152. Where circuits cannot be supported on porcelain or glass, in knob-and-tube work, approved metal conduit or approved armored cable must be used, except that for voltages of less than 300, where the wires are not exposed to moisture, they may be fished from outlet to outlet on the loop system if each is encased throughout in continuous lengths of approved flexible tubing.

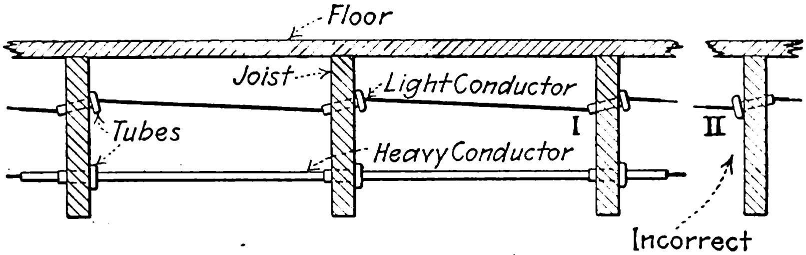


FIG. 116.—Wires through joists in tubes.

153. In wiring in thin partitions where there will not be at least 1 in. clear space between the surface of the wires and the plaster that oozes between the laths, the wires must be encased in loom (flexible conduit). This construction is required in the so-called 2 in. partitions.

154. Knobs for knob-and-tube work are of either the solid type (Fig. 8B and Table **16D**), or of the split type (Fig. 8A). Split knobs are required for conductors smaller than No. 8, except at the ends of runs. Solid knobs are permitted only when used to take the strain from the circuit wires—at the ends of runs and to

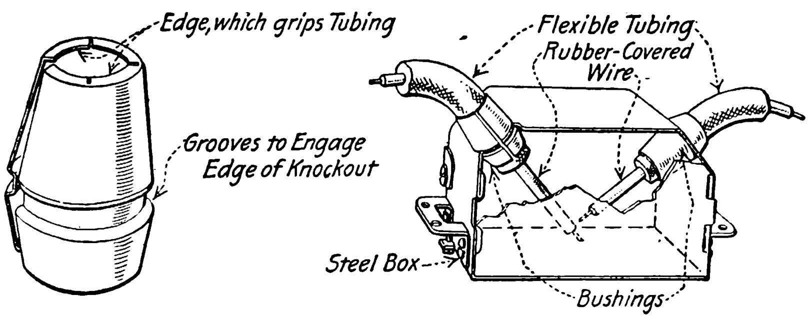


FIG. 116A.—Bushing for flexible tubing.

support outlets. The knob must provide at least a 1-in. separation from the surface wired over. See **16A** for further information about knobs.

155. Porcelain tubes provide insulation where the wires are carried through joists. (See **16F** for further information on tubes.) The holes for the tubes should (Fig. 116) preferably be slightly smaller than the tubes, so that the tubes when driven home with a block of wood will stay in place. The holes for tubes for small wires should be pitched as this tends to retain the tubes in position in the timber. A long bit, the shank of which when in use rests on the joist next to the one being bored, is the best tool for boring pitched, tube holes. Tubes should always be so placed in pitched holes that their enlarged ends will be at the top, as a (Fig. 116, *I*), which will prevent their falling through. Never place tubes as at *II*, because when the wire loosens, as it will in old installations, they will fall out. For heavy conductors the tube holes should be bored with a beam-boring machine, at right angles to the beam. If they are not, it is difficult to pull in the wire and tube breakages will result. About 10 per cent. more wire is required where conductors are "zigzagged" through timbers than when they are carried straight through.

156. Porcelain tubes must be used on wires at the bottoms of plastered partitions (Fig. 114), an additional tube being placed where the wires pass through the sill or floor to protect from plaster droppings. The tubes must extend to at least 4 in. above the timber. Knobs must be so arranged that no strain that might tend to break them can come on tubes. Fig. 115 shows how a wire crossing a pipe should be protected by a procelain tube.

157. Flexible tubing must be used at all knob-and-tube work outlets to encase each wire. (See **16K** for properties of flexible tubing.) It should be used at distributing center, switch, fixture and similar outlets, and at all points where the wires cannot be separated from one another or from the surface wired over the distances specified for unprotected wire. The flexible tubing or loom must encase each wire from the last porcelain support (knob or tube), to 1 in. below the outlet, or with combination fixtures, to a point opposite the gas cap. The tubing must be firmly secured in position in outlet and switch boxes by some approved device that may or may not be a part of the box. See Fig. 116A for a flexible tubing bushing designed for this purpose.

The bushing shown in Fig. 116A grips the tubing and the pressure of the "knockout" holds the bushing securely to the tubing. The bushing is installed by slipping it over the tubing to the desired position and then forcing it into the "knockout" in the outlet or switch box. Not only does the bushing hold the tubing in place but it fills the space around the tubing, thus preventing the entrance into the box of plaster and dirt.

158. Fixture outlets are shown in Figs. 117 and 118. For an electric fixture a cleat, a piece of board at least $\frac{7}{8}$ in. thick (Fig. 117), into which the wood screws supporting the electrolier can turn, should be nailed between the joists or studs. Holes are bored through the cleat, through which the loom can pass. With a combination fixture (gas and electric) (Fig. 118) no cleat is necessary, because the gas pipe supports the fixture. The loom should be wired—iron wire will do—to the gas pipe, to prevent displacement by artisans that have occasion to work around the outlet.

159. In wiring for switches, loom must be used on the conductor ends from the last porcelain support, (Figs. 119, 120 and

121), the same as on conductor ends for other outlets. A pressed steel switch box (Fig. 122), should be used to encase each flush switch mechanism, even though it already be encased in porcelain. A $\frac{7}{8}$ in. wood cleat or cleats are arranged to support the switch

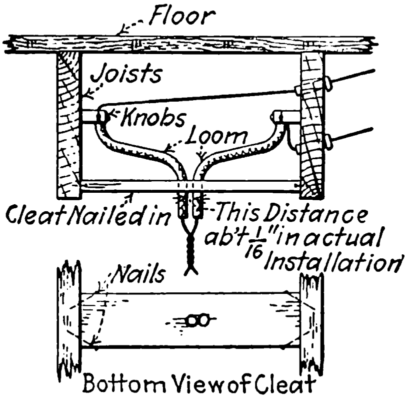


FIG. 117.—Outfit for an electric fixture.

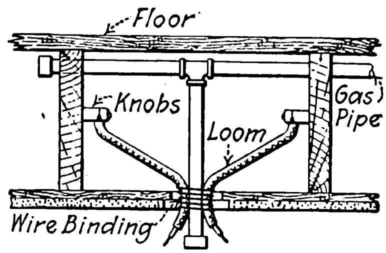


FIG. 118.—Loom protection at combination fixture outlet.

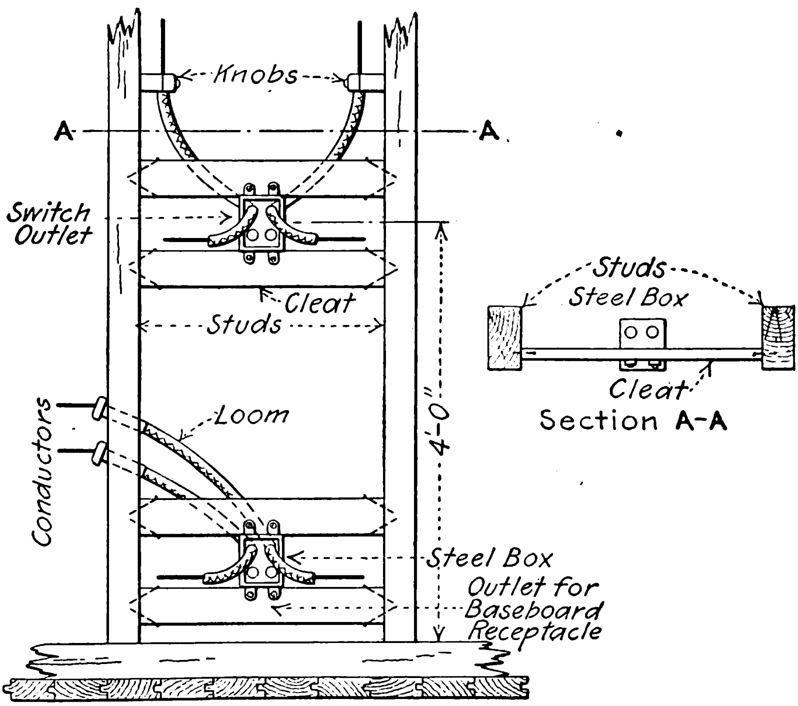


FIG. 119.—Switch and receptacle outlets.

box. These wooden cleats should not be set out flush with the outer edges of the studs, but should be set about $\frac{3}{8}$ in. back, as illustrated, to allow a space in which the plaster can take a "grip." (See Fig. 121.) For a surface snap switch outlet (Fig. 121), an iron box is not necessary, but a $\frac{7}{8}$-in. cleat must be installed to hold the loom in place and to provide a proper support for the screws that hold the switch. In wiring old buildings, where supporting cleats were not originally provided back of the plaster, a $\frac{3}{4}$ in. wooden block or plate should be installed on the surface, to which the switch can be attached.

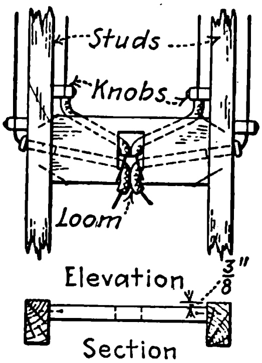


FIG. 120.—Arrangement of switch outlet wiring.

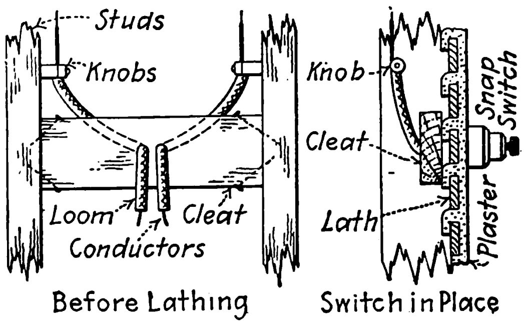


FIG. 121.—Surface switch wiring.

160. Steel switch boxes for knob-and-tube work, flush switches are formed from sheet steel, as shown in Fig. 122. A single-switch box can be expanded into one for any number of switches by using the proper number of spacers. Single- and double-switch boxes can be supplied already assembled and are used where feasible, because it is cheaper to buy them this way than to assemble them on the job. Holes partially punched, which can be knocked out

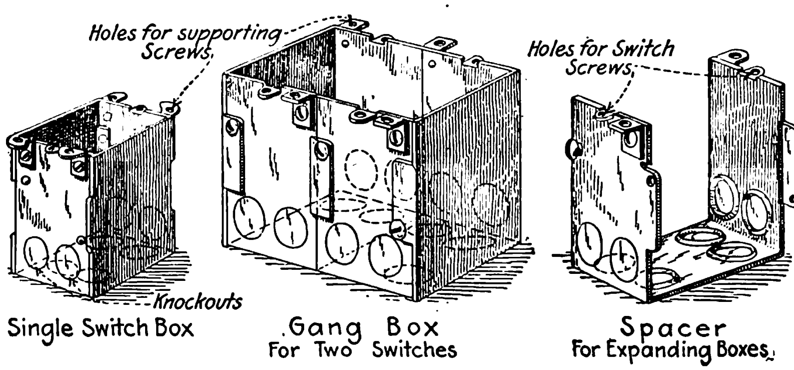


FIG. 122.—Switch box for knob-and-tube wiring.

with a hammer blow, are provided in the sides and back through which the flexible conduit wire protection can be extended. Boxes can be purchased which are adaptable for either knob-and-tube (flexible conduit or loom) or wrought-iron conduit work. Boxes which have adjustable supporting lugs, so the box can be moved in and out in relation to them to provide for adjustment to the surface of the plaster, are preferable. (See also 190 under "Conduit Wiring" for further information on steel switch boxes.)

CONDUIT WIRING

161. **There are two classes of conduit wiring,** rigid or iron conduit wiring, and flexible metal conduit wiring. Although steel-armored conductor wiring is not truly conduit wiring it is usually treated in the conduit wiring group and is so described in this book. (The material that follows on Conduit Wiring is largely from a series of articles on the subject written by the compiler of this book and printed, under the pen name of O. N. Casey, in *The Practical Engineer* commencing with the March 1, 1913 issue.)

162. **Rigid iron conduit wiring** is approved for both exposed and concealed work and for use in nearly all classes of buildings. For ordinary conditions wiring in iron conduit is probably the best although it is the most expensive. The advantages of iron conduits are: (1) It is fire-proof; (2) it is moisture-proof; (3) it is strong enough mechanically so that nails cannot be driven through it and so that it is not readily deformed by blows or by wheelbarrows being run over it; (4) it successfully resists the normal action of cement when imbedded in partitions or walls of fire-proof buildings.

163. **Lined and unlined iron conduit** can be obtained. The lined conduit is merely ordinary conduit lined with a paper tube that is treated with an insulating water-proof compound. The lining is cemented to the interior of the conduit by the compound.

164. **The advantages of unlined conduit** over lined conduit are (*Electric Light Wiring, Knox.*): (1) It is cheaper because it has no lining. A smaller size conduit can be used for conductors of a given size; (2) it is cheaper to install, as it can be bent, threaded and cut more readily than can lined conduit; (3) it is easier to draw wires into and out of unlined conduit than into and out of lined conduit; (4) in lined conduit in hot places the conductors sometimes stick to the lining which prevents their withdrawal.

165. **The disadvantages of unlined conduit** are (*Electric Light Wiring, Knox.*): (1) The unlined iron conduit may rust through due to the combined action of water or steam and the chemical elements in ash or other cements; (2) double-braided conductors must be used in unlined conduit to satisfy code rules. The increase in cost due to this requirement is slight as compared with the greater cost of lined conduit and the cost of installing it.

166. **Lined conduit is very seldom used now.** It sometimes finds application where every precaution must be taken to protect against trouble that might occur if the outer iron tube rusted through.

167. **Galvanized iron conduit** should be used if conduit is installed out of doors or in damp places or where it is imbedded in cement.

168. **When to use Iron Conduit Wiring.**—As a general proposition, conduit wiring should be used whenever the job will stand the cost. Ordinances of some cities now require that all

concealed wiring shall be in iron conduit. It is probable that the method will, because of its inherent advantages, grow in popularity and will ultimately be almost universally used. Iron conduit protects the conductors it contains and provides a smooth race-way permitting ready insertion or removal.

169. **Use of Iron Pipe in Place of Conduit.**—Electrical conduit is merely commercial standard-weight wrought-iron pipe that has been carefully reamed inside to remove burrs and then treated with zinc, or an enamel, baked on, to prevent rust. The threads on the ends of conduit lengths are standard pipe threads. Hence, where underwriters' inspectors do not have jurisdiction iron pipe can be used instead of conduit. The pipe is cheaper, and in dry locations it appears to serve as well as conduit. A coat of black stove-pipe enamel on the outside of the pipe will give it a finished appearance, and more than a superficial inspection is required to distinguish a pipe so treated from conduit. It is the practice in some plants where the buildings are fire-proof and where no insurance is carried to use galvanized iron pipe instead of conduit.

170. **Wire for use in unlined wrought-iron conduit** must be rubber-covered except in permanently dry, hot locations where slow-burning insulation may be permitted. Single-braid wire is permitted for conductors smaller than No. 6. Conductors No. 6 and larger should be double-braid. Duplex or multiple conductor cables must be double braid. Each conductor must be continuous from outlet to outlet without splices or taps. The same conduit can contain as many as four 2-wire or three 3-wire circuits of the same system. The same conduit must never contain circuits of different systems. Duplex wire (see Sect. I) particularly No. 14 is largely used for branch circuits in conduit wiring. Solid wire is used for conductors up to and including No. 8 or No. 6. Larger conductors should be stranded so that they can be readily pulled into the ducts.

171. **Where alternating-current circuits** are in conduit, all of the wires (two wires for a single-phase, three wires for a three-wire or three-phase and three or four wires for a two-phase circuit) of the circuit must be carried in the same conduit to prevent inductive voltage drop and dangerous overheating of the conduit.

172. **Table 173 of Conduit, Elbows and Couplings.**—Electrical conduit is merely standard-weight wrought-iron pipe, enameled, Sherardized or galvanized. The diameters are given in decimals, common fractions and sixty-fourths for convenience, because there are times when the values are needed expressed in each of these ways. When figuring wire and wire insulation diameters, all values are usually expressed in sixty-fourths which makes the sixty-fourths columns very valuable for ready reference. The weight columns are convenient for estimating transportation charges, and from the values in the list price columns, the cost of the materials can be obtained by applying the discount that one receives. As an estimating discount 50 per cent. can be safely used. Dimensions of elbows and couplings are often used in laying out work on the drawing-board or in cases where clearances must be estimated in advance. Table 185 gives the dimensions of standard conduit threads.

173. Unlined Wrought-iron Electrical Conduit, Elbows and Couplings

Conduit

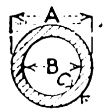


FIG. 123.—Section of conduit.

Elbows

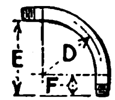


FIG. 124.—Conduit elbow.

Couplings

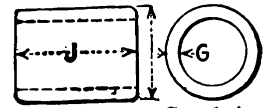


FIG. 125.—Conduit coupling.

Nominal size	A Outside diameter. Actual	A Fractional in. to 64ths.	A In 64ths to nearest 64th.	B Inside diameter. Nominal	B Fractional in. to 64ths.	B In 64ths to nearest 64th.	C Thickness of walls. Nominal	C Fractional in. to 64ths.	C 64 ths to nearest 64ths.	Nominal weight lb. per ft.	List price per 100 ft.
$\frac{1}{2}$	0.84	$\frac{27}{32}$	$\frac{54}{64}$	0.623	$\frac{5}{8}$	$\frac{40}{64}$	0.109	$\frac{3}{32}$	$\frac{6}{64}$	0.85	$ 8.50
$\frac{3}{4}$	1.05	$1\frac{1}{16}$	$\frac{68}{64}$	0.824	$\frac{53}{64}$	$\frac{53}{64}$	0.113	$\frac{7}{64}$	$\frac{7}{64}$	1.12	11.50
1	1.315	$1\frac{21}{64}$	$\frac{84}{64}$	1.048	$1\frac{3}{64}$	$\frac{67}{64}$	0.134	$\frac{1}{8}$	$\frac{8}{64}$	1.67	17.00
$1\frac{1}{4}$	1.66	$1\frac{42}{64}$	$\frac{106}{64}$	1.380	$1\frac{24}{64}$	$\frac{88}{64}$	0.140	$\frac{9}{64}$	$\frac{9}{64}$	2.24	23.00
$1\frac{1}{2}$	1.90	$1\frac{29}{32}$	$\frac{122}{64}$	1.611	$1\frac{39}{64}$	$\frac{103}{64}$	0.145	$\frac{9}{64}$	$\frac{9}{64}$	2.68	27.50
2	2.375	$2\frac{3}{8}$	$\frac{152}{64}$	2.067	$2\frac{1}{16}$	$\frac{132}{64}$	0.154	$\frac{5}{32}$	$\frac{10}{64}$	3.61	37.00
$2\frac{1}{2}$	2.875	$2\frac{7}{8}$	$\frac{184}{64}$	2.468	$2\frac{15}{32}$	$\frac{158}{64}$	0.204	$\frac{13}{64}$	$\frac{13}{64}$	5.94	58.50
3	3.50	$3\frac{1}{2}$	$\frac{224}{64}$	3.067	$3\frac{1}{16}$	$\frac{196}{64}$	0.217	$\frac{7}{32}$	$\frac{14}{64}$	7.54	76.50
$3\frac{1}{2}$	4.00	4	$\frac{256}{64}$	3.548	$3\frac{35}{64}$	$\frac{227}{64}$	0.266	$\frac{7}{32}$	$\frac{14}{64}$	9.00	92.00
4	4.50	$4\frac{1}{2}$	$\frac{288}{64}$	4.026	$4\frac{1}{32}$	$\frac{258}{64}$	0.237	$\frac{15}{64}$	$\frac{15}{64}$	10.66	109.00

Nominal size	Elbows D Radius of ϕ in.	E Offset ins.	Weight, lb. of 100	List price, per 100	F Length, straight portion	Couplings I Outside diam.	J Length	G Thickness	Weight of 100 in lb.	List price, per 100
$\frac{1}{2}$	$4\frac{1}{2}$	$7\frac{1}{2}$	73	$19.00	$2\frac{9}{16}$	$1\frac{3}{32}$	$1\frac{5}{16}$	$\frac{1}{4}$	$15\frac{1}{2}$	$ 7.00
$\frac{3}{4}$	$5\frac{3}{8}$	$9\frac{1}{4}$	132	25.00	$3\frac{1}{4}$	$1\frac{11}{32}$	$1\frac{9}{16}$	$\frac{19}{64}$	$25\frac{1}{2}$	10.00
1	$5\frac{3}{4}$	$10\frac{1}{8}$	200	37.00	$4\frac{5}{8}$	$1\frac{21}{32}$	$1\frac{3}{4}$	$\frac{11}{32}$	$40\frac{1}{2}$	13.00
$1\frac{1}{4}$	$7\frac{1}{4}$	$11\frac{1}{2}$	300	45.00	$3\frac{7}{16}$	2	$1\frac{15}{16}$	$\frac{11}{32}$	$57\frac{1}{2}$	17.00
$1\frac{1}{2}$	$8\frac{1}{2}$	$12\frac{5}{8}$	415	60.00	$3\frac{3}{16}$	$2\frac{9}{32}$	$2\frac{3}{16}$	$\frac{3}{8}$	$71\frac{1}{4}$	21.00
2	$9\frac{1}{2}$	$15\frac{1}{4}$	700	110.00	$4\frac{9}{16}$	$2\frac{27}{32}$	$2\frac{5}{16}$	$\frac{15}{32}$	132	28.00
$2\frac{1}{2}$	$10\frac{1}{2}$	$17\frac{3}{4}$	1,138	180.00	$5\frac{13}{16}$	$3\frac{9}{32}$	$2\frac{11}{16}$	$\frac{17}{32}$	185	40.00
3	13	$19\frac{3}{8}$	1,885	480.00	$4\frac{5}{8}$	$4\frac{1}{64}$	3	$\frac{33}{64}$	300	60.00
$3\frac{1}{2}$	15	21	2,100	1060.00	4	$4\frac{1}{2}$	$2\frac{1}{8}$	$\frac{1}{2}$	400	80.00
4	16	$22\frac{1}{2}$	2,160	1225.00	$4\frac{1}{4}$	$5\frac{3}{32}$	$3\frac{1}{8}$	$\frac{1}{2}$	412	100.00

All tubes 10 ft. long, threaded, both ends with coupling.

Price list in effect Aug. 1, 1913.

174. Table 178 of conduit bushing dimensions, gives values which are helpful when laying out conduit holes in outlets or panel boxes. Clearances can be provided and holes can be so disposed that the bushings will have ample turning room. The dimensions in the table were taken from samples.

175. Table 179 of conduit nipple dimensions is, since the function of the nipple is about the same as that of the bushing, used for the same purposes as the bushing table. The nipple screws into a coupling (see Table 181), while the bushing screws onto the threaded end of a length of conduit. The nipple is more compact than the bushing, hence is preferable for some work.

176. Punched steel lock-nuts are shown in Table 180. Lock-nuts are used on conduit on the outside of the box wherever the conduit enters an outlet-box, and their dimensions must often be known in laying out panel or outlet boxes, so that proper turning clearances can be provided for the nuts.

177. Galvanized iron pipe straps (Table 183), are used for supporting conduit to surfaces. The dimensions in the table are valuable, when laying out multiple conduit runs, to determine the spacings necessary between the conduits to allow for proper placing of the straps. The screw hole dimensions enable one to order in advance screws of the proper diameters to support the straps. Unfortunately, there are no standard dimensions in use by all the manufacturers of pipe straps, and those furnished by different makers will vary somewhat in size. The dimensions given are from one manufacturer's line, and are typical.

178. Malleable-iron Conduit Bushings

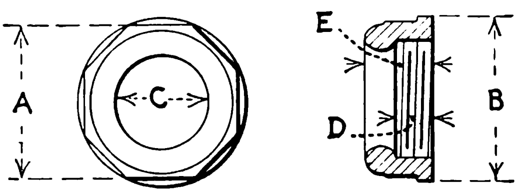


FIG. 126.—Conduit bushing.

