 feet distance at 5 per cent. loss.

Demonstration: 50 × 100=5,000 lamp-feet. We find 5 in the middle lower column, and a glance shows us that the wire is over 9,300 circular mils or a little larger than No. 11 B. & S. gauge. We can find the same result by taking 5,000 in the outside horizontal column.

RULE XIV.—The number of lamp-feet within moderate numbers can always be found in one of the three horizontal columns. Select the one which will intersect with the desired percentage line farthest from the left lower corner. If the number of lamp-feet is too great, and cannot be found in the table, divide it by 10 and find the circular mils for $\frac{1}{10}$ the number of lamp-feet first, and then multiply the result by 10.

EXAMPLE: Find the size of wire for 1,000 110 volt lamps, 1,000 feet distance at 10 per cent loss,

Demonstration: 1,000 × 1,000 = 1,000,000 lamp-feet. Divide by 10 = 100,000 lamp-feet. Size of wire for 100,000 lamp-feet = 88,000 circular mils, for 10 × 100,000 = 1,000,000 lamp-feet = 10 × 88,000 = 880,000 circular mils.

The 55 and 75 volt tables, of course, are to be used in the same manner as explained in the case of the 110 volt table.

It will be noticed that the small spaces in the three *vertical* columns of all three tables represent the same values while the values in the *horizontal* columns of the three tables differ as follows:

Number of Lamp-feet per Small Space.	Tables.		
	55 Volt.	75 Volt.	110 Volt.
Inside Horizontal Column...	500	1000	2000
Middle Horizontal Column..	125	250	500
Outside Horizontal Column..	31.25	62.5	125

The tables are very simple, and will become familiar to the user after a short practical experience.

The 55 volt table may be used for lamps of a voltage between 50 and 60 volts, the 75 volt table for lamps of a voltage between 70 and 80 volts, and the 110 volt table for lamps of a voltage between 100 and 115 volts. The results will be accurate enough for all practical purposes.

In calculating the tables, lamps requiring 55 watts were assumed. The following table gives the electrical data of such lamps:

16 CANDLE-POWER LAMP REQUIRING 55 WATTS.

Electromotive Force in Volts.	Current in Amperes.	Resistance hot in Ohms.
110	.50	220
75	.7338	102.207
55	1.00	55

Under Rule VII, page 49, it was shown that Rule VI could be simplified by calculating the constants for each kind of lamp and each percentage of loss. In the following table are given the constants for 55 watt lamps at different percentages of loss in the conductors.

TABLE OF CONSTANTS.

	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%	12½%	15%
55 Volt Lamp.	38.8	19.2	12.7	9.4	7.5	6.1	5.2	4.5	4.0	3.6	2.7	2 2
75 Volt Lamp.	20.9	10.3	6.8	5 1	4.0	3.3	2.8	2.4	2.1	1.9	1.5	1.2
110 Volt Lamp.	9.7	4.8	3.2	2.4	1 86	1.5	1.3	1 1	.99	.88	.6[illegible]	.56

The wiring formula, Rule VI, can now be written $d^2 = N \times D \times K$, or, the size of wire in circular mils = lamp-feet multiplied by constant. The constant K is found from the formula:

$$K = \frac{21.58}{r \text{ hot}} \times \frac{100 - \%}{\%}$$

From the foregoing it will be very easy to find the constant for any lamp and any percentage of loss, and calculate the size of wire without the aid of any tables whatever.

GAUGES IN CIRCULAR MILS AND SAFE CARRYING CAPACITY.