Nominal size of conduit	A	B	C	D	E
$\frac{3}{8}$	$\frac{15}{32}$	$\frac{27}{32}$	$\frac{25}{32}$	$\frac{3}{16}$	$\frac{11}{32}$
$\frac{1}{2}$	$\frac{19}{32}$	$1\frac{1}{32}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{13}{32}$
$\frac{3}{4}$	$\frac{3}{4}$	$1\frac{1}{4}$	$1\frac{5}{32}$	$\frac{1}{4}$	$\frac{15}{32}$
1	$\frac{31}{32}$	$1\frac{17}{32}$	$1\frac{13}{32}$	$\frac{5}{16}$	$\frac{17}{32}$
$1\frac{1}{4}$	$1\frac{5}{16}$	$1\frac{29}{32}$	$1\frac{11}{16}$	$\frac{3}{8}$	$\frac{19}{32}$
$1\frac{1}{2}$	$1\frac{17}{32}$	$2\frac{5}{32}$	$1\frac{31}{32}$	$\frac{13}{32}$	$\frac{5}{8}$
2	$1\frac{15}{16}$	$2\frac{11}{16}$	$2\frac{15}{32}$	$\frac{13}{32}$	$\frac{21}{32}$
$2\frac{1}{2}$	$2\frac{11}{32}$	$3\frac{5}{32}$	$2\frac{7}{8}$	$\frac{15}{32}$	$\frac{3}{4}$
3	$2\frac{27}{32}$	$3\frac{25}{32}$	$3\frac{17}{32}$	$\frac{17}{32}$	$\frac{7}{8}$

179. Conduit Nipples

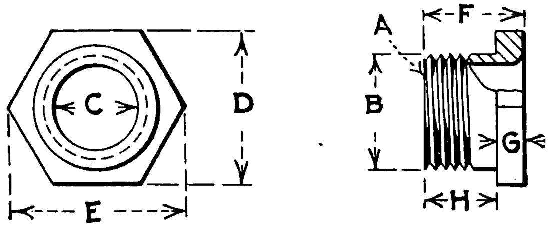


FIG. 127.—Conduit nipple.

Size of conduit	A Threads per inch	B Diameter of threads	C	D	E	F	G	H
$\frac{1}{2}$	14.0	0.82	0.62	1.00	1.15	0.62	0.12	0.50
$\frac{3}{4}$	14.0	1.02	0.82	1.25	1.44	0.81	0.19	0.62
1	11.5	1.28	1.04	1.37	1.59	0.94	0.25	0.69
$1\frac{1}{4}$	11.5	1.63	1.38	1.75	2.02	1.06	0.25	0.81
$1\frac{1}{2}$	11.5	1.87	1.61	2.00	2.31	1.12	0.31	0.81
2	11.5	2.34	2.06	2.50	2.89	1.31	0.31	1.00
$2\frac{1}{2}$	8.0	2.82	2.46	3.00	3.46	1.44	0.37	1.06
3	8.0	3.44	3.06	3.75	4.33	1.50	0.37	1.12
$3\frac{1}{2}$	8.0	3.94	3.54	4.25	4.91	1.62	0.44	1.19

180. Punched Steel Conduit Lock-nuts

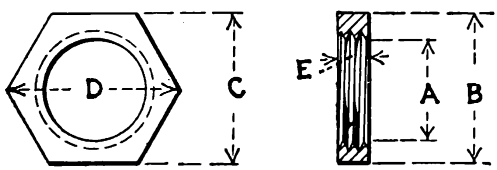


FIG. 128.—Conduit lock-nut.

Nominal size of conduit	Threads per in.	A	B	C	D	E
$\frac{3}{8}$	18	0.568	0.658	1	$1\frac{1}{8}$	$\frac{3}{16}$
				oct. hex.	oct. hex.	oct. hex.
$\frac{1}{2}$	14	0.701	0.815	$1-1\frac{1}{16}$	$1\frac{1}{16}-1\frac{7}{32}$	$\frac{5}{32}-\frac{1}{8}$
$\frac{3}{4}$	14	0.911	1.025	$1\frac{1}{4}$	$1\frac{7}{16}$	$\frac{5}{32}$
1	$11\frac{1}{2}$	1.144	1.283	$1\frac{1}{2}$	$1\frac{23}{32}$	$\frac{3}{16}$
$1\frac{1}{4}$	$11\frac{1}{2}$	1.488	1.627	$2\frac{1}{32}$	$2\frac{5}{16}$	$\frac{3}{16}$
$1\frac{1}{2}$	$11\frac{1}{2}$	1.727	1.866	$2\frac{1}{4}$	$2\frac{9}{16}$	$\frac{3}{16}$
2	$11\frac{1}{2}$	2.223	2.339	$2\frac{23}{32}$	$3\frac{1}{8}$	$\frac{7}{32}$
$2\frac{1}{2}$	8	2.620	2.820	$3\frac{1}{4}$	$3\frac{3}{4}$	$\frac{1}{4}$
3*	8	3.241	3.441	$4\frac{11}{32}-3\frac{11}{16}$	$4\frac{11}{16}-4$	$\frac{11}{32}-\frac{17}{32}$

* The 3 in. lock-nut is octagonal instead of hexagonal.

181. Spacings for Conduit with Given Clearances

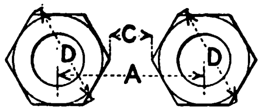


Fig. 129.—End View.

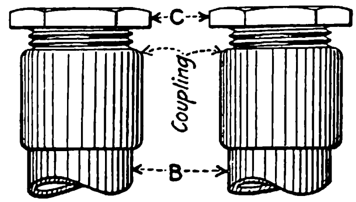


Fig. 130.—Elevation.

C = 1/8 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 1/4	1 3/8	1 1/2	1 11/16	1 13/16	2 1/8	2 7/16	2 3/4	3 1/3
	B	.41	.43	.42	.43	.44	.52	.58	.58	.70
3/4	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	3	3 1/4
	B	.43	.45	.44	.45	.46	.54	.60	.60	.72
1	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.43	.45	.44	.46	.46	.54	.60	.60	.72
1 1/4	A	1 11/16	1 13/16	1 15/16	2 1/8	2 1/4	2 9/16	2 7/8	3 1/4	3 3/16
	B	.43	.46	.46	.46	.47	.55	.62	.67	.74
1 1/2	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 1/16	3	3 3/8	3 11/16
	B	.44	.46	.46	.47	.47	.56	.62	.67	.74
2	A	2 1/8	2 1/4	2 3/8	2 3/16	2 11/16	3	3 5/16	3 5/8	4
	B	.52	.54	.53	.55	.56	.63	.63	.69	.82
2 1/2	A	2 7/16	2 9/16	2 11/16	2 7/8	3	3 5/16	3 5/8	3 15/16	4 5/16
	B	.58	.60	.60	.61	.62	.69	.76	.76	.89
3	A	2 3/4	3	3	3 1/4	3 3/8	3 5/8	3 15/16	4 7/16	4 3/4
	B	.58	.60	.60	.67	.67	.69	.74	.94	1.00
3 1/2	A	3 1/8	3 1/4	3 3/8	3 9/16	3 11/16	4	4 5/16	4 3/4	5
	B	.70	.72	.73	.74	.74	.82	.89	1.00	1.00

C = 3/8 in.

Size conduit		1/2	3/4	1	1 1/4
1/2	A	1 1/2	1 5/8	1 3/4	1 15/16
	B	.66	.68	.67	68
3/4	A	1 5/8	1 3/4	1 7/8	2 1/16
	B	.68	.70	.69	.71
1	A	1 3/4	1 7/8	2	2 3/16
	B	.68	.69	.69	.71
1 1/4	A	1 15/16	2 1/16	2 3/16	2 3/8
	B	.68	.71	.71	.71
1 1/2	A	2 1/16	2 3/16	2 5/16	2 1/2
	B	.69	.71	.71	.72
2	A	2 3/8	2 1/2	2 5/8	2 13/16
	B	.77	.79	.78	.80
2 1/2	A	2 11/16	2 13/16	2 15/16	3 1/8
	B	.83	.85	.85	.86
3	A	3	3 1/8	3 1/4	3 1/2
	B	.83	.85	.85	.92
3 1/2	A	3 3/8	3 1/2	3 5/8	3 13/16
	B	.96	.98	.98	.99

C = 1/4 in.

Size conduit		1/2	3/4	1	1 1/4	1 1/2	2	2 1/2	3	3 1/2
1/2	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 9/16	2 7/8	3 1/4
	B	.53	.55	.54	.55	.56	.64	.70	.70	.83
3/4	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3	3 3/8
	B	.55	.57	.56	.58	.58	.66	.72	.72	.86
1	A	1 3/8	1 3/4	1 7/8	2 1/16	2 3/16	2 1/2	2 13/16	3 1/8	3 1/2
	B	.55	.57	.56	.58	.58	.66	.72	.72	.85
1 1/4	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 11/16	3	3 3/8	3 11/16
	B	.55	.58	.58	.58	.59	.67	.73	.79	.86
1 1/2	A	1 15/16	2 1/16	2 3/16	2 3/8	2 1/2	2 13/16	3 1/8	3 1/2	3 13/16
	B	.56	.58	.58	.59	.59	.68	.74	.79	.87
2	A	2 1/4	2 3/8	2 1/2	2 11/16	2 13/16	3 1/8	3 7/16	3 3/4	4 1/8
	B	.64	.66	.65	.67	.68	.75	.81	.81	.94
2 1/2	A	2 9/16	2 11/16	2 13/16	3	3 1/8	3 7/16	3 3/4	4 1/16	4 7/16
	B	.70	.72	.72	.73	.74	.81	.87	.88	1.00
3	A	2 7/8	3	3 1/8	3 3/8	3 1/2	3 3/4	4 1/16	4 3/16	4 7/8
	B	.70	.72	.72	.79	.79	.81	.88	1.06	1.12
3 1/2	A	3 1/4	3 3/8	3 1/2	3 11/16	3 13/16	4 1/8	4 7/16	4 7/8	5 1/8
	B	.83	.86	.85	.86	.87	.94	1.00	1.12	1.12

C = 1/2 in.

Size conduit		1/2	3/4	1	1 1/4
1/2	A	1 5/8	1 3/4	1 7/8	2 1/16
	B	.78	.80	.79	.80
3/4	A	1 3/4	1 7/8	2	2 3/16
	B	.80	.82	.81	.83
1	A	1 7/8	2	2 1/8	2 5/16
	B	.80	.81	.81	.83
1 1/4	A	2 1/16	2 3/16	2 5/16	2 1/2
	B	.80	.83	.83	.83
1 1/2	A	2 3/16	2 5/16	2 7/16	2 5/8
	B	.81	.83	.83	.84
2	A	2 1/2	2 5/8	2 3/4	2 15/16
	B	.89	.91	.90	.92
2 1/2	A	2 13/16	2 15/16	3 1/16	3 1/4
	B	.95	.97	.97	.98
3	A	3 1/8	3 1/4	3 3/8	3 5/8
	B	.95	.97	.97	1.04
3 1/2	A	3 1/2	3 5/8	3 3/4	3 15/16
	B	1.01	1.04	1.03	1.04

181. Spacings for Conduit with Given Clearances (*Continued*)

D in nearest practical dimension			
Conduit	D	Conduit	D
$\frac{1}{2}$	$1\frac{1}{8}$	2	$2\frac{7}{8}$
$\frac{3}{4}$	$1\frac{3}{8}$	$2\frac{1}{2}$	$3\frac{1}{2}$
1	$1\frac{5}{8}$	3	$4\frac{5}{16}$
$1\frac{1}{4}$	2	$3\frac{1}{2}$	$4\frac{7}{8}$
$1\frac{1}{2}$	$2\frac{1}{4}$	....	....

$C = \frac{3}{8}$ in.				
$1\frac{1}{2}$	.2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
$2\frac{1}{16}$	$2\frac{3}{8}$	$2\frac{11}{16}$	3	$3\frac{3}{8}$
.69	.77	.83	.83	.96
$2\frac{3}{16}$	$2\frac{1}{2}$	$2\frac{13}{16}$	$3\frac{1}{8}$	$3\frac{1}{2}$
.71	.79	.85	.85	.98
$2\frac{5}{16}$	$2\frac{5}{8}$	$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$
.71	.78	.85	.85	.98
$2\frac{1}{2}$	$2\frac{3}{16}$	$3\frac{1}{8}$	$3\frac{1}{2}$	$3\frac{13}{16}$
.72	.80	.87	.92	.99
$2\frac{5}{8}$	$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{15}{16}$
.72	.81	.87	.92	.99
$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{7}{16}$	$3\frac{7}{8}$	$4\frac{1}{4}$
.81	.88	.88	.94	1.07
$3\frac{1}{4}$	$3\frac{9}{16}$	$3\frac{1}{8}$	$4\frac{3}{16}$	$4\frac{7}{16}$
.87	.94	1.01	1.01	1.13
$3\frac{5}{8}$	$3\frac{7}{8}$	$4\frac{3}{16}$	$4\frac{11}{16}$	5
.92	.94	.99	.99	1.25
$3\frac{15}{16}$	$4\frac{1}{4}$	$4\frac{9}{16}$	5	$5\frac{1}{4}$
.99	1.07	1.13	1.25	1.25

$C = \frac{5}{8}$ in.										
Size conduit		$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
$\frac{1}{2}$	A	$1\frac{3}{4}$	$1\frac{7}{8}$	2	$2\frac{3}{16}$	$2\frac{5}{16}$	$2\frac{5}{8}$	$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$
	B	.91	.93	.92	.93	.94	1.02	1.08	1.08	1.14
$\frac{3}{4}$	A	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{3}{4}$	$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{3}{4}$
	B	.93	.95	.94	.96	.96	1.04	1.10	1.10	1.17
1	A	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{7}{8}$	$3\frac{3}{16}$	$3\frac{1}{2}$	$3\frac{7}{8}$
	B	.92	.94	.94	.96	.96	1.03	1.10	1.10	1.16
$1\frac{1}{4}$	A	$2\frac{3}{16}$	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{5}{8}$	$2\frac{3}{4}$	$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{3}{4}$	$4\frac{1}{16}$
	B	.93	.96	.96	.96	.97	1.05	1.12	1.17	1.24
$1\frac{1}{2}$	A	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{3}{16}$	$3\frac{1}{2}$	4	$4\frac{3}{16}$
	B	.94	.96	.96	.97	.97	1.06	1.11	1.17	1.24
2	A	$2\frac{5}{8}$	$2\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{1}{16}$	$3\frac{3}{16}$	$3\frac{1}{2}$	$3\frac{13}{16}$	$4\frac{1}{4}$	$4\frac{1}{2}$
	B	1.02	1.04	1.03	1.05	1.05	1.13	1.13	1.19	1.32
$2\frac{1}{2}$	A	$2\frac{15}{16}$	$3\frac{1}{16}$	$3\frac{3}{16}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{13}{16}$	$4\frac{1}{8}$	$4\frac{1}{2}$	$4\frac{13}{16}$
	B	1.08	1.10	1.10	1.11	1.12	1.19	1.26	1.26	1.39
3	A	$3\frac{1}{4}$	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{3}{4}$	4	$4\frac{1}{4}$	$4\frac{1}{2}$	$4\frac{15}{16}$	$5\frac{1}{4}$
	B	1.08	1.10	1.10	1.17	1.17	1.19	1.24	1.24	1.44
$3\frac{1}{2}$	A	$3\frac{5}{8}$	$3\frac{3}{4}$	$3\frac{7}{8}$	$4\frac{1}{16}$	$4\frac{3}{16}$	$4\frac{1}{4}$	$4\frac{13}{16}$	$5\frac{1}{4}$	$5\frac{1}{2}$
	B	1.14	1.17	1.16	1.24	1.24	1.32	1.39	1.44	1.56

$C = \frac{1}{2}$ in.				
$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
$2\frac{3}{16}$	$2\frac{1}{2}$	$2\frac{13}{16}$	$3\frac{1}{8}$	$3\frac{1}{2}$
.81	.89	.95	.95	1.08
$2\frac{5}{16}$	$2\frac{5}{8}$	$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$
.83	.91	.97	.97	1.10
$2\frac{7}{16}$	$2\frac{3}{4}$	$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{3}{4}$
.83	.90	.97	.97	1.10
$2\frac{5}{8}$	$2\frac{15}{16}$	$3\frac{1}{4}$	$3\frac{5}{8}$	$3\frac{15}{16}$
.84	.92	.99	1.04	1.11
$2\frac{3}{4}$	$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{3}{4}$	$4\frac{1}{16}$
.84	.93	.98	1.04	1.11
$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{11}{16}$	4	$4\frac{3}{8}$
.93	1.00	1.00	1.06	1.20
$3\frac{3}{8}$	$3\frac{11}{16}$	4	$4\frac{5}{16}$	$4\frac{11}{16}$
.99	1.06	1.13	1.13	1.26
$3\frac{3}{4}$	4	$4\frac{5}{16}$	$4\frac{13}{16}$	$5\frac{1}{8}$
1.04	1.06	1.14	1.14	1.31
$4\frac{1}{16}$	$4\frac{1}{8}$	$4\frac{11}{16}$	$5\frac{5}{16}$	$5\frac{3}{8}$
1.11	1.13	1.31	1.31	1.37

$C = \frac{3}{4}$ in.										
Size conduit		$\frac{1}{2}$	$\frac{3}{4}$	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$
$\frac{1}{2}$	A	$1\frac{7}{8}$	2	$2\frac{1}{8}$	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{3}{4}$	$3\frac{1}{16}$	$3\frac{3}{8}$	$3\frac{3}{4}$
	B	1.03	1.05	1.04	1.05	1.06	1.14	1.20	1.20	1.26
$\frac{3}{4}$	A	2	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{7}{8}$	$3\frac{3}{16}$	$3\frac{1}{2}$	$3\frac{7}{8}$
	B	1.05	1.07	1.06	1.08	1.08	1.16	1.22	1.22	1.29
1	A	$2\frac{1}{8}$	$2\frac{1}{4}$	$2\frac{3}{8}$	$2\frac{9}{16}$	$2\frac{11}{16}$	3	$3\frac{5}{16}$	$3\frac{5}{8}$	4
	B	1.04	1.06	1.06	1.08	1.08	1.15	1.22	1:22	1.35
$1\frac{1}{4}$	A	$2\frac{5}{16}$	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{3}{4}$	$2\frac{7}{8}$	$3\frac{3}{16}$	$3\frac{1}{2}$	$3\frac{7}{8}$	$4\frac{3}{16}$
	B	1.05	1.08	1.08	1.08	1.09	1.17	1.24	1.29	1.36
$1\frac{1}{2}$	A	$2\frac{7}{16}$	$2\frac{9}{16}$	$2\frac{11}{16}$	$2\frac{7}{8}$	3	$3\frac{5}{16}$	$3\frac{5}{8}$	$4\frac{1}{8}$	$4\frac{5}{16}$
	B	1.06	1.08	1.08	1.09	1.09	1.18	1.25	1.29	1.37
2	A	$2\frac{3}{4}$	$2\frac{7}{8}$	3	$3\frac{3}{16}$	$3\frac{5}{16}$	$3\frac{5}{8}$	$3\frac{15}{16}$	$4\frac{3}{8}$	$4\frac{5}{8}$
	B	1.14	1.16	1.15	1.17	1.18	1.25	1.25	1.31	1.45
$2\frac{1}{2}$	A	$3\frac{1}{16}$	$3\frac{3}{16}$	$3\frac{5}{16}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{15}{16}$	$4\frac{1}{4}$	$4\frac{5}{8}$	$4\frac{15}{16}$
	B	1.20	1.22	1.22	1.23	1.24	1.31	1.36	1.38	1.51
3	A	$3\frac{3}{8}$	$3\frac{1}{2}$	$3\frac{5}{8}$	$3\frac{7}{8}$	$4\frac{1}{8}$	$4\frac{3}{8}$	$4\frac{5}{8}$	$5\frac{1}{16}$	$5\frac{3}{8}$
	B	1.20	1.22	1.22	1.29	1.29	1.31	1.45	1.36	1.56
$3\frac{1}{2}$	A	$3\frac{3}{4}$	$3\frac{7}{8}$	4	$4\frac{3}{16}$	$4\frac{5}{16}$	$4\frac{3}{8}$	$4\frac{15}{16}$	$5\frac{3}{8}$	$5\frac{5}{8}$
	B	1.26	1.29	1.28	1.36	1.37	1.45	1.51	1.56	1.68

182. Table 181 of conduit spacings for different clearances between conduits and their lock-nuts, is exceedingly valuable to a man who is designing or erecting conduit work. From it he can determine directly just what the distance between centers of conduits should be for given clearances between nipples or conduit. This data is indispensable when laying out the centers of a row of holes through which conduit is to enter a panel box, or in laying out the supports for a multiple conduit run.

183. Galvanized Iron Pipe Straps

All dimensions are in inches

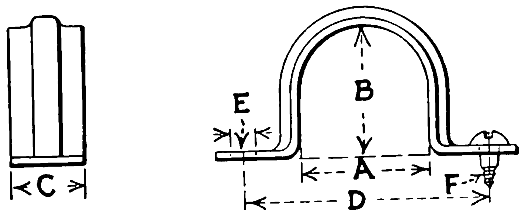


FIG. 131.—Pipe strap.

	A	B	C	D	E	F		
Nominal size of conduit	Width of opening	Height of opening	Width of strap	Distance between centers of screw holes	Diameter of screw hole	Size of wood screw to use	Approximate cost per 100	Approximate number per pound
						No. in.		
1/4	9/16	17/32	5/8	1 9/16	0.20	8 × 5/8	$0.40	75
3/8	11/16	21/32	5/8	1 3/8	0.20	8 × 3/4	0.45	72
1/2	7/8	25/32	5/8	1 5/8	0.20	8 × 3/4	0.50	40
3/4	1 1/8	1	3/4	2 1/8	0.22	10 × 3/4	0.75	29
1	1 3/8	1 11/32	3/4	2 3/8	0.22	10 × 7/8	1.00	21
1 1/4	1 3/4	1 5/8	13/16	2 3/4	0.22	10 × 1	1.25	18
1 1/2	2	1 7/8	13/16	3	0.22	10 × 1	1.50	14
2	2 1/2	2 5/16	1	3 3/4	0.22	10 × 1 1/4	2.00	12
2 1/2	2 3/4	2 15/16	7/8	4 3/8	0.25	11 × 1 1/4	2.75	6

184. That the conductors can be removed and replaced in conduit is one of the advantages of conduit wiring. If a size of conduit is selected that is too small for the wires, they will become wedged in, particularly in a warm location and withdrawal will be impossible.

184A. In selecting a conduit size for the conductors of a three-wire system with a neutral twice the size of the outer conductors, use a conduit of a size to take four wires the size of the outers. For example, the conduit for a three-wire main composed of 2–200,000 cir. mil outers and 1–400,000 cir. mil neutral should be large enough to accommodate 4–200,000 cir. mil conductors. The Underwriters (except by special permission) permit but four 2-wire circuits or three 3-wire circuits in one conduit. Circuits of different systems must never be carried in the same conduit.

185. Standard Conduit and Pipe Threads

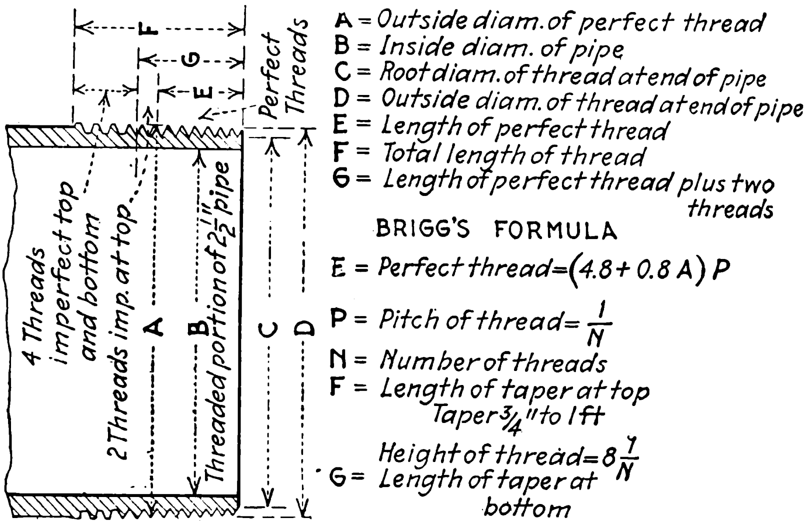


FIG. 132.—Standard conduit and pipe threads.

Size, pipe	No. of threads per in.	A	B	C	D	E	F	G	Diameter drill
$\frac{1}{8}$	27	0.405	0.270	0.334	0.393	0.19	0.41	0.264	$\frac{21}{64}$
$\frac{1}{4}$	18	0.540	0.364	0.433	0.522	0.29	0.62	0.402	$\frac{7}{16}$
$\frac{3}{8}$	18	0.675	0.494	0.567	0.656	0.30	0.63	0.408	$\frac{9}{16}$
$\frac{1}{2}$	14	0.840	0.623	0.702	0.816	0.39	0.82	0.534	$\frac{11}{16}$
$\frac{3}{4}$	14	1.050	0.824	0.911	1.025	0.40	0.83	0.546	$\frac{29}{32}$
1	$11\frac{1}{2}$	1.315	1.048	1.144	1.283	0.51	1.03	0.683	$1\frac{5}{32}$
$1\frac{1}{4}$	$11\frac{1}{2}$	1.660	1.380	1.488	1.627	0.53	1.06	0.707	$1\frac{15}{32}$
$1\frac{1}{2}$	$11\frac{1}{2}$	1.900	1.611	1.727	1.866	0.55	1.07	0.724	$1\frac{23}{32}$
2	$11\frac{1}{2}$	2.375	2.067	2.200	2.339	0.58	1.10	0.757	$2\frac{7}{32}$
$2\frac{1}{2}$	8	2.875	2.468	2.618	2.818	0.89	1.64	1.138	$2\frac{5}{8}$
3	8	3.500	3.067	3.243	3.443	0.95	1.70	1.200	$3\frac{1}{4}$
$3\frac{1}{2}$	8	4.000	3.548	3.738	3.938	1.00	1.75	1.250	$3\frac{21}{64}$
4	8	4.500	4.026	4.233	4.443	1.05	1.80	1.300	$4\frac{1}{4}$

186. Conduit Wire Capacity.—187, 188 and 188A, which gives *Nat. Elec. Code* recommendations, show how many rubber-covered conductors can be pulled into standard, iron conduit (iron pipe sizes). Table 187 gives values for medium runs,—average runs as defined under Table 187. Where runs are short or have few turns smaller conduit can be used than for long runs with several sharp turns. Table 188 indicates about the minimum and maximum limits. Conduit smaller than $\frac{1}{2}$ in. is not permitted for light or power wiring, but $\frac{3}{8}$-in. conduit is used for signal work. No wire smaller than No. 14 is permitted for light or power, but smaller ones are used for signal work.

Conduit should always be large enough that great force will not be necessary to pull wires into it. Where too much force is used the insulation will be injured and the wires wedged so that they cannot be withdrawn. Conduit is too small if block-and-tackle must be used to pull in small- and medium-sized wire. Wire larger than No. 8 should be stranded.

187. Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs (See Par. 186)

Size wire			Safe carrying capacity, amp. Rubber insulation 1915 Code Rules	Diam. rubber insul. double braid. in 32ds in.	Size of unlined, wrought-iron conduit for 0–600 volts, rubber-insulated double-braid wires — Permissible number of wires in one conduit															
	American or B. & S. gage	Circular mils			1	2	3	4	5	6	7	8	9	10	11 12	13 14	15 16	17 18	19	20 21
Solid	18	1,624	3	6	3/8	3/8	3/8	1/2	3/4	3/4	3/4	3/4	3/4	1	1	1	1¼	1¼	1¼	1¼
	16	2,583	6	7	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1	1	1	1¼	1¼	1¼	1¼	1¼
	14	4,107	15	8	3/8	1/2	3/4	3/4	1	1	1	1	1¼	1¼	1¼	1¼	1½	1½	1½	2
	12	6,530	20	9	3/8	3/4	3/4	3/4	1	1	1¼	1¼	1¼	1¼	1¼	1½	1½	2	2	2
	10	10,380	25	10	3/8	3/4	1	1	1	1¼	1¼	1¼	1¼	1½	1½	1½	2	2	2	2
	8	16,510	35	11	3/8	3/4	1¼	1¼	1¼	1¼	1¼	1½	1½	1½	2	2	2	2	2½	2½
Stranded	6	26,250	50	14	1/2	1	1¼	1¼	1½	1½	1½	2	2	2	2½	2½	2½	3	3	3
	5	33,100	55	15	3/4	1¼	1¼	1¼	1½	2	2	2	2½	2½	2½	2½	3	3	3	3
	4	41,740	70	16	3/4	1¼	1¼	1½	1½	2	2	2	2½	2½	2½	3	3	3	3	3½
	3	52,630	80	17	3/4	1¼	1¼	1½	2	2	2	2½	2½	2½	3	3	3	3½	3½	3½
	2	66,370	90	19	3/4	1½	1½	2	2	2½	2½	2½	3	3	3	3½	3½	4	4	4
	1	83,690	100	21	1	1½	2	2	2½	2½	3	3	3	3	3½	3½	4	4	4½	4½
	0	105,500	125	23	1	2	2	2	2½	3	3	3	3½	3½	3½	4	4½	4½	5	5
	00	133,100	150	24	1	2	2	2½	2½	3	3	3	3½	3½	4	4	4½	5	5	5
	000	167,800	175	26	1¼	2	2½	2½	3	3	3½	3½	3½	4	4	4½	5	5	6	6
	0000	211,600	225	28	1¼	2	2½	3	3	3½	3½	3½	4	4	4½	5	5	6	6	6
	....	250,000	260	30	1¼	2½	2½	3	3½	3½	4	4	4½	4½	5	5	6	6	6	......
	....	300,000	275	32	1½	2½	3	3	3½	4	4	4½	4½	5	5	6	6	......	....	....
	....	350,000	300	1″ 2	1½	3	3	3½	3½	4	4½	4½	5	5	6	6	6	......	....	....
	....	400,000	325	1″ 3	1½	3	3	3½	4	4½	4½	4½	5	5	6	6	....	....	....	....
	....	450,000	360	1″ 5	1½	3	3	3½	4	4½	4½	5	5	6	6	6	....	....	....	....

187. Wire Capacity of Unlined, Wrought Iron Conduit—Medium Runs (See Par. 186) (*Continued*)

Stranded	500,000	400	1″	6	2	3	3½	3½	4	4½	5	5	6	6	6		
	550,000	450	1″	8	2	3	3½	4	4½	5	5	6	6	6			
	600,000	450	1″	9	2	3½	3½	4	4½	5	5	6	6	6			
	650,000	475	1″	11	2	3½	3½	4	4½	5	6	6	6	6			
	700,000	500	1″	12	2½	3½	4	4½	5	6	6	6	6				
	750,000	525	1″	13	2½	3½	4	4½	5	6	6	6					
	800,000	550	1″	14	2½	3½	4	4½	5	6	6	6					
	850,000	575	1″	15	2½	3½	4	4½	5	6	6	6					
	900,000	600	1″	16	2½	4	4	4½	5	6	6	6					
	950,000	625	1″	17	2½	4	4½	5	6	6	6						
	1,000,000	650	1″	18	2½	4	4½	5	6	6							
	1,100,000	690	1″	20	2½	4	4½	5	6	6							
	1,200,000	730	1″	22	2½	4½	5	5	6								
	1,300,000	770	1″	24	3	4½	5	6	6								
	1,400,000	810	1″	25	3	4½	5	6	6								
	1,500,000	850	1″	27	3	4½	5	6									
	1,600,000	890	1″	28	3	5	5	6									
	1,700,000	930	1″	30	3	5	6	6									
	1,800,000	970	1″	31	3	5	6	6									
	1,900,000	1,010	2″	1	3	5	6	6									
	2,000,000	1,050	2″	2	3	6	6										

Table of conduit sizes for No. 14 B. & S. duplex, double-braided cables for 0 to 600 volts

Size conduit	No. of duplex cables, ordinary runs
½	1
¾	2
1	3
1¼	6
1½	8
2	15

A **short run** is one that is not over 150 ft. in length and that is almost straight but it may have one or two bends of a radius not less than 3 ft. Good conditions for pulling and feeding wire are assumed.

A **medium run** is one that does not exceed 150 ft. in length and has not more than three or four easy bends. Or it may be 250 ft. long and nearly straight. Or it may be a short run with one close bend and one or two easy ones.

A **long run** is one of a length exceeding 150 ft. with close or medium bends: a run with more than one close bend, or any run with an extra close bend.

188. Wire Capacity of Unlined Wrought-iron Conduit for Short, Medium and Long Runs. (See Pars. 186 and 187.)

Size of wire			Size of conduit, inches							
			1 wire in conduit			2 wires in conduit			3 wires in conduit	
	B. & S. Gage	Circular mils	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run	Short Run	Medium Run	Long Run
Solid	14	4,107	3/8	3/8	1/2	1/2	1/2	3/4	1/2	3/4	1
Solid	12	6,530	3/8	3/8	1/2	1/2	3/4	3/4	3/4	3/4	1
Solid	10	10,380	3/8	3/8	1/2	1/2	3/4	3/4	3/4	1	1
Solid	8	16,510	3/8	3/8	1/2	3/4	3/4	1	1	1 1/4	1 1/4
Stranded	6	26,250	1/2	1/2	3/4	1	1	1 1/4	1	1 1/4	1 1/4
Stranded	4	41,740	1/2	3/4	3/4	1	1 1/4	1 1/4	1 1/4	1 1/4	1 1/2
Stranded	3	52,630	1/2	3/4	3/4	1 1/4	1 1/4	1 1/2	1 1/4	1 1/4	1 1/2
Stranded	2	66,370	1/2	3/4	1	1 1/4	1 1/2	1 1/2	1 1/4	1 1/2	2
Stranded	1	83,690	1/2	1	1	1 1/4	1 1/2	2	1 1/2	2	2
Stranded	0	105,500	3/4	1	1	1 1/2	2	2	2	2	2
Stranded	00	133,100	1	1	1	1 1/2	2	2	2	2	2
Stranded	000	167,800	1	1 1/4	1 1/4	2	2	2	2	2 1/2	2 1/2
Stranded	0000	211,600	1	1 1/4	1 1/4	2	2	2 1/2	2	2 1/2	3
Stranded	.....	300,000	1 1/4	1 1/2	1 1/2	2	2 1/2	2 1/2	2 1/2	3	3
Stranded	.....	400,000	1 1/2	1 1/2	2	2 1/2	3	3	3	3	3 1/2
Stranded	.....	500,000	2	2	2 1/2	3	3	3 1/2	3 1/2	3 1/2	4
Stranded	.....	700,000	2	2 1/2	2 1/2	3	3 1/2	4	4	4	4 1/2
Stranded	.....	1,000,000	2	2 1/2	3	4	4	4 1/2	4 1/2	4 1/2	5
Stranded	.....	1,500,000	3	3	4	4 1/2	4 1/2	5	5	5	6
Stranded	.....	2,000,000	3	3	4	6	6	7	6	6	7

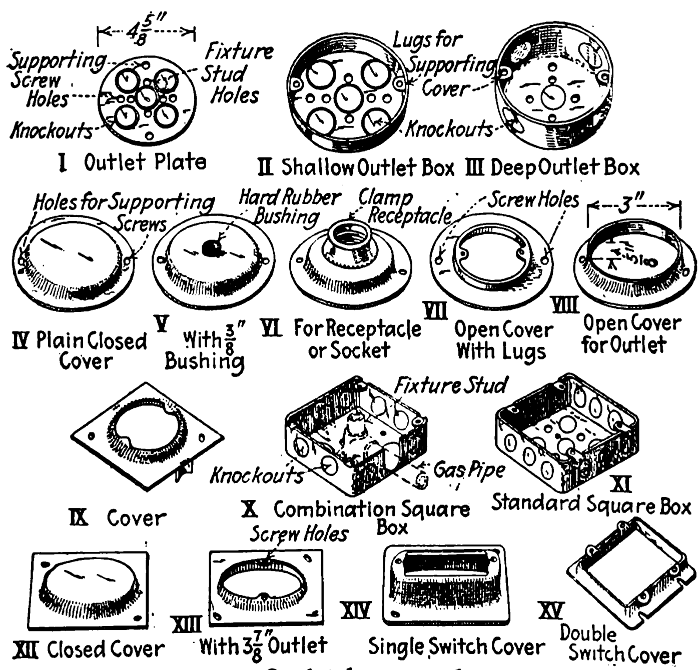


FIG. 133.—Outlet boxes and covers.

188A. Standard Code Sizes of Unlined Wrought-iron Conduit for Installation of Wire and Cables.—Conduit sizes based on the use of not more than three 90-degree elbows in runs taking up to and including No. 10 wire, and two elbows for wires larger than No. 10. Wires No. 8 and larger are stranded. Special permission is required of the inspection department having jurisdiction for the installation of more than nine wires in the same conduit. The wires used by the telephone companies of various cities differ as to thickness of insulation. The table "A" gives values satisfactory for both light and heavy insulation. For explanation of column heading reference letters for this table A, see footnotes. All data in following table from 1915 Nat. Elec. Code, except those in *italics* which are Nat. Elec. Contr's Ass'n recommendations.

Size of wire		Single wires			
B. & S. or A.W.G.	Circular mils	1 wire	2 wires	3 wires	4 wires
14	4,107	½	½	½	¾
12	6,530	½	¾	¾	¾
10	10,380	½	¾	¾	1
8	16,510	½	1	1	1
6	26,250	½	1	1¼	1¼
5	33,100	¾	1¼	1¼	1¼
4	41,740	¾	1¼	1¼	1½
3	52,630	¾	1¼	1¼	1½
2	66,370	¾	1¼	1½	1½
1	83,690	¾	1½	1½	2
0	105,500	1	1½	2	2
00	133,100	1	2	2	2½
000	167,800	1	2	2	2½
0000	211,600	1¼	2	2½	2½
	200,000	1¼	2	2½	2½
	250,000	1¼	2½	2½	3
	300,000	1¼	2½	2½	3
	400,000	1¼	3	3	3½
	500,000	1½	3	3	3½
	600,000	1½	3	3½	..
	700,000	2	3½	3½	..
	800,000	2	3½	4	..
	900,000	2	3½	4	..
	1,000,000	2	4	4	..
	1,250,000	2½	4½	4½	..
	1,500,000	2½	4½	5	..
	1,750,000	3	5	5	..
	2,000,000	3	5	6	..

Twin or duplex wires		
Size, A.W.G. or B. & S.	Number of wires	Size of conduit
14	1	½
14	2	¾
14	3	1
14	4	1
12	1	½
12	2	¾
12	3	1
12	4	1¼
10	1	¾
10	2	1
10	3	1¼
10	4	1¼

A Conduit capacities for various wires

Conduit	1 a	1 b	1 c	d	e
½	3	*10*	*18*	*5*	*3*
¾	5	*20*	*30*	*10*	*6*
1	10	*30*	*40*	*15*	*10*
1¼	18	*70*	*100*	*25*	*16*
1½	24	*90*	*130*	*35*	*25*
2	40	*150*	*200*	*50*	*35*
2½	74	...	...	..	..
3	90	...	...	..	..

1—Based on straight run without elbow.

Three-wire convertible system		
Size of conductors, A.W.G. or B. & S. — 2 conductors	Size of conductors, A.W.G. or B. & S. — 1 conductor	Conduit size, in.
14	10	¾
12	8	¾
10	6	1
8	4	1
6	2	1¼
5	1	1¼
4	0	1½
3	00	1½
2	000	1½
1	0000	2
0	250,000	2
00	350,000	2½
000	400,000	2½
0000	550,000	3
250,000	600,000	3
300,000	800,000	3
400,000	1,000,000	3½
500,000	1,250,000	4
600,000	1,500,000	4
700,000	1,750,000	4½
800,000	2,000,000	4½
....	....	....
....	....	....
....	....	....

a—No. 14 R. C. d. b. solid wires. **b**—No. 16 light insulation fixture wires. **c**—No. 18 light insulation fixture wires. **d**—No. 20 braided and twisted pair. Switchboard or desk instrument wire. Based on not more than two 90-degree elbows. **e**—No. 19 braided and twisted pair. Standard 3/32 insulation telephone wire. Based on not more than two 90-degree elbows.

189. Conduit should run as straight and direct as possible. There should never be more than the equivalent of four right-angle bends between drawing-in outlets.

190. Outlet boxes that are used for conduit wiring are of sheet steel, preferably coated with zinc. They not only hold the conduit ends firmly in position and form a pocket for enclosing wire joints but they constitute electrical connectors between the elements of the conduit system all of which must be in good electrical contact. Each conduit run in an installation must terminate in an accessible outlet box. Outlet plates are thinner than boxes and are used where the installation of outlet boxes is not feasible.

191. **Conduit outlet boxes** are made in many different forms (Figs. 133 and 134) and covers for them are also made in many different forms adaptable for special purposes. For ordinary work it is necessary to stock boxes of but two of these forms, the shallow box *II* and the combination box *X*. The shallow box which is designed primarily for outlets on terra cotta (Fig. 159) in fire-proof buildings can be used for ceiling outlets where it is convenient to enter the conduits into it from the back. Where the conduits should enter the sides or for combination fixture outlet work the combination box of Fig. 133, *X* can be used, when equipped with a suitable cover. Two of the knock-outs in the combination box are so formed that, when they are removed, either a round opening for conduit or an oblong opening for pipe is afforded. The shallow box which can be purchased with or without screw lugs for covers is cheaper than the combination box. The outlet plate *I* may be used where it is not feasible to use an outlet box.

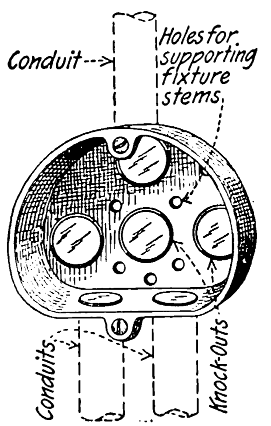


FIG. 134.—Bracket, outlet and junction box.

Outlet boxes are made of No. 10 to 12 gage sheet steel and Sherardized or galvanized ones are preferable to the japanned as with them the electrical conductivity of the conduit system is better preserved. Round boxes are made 3 in. and 4 in. in diameter. The 3-in. size is large enough for ordinary building wiring. Shallow boxes are about $\frac{1}{2}$ in. or $\frac{3}{4}$ in. deep. Standard round boxes for installation in brick are about $1\frac{1}{2}$ or $1\frac{5}{8}$ in. deep while those for lath and plaster are about $2\frac{1}{4}$ in. deep. This depth is necessary to insure that conduits entering the side knock-outs will clear the plaster. Square boxes are about 4 in. square and about $1\frac{5}{8}$ in. deep for brick and $2\frac{1}{4}$ in. deep for lath and plaster.

192. **All boxes should be installed** so that the outer edge of the box or the cover mounted on the box will come flush with the surface of the plaster. An outlet or junction box should never be concealed as concealment would defeat its purpose.

192A. **Switch outlet boxes** for one or two switches can be formed by equipping a square box with switch cover as at *XIV* and *XV*, Fig. 133. Where more than two switches are required in one group special outlet boxes for the group can be purchased.

193. **A special bracket, outlet and junction box** (Fig. 134) $3\frac{15}{16}$ in. in diameter and 2 in. deep is of great convenience where there are many bracket outlets to install in that two parallel conduits can be run into it as with a square box but at the same time its

diameter is such that a bracket canopy will cover it. A square box with a round-opening cover will accomplish the same end but the combination will cost more than the special box illustrated.

194. Every conduit outlet should be equipped with an outlet box or plate to satisfy code requirements. Although inspectors

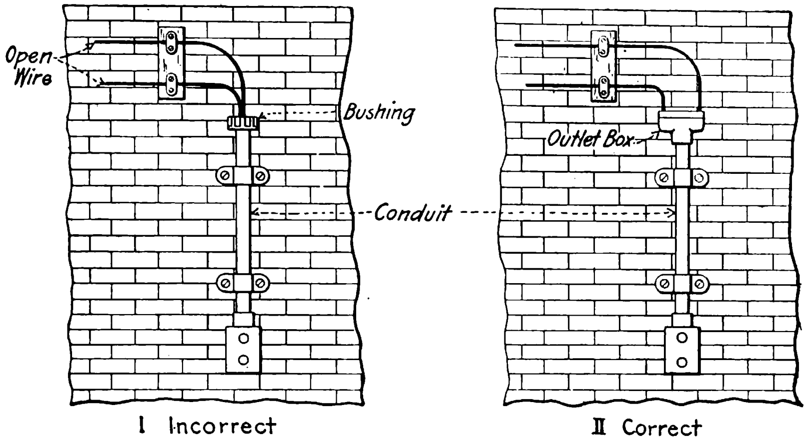


FIG. 135.—Outlet box on conduit.

sometimes accept the arrangement of Fig. 135 *I*, that shown in *II* is much better and should be used inasmuch as it provides the $2\frac{1}{2}$-in. separation required for open wiring when the conductors are not enclosed in flexible tubing.

195. Conduit junction boxes which are in reality nothing more than pull boxes on a large scale are often very convenient at points

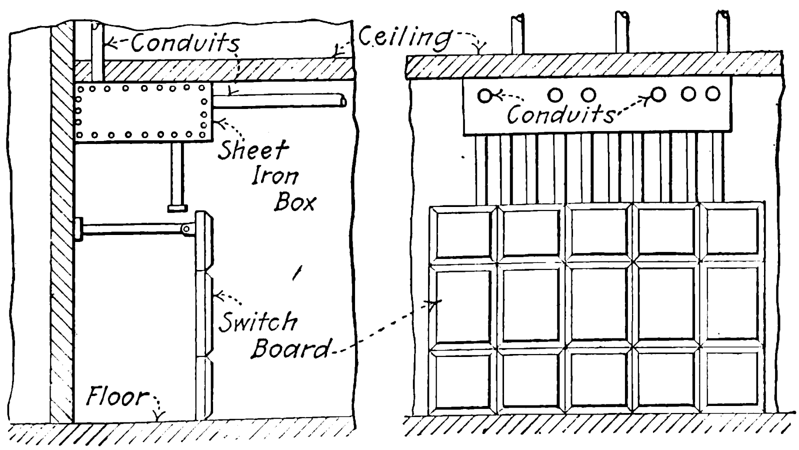


FIG. 136.—A sheet-iron conduit junction box.

where several conduit lines intersect, as for instance over a switchboard (Fig. 136) from which conduit lines radiate. The junction box is usually supported from the ceiling and is best made of sheet iron on an angle iron frame. The sides should be held on with machine screws turning into tapped holes in the frame so that they can be readily removed. Round holes can be cut in the sheet-iron sides for the conduits or instead, and often preferably, slots can be provided. The conductors within the box can be carried from conduit outlet to conduit outlet in any direction desired, and the use of elbows and troublesome conduit crossings can, thereby, be avoided.

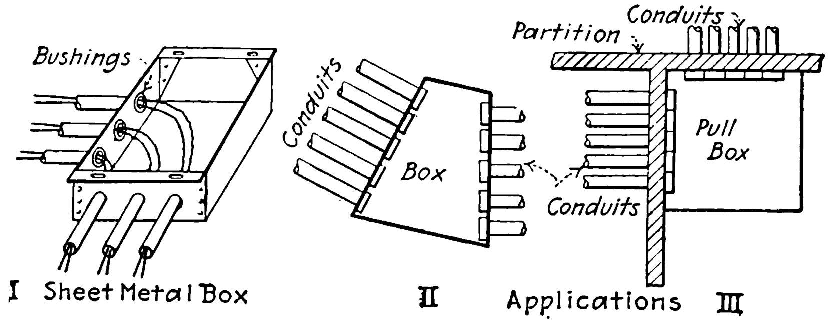


FIG. 137.—Conduit pull boxes.

196. Pull Boxes can often be Advantageously Substituted for Elbows (Fig. 137).—Large elbows are expensive. Where there are three or more right-angle turns in a run, a pull box should be inserted in any event. One pull box may be substituted for several elbows. Wire can be pulled in more readily where there are pull boxes hence, with them smaller conduit can often be used. Pull boxes can be made of sheet steel (Fig. 137, *I*) or of wood lined with sheet steel. Iron boxes should be made in accordance with the directions of a preceding paragraph (191). Boxes should be made and drilled in the shop where proper tools are available rather than on the job.

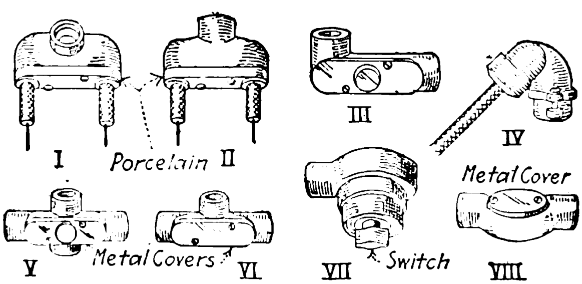


FIG. 138.—Some popular conduit fittings.