Table No. I.

d² Circular Mils.	B.&S. Brown & Sharpe Gauge.	B.W.G Birmingham Wire Gauge.	E. S. G. Edison Standard Gauge.	Safe Carrying Capacity. Wire heated to 30 deg. F. above temperature of surrounding air. Number of Amperes.	Number of 55 Volt Lamps. 16 c. p.	Number of 75 Volt Lamps. 16 c. p.	Number of 110 Volt Lamps 16 c. p.
220,000			220	203	203	278	406
211,600	0000			197.3	197	270	395
206,116		0000		193.5	193	264	387
200,000			200	189.15	189	259	378
190,000			190	182	182	249	364
180,625		000		179.3	179	245	359
180,000			180	174.8	175	240	330
170,000			170	167.4	167	229	335
167,805	000			165.8	166	227	332
160,000			160	160	160	219	320
150,000			150	152.5	152	208	305
144,400		00		148.2	148	203	296
140,000			140	144.8	145	199	290
133,079	00			139.4	139	190	279
180,000			130	136.9	137	188	274
120,000			120	129	129	177	258
115,600		0		125.4	125	171	251
110,000			110	120.8	121	166	242
105,592	0			117.2	117	160	234
100,000			100	112.5	112	153	225
95,000			95	108.2	108	148	216
90,000		1	90	103.9	104	142	208
85,000			85	99.5	99	136	199
83,694	1			93.4	98	134	197
80,656		2		95.7	96	131	191
80,000			80	95.1	95	130	190
75,000			75	90.6	91	125	181
70,000			70	86	86	118	172
67,081		3		84	84	115	168
66,373	2			83.1	83	114	166

GAUGES IN CIRCULAR MILS AND SAFE CARRYING CAPACITY.

TABLE NO 1.

	B. & S	B.W.G.	E. S. G.	SAFE CARRYING CAPACITY. Wire heated to 30 deg. F. above temperature of surrounding air.			
d^2 Circular Mils.	Brown & Sharpe Gauge.	Birmingham Wire Gauge.	Edison Standard Gauge.	Number of Amperes.	Number of 55 Volt Lamps. 16 c. p.	Number of 75 Volt Lamps. 16 c. p.	Number of 110 Volt Lamps 16 c. p.
65,000			65	81.4	81	111	163
60,000			60	78.4	78	107	157
56,644		4		73.4	73	100	147
55,000			55	71.8	72	99	144
52,634	3			69.5	69	94	139
50,000			50	66.8	67	92	134
48,400		5		65.2	65	89	131
45,000			45	61.7	62	85	123
41,742	4			58.4	58	79	117
41,209		6		57.8	58	79	116
40,000			40	56.5	56	77	113
35,000			35	51.1	51	70	102
33,102	5			49.1	49	67	98
32,400		7		48.3	48	66	97
30,000			30	46.6	46	63	93
27,225		8		42 4	42	57	85
26,250	6			41.2	41	56	82
25,000			25	39.7	40	55	79
21 904		9		36	36	49	72
20,816	7			34.6	34	47	69
20,000			20	33.6	33	45	67
17,956		10		31	31	42	62
16,509	8			29.1	29	40	58
15,000			15	27.1	27	37	54
14,400		11		26 3	26	36	52
13,094	9			24.4	24	33	49
12,000			12	22.9	23	31	45
11,881		12		22.7	23	31	46
10,381	10			20.5	20	27	41
9,025		13		18.5	18	25	37

GAUGES IN CIRCULAR MILS AND SAFE CARRYING CAPACITY.

TABLE NO. 1.

d^2 Circular Mils.	B.& S. Brown & Sharpe Gauge.	B.W.G. Birmingham Wire Gauge.	E. S. G. Edison Standard Gauge.	Safe Carrying Capacity. Wire heated to 30 deg. F. above temperature of surrounding air.			
				Number of Amperes.	Number of 55 Volt Lamps. 16 c. p.	Number of 75 Volt Lamps. 16 c. p.	Number of 110 Volt Lamps 16 c. p.
8,234	11			17.3	17	23	34
8,000			8	16.9	17	23	34
6,889		14		15.1	15	20	30
6,530	12			14.5	14	19	29
5,184		15		12.2	12	16	24
5,178	13			12.2	12	16	24
5,000			5	11.9	12	16	24
4 225		16		10.5	10	14	21
4,107	14			10.2	10	14	20
3,364		17		8.8	9	12	17
3,257	15			8.6	9	12	17
3,000			3	8.1	8	11	16
2,583	16			7.2	7	10	14
2,401		18		6.8	7	10	14

1. In this table it is estimated that 1 55 volt, 16 candle power lamp requires about 1 ampere of current; 1 75-volt, 16 candle power lamp requires about .73 ampere of current; 1 110-volt, 16 candle power lamp requires about .5 ampere of current.