197. Conduit fittings are appliances used to adapt conduit to different situations and conditions. Fig. 138 shows some popular fittings, the applications of which are obvious. The code specifies that every conduit outlet must be equipped with an outlet box or plate. A fitting like that of *I* or *II* placed on a conduit end fulfils this requirement. Crosses, tees, and elbows *V*, *VI* and *III* can be obtained fitted with either metal covers or with outlet or other devices. The fitting of *IV* is used on the end of an out-of-door piece of conduit into which wires enter. Its shape is such that wires must enter upwardly preventing the entrance of moisture. As it is almost impossible to pull wires through a fitting of this kind after it is in place it is therefore held to coupling on the end of the conduit with screws turning into a flange. The wires can be pulled into the conduit and the fitting slipped over them and attached to the flange without its being necessary to turn the fitting. The fittings of *VII* and *VIII* can be used either as pull boxes to support switches or for a number of other purposes. Everyone

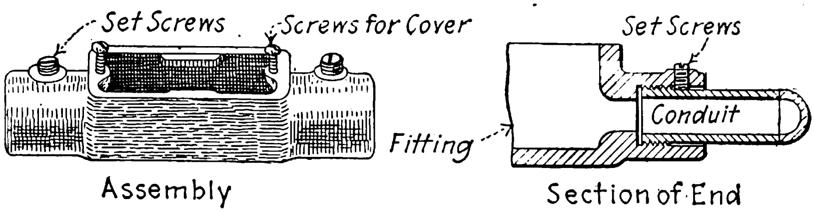


FIG. 139.—Pipe taplet.

interested in wiring should have the catalogues of the fitting manufacturers. These illustrate a great number of fitting combinations and applications.

198. "Pipe Taplet" fittings for conduit, Fig. 139 (H. T. Paiste, Philadelphia) have a set screw which assists the usual pipe threads holding the conduit. With Pipe Taplets it is necessary to cut only 4 or 5 full threads on the conduit. The steel set screws in the hubs of the fittings insure secure attachment and enable the wireman to accurately line up his conduit. Many different forms

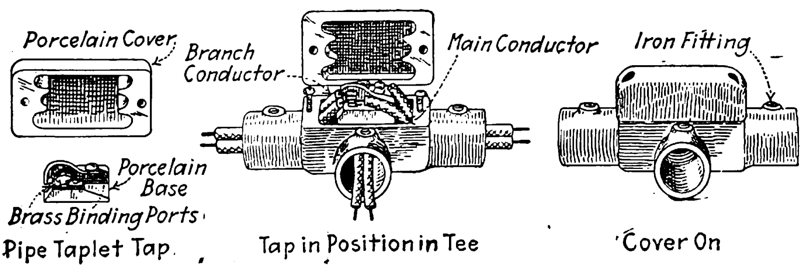


FIG. 140.—Pipe taplet tap.

of these fittings are made and many different kinds of outlet and appliance covers can be supplied for them. See the manufacturer's catalogue.

199. The Pipe Taplet Tap, Fig. 140 (H. T. Paiste, Philadelphia), is an exceedingly convenient appliance of porcelain with brass binding screws and strip. It fits in the Pipe Taplets described in the preceding paragraph. It is used for joining branch circuits to main circuits in conduit wiring. No soldering is necessary as the conductors are connected by clamping them under the binding posts. The porcelain cover encloses the completed splice. A similar appliance is made for molding wiring applications. See the manufacturer's catalogue.

200. **"No-thread" fittings,** Fig. 141 (*Appleton Electric Co., Chicago*), can be used with unthreaded conduit. Tightening a bushing or a lock-nut, clamps the conduit within the fitting. Their application is objectionable in some instances because they do not look as well as fittings that expose no threads.

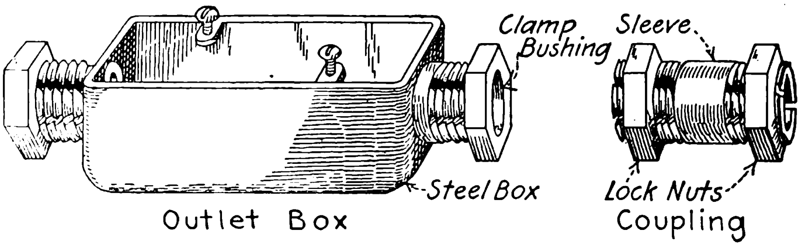


FIG. 141.—"No-thread" fitting.

201. **Properly bent conduit turns look better than elbows** and are therefore preferable for exposed work. See Fig. 142. If bends are formed to a chalk line, drawn as suggested in **202,** the conduits can be made to lie parallel at a turn in a multiple run as shown at Fig. 142, *II*. If standard elbows are used it is impossible to make them lie parallel at the turns. They will have an appearance similar to that shown at *I*.

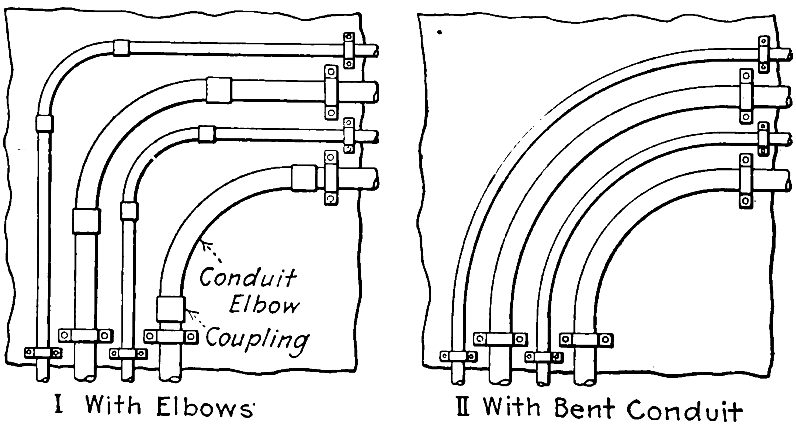


FIG. 142.—Right angle turns with elbows and with bent conduit.

202. **To Lay out a Right-angle Conduit Bend.**—Draw a chalk-line diagram of the contour of the bend on the floor as follows: See Fig. 143. Draw a base line *CO* of any length. Lay off *AO* 4 units long. (The units may be any dimensions whatever.) With a cord and a piece of chalk with *O* as a center and a radius of 3 units describe the arc *IJ*. With *A* as a center and a radius of 5 units describe the arc *EH*. The line *OD* drawn from *O* through *B*, the intersection of the two arcs, will be at right angles with *CO*.

CO and *OD* may now be prolonged for any desired distance. The arc *CD* is drawn with the cord and chalk with any required radius *R*. The conduit bend should lie parallel to this arc when the bend is laid on the floor for inspection as shown in Fig. 144. Table

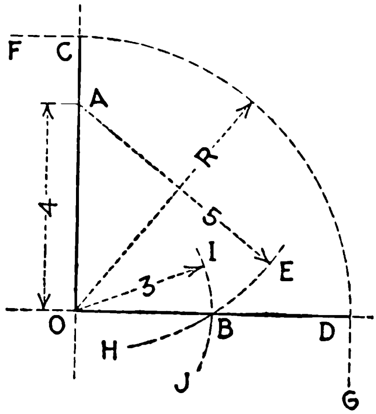


FIG. 143.—Laying out a right angle.

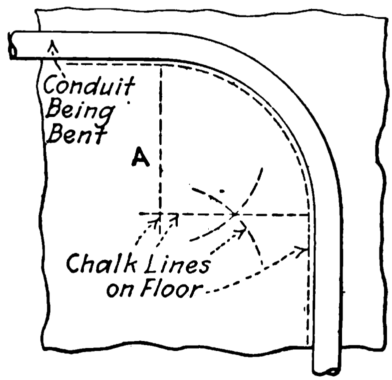


FIG. 144.—Forming a conduit to chalk lines.

173 shows the minimum radii that should be used for conduit bends.

203. Hand conduit benders are shown in Fig. 145. Many satisfactory commercial benders are obtainable but they usually

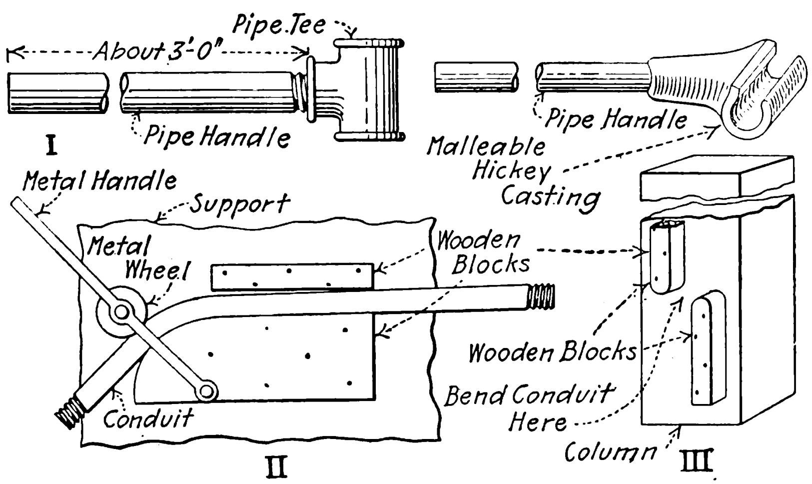


FIG. 145.—Some conduit-bending appliances.

have the disadvantage that the work must be carried to them to be bent. The "hickeys" shown at *I* can be used anywhere, hence are very popular. For ½- or ¾-in. conduit the "hickey" should be a 1-in. tee and pipe. A bender with a grooved metal wheel that any one can make is shown at *II*. The arrangement of *III* can be used for large conduit. It consists of two heavy wooden blocks bolted to a column or other substantial vertical support.

204. **To bend conduit by hand,** butt the end in which the bend is not to be made against a wall or other vertical substantial object and mark off on the floor, with a line, the point where the bend should come. Slip the bender onto the pipe to a point within a

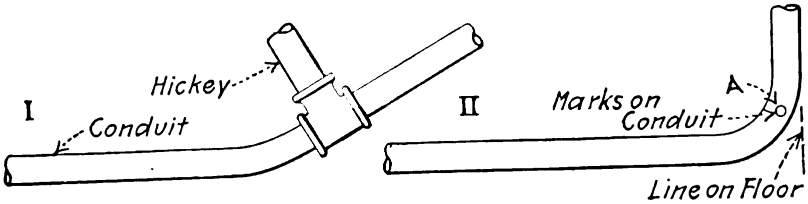


FIG. 146.—Bending conduit by hand.

couple of inches of the mark. Then bend the conduit about 20 degrees (Fig. 146, *I*). Move the bender back an inch or so and bend some more. Repeat until the bend assumes the proper form. Make all bends with as large a radius as possible. The minimum radius of inside of bend for any bend is $3\frac{1}{2}$ in. Where a line is drawn on the floor, conduit can be bent accurately to it (Fig. 146, *II*) but if a mark is placed on the conduit as at *A* it very difficult to make a proper bend.

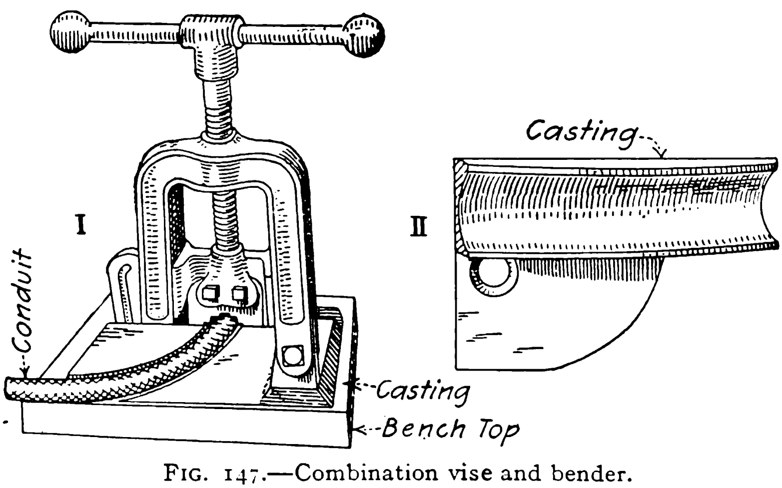


FIG. 147.—Combination vise and bender.

205. **A combination conduit vise and bender** for conduit of the smaller sizes is shown in Fig. 147. By bolting the casting shown at *II* to a commercial vise the arrangement shown at *I* results.

206. **The best vise for large conduit** is the so-called combination vise which is a combination of a pipe vise and a machinist's vise.

207. **Cold Bending Large Conduit.**—A rig for doing this is shown in Fig. 148. The bending rig can be set up in a door-way or between any strong vertical supports. It is usually cheaper to bend large elbows than to buy them. Always carefully lay out a

chalk line (see **202**) on the floor to bend to before starting. In forming a bend, start at one end of the curve that is to be, bend a little with the jack screw and then take the conduit out and to the chalk line and compare it therewith. Proceed thus until the bend required is formed. A hydraulic rather than a screw jack may be necessary for conduits larger than 2 in. diameter.

The wooden form by means of which the jack screw's pressure is applied to the conduit is detailed in Fig. 149. It should be of a

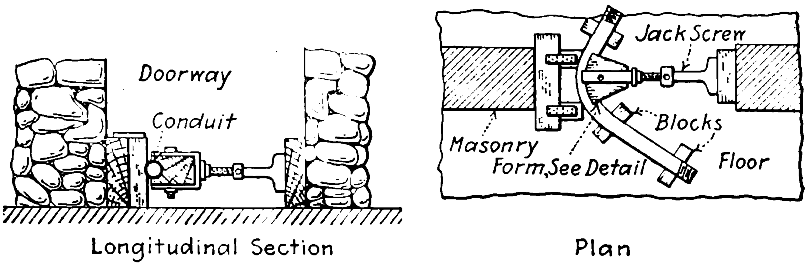


FIG. 148.—Cold bending conduit with a jack-screw.

hard close-grained wood such as maple. The diameter of the groove should be a trifle larger than that of the conduit. There should be a block for each size conduit, but sometimes a conduit can be successfully bent with a block for a larger size. If the groove does not fit, the pipe may crush. The iron strap reinforces the groove. The bolt should fit the hole for it in the block tightly or the block may crush. The radius *R* (Fig. 143) should be not less than that of standard elbows; see Table **173**. The minimum, inside radius, is $3\frac{1}{2}$ in.

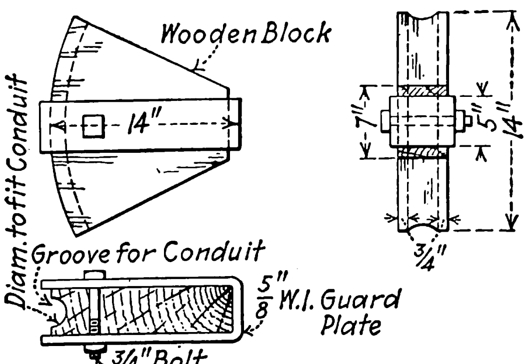


FIG. 149.—Wooden form for bending conduit.

208. Threading Conduit.—The same dies that are used by steam and gas fitters for threading pipe are used for threading conduit. It is usual practice when a lot of conduit is received to rethread all of the ends which may have become filled with paint or dirt or distorted by blows. Rethreading will save more than its cost in that it insures rapid erection. Always meream conduit after cutting a thread on it.

209. Pipe-threading machines for threading conduit, preferably those operated by motors, should be used on big jobs and will soon pay for themselves in the time that they save.

210. Running thread joints (Fig. 150) are sometimes used when it is necessary to connect the ends of two lengths of conduit neither of which can be turned. Running threads are often used in making

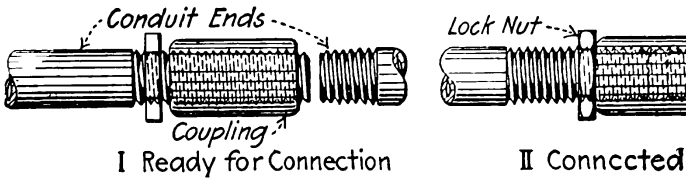


FIG. 150.—A running thread.

repairs to or alterations in existing conduit installations. The function of a running thread joint is similar to that of the pipe union used in steam and gas fitting.

To make a running thread joint, the thread on one length of conduit (Fig. 150) is cut sufficiently long that the coupling can be run entirely on it while the adjacent length is being fitted into

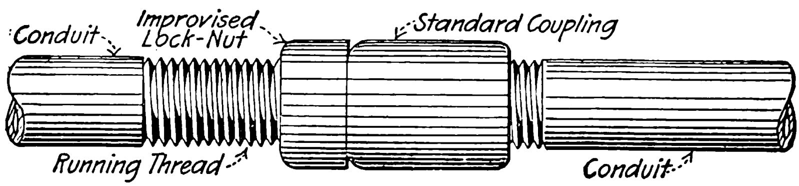


FIG. 151.—Showing lock-nut sawed from coupling.

position. The adjacent length has the usual "short thread." After both lengths are in position the coupling is turned until it wedges up tightly on the short thread. About half of the coupling should, in the completed joint, rest on each length (Fig. 150, *II*).

A lock-nut should be used, as shown, on the long thread length to hold the coupling firmly in the conduit as it is apt, otherwise,

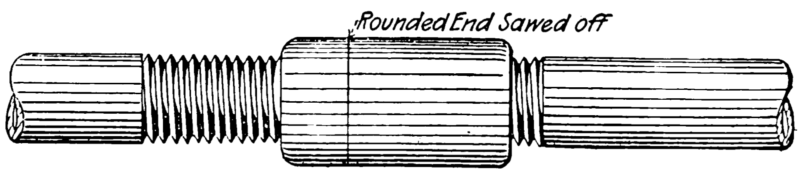


FIG. 152.—Coupling end sawed off to make flush joint.

to fit loosely because of the long thread. An excellent lock-nut can be made by sawing off, with a hack-saw, about one-third of a coupling and using this third, as shown in Fig. 151. The standard, hexagonal, conduit lock-nut often gives trouble because it has only a few threads and they may be "loose." Where a very neat job is required, saw off the rounded end of the standard coupling so that the sawed end of the improvised coupling lock-nut will have a square surface on which to abut. See Fig. 152 for an illustration.

210A. The Erickson coupling (Fig. 152, *A*), was devised for the same applications as those for which the running thread is used. The illustration shows the construction of the device.

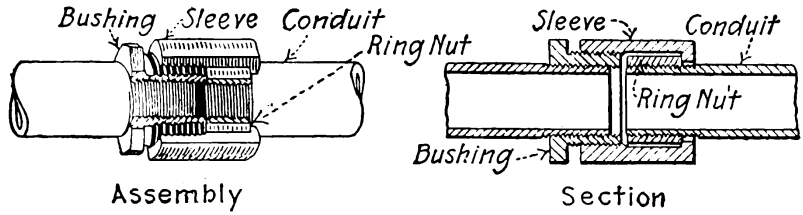


FIG. 152A.—The Erickson coupling.

211. Wrenches for Turning Conduit.—The form of wrench shown in Fig. 153, *I*, appears to be the most popular for turning conduit. Chain wrenches (*II*) are not as yet much used for conduit work but in instances where they have been tried they have proven very satisfactory. Their advantages lie in the facts that they can be used with one hand after the chain is around the conduit and

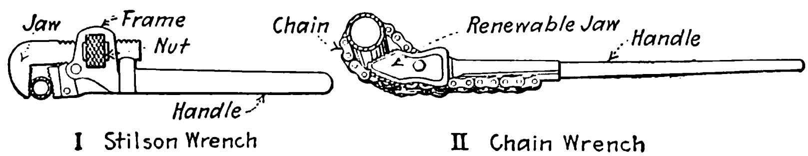


FIG. 153.—Wrenches for conduit.

that they can be used in confined places and close to walls where a Stilson wrench could not be utilized.

212. Conduit ends should always be reamed. A reamer like that of Fig. 154 that can be turned by a bit brace is a good tool for small and medium size conduit. For conduit of the larger sizes, reamers can be obtained which have long handles attached, giving

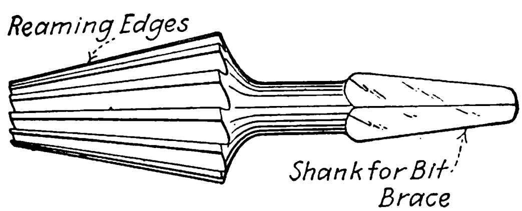


FIG. 154.—A bit-brace reamer.

the needed leverage. When conduit is received, and after it is cut, the ends are frequently turned in (Fig. 155, *I*) and when screwed together in a coupling form a knife-like edge which will abraid insulation. When the ends are properly reamed they appear as shown in Fig. 155, *II*, but if they are screwed together too tightly they may turn up as at *I*, defeating the thing that reaming should accomplish. Where no other tool is available, conduit can be reamed by hand with a half-round file.

213. **The best tool for cutting conduit** is a hack saw. Pipe

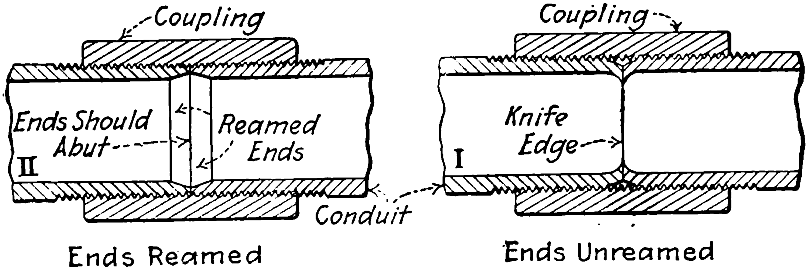


FIG. 155.—Reamed and unreamed conduit ends.

cutters are frequently used but leave a large burr on the inside of the conduit which takes time to ream out. While cutting, the conduit should be held in a vice. On jobs where there is a great deal of conduit to cut, the installation of a motor-driven cold-cut-off saw, such as is used for cutting structural steel and rails, will prove economical. A rapidly rotating steel disc without teeth cuts the pipe. Water must be sprayed on the disc to keep it cool.

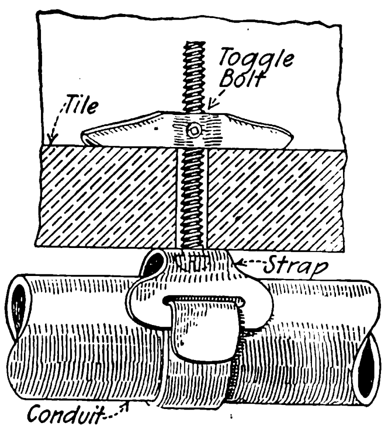


FIG. 156.—Conduit toggle bolt.

214. **In installing exposed conduit runs** where there are several conduits in the run it is usually better to carry the erection of all of them along together rather than to complete one line before starting the others. If all are carried along together it is easier to maintain all of the ducts parallel, particularly at turns, and the chances are that the job will thereby look better.

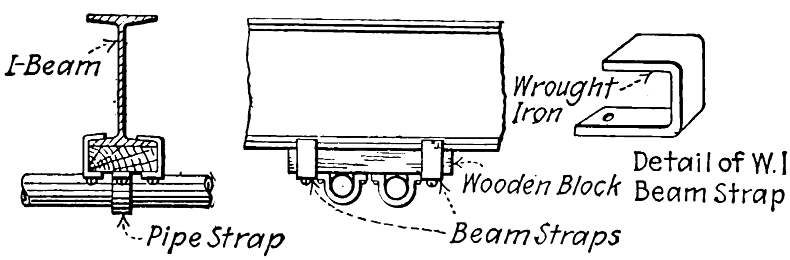


FIG. 157.—Application of beam straps.

215. **A hanger for supporting conduit on hollow tile** (Fig. 156) is made by the Yonkers Specialty Co., Yonkers, New York. With it only one hole is necessary through the tile which is considerably

weakened by the two holes and plugs close together that are necessary for a pipe strap. The flexible metal strap is bent around the pipe and through the slot after the conduit is in position.

216. Conduit can be supported on surfaces with pipe straps (Table 183). On wooden surfaces wood screws secure the straps in position. On masonry surfaces wood screws turning into wooden plugs driven in holes in the surface or turning into lead expansion anchors can be used. Wooden plugs are apt to be unsatisfactory because no matter how well seasoned a plug appears to be it will usually dry out some and loosen in the hole. Where

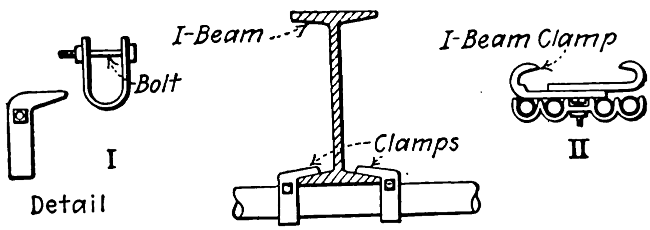


FIG. 158.—Commercial conduit clamps.

conduit is carried on the flanges of I-beams one of the many commercial clamps can be used or the one referred to in 219 can be applied. Conduit can also be supported on an I-beam by first clamping a wooden block to the beam and then securing the conduit to the block with pipe straps. (See Fig. 157.)

217. Some commercial I-beam conduit hangers are shown in Fig. 158. The one at *I* is an I-beam clamp formed from wrought-iron strap. The hanger or clamp—the part that grips the beam—of that at *II* can be purchased of either stamped steel or malleable

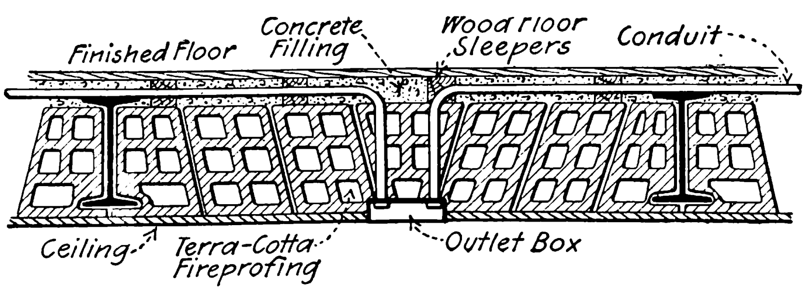


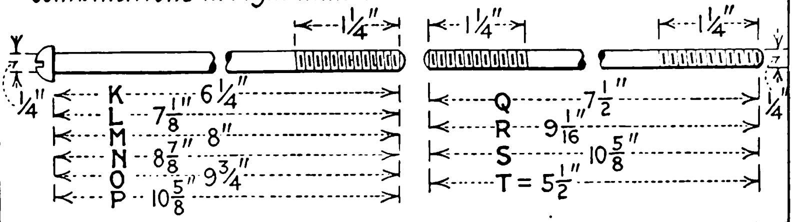
FIG. 159.—A fixture outlet in a terra-cotta ceiling.

iron. The support—the yoke in which the conduits rest—is of malleable iron and can be purchased to accommodate one or several conduits of different sizes.

218. Conduit in fire-proof buildings is usually carried over and is supported by the floor beams (Fig. 159) when carried within the floors. Where necessary the terra-cotta fire-proofing is channeled to receive it. In vertical runs in walls or partitions the fire-proofing is either channeled for or built around the conduit which is held in place prior to plastering with cut nails or pipe hooks.

219. The I-beam conduit clamps of Table 220 will be found of great convenience in steel mill and fire-proof building work. Their principal advantage is that they draw the conduit up closely against the I-beam and grip it very firmly. In a multiple-conduit run each conduit can be secured to a given beam with its own pair of clamps. Where the clamps are used on conduits in a group that lie close together the stove bolts should be used in

In case studs are used instead of stove bolts:– Use "Q" studs for all combinations in left hand section of table, use "R" studs for all combinations in center section, and "S" studs for all combinations in right hand section.



CONDUIT	SIZE OF I BEAMS								
	4"	6"	7"	8"	9"	10"	12"	15"	18"
½"	T 5½"	K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
¾"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1¼"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1½"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2½"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3½"		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
4		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
		←— Q —→				←— R —→		←— S —→	

FIG. 160.—Dimensions of store bolts and studs for the conduit clamps of Fig. 161.

preference to the studs so that they can be drawn up with a screw driver. For a single isolated conduit either studs or stove bolts can be used.

Fig. 160 shows the size of the stove bolts or of the studs, that should be used with a given I-beam and a conduit of a given size. Stove bolts of the sizes indicated are regularly manufactured, but are not always readily obtained. The studs can be easily made by threading the ends of ¼-in. wrought iron rod. In cramped locations the nuts on the studs can be tightened with pliers.

220. Dimensions of I-beam Conduit Clamps.—Clamps to be made of cast or malleable iron. See Fig. 160 showing dimensions of stove bolts and studs for clamps.

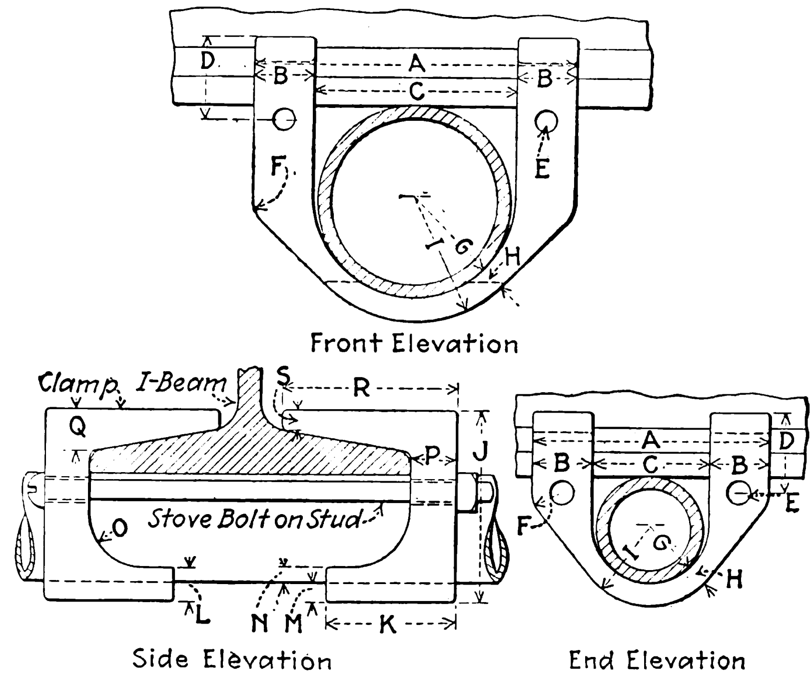


FIG. 161.—I-beam conduit clamp.

Size conduit, inches	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1 ½[1] 4″ beam	2 5/16	11/16	15/16	3/4	5/16	11/32	15/32	1/4	23/32	1 11/16	1 1/2	3/8	1/4	1/8	1/2	1/2	11/32	1 1/2	3/16
½	2 5/16	11/16	15/16	1 1/8	5/16	11/32	15/32	1/4	23/32	2	1 1/2	3/8	1/4	1/8	1/2	1/2	15/32	2 1/8	3/16
¾	2 1/2	11/16	1 1/8	1 1/8	5/16	11/32	9/16	1/4	13/16	2 1/4	1 1/2	3/8	1/4	1/8	1/2	9/16	15/32	2 1/8	3/16
1	3	3/4	1 1/2	1 7/32	5/16	3/8	3/4	1/4	1	2 5/8	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1 ¼	3 1/4	3/4	1 3/4	1 3/16	5/16	3/8	7/8	1/4	1 1/8	2 29/32	1 5/8	7/16	1/4	3/16	11/16	9/16	33/64	2 3/16	1/4
1 ½	3 1/2	3/4	2	1 3/16	5/16	3/8	1	5/16	1 5/16	3 3/16	1 7/8	1/2	5/16	3/16	11/16	9/16	33/64	2 3/16	1/4
2	4	3/4	2 1/2	1 1/4	5/16	3/8	1 1/4	5/16	1 9/16	3 3/4	1 7/8	1/2	5/16	3/16	1 1/8	5/8	37/64	2 1/4	5/16
2 ½	4 3/4	7/8	3	1 15/32	5/16	7/16	1 1/2	5/16	1 13/16	4 1/2	2	9/16	15/16	1/4	1 1/4	11/16	41/64	2 5/16	3/8
3	5 3/4	1	3 3/4	1 5/16	5/16	1	1 7/8	3/8	2 1/4	5 1/8	2 1/8	9/16	3/8	3/16	1 1/4	11/16	41/64	2 3/8	3/8
3 ½	6 3/4	1 1/4	4 1/4	1 3/8	5/16	1 1/4	2 1/8	1/2	2 5/8	5 11/16	2 1/4	11/16	1/2	3/16	1 1/4	13/16	11/16	2 15/32	7/16
4	7 1/2	1 3/8	4 3/4	1 7/16	5/16	1 3/8	2 3/8	1/2	2 7/8	6 1/4	2 1/4	3/4	1/2	1/4	1 1/4	13/16	29/32	2 7/16	1/2

[1] This clamp is designed for 4-in. I-beams only.

221. Conduit in concrete buildings—much of it at any rate—should be installed while the building is being erected. The outlets and the conduit between outlets should be attached to the forms and the concrete can be poured around them (Fig. 162). Where several conduits are to pass through a wall, partition or floor, a plugged sheet-iron tube (Fig. 163, *I*) should be set in the forms to provide a hole for them in the concrete. Where a single conduit is to pass through, a nipple (Fig. 163, *II*) can be set in the forms. A running thread should be provided on the nipple so that the adjacent conduit lengths can be connected to it.

222. **Another method of supporting conduit in concrete buildings** is described in **83** and is illustrated in Fig. 60.

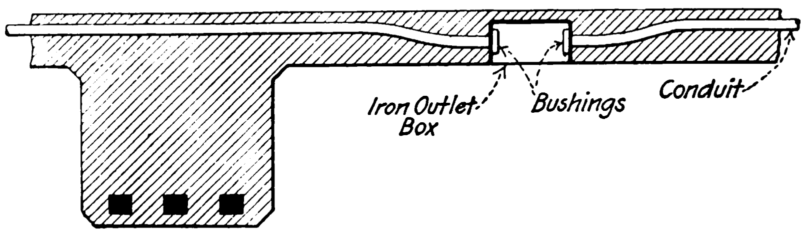


FIG. 162—Conduit and outlet box in concrete.

223. **Conductors in vertical conduits must be supported** within the conduit system as indicated in the following table.

No. 14 to 0 inclusive every 100 ft.
00 to but not including 0000 every 80 ft.
0000 to but not including 350,000 C. M. every 60 ft.
350,000 C. M. to but not including 500,000 C. M. every 50 ft.
500,000 C. M. to but not including 750,000 C. M. every 40 ft.
750,000 C. M. and over every 35 ft.

The following methods of supporting cables are recommended by the Underwriters:

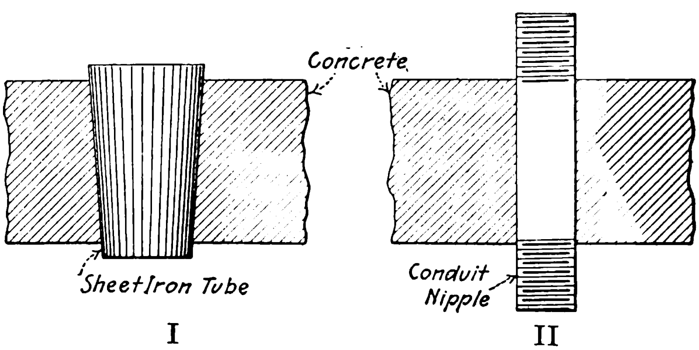


FIG. 163.—Methods of providing passages through concrete.

1. Approved clamping devices constructed of or employing insulated wedges inserted in the ends of the conduits.

2. Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of *approved* type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

3. Cables may be supported (Fig. 164) in *approved* junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 degrees, and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

Other methods, if used, must be approved by the Inspection Departments having jurisdiction.

224. Fishing wire (*Popular Electricity*, Apr. 7, 1912) is tempered steel wire of rectangular cross-section. It is a grade of wire that is used sometimes for corset steels and can be obtained at corset factories and at electrical supply houses. A fishing wire is termed a "snake" by some wiremen. See Table 227. So that a fishing wire will slide readily past small obstructions, hooks should be bent in its ends as shown in Fig. 165. Before bending, the ends should be annealed by heating them to a red heat and allowing them to cool slowly. A small brass knob riveted to the end of a fishing wire (Fig. 166), is better than a hook as regards the ease with which the wire can be pushed through conduit. Where fishing is difficult, it is sometimes necessary to push two "snakes" with hook ends into the wire way, one from each of the outlets, as shown in Fig. 165. The wires must be worked back and forth and twisted around until the two hooked ends engage. Then one wire can be pulled into the duct with the other. The Swan fishing wire for conduit, shown in Fig. 167, has a patented coupling on one end and a patented "drawing-in-eye" on the other, which can be made to engage within conduit, as shown in the illustration.

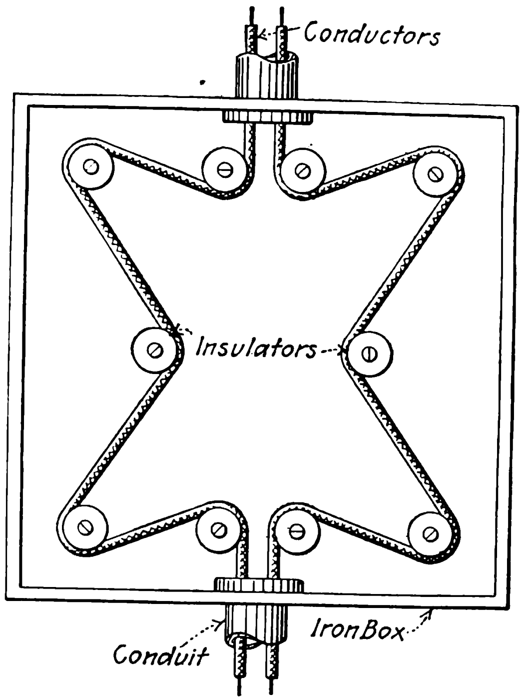


FIG. 164.—Supporting conductors in a vertical conductor run.

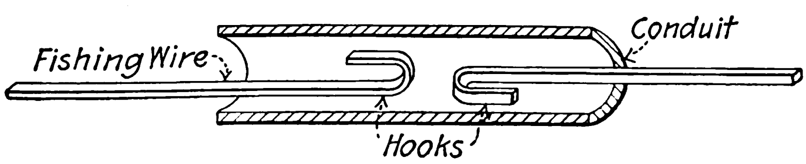


FIG. 165.—Hooks bent in fishing wire ends.

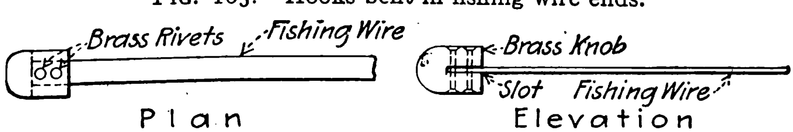


FIG. 166.—Knob on end of fishing wire.

When fishing from two ends, as in Fig. 165, it is often advisable to tie a loop, possibly a foot long, of cord, in the hook of one wire and bend down the hook (Fig. 168). The other wire has an open hook which can be made to engage in the cord loop quite readily.

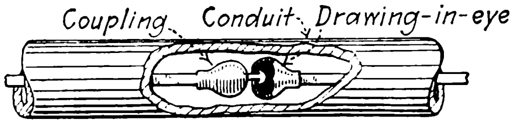


FIG. 167.—"Swan" coupling and drawing-in eye.

It has been found that a fish wire will go through conduit more readily if prepared as in Fig. 169, by loosely winding the end with small wire or cord, so that the wire or cord cannot pull off. Oiling a fish wire or attaching an oil-soaked piece of waste to its end often helps in fishing conduit.

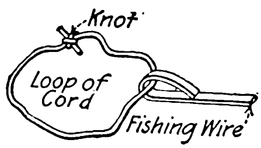


FIG. 168.—Cord loop on end of fishing wire.

225. Chain is used for vertical fishing. A small chain can be made to drop down a vertical wire way with little difficulty. Within a partition, the noise made by the lower end of a chain that is jiggled up and down will disclose its location almost exactly.

226. Galvanized steel wire can be used for fishing. Any size from No. 14 up to, possibly, No. 6, as occasion demands, may be utilized, but in nearly every case the flat steel ribbon wire will be found preferable.

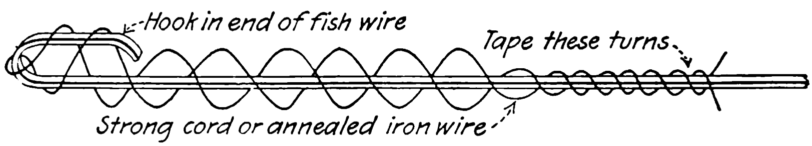


FIG. 169.—Fish wire end prepared with cord.

227. Dimensions of Steel Fish Wire

The ¼-in. wide wire is the size most frequently used. The wire is usually put up in coils of 50, 75, 100, 150 and 200 ft.

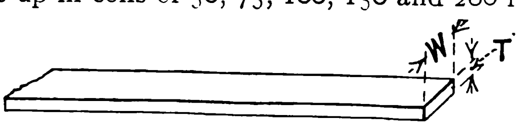


FIG. 170.—Steel fishing wire.

W Width, inches	T Thickness, inches	Weight, per 100 ft.	Approximate price, cents	
			Per pound	Per foot
1/8	0.015	11 oz.	90.0	0.62
1/8	0.030	1 lb. 4 oz.	60.0	0.75
3/16	0.030	1 lb. 14 oz.	60.0	1.13
1/4	0.030	2 lb. 8 oz.	60.0	1.50
5/16	0.035	3 lb. 8 oz.	55.0	1.93
3/8	0.035	3 lb. 12 oz.	55.0	2.06

228. Where conduit cannot be fished with a steel fishing wire because of some obstruction, it is often possible to blow through, with the mouth or with a plumber's force pump, a ball of cork of a diameter somewhat less than that of the conduit. Attached to the cork ball is a small strong cord (fish line) which can be used for pulling in a length of small wire which, in turn, can be used for drawing in the conductors. Put the ball in the conduit and feed

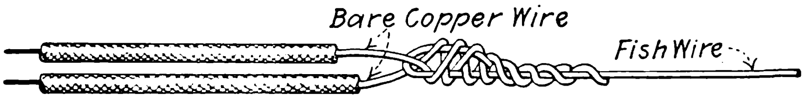


FIG. 171.—Attachment of conductor to fishing line.

in some string, then blow. With a plumber's pump, a tee is necessary on the end of the conduit; one opening is used for feeding in the string and the other for the pump blast. Close the cord opening when blowing.

229. In drawing wire into conduit (*Practical Engineer*, Apr. 17, 1912), it is a mistake to use so much force that the wire cannot be withdrawn. Conduits should be big enough so that excessive force

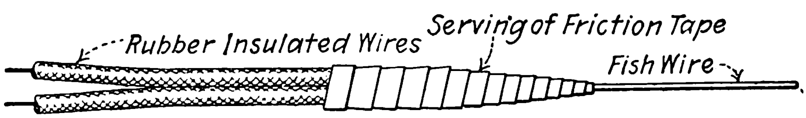


FIG. 172.—Attachment taped over.

is not necessary. Duplex No. 14 conductors can often be pushed through "easy" runs. Small conductors (No. 14 and No. 12) can be pulled in with the fish wire. Fig. 171 shows how they can be attached to the fish wire and Fig. 172 how the attachment should be served with tape to render pulling easy. It spoils any fishing wire to draw in with it conductors that pull hard.

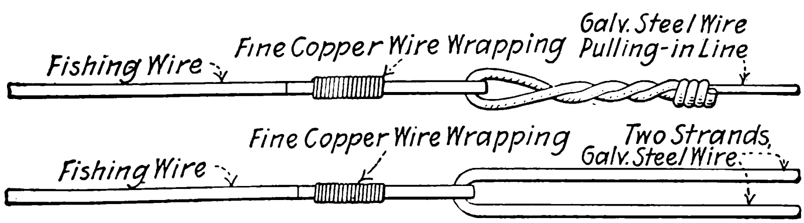


FIG. 173.—Attachment of pulling-in line to fish wire.

For conductors larger than No. 12 and No. 14, unless the "pulls" are "very easy," a pulling-in-line which is drawn into the conduit with the fish wire should be used for hauling in the conductors. No. 10 or No. 12 B.W.G. galvanized steel wire makes a good pulling-in-line and is probably better for heavy work than rope. Two strands can be used if necessary. Braided cord is better than twisted rope for a pulling-in-line, because when tension is applied, the rope tends to untwist. Sash cord is satisfactory for light work. Galvanized steel pulling-in-wire can be attached to fish wire as in Fig. 173.

Three or four links from a chain of no greater diameter than the line should be made up in the end of a rope or cord pulling-in-line. Wires to be drawn in or a fish line can be attached to the links (Fig. 174). One stranded conductor can be attached to a pulling-in-line as in Fig. 175. The attachment should be taped over to make it smooth. If two conductors are to be pulled in, one of them is "made up" into a loop in the end of the pulling-in-line, as shown in Fig. 175. The insulation is trimmed from this conductor for

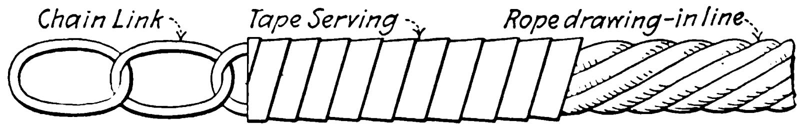


FIG. 174.—Chain links in end of pulling-in line.

6 in. or more and the bared end of the other conductor is made up about the first one, forming a long tapering connection. If a hard pull is expected, it is advisable to solder the connection. The whole should be served with tape as in Fig. 172. If three wires are to be drawn in instead of two, the attachment is the same with the addition that the bared end of the third conductor is made up around the other two. The diameter at any section of the attachment must not exceed the over-all diameter of the wires and the attachment should be in the form of a conical wedge. It is sometimes necessary to cut off, possibly, half of the strands of the bared ends and make up only the strands that remain to insure that the attachment will be of sufficiently small diameter.

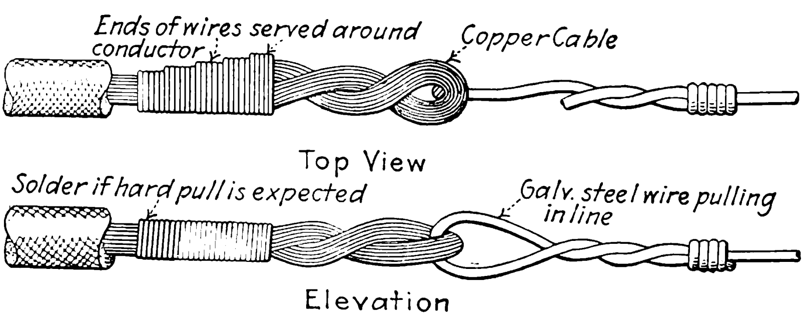


FIG. 175.—Attachment of stranded conductor to pulling-in line.

230. Force for pulling in conduit is, in the case of easy pulls, supplied by men. Tackle blocks are permissible for heavy pulls. Cranes can often be used very effectively where they are available. Snatch blocks can be used to guide the pulling-in-line to some point where it can be either pulled with the crane hook or by the crane in traveling along its runway. A lever can be used for hard pulls by either repeatedly fastening the pulling-in-line to the lever or by gripping it with a pair of pliers and then prying against the pliers with the lever. Only a short pull is possible with each setting and a succession of settings and prys is necessary to draw the conductor in.

231. **In feeding conductors into conduit,** care must be taken that they go in symmetrically and without lapping or twisting. If one conductor crosses another it may make a "hump" that will wedge in the conduit. Soapstone blown into conduit renders pulling easier. One convenient way to get the powdered soapstone into the ducts is to place it in an elbow, place the elbow to the conduit and then blow on the elbow. Powdered soapstone should be rubbed on the conductors as they are drawn into conduits where the pulls are hard.

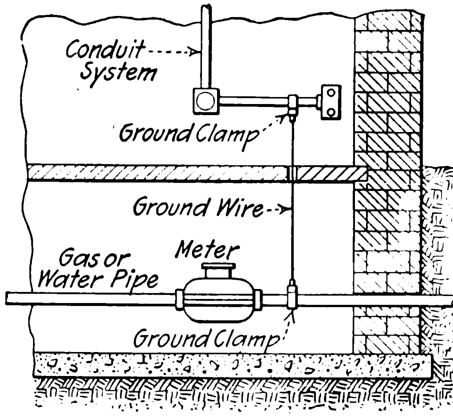


FIG. 176.—Method of installing ground on conduit system.

232. **Conduit systems must be grounded** by attaching a ground clamp (Fig. 176) to a conduit of the system and connecting it by a ground wire with a similar clamp attached to a water or gas pipe outside of the meter. The wire must be soldered in the clamps. All parts of the conduit system must be in good electrical contact. It may be necessary to scrape or file enamel from fittings or from conduit threads to effect this. If a conduit system is not grounded and one side of the circuit comes in contact with the conduit, an electrical path may be completed if the other side of the circuit happens to be grounded. (The neutral wire of a three-wire system is usually grounded.) The electrical path thus completed might be through damp wood or a contact with a gas pipe. A fire might result. With the conduit well grounded such a short-circuit would blow a fuse and thereby reveal itself. With combination fixtures the gas pipe should be in firm electrical contact with the conduit system at each outlet box.