2. Lamps supposed to be in multiple arc. On the three-wire system the same current in amperes will suffice for a series of two lamps. Hence twice the number of lamps as given in the above table can be safely carried on the same size wires.

ELECTRIC LIGHT CONDUCTORS.

I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
Brown & Sharpe	Diameter.		Square of Diam.	Sectional Area.	Weight.			Length.		Resistance of pure copper wire at 75 degrees F. (23.89 deg. cent.)		
					Naked.		* Insul.	Naked.	* Insul.			
No.	Mils.	Millimetres.	Circular Mils.	Square millimetres.	Grains per Foot.	Pounds per 1000 ft.	Po'nds per 1000 ft.	Feet per Pound.	Feet per Pound.	Ohms per 1000 ft.	Feet per Ohm.	Ohms per Pound (naked)
0000	460.000	11.684	211600.0	107.219	4475.33	639.33	......	1.56	....	.051	19605.69	.0000798
000	409.640	10.405	167805.0	85.028	3549.07	507.01	......	1.97	....	.064	15547.87	.000127
00	364.800	9.266	133079.4	67.431	2814.62	402.09	440.6	2.49	2.27	.081	12330.36	.000202
0	324.950	8.254	105592.5	53.504	2233.28	319.04	355.9	3.13	2 81	.102	9783.63	.000320
1	289.300	7.348	83694.2	42.409	1770.13	252.88	284.8	3 95	3.52	.129	7754.66	.000510
2	257.630	6.544	66373.0	33 632	1403.79	200.54	235.3	4.99	4.25	.163	6149.78	.000811
3	229.420	5.827	52634.0	26.670	1113 20	159.03	190.5	6.29	5.25	.205	4876.73	.001289
4	204.310	5.189	41742.0	21 151	882.85	126.12	158.0	7.93	6.33	.259	3867.62	.00205
5	181.940	4.621	33102.0	16.773	700.10	100.01	126.9	10.00	7.88	.326	3067.06	.00326
6	162.020	4.115	26250.5	13.301	555.20	79.32	101.7	12.61	9.83	.411	2432.22	.00518
7	144.280	3.665	20816.0	10 548	440.27	62.90	85.7	15.90	11.67	.519	1928.75	.00824
8	128.490	3.264	16509.0	8 366	349.18	49.88	68.8	20.05	14.54	.654	1529.69	.01311
9	114.430	2.907	13094.0	6.635	276 94	39.56	53.8	25.28	18.58	.824	1213.22	.02083
10	101.890	2.588	10381.0	5.260	219.57	31.37	46.9	31.88	21.33	1.040	961.91	.03314
11	90.742	2.305	8234.0	4.172	174.15	24.88	36 4	40.20	27.46	1.311	762.93	.05269
12	80.808	2.053	6529.9	3 309	138.11	19.73	30 9	50.69	32.38	1.653	605.03	.08377
13	71.961	1.828	5178.4	2.618	109.52	15 65	25.5	63.91	39.25	2.084	479.80	.1332
14	64.084	1 628	4106.8	2.081	86.86	12.41	20.3	89.59	49.21	2.628	380.51	.2118
15	57.068	1.450	3256.7	1.650	68.88	9.84	15.8	101.63	63 29	3.314	301.75	.3368
16	50.820	1.291	2582.9	1.309	54.63	7.81	14.8	128.14	67.60	4.179	239.32	.5355
17	45.257	1.150	2048.2	1.038	43.32	6.19	12 6	161.59	79.58	5.269	189.78	.8515
18	40.303	1.024	1624.3	.8230	34.35	4.91	10.8	203.76	92.46	6.645	150.50	1.354
19	35.390	.899	1252.4	.6346	26.49	3.78	9.3	264.26	107.83	8.617	116.05	2.277
20	31.961	.812	1021.5	.5176	21.61	3.09	9.1	324.00	110.25	10.566	94 65	3.423

* Approximate.