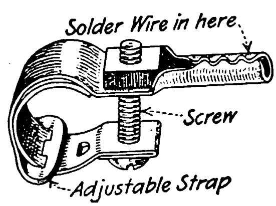


FIG. 177.—The "American" adjustable ground clamp.

233. **Wire for grounding conduit** must be of copper, at least No. 10 B. & S. gage, where the largest wire contained in conduit is not greater than No. 0 B. & S. gage. It need not be greater than No. 4 B. & S. gage where the largest wire contained in conduit is greater than No. 0 B. & S. gage. The wire must be protected from mechanical injury.

234. **An excellent ground clamp** (the American made by the Chelten Electric Company, Philadelphia) is shown in Fig. 177. It is adjustable and is made in four sizes. No. 1 fits $\frac{3}{8}$-in., $\frac{1}{2}$-in.,

$\frac{3}{4}$-in., and 1-in. conduit or pipe. No. 2 fits 1 $\frac{1}{4}$-in., 1 $\frac{1}{2}$-in., and 2-in. and No. 3 fits 2 $\frac{1}{2}$-in. and 3-in.

235. **Flexible metallic conduit** (*Standard Handbook*) may be used for all kinds of wiring; being in some cases preferable to rigid conduit. Its installation is much easier and quicker than the installation of rigid conduit, the latter coming in short pipe lengths, whereas the former may be had in lengths of 50 to 200 ft. depending on the size of the conduit. Practically the same *Nat. Elec. Code* rules apply to the flexible as to the rigid conduit. Rubber-covered wire must be used; outlet or switch boxes must be installed at all outlets or switches; the conduit must be continuous from outlet to outlet, must be securely fastened to the boxes and provided with proper bushings and must be permanently and effectually grounded with a copper wire. (See Par. 233.)

Its flexibility together with the continuous length procurable make its use practicable when rigid conduit would be out of the question. For this reason it may be employed to advantage in finished houses and in frame buildings in place of the other forms of wiring so largely employed in these structures. The conduit is easily fished and requires no elbow fittings. These may be made with the conduit itself; but care should be exercised in properly fastening the conduit at elbows. (Fig. 180.) Fittings are on the market whereby changes from other forms of wiring may be easily made to flexible conduit wiring. Iron plates should be used to protect the conduit from nails, where it passes through slots in floor beams or studding.

235A. Greenfield Flexible Steel Conduit

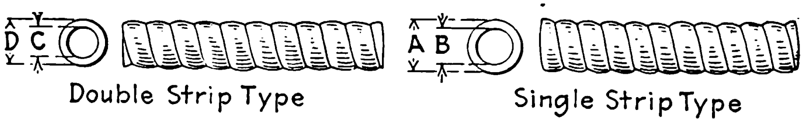


FIG. 178.—"Greenfield flexible steel conduit.

SINGLE-STRIP TYPE

B Nominal inside diameter in inches	A Approximate outside diameter in inches		Weight per 100 ft. in pounds	Approximate feet in coil	List price per 100 ft.	Largest wires accommodated: 1 wire	2 wires	3 wires
$\frac{5}{16}$	0.523	$\frac{17}{32}$	24	250	$5.00	....	....	.....
$\frac{3}{8}$	0.605	$\frac{39}{64}$	30	250	7.50	....	....	.....
$\frac{1}{2}$	0.875	$\frac{7}{8}$	55	100	10.00	8	12	.....
$\frac{3}{4}$	1.079	1 $\frac{3}{32}$	75	50	13.00	2	10	12
1	1.312	1 $\frac{5}{16}$	122	50	21.00	00	0	8
1 $\frac{1}{4}$	1.59	1 $\frac{19}{32}$	170	50	31.00	200,000	3	5
1 $\frac{1}{2}$	1.875	1 $\frac{7}{8}$	188	25–50	42.00	400,000	1	3
2	2.375	2 $\frac{3}{8}$	263	25–50	57.00	800,000	200,000	00
2 $\frac{1}{2}$	3	3	306	25	70.00	....	....	.....

DOUBLE-STRIP TYPE

C	D							
$\frac{5}{16}$	0.485	$\frac{1}{2}$	20	250	$5.00	....	....	.....
$\frac{3}{8}$	0.61	$\frac{5}{8}$	34	250	7.50	....	....	.....
$\frac{1}{2}$	0.92	$\frac{59}{64}$	68	100	10.00	8	12	.....
$\frac{3}{4}$	1.18	$1\frac{3}{16}$	95	50	13.00	2	10	12
1	1.49	$1\frac{1}{2}$	144	50	21.00	00	0	8
$1\frac{1}{4}$	1.75	$1\frac{3}{4}$	182	50	31.00	200,000	3	5
$1\frac{1}{2}$	2.06	$1\frac{1}{16}$	217	25-50	42.00	400,000	1	3
2	2.56	$1\frac{9}{16}$	265	25-50	57.00	800,000	200,000	00

236. Installation of Flexible Steel Conduit and Flexible Steel Armored Conductors.—Where exposed they may be clamped to the surface wired over either with pipe hooks or with pipe straps. Where concealed they can be fished into place just as any other concealed conductors are fished in.

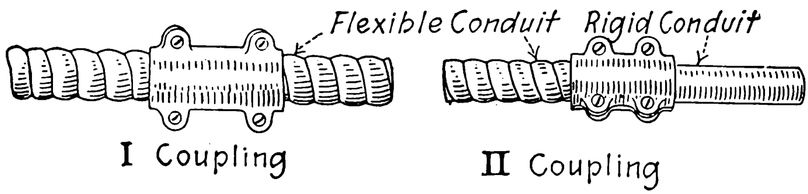


FIG. 179.—Couplings for flexible steel conduit.

237. Flexible steel conduit is joined with clamps as illustrated in Fig. 179. Short lengths can be coupled to longer pieces with the clamp of *I* and waste thereby prevented. The clamp at *II* is used for coupling rigid to flexible conduit.

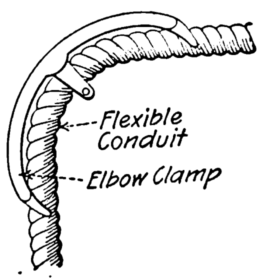


FIG. 180.—Elbow clamp.

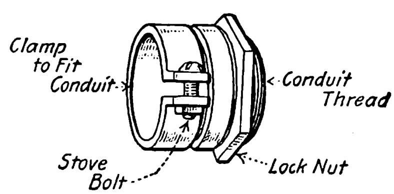


FIG. 181.—Connector for attaching flexible steel conduit to an outlet box.

238. Where elbows are formed in flexible conduit some provision must be made to prevent the conduit from straightening out thereby preventing the withdrawal of the conductors. Pipe straps can be used in some cases and in others an elbow clamp (Fig. 180) can be applied.

239. Flexible steel armored conductors and flexible steel conduit can be connected into steel boxes with the connector illustrated in Fig. 181. The fitting shown is of Sprague manufacture and is formed from sheet steel and galvanized. It is clamped to the armor with a bolt which insures good electrical connection between armor and steel box. Fig. 182 shows flexible steel conduit connected into an outlet box.

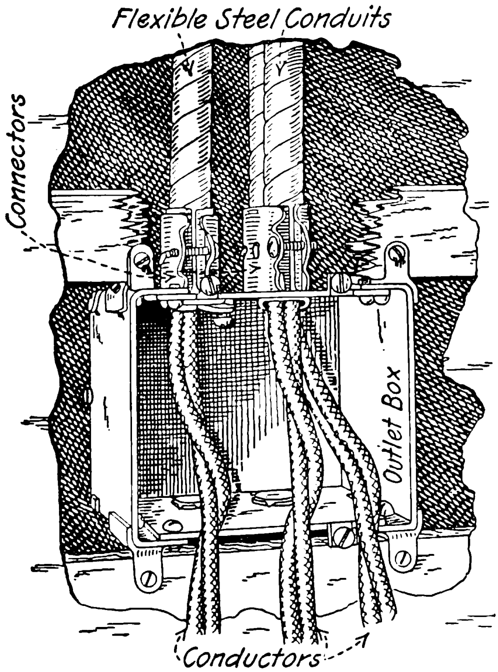


FIG. 182.—Flexible steel conduit outlet box.

240. To cut flexible steel conduit a fine hack saw should be used. Special vices can be purchased which have a slot across their jaws to guide the saw blade, the conduit being held between grooves in the jaws.

241. For reaming flexible steel conduit a special reamer (Fig. 183) has been made but inasmuch as the burr resulting from the hack-saw cut is very small, it can be readily removed with a three-cornered scraper made from a three-cornered file or with an ordinary file. The reamer illustrated is for conduit of $1\frac{1}{4}$ in. or less diameter.

242. Fish plugs for pulling in flexible conduit (Fig. 184) are furnished by the conduit manufacturer for $\frac{3}{8}$-in., $\frac{1}{2}$-in. and $\frac{3}{4}$-in. double and single flexible conduit. After the conduit has been cut off square in a vice with a hack-saw the fish plug is screwed into the tube and the fish or drawing-in wire attached to the plug for pulling in.

243. Flexible steel armored conductor (Fig. 185) (*Standard Handbook*) consists of rubber-covered wire protected from injury and to a certain extent from dampness by two layers of flexible steel armor. The cable may be obtained leaded or unleaded, both being protected with the steel armor. The leaded cable differs from the unleaded in that it has a lead covering between the wire and steel armor to protect it from excessive dampness. Both the unleaded and leaded cables are made with single and multiple conductors of almost any gage wire. The leaded armored cable is approved and can be used for all classes of work, open or concealed, in fire-proof or non-fire-proof buildings, and during or after construction. The unleaded cable is approved

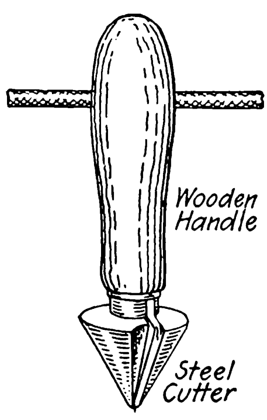


FIG. 183.—Reamer for flexible conduit.

and can be used, open or concealed, in non-fire-proof buildings provided they are not subject to moisture.

The proper way to install armored cables in new buildings is to bore holes in the joists and partitions and to lace the cable in the same manner as wires in concealed knob-and-tube work; but it should always be looped from outlet to outlet. Where the cable is placed in slots nails are liable to be driven into it and not being nail-proof, it must be protected at such points with 0.125-in. iron plates. None of the cable should be installed until the roof and floor are in position. In running between joists and at outlets

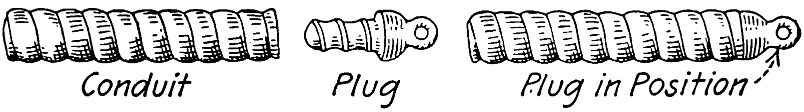


FIG. 184.—Plug for pulling-in flexible conduit.

the cable should be securely fastened if possible with pipe hooks or straps, so that in case the lock-nuts or bushings should fall off at outlets, the fastenings will prevent the cable from pulling out of the box and becoming lost between the joists or studs.

The wires should extend about one-half a foot beyond the outlet box in order to permit the proper connection of fixtures and switches, In some cities unleaded armored cable is not permitted to be plastered in brick walls or on metal partitions; but where allowed it should be cemented in place and allowed to stand several days before the walls are plastered so that the cable will be protected

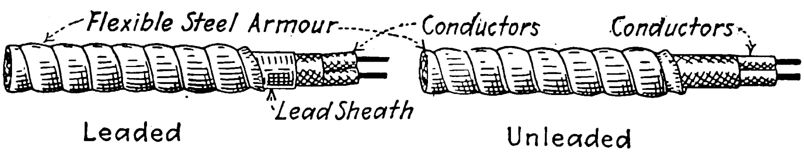


FIG. 185.—Steel armored conductors.

from the dampness caused by the wet plaster. The unleaded cable should not be run under tile or cement floors until after these have been laid because of the dripping water. Armored cable is the best substitute, not including rigid conduit, for concealed knob-and-tube work and also for molding work.

244. Manipulating Flexible Steel Armored Conductor.—It should never be spliced except at outlets. Many methods of fastening cable in outlet boxes are in vogue. Outlet bushings are very widely used. Outlet and switch boxes specially adapted for flexible armored cable are on the market. Many special cutters are on the market. The armor should be cut square so as not to leave sharp corners which cut into the insulation of the wires.

245. Steel Armored Conductor for Old Building Wiring.—It can be used to great advantage in this work. An advantage possessed by it is that it can be run with almost utter disregard to its contact with pipes or other materials and can be fished for long distances. Its own weight is sufficient to carry it down partitions and it is stiff enough to fish between joists without the use of a fish wire. It can also be installed quicker and with less cutting of walls, floors, etc., than can wires in flexible tubing or concealed knob-and-tube work, and although a trifle more expensive, it makes a better job. Care should be taken in setting outlet boxes not to depend on laths to hold them because almost invariably in

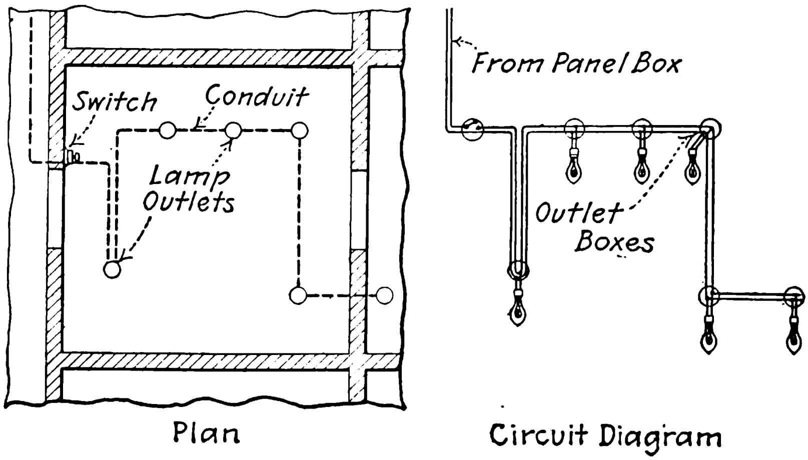


FIG. 186.—Loop system of conduit wiring.

hanging and straightening fixtures, they are pulled loose if not securely fastened to a joist, stud or backboard. Fixture stems should be fastened to boxes with stove bolts, riveted over the nuts.

246. The sheaths of flexible steel conduit and of flexible steel armored conductors must be grounded. The methods used for grounding are similar to those for rigid conduit which are described

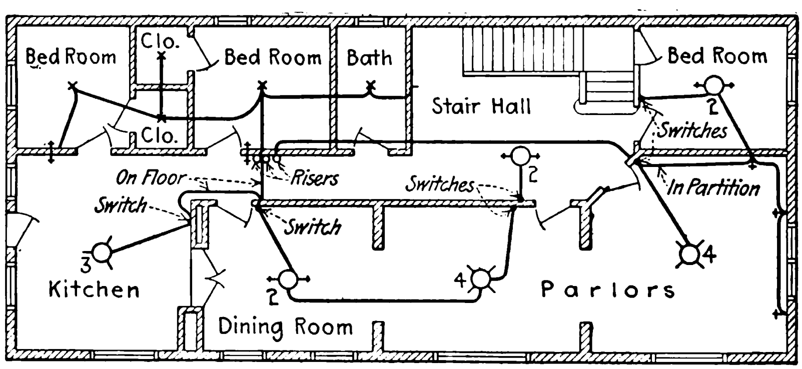


FIG. 187.—Example of loop system of wiring in a flat.

on another page. Suitable clamps which are required hold the steel sheaths in position in outlet boxes, serve to complete an electrical connection through the box. Where a group of these flexible steel armored conductors or conduit enters a wooden panel box all of the sheaths must be bonded together with a copper wire, No. 4 or larger, soldered to them, which connects to ground.

247. The **loop system of wiring** is nearly always used where conduit is concealed. (See Figs. 186 and 187.) The conductors loop to each outlet and the use of junction boxes is thereby avoided. Splices should be made only in junction boxes and the boxes should always be available for inspection.

ELECTRIC LIGHT WIRING

248. The maximum incandescent lamp load permissible on any branch circuit is, except in special cases, 660 watts. That is, wiring should ordinarily be so arranged that no set of incandescent lamps requiring more than 660 watts (16 sockets), whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out. Permission may be given in special cases, for departures from the rule. Although a branch circuit feeding ten 66 watt lamps would satisfy the requirements, it is not usually the practice to connect more than 8 or 12 incandescent lamp outlets to any one branch.

Gas-filled lamps to a capacity of 1320 watts (32 sockets) may be dependent on one cut-out *provided* No. 14 wire is carried directly into the keyless sockets or receptacles.

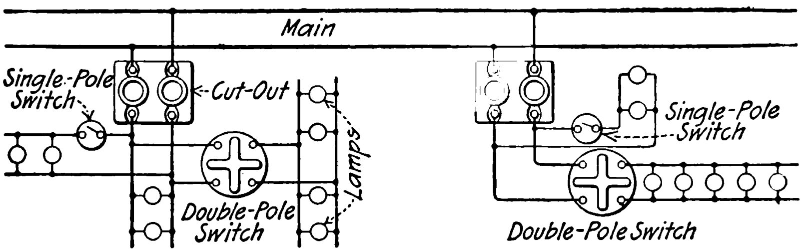


FIG. 188.—Connections of lamps to circuit.

249. The Connection of Lamps to Circuits.—The principles outlined in Fig. 188 are general. The lamps on the circuit extending vertically downward from the cut-out at the left of the illustration would burn as long as the main was alive. The other lamps are controlled by either single-pole or double-pole switches. Single-pole switches should not be used for the control of loads exceeding 660 watts. Three-way switches are considered the equivalent of single-pole switches in this respect.

250. Panel-box panels are illustrated in Figs. 189, 190 and 191. A panel provides a means of connecting (through fuses) the branch circuits to a main. Switches may be used as in Fig. 189, in both the main and branch circuits, or switches may be omitted, as in Fig. 191. Whether or not switches should be provided, is determined by conditions. Many satisfactory installations are in operation without switches, but switches are of great convenience for opening the circuits, for replacing fuses, or for testing. In general, knife switches in branch circuits should not be used for throwing on and off lights, as they are not usually of sufficiently strong construction to stand up long in such service.

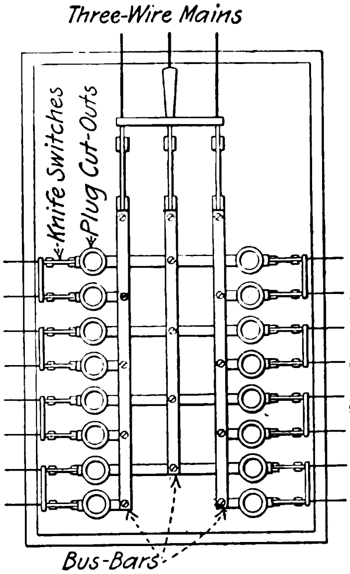


FIG. 189.—Three-wire distributing panel.

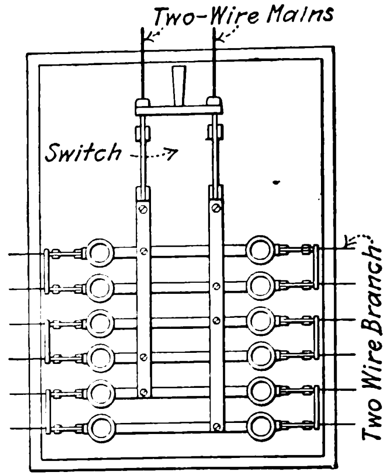


FIG. 190.—Two-wire distributing panel.

Branch lighting circuits should be controlled by either flush or surface snap switches, mounted outside of the panel box. See index for further information on panel boxes.

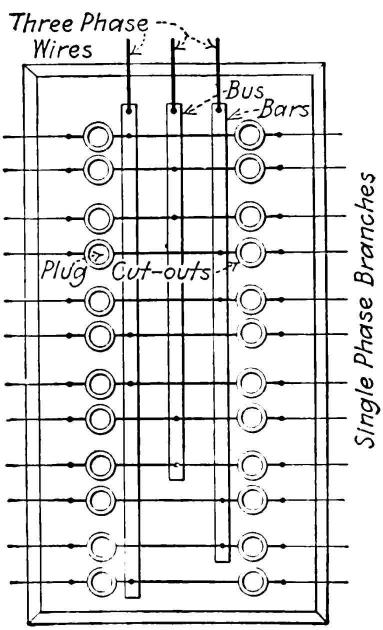


FIG. 191.—Three-phase to single-phase distributing panel.

251. **The method of controlling a group of lamps from either of two locations, with snap or flush switches,** is shown in Fig. 192. Two special "three-way" switches, of either the flush or surface type which can be readily purchased, are required. This scheme of wiring is much used for hall lights, so they can be controlled from either the first or second floor. Either of the schemes of wiring described in connection with Fig. 192 may be employed.

252. **The method of controlling a group of lamps from either of two locations, with knife switches,** is shown in Fig. 193. The method of *I* is preferable if both switches are near the lighting circuits, because it is economical of wire. If both switches are far from the lighting circuit, the method of *II* may be preferable. Where one of the switches is far from the

circuit, there is not much choice. In any case where there is a question, draw diagrams approximately to scale, and which method is preferable will be evident. The method of *II* cannot be used with direct-current arc lamps, because throwing the switches will

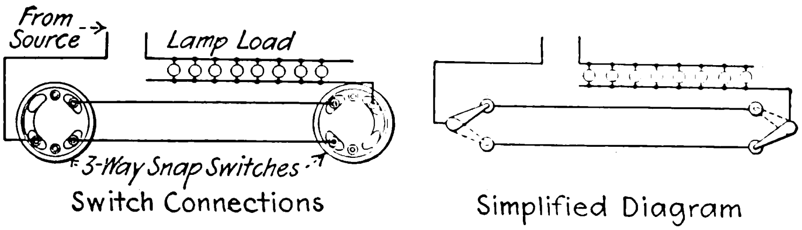


FIG. 192.—Circuits controlled from two locations.

reverse their polarity. Snap or flush switches are preferable to knife for two-location control, because a person may leave a knife switch open.

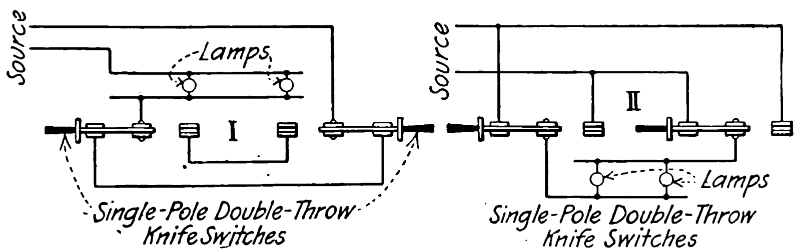


FIG. 193.—Circuit controlled from two locations with knife switches.

253. Two-location control with double-pole switches is shown in Fig. 194. This or some similar method must be adopted where the load exceeds 660 watts, as a greater load than this should not be controlled with single-pole switches.

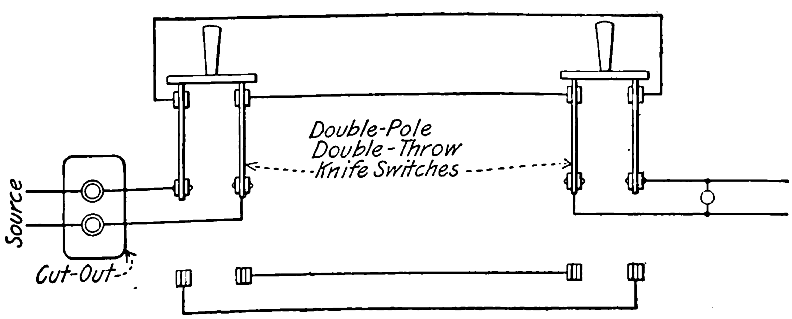


FIG. 194.—Double-pole-switch, two-location control.

254. The method of controlling a group of lamps from any one of more than two locations, with flush or snap switches, is shown in Fig. 195. Special switches made for the purpose are required. A "three-way" switch is used at each end of the circuit, and as many additional "four-way" switches are necessary as there are additional control locations. This method is also much used for wiring for hall lights, so that all can be controlled from any floor.

255. **For controlling a group of lamps from any one of more than two locations with knife switches,** the wiring of Fig. 196 may be used. One single-pole, double-throw, knife switch is required for the two end locations and as many additional double-pole,

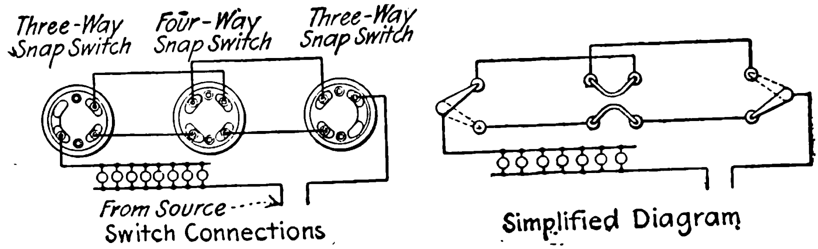


FIG. 195.—Circuit controlled from three locations.

double-throw switches are required as there are additional control locations. As above noted, knife switches have the disadvantage that one may be left open and interfere with the operation of the circuit.

256. **An emergency or burglar circuit** is shown in Fig. 197. This arrangement can be used where it must be possible to light certain lamps in a building from a certain location, irrespective of whether the switches normally controlling the lamps are closed

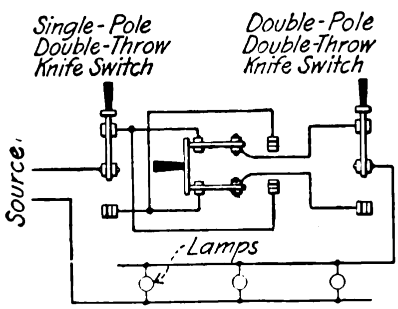


FIG. 196.—Circuits controlled from three locations with knife switches.

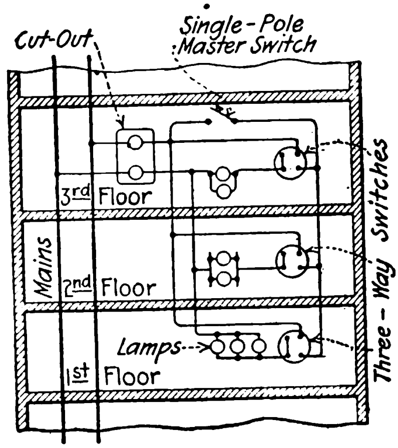


FIG. 197.—Emergency circuit.

or not. The master switch is usually located in the owner's room, so that he can illuminate the house in case of fire, an invasion by burglars, or other emergency. The method shown cannot be used for an installation involving more than 660 watts' capacity of incandescent lamps, because this is the maximum capacity that is permitted on a single-pole switch. Where a load of more than 660 watts is involved, two or more single-pole master switches can be applied, and each used for an independent emergency circuit;

or a double-pole or triple-pole switch can be installed and each pole used for an independent circuit. In some cases to control hall lights, it is necessary to substitute "four-way" for "three-way" switches. Fig. 198 shows a method of arranging an emer-

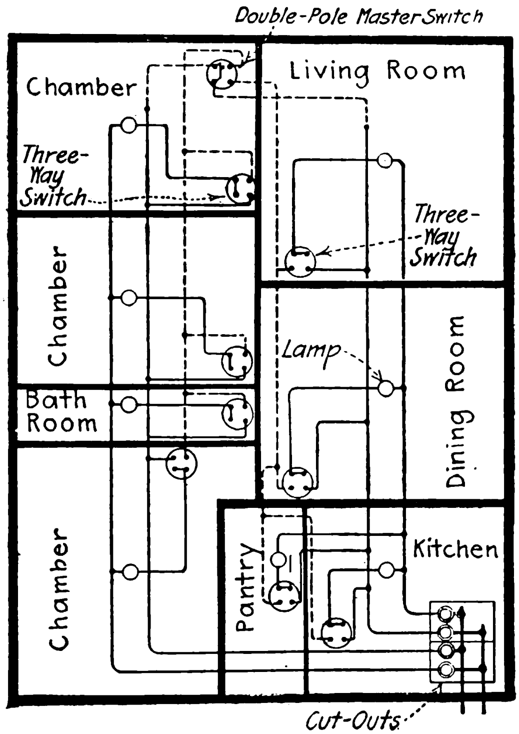


FIG. 198.—Emergency switch wiring in an old building.

gency switch in a building that has already been wired. The dotted lines represent the wiring that should be added to the existing wiring, to provide for the emergency switch feature.

257. Electrolier switches for controlling lamps in groups,

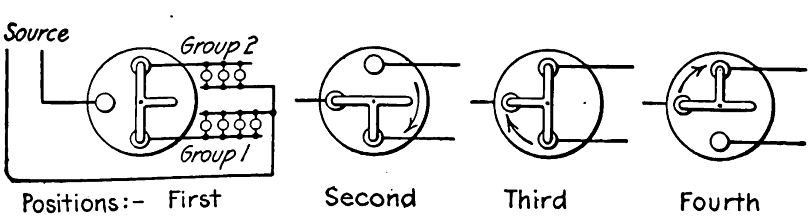


FIG. 199.—Two-circuit electrolier switch.

which control is often necessary in room lighting where there is a dome or electrolier having several distinct circuits, are wired as shown in Figs. 199 and 200. Special snap switches, which are made of either the flush, pull, or surface type, are necessary. With the two-circuit switch, Fig. 199: With the switch handle in the first position all lamps are off—in the second position only those of *group* 1 are on—in the third position those in both groups are on—in the fourth position only those in *group* 2 are on. Then with the next quarter turn of the switch the first position is again assumed and all lights are extinguished. While the same principle is always used, all commercial electrolier switches are not arranged exactly as illustrated.

For controlling three groups of lamps, a three-circuit switch, Fig. 200, is used. It is not possible to illustrate the operation of this switch with a simple diagram, and different makes operate differently. With one kind the operation is as follows: First turn connects *group* 1; second turn connects *groups* 1 and 2; third turn connects *groups* 1, 2 and 3; fourth turn disconnects all lamps.

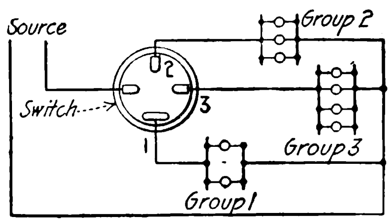


FIG. 200.—Three-circuit electrolier switch.

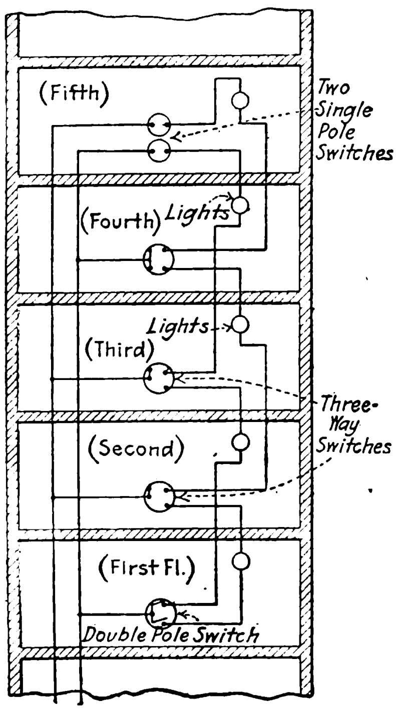


FIG. 201.—Stairway wiring.

258. **A circuit arrangement for stairway lighting** is shown in Fig. 201, whereby one can illuminate the landing that he is on and the one above or below him, as he goes up or comes down the stairs. The switch at each landing must be operated in passing. Two single-pole switches are shown on the fifth floor. With the two switches the lamp on that floor can be left burning if desired. Simpler arrangements than that shown are possible, but with them when a person turns a switch, the lamp on the floor on which he is, is extinguished as the one ahead is lighted.

CRANE WIRING

259. **Cranes collect their current** by means of trolley wheels or shoes which bear against copper trolley wires or structural steel conductors that are erected parallel to the crane runway. The location of the conductors is determined by conditions. Sometimes the crane builder specifies that the conductors must be located in a certain position; and in other cases the purchaser selects and specifies the position of the conductors and the crane manufacturer

arranges the current collectors on the crane accordingly. Probably the best location for the collector conductors on a bridge crane runway, is between the flanges of and parallel to one of the crane girders. Here the conductors are out of the way, well protected and can be readily supported. It is not often that they are erected in any other position. Occasionally the trolley wires can be supported from the roof trusses above the crane runway, and are installed similarly to the trolley wires for trolley cars. A pole collector with a wheel at its upper end, exactly like a trolley car pole but much shorter, is used. Where the spacing between roof trusses is very great this method may not give good results, because of the wire swinging and the trolley coming off. (Much of the following material on Crane Wiring is from an article on that subject, which was written by the compiler of this book and printed in *American Machinist*, Oct. 17, 1912, under the pen name of Ernest G. Bradshaw.)

260. Trolley wire for cranes is hard drawn copper, the same as used in electric traction. Hard drawn wire must be used to prevent excessive stretching. Round wire is erected where the method of support adopted does not involve the use of trolley ears for holding it at intermediate points between the ends of the run. Where trolley ears are used "Fig. 8," or preferably, grooved trolley wire should be used, because they can be readily held in screw-clamp trolley ears. Round wire can be used with trolley ears, but the ear flanges of these must be hammered down around the

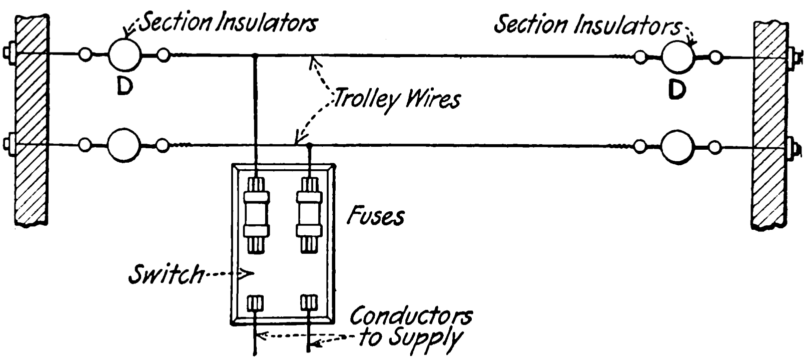


FIG. 202.—Crane wiring service switch.

wire, a time consuming operation requiring some skill; also, a round-wire ear introduces a hump on the wire and makes the trolley wheel jump and draw an arc when the wheel passes over the raised place. Either 0, 2/0, 3/0 or 4/0 wire is usually required. The wire size required is ordinarily specified by the crane builder, but in any case it should be large enough that the voltage drop in it will not much exceed 3 or 4 per cent. of the line voltage with all of the crane motors operating at full-load.

261. A crane service switch (Fig. 202) should be installed for feeding every crane circuit. A fused switch is most frequently used to provide overload protection, although in important installations, where reliability is essential—where equipment must be placed back in service after an accident, in minimum time—circuit-breakers are used. From an electrical standpoint, the best location for the service switch is at the center of the run. In practice, however, it should be placed where it can always be reached from a ladder running to the floor and so the operator can open his circuit when he leaves his machine.

262. **Methods of supporting crane trolley wires** differ with conditions. If the crane is provided with hook-shoe collectors (Fig. 203), which slide along under and carry the weight of the trolley wire, the wire is rigidly held only at the terminations at the ends of the run, and is kept from sagging by intermediate, insulating brackets, like those shown in Fig. 203. If trolley wheel current collectors are used (and they probably provide the best means of collecting current), the tension in the wire is taken by the terminations, and the wire is also rigidly held by trolley ears at intermediate points.

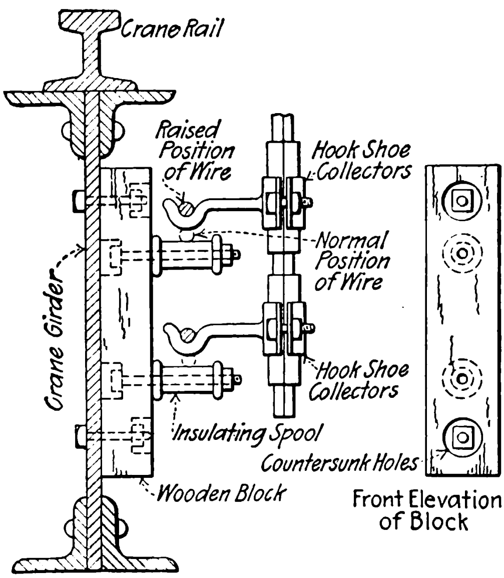


FIG. 203.—Intermediate bracket for trolley wire.

263. **Terminations** are made as shown in Fig. 204. Strain insulators separate the trolley wire electrically from the building members, and either a turn-buckle, or an eye-bolt with a long thread, can be used for pulling the slack from the wire and adjusting its tension. The terminations should be depended upon to assume the entire tension of the wire. The intermediate supports are placed merely to prevent excessive sagging. The members which take the stresses of the eye-bolts at the terminations should be very substantial, or thoroughly braced, because on them depends the reliability of the entire installation. The eye-bolts, turn-buckles and strain insulators should be not smaller than the $\frac{5}{8}$-in. size.

264. **Intermediate supports for crane trolley wires,** the supports installed between the terminations to prevent sagging, can be arranged as shown in Figs. 203, 205 and 206. The bracket of Fig. 203 is, as above outlined, applicable only where the crane has hook-shoe collectors. The block of wood that supports the insulating spools should be thoroughly dry and treated with an insulating paint. The bolt holes in it should be deeply countersunk, to eliminate the possibility of grounds. The spools can be of dry, painted wood—where the Underwriters will permit—but should be

of porcelain. Porcelain tubes with porcelain knobs at the ends to form flanges will do. The length of the insulator between flanges should be at least 4 in. Spools turned from fiber are sometimes used. The spools should be so arranged that there will be at least a $\frac{1}{2}$-in. clearance between them and the hook-shoe when it passes along.

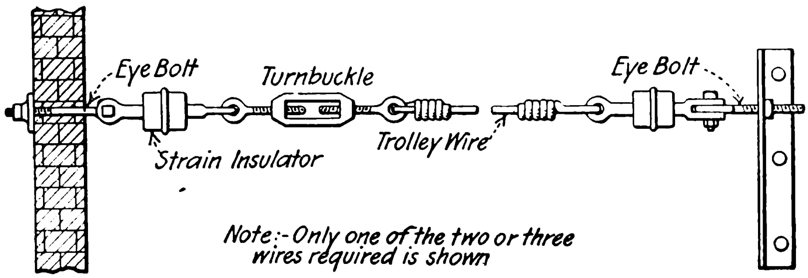


FIG. 204.—Trolley supports at ends of run.

In a fire-proof building, where the crane has trolley wheel collectors, the wires can be supported by trolley ears as in Fig. 205. The wooden supporting block must be thoroughly painted and the bolt holes in it deeply countersunk, to prevent the possibility of grounds. Tap bolts, screwing in from the rear, support the screw-

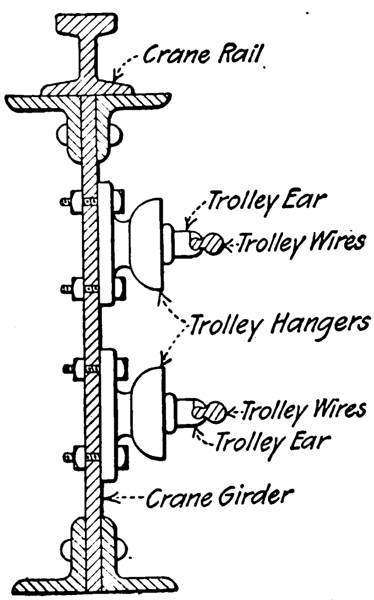


FIG. 205.—Trolley ear supports.

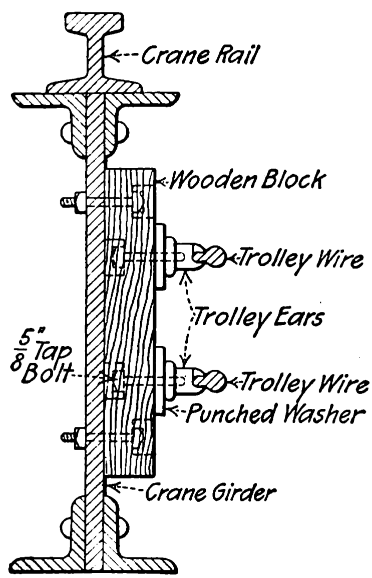


FIG. 206.—Trolley hanger support.

clamp trolley ears which seat against washers. "Figure-8" or, preferably, grooved trolley wire is used. The wire should be drawn tightly at the terminations and the ears should be installed every 8 or 10 ft.

For an out-door crane, or for applications where the Underwriters have jurisdiction, the wires can be supported as shown in

Fig. 206. Standard street railway type trolley hangers and ears are used, which provide excellent insulation. The hangers can, provided a proper location of the trolley wires results, be bolted directly to the crane girder.

265. **Trolley rails of structural steel** are being used to some extent instead of copper trolley wire to supply current to cranes and other moving electrical machinery. The steel rails are made sufficiently heavy that they cannot break and fall as copper wires occasionally do. Sometimes strap steel bars are used, but more frequently a section is adopted, such as an angle or a tee, which has considerable stiffness in all directions. Steel conductors should be painted, except on the contact edge or face, to prevent corrosion. Either a shoe or a trolley wheel can be used to collect current from a steel conductor rail. A shoe or spoon, which makes a rubbing contact, is probably preferable for the average application. Trolley-wheel collectors that travel at high speeds are not successful for current collection from steel conductors, because the wheel tends to bounce and jump from the rigid rail at joints and uneven places. There are almost numberless ways in which steel conductor rails can be arranged and supported. The arrangement described in the following paragraph is typical.

266. **An installation of a structural steel tee conductor or trolley rail** is shown in Fig. 207. While the arrangement illustrated was developed for serving mono-rail cranes, which travel on the lower flanges of I-beams, only minor modifications in the supporting forging would be required to adapt it for serving bridge cranes or other similar traveling electrical machines. Note that a feature of the method is that no drilling or close fitting is required in the field. The only piece that is different for different jobs is the supporting forging, but this can be formed and drilled in the shop. The only tools required to erect the rail are a hack-saw for cutting the tee, which is purchased in 30-ft. lengths, and a wrench for setting the bolts. No bolt smaller than $\frac{5}{8}$-in. diameter is used, because smaller ones than this can be twisted asunder too easily. A tee $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. in dimensions was selected, because this is about the smallest size that is rigid enough to effectively sustain itself between supports. A tee of this size has a conductively equivalent to that of a 109,800 cir. mil copper conductor, that is, a copper conductor between No. 0 and No. $\frac{2}{0}$ in size.

The insulating hanger (Fig. 207, *II*), is similar to a trolley hanger, but smaller. A mallable iron bell encloses the molded material that supports and insulates the hanger stud. The Johns-Manville Company makes the insulator to special order and its mold number is 4689-B. The splicing plate (*IV*) and the clamp (*V*) are castings, preferably malleable iron, and the only machine work on them is the drilling and tapping of the holes. The section insulator (*VI*) consists of two castings, a fiber dividing-block and two wrought-iron clamping plates. Directions for spacing the insulating supports when erecting the conductor are given on the illustration. The terminal lug (*VIII*) is forked instead of annular, so that it can be readily disconnected for isolating circuits for testing without taking out a bolt.

267. **In computing the resistance of steel trolley rails,** the area in square inches, of the section involved, can be taken from

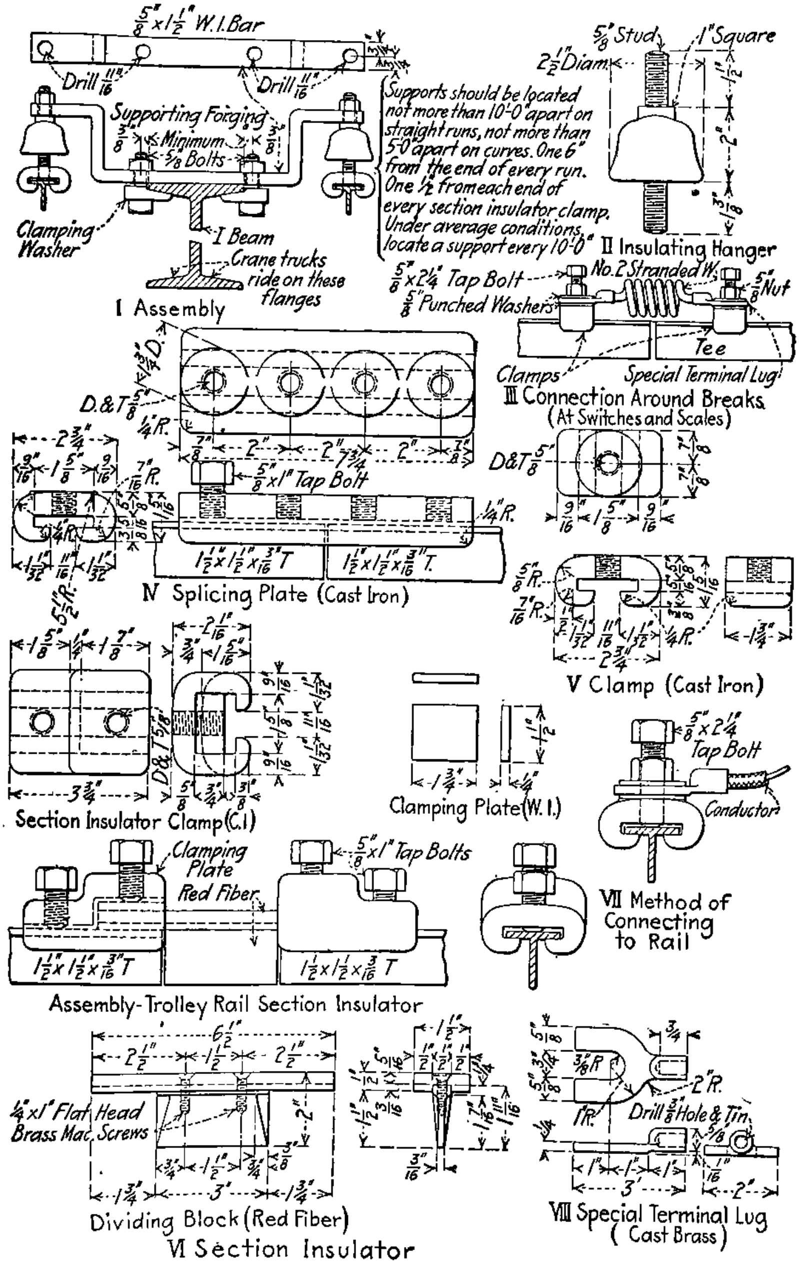


FIG. 207.—Steel trolley rail.

one of the steel company's handbooks, such as are issued by the Cambria and Carnegie steel companies; the area in cir. mils can then be obtained by using the rule given below. By dividing this area by 6.14, which is the approximate ratio of the resistance of mild steel to that of copper, the equivalent copper area of the steel conductor results. Then by using the standard formula for the resistance of a copper conductor, the actual resistance of the steel is obtained.

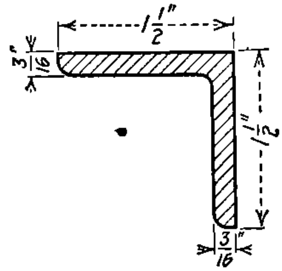


FIG. 208.—Section of $1\frac{1}{2}$ in. $\times$ $1\frac{1}{2}$ in. $\times$ $\frac{3}{16}$ in. steel angle.

Example.—What is the resistance of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle? (See Fig. 208 for a picture of the section.)

Solution.—By referring to a handbook, it will be noted that the area of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.53 sq. in. Then to find its area in cir. mils:

$$\text{cir. mils} = \frac{\text{area in sq. in.}}{0.0000007854} = \frac{0.53}{0.0000007854} = 674{,}800 \text{ cir. mils.}$$

Then:

$$\text{equivalent in copper} = \frac{\text{cir. mils area of steel}}{6.14} = \frac{674{,}800}{6.14} = 109{,}800 \text{ cir. mils.}$$

Then the resistance of the 160 ft. length will be:

$$\text{Resistance (for copper)} = \frac{11 \times \text{ft.}}{\text{cir. mils}} = \frac{11 \times 160}{109{,}800} = 0.016 \text{ ohms.}$$

The resistance, therefore, of 160 ft. of $1\frac{1}{2}$ in. by $1\frac{1}{2}$ in. by $\frac{3}{16}$ in. steel angle is 0.016 ohms. It is evident from the equivalent copper area of the steel (109,800 cir. mils), that the conductivity of the steel section will lie between the conductivities of No. 0 (105,500 cir. mils) and No. 00 (133,100 cir. mils,) copper wire.

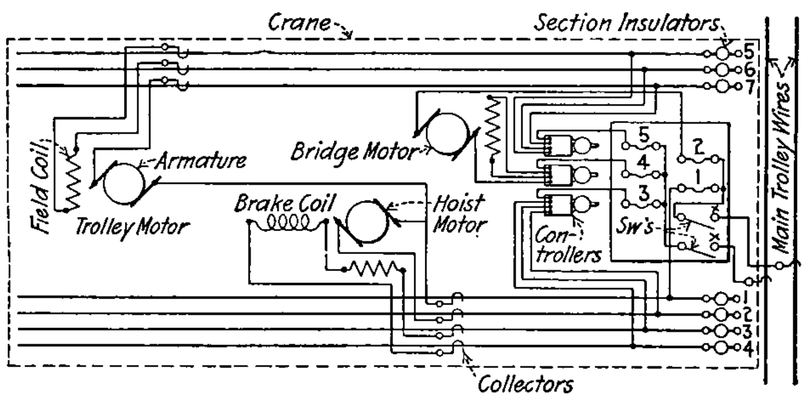


FIG. 209.—Direct-current crane wiring diagram.

The equivalent copper area in cir. mils can be used in any of the wiring formulas for computing drop in a steel conductor, just as the actual area of a copper conductor is used in the same formulas, and the result will be a correct one for the steel section. Obviously the above method is approximate, because the constants are approximate, but it is quite accurate enough for wiring computations which always involve necessarily inaccurate assumptions.

268. A crane wiring diagram is given in Fig. 209, which is typical for a direct-current, three-motor, traveling bridge crane. Variations in crane wiring and control schemes are practically numberless. For direct-current cranes, series motors are almost invariably used, while for alternating-current cranes, wound rotor motors are used.

SIGNAL WIRING—BELL, ANNUNCIATOR, BURGLAR-ALARM, TELEPHONE AND ELECTRIC GAS LIGHTING WIRING

269. **Brief of Underwriters' Rules Covering the Installation of Telephone, Call Bell, and Similar Circuits** (*Factory Mutual Wiring Rules*).—The arrangement of these wires should be as carefully planned as that of the lighting or power circuits. They should be so placed as never to be in the way of fire streams or ladders. Where possible, the signal wires about the yard should be kept entirely away from lighting or power circuits. This avoids the liability of the two systems crossing if breaks occur and of dangerous currents being conducted into buildings over wires ordinarily considered harmless. Where the arrangement is of necessity such that crosses might occur if wires broke, protectors should be provided near the point where the signal wires enter each building. Protectors should also be provided on all foreign lines, such as public telephone or fire-alarm wires, and on all private lines which are liable to receive lightning discharges.

Where signal circuits are operated from electric-lighting or power circuits with or without lamps or other resistors in series, the signal circuits must be insulated on porcelain and the same construction followed as for lighting circuits. The bells and buttons or switches must be of non-combustible materials and held away from the supporting surface with porcelain knobs.

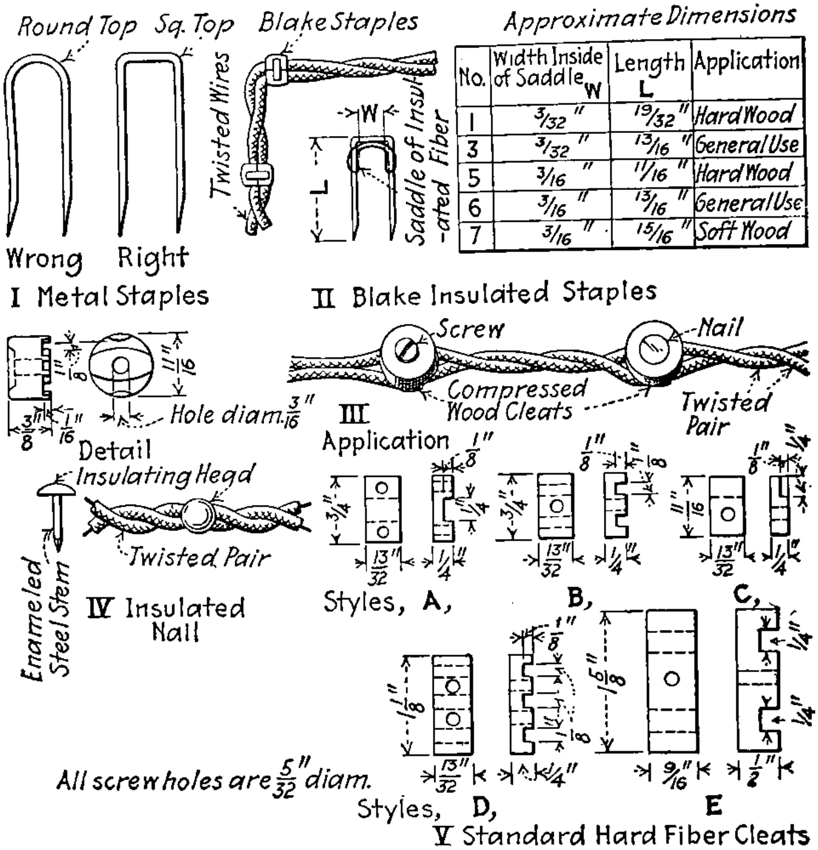
No signal wire should be closer than 2 in. to any electric light or power wire unless additionally insulated therefrom by some firmly fixed non-conductor such as a piece of flexible tubing or, preferably, a porcelain tube.

270. **In installing signal wires in finished buildings** the rubber-covered twisted pair copper wires may be used. They may be run along the top of the baseboard or along the picture molding. Where it is desirable to conceal the wiring and where expense is no consideration, the wires may be fished like lighting wires in concealed work. Where wires are bunched together in a vertical run, a fire-resisting covering sufficient to prevent fire from traveling from floor to floor, must be provided. Signal or telephone wires cannot be run in the same conduit with lighting wires. (The material that follows on Signal Wiring is largely from a series of articles on that subject, by the compiler of this book, printed in *Popular Electricity* during 1912 and 1913.)

271. **Signal wires may be supported on wood in dry places with metal staples** (Fig. 210) driven into the timber. Never fasten more than one wire under a staple, unless the wires are first protected with a tape wrapping. In damp places ordinary staples rust and eat through the insulation. Electrolytic action may ensue, whereby the wire will be eaten through. It is very difficult to drive round top staples in straight; hence staples having

square tops, of a style narrower than the ordinary double pointed tacks, should be used. Zinc coated staples are preferable to coppered ones. Insulating saddle staples (see illustration *II*), are probably as cheap in the long run as the ordinary metal ones, as two wires can be safely held under one saddle staple, and time is thereby saved. Insulating saddle staples secure the wire well at turns and prevent the metal from cutting into the insulation. In stringing a long run, a saddled staple at the end will hold the slack until the intermediate staples are placed.

272. Cleats of compressed, impregnated wood (see Fig. 210) are good for supporting a twisted pair conductor in an exposed place,



No.	Width Inside of Saddle W	Length L	Application
1	3/32"	19/32"	Hard Wood
3	3/32"	13/16"	General Use
5	3/16"	11/16"	Hard Wood
6	3/16"	13/16"	General Use
7	3/16"	15/16"	Soft Wood

FIG. 210.—Fasteners for signal wiring.

as they are very neat in appearance. Either nails or screws can be used to hold them. The compressing of the wood prevents the cleats from splitting. They are particularly useful for runs over plastered surfaces, and in other places where staples cannot be used. When stringing long runs of wire, compressed wood cleats at the run ends will hold the slack until the intermediate cleats are placed. These wood cleats cost less than those of either porcelain or fiber. They can also be used to support single wires, one wire under a cleat.

273. **Insulated nails** (Fig. 210, *IV*) having a metal stem and a head of insulating material, are used for supporting twisted pair conductors, and while they are cheap, they do not support the wires as well as does the wood cleat. They do not hold a single wire well and do not properly hold back slack in long runs. The nails are made in different lengths and with heads of different colors to match surroundings.

274. **Hard fiber cleats** (Fig. 210, *V*) are used where one or more single conductors are to be supported, but are not as good as the wood cleats, although they cost more. It is sometimes necessary to use them where the wire supported is too large for the standard wood cleat.

275. **Wire for bell work** in dry places is usually No. 18 copper, double cotton covered and paraffined. Where more than two or three bells are connected to the circuit, or where the circuits are long, No. 16 wire should be used. No. 14 is frequently used for battery wires. Rubber covered twisted pair wires, like those used for interior telephone wiring by the telephone companies, can often be used to advantage in damp places or where the circuits are exposed. No. 20 wire, although sometimes used, is too small for reliable work. Annunciator and twisted pair wire is made with insulating coverings of different colors, so one can be selected that will match the surroundings, and, thereby, be inconspicuous. Cables of annunciator wire, which can be obtained with practically any number of conductors from 2 up to 200, are very convenient and economical for large installations. In perfectly dry locations, a cable having a paraffined, braided cotton covering can be used, but if it is to be exposed to dampness a lead covered cable should be installed. By having the cable conductors covered with braids of different colors, the conductors can be readily identified. A kind of weather-proof wire called "damp-proof," is quite satisfactory for exposed wiring in damp places. It is more expensive than annunciator wire, but it has a better appearance when installed.

276. **The installation of signal wiring in wooden framed buildings** requires great care. The conductors are so weak mechanically, so poorly insulated and there are frequently so many of them, that if work is not systematically and thoroughly erected, trouble invariably results. The wires can be supported in unfinished houses by fastening them to the studs and joists with staples. In finished houses wires can be run behind a base board or under the molding at its top; or by prying up a floor board the wires can be placed under it. A saw cut, into which the wires can be dropped, can be made in any joist that lies across the path of the wire. Wires can be run on the tops of picture moldings.

277. **In fishing for vertical wires** a piece of small chain 2 ft. long is attached to a length of strong cord. The chain and cord is pushed through a hole bored for the wire at the top of the partition, and the noise made by the chain when the cord is pulled up and down, will indicate the location of any obstruction. With the obstruction located, the baseboard or floor board can be taken out and a hole can be bored or some other means adopted to provide a pocket whereby the chain can be reached.

278. The steel fish bit (Fig. 211) is a useful tool in installing signal wires. The bit has a hole in its end. After the bit has been bored through an orifice, the wire to be drawn through is made up through the hole and the wire and bit are together drawn back through the orifice. The use of a fish wire is thereby eliminated. In a floor or ceiling, the orifice having been bored, it may be more convenient to first withdraw the bit and then to thread the wire through the hole at the end of the bit, and to push the bit back through the hole. Good bits of this type are so tempered that they will drill through wood, masonry, wrought iron or structural steel.

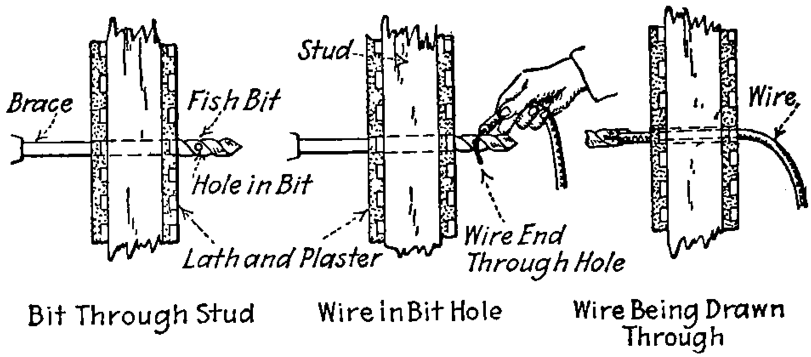


FIG. 211.—Use of steel fish-bit.

279. Electric bell circuits are shown in Fig. 212. Many of these are quite simple but are included so that all will be together for the electrician's reference. Two ordinary vibrating bells will not work well together in series, so, when it is necessary to connect two or more in series, one should be a single stroke bell, as in *IV*. A multiple arrangement *II* is preferable to a series arrangement, and the batteries for a multiple arrangement are more effective if connected in multiple. Try a series and a multiple arrangement of cells and ascertain which works best. Where several signal bells must be located together, gongs of different types (*VI*), each of which gives a different sound, can be used, In operating bells from an electric light circuit, incandescent lamps (*VII* and *VIII*) can be used for resistance. An ordinary bell usually requires about 0.1 amp. for its operation, and enough lamps should be used to cut down the current to this value. It is best to connect the bell in multiple with a lamp, as at *VII*, as thereby the arcing at the vibrating contact is minimized. At least one lamp should be connected in each side of the circuit at the cut-out, to prevent difficulties if a ground should occur on the bell circuit. Bells with platinum contacts are preferable for all services, but are expensive. A differential or short-circuiting bell (Fig. 215) can be used with good results, with lamps in series, on lighting circuits or high voltage battery circuits.

280. Return-call bell circuits for different services are shown in Fig. 213. With these, when a station is signaled, the party called can signal back by pressing his button. As a general proposition, ground return circuits are undesirable, as one ground on one of the normally ungrounded wires may render the system inoperative; furthermore, there are often "stray" currents from electric railway circuits flowing in the earth, which may interfere with the operation of the bell circuits. With the arrangement of Fig. 213 *VII*, when the calling station is the one at the single stroke bell, the

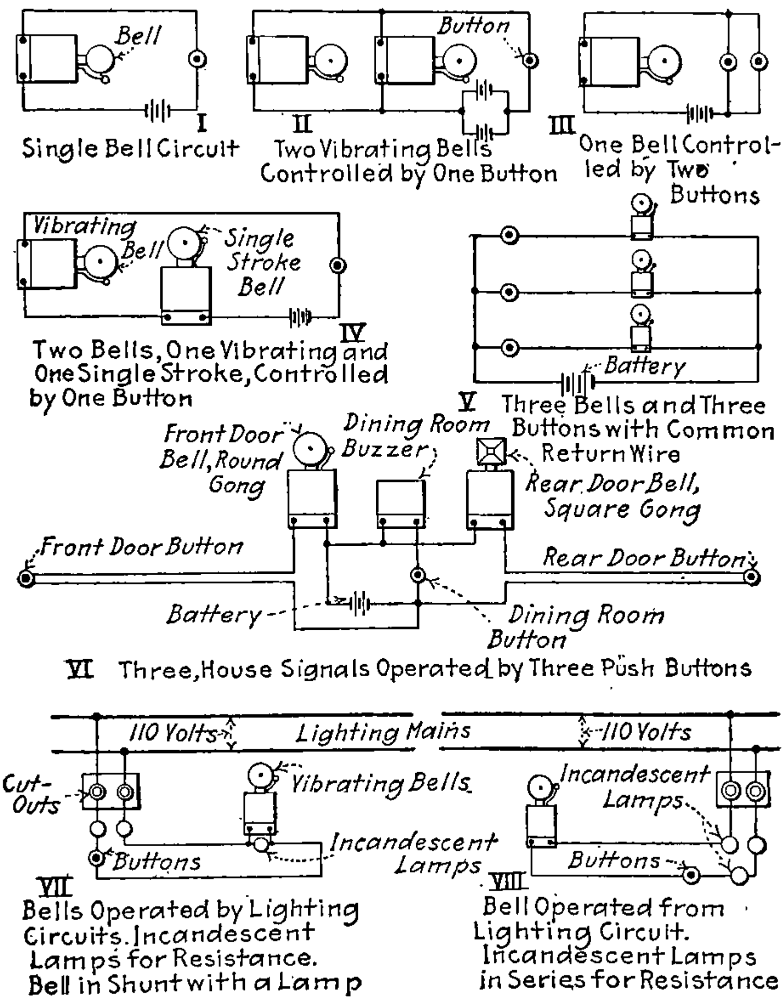


FIG. 212.—Elementary electric bell circuits.

caller may be sure that the called station is ringing, because it is the vibrating bell at that station that causes the single stroke bell to ring.

281. Apartment house and speaking tube bell wiring circuits are shown in Fig. 214. One battery serves for all stations. Frequently a larger sized wire is used for the battery wire, which supplies all of the stations, than for the other wiring.

282. Electric bells of different types are shown in Fig. 215. The vibrating bell is the one commonly used. The single stroke bell can be used in series with a vibrating bell, which will open and

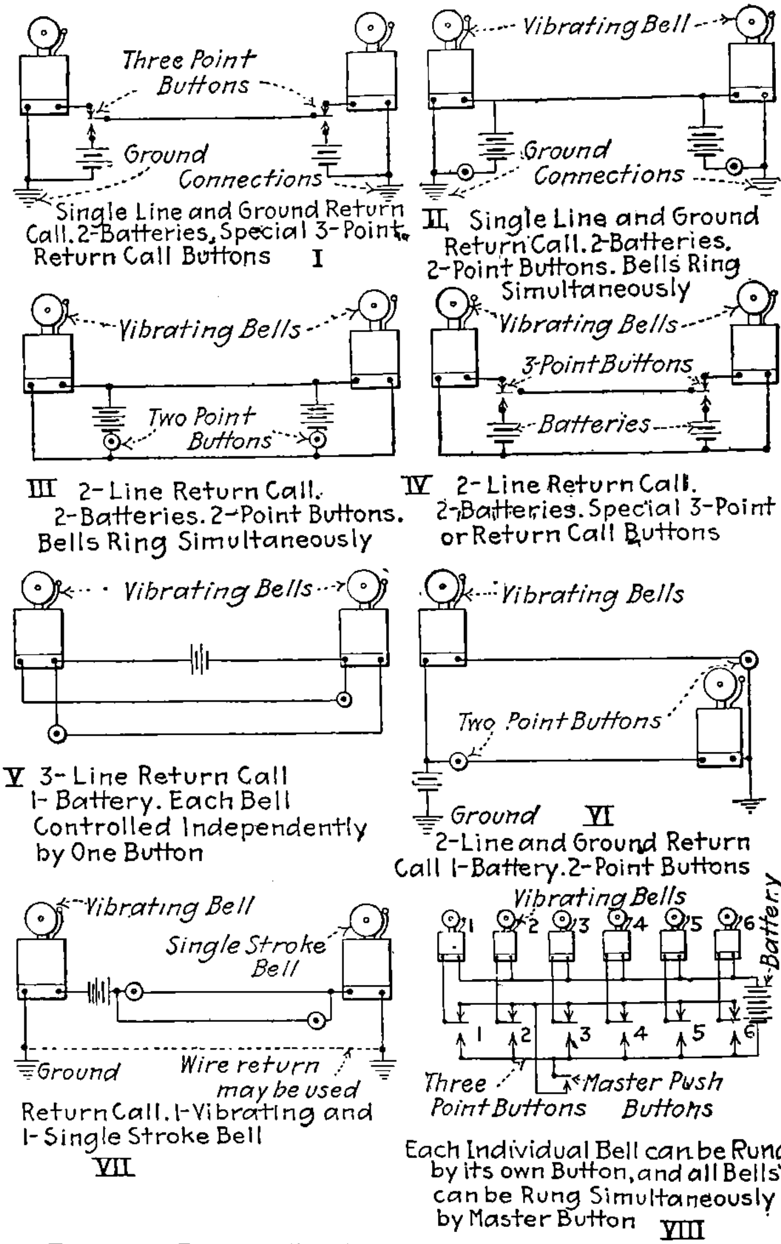


FIG. 213.—Return call and master button electric bell circuits.

close the circuit, and thereby make the single stroke bell also operate. It is essential for satisfactory operation, that the natural periods of vibration of the armatures and tappers for both bells, be the same. If the armatures, tappers and springs of both are the same in weight, dimensions and construction, the natural

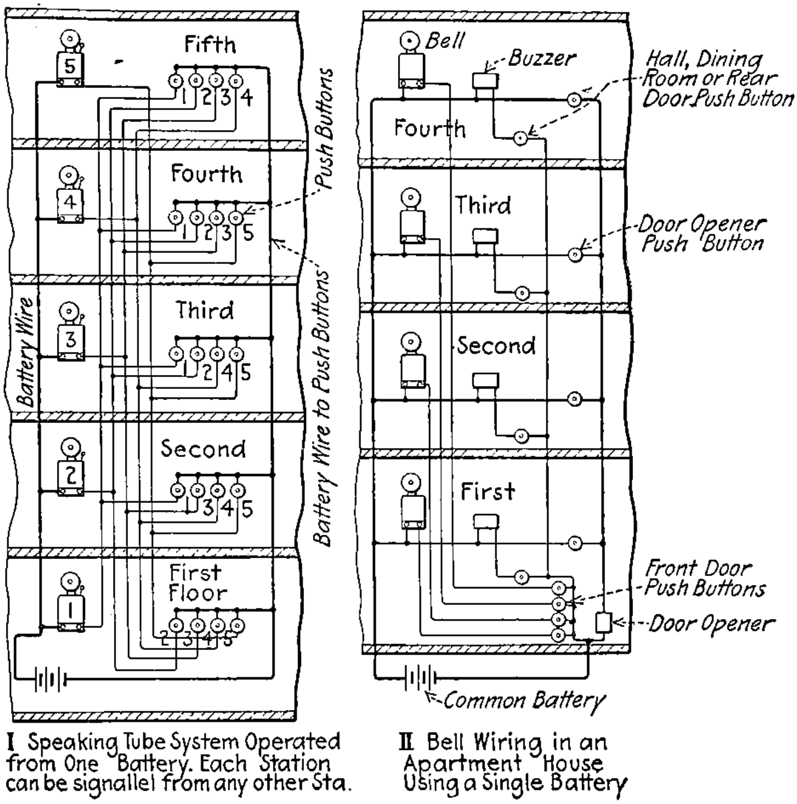


FIG. 214.—Apartment house bell circuits.

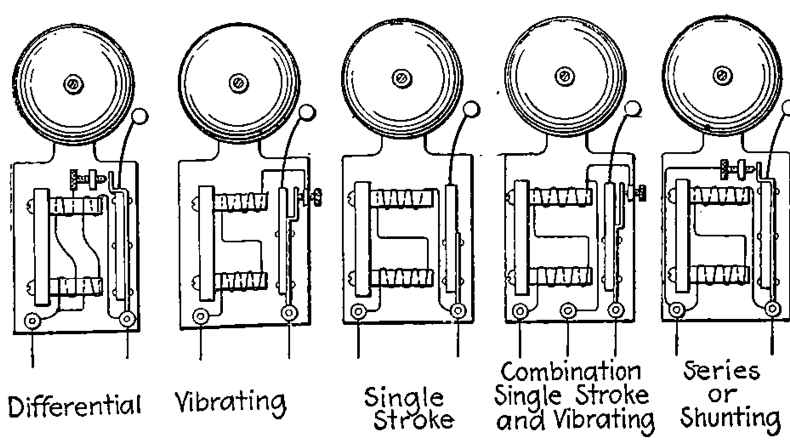


FIG. 215.—Electric bells of different types.

periods of vibration will be the same; small differences will not appreciably affect satisfactory operation. A vibrating bell can be changed into a series bell by so adjusting the vibrating contact screw that the circuit will not be opened when the armature is drawn over.

283. A combination single stroke and vibrating bell is a combination of a vibrating and a single stroke bell, and can be used as either by properly connecting it. A two point switch can be arranged so that a bell of this kind can be made to operate at will, as either a single stroke or a vibrating bell.

284. In series or shunting bells, each time the armature is drawn over it makes a contact and short-circuits the magnets, thereby demagnetizing them; the armature spring draws it back and the operation is repeated. Bells of this type have been designed for use on circuits of voltages exceeding say 5 volts, to minimize arcing at the vibrating contact, but their operation has not been wholly satisfactory.

285. In the differential bell, the magnets are wound differentially, that is, so as to oppose one another. Hence, when the armature is drawn over by one magnet winding, it makes a contact

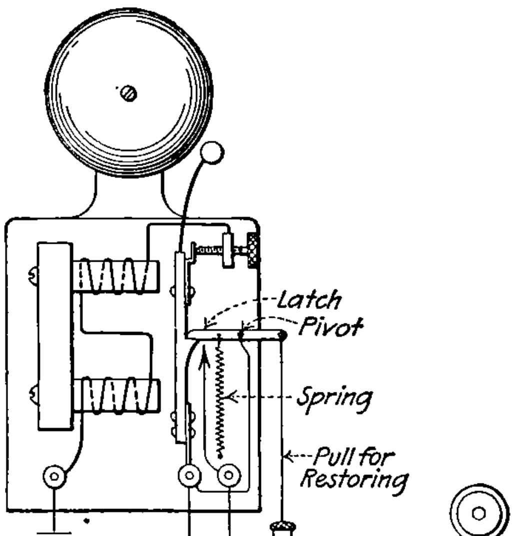


FIG. 216.—Continuous ringing bell.

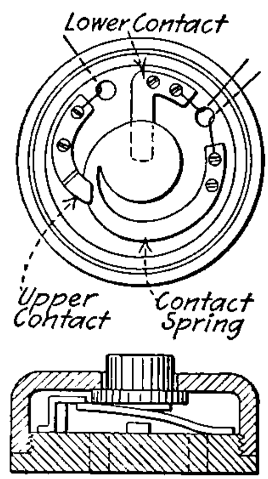


FIG. 217.—Double contact, three-point or return call push button.

which energizes the other winding, and, since the two oppose, the cores are demagnetized and the armature is drawn back by its spring. In operation this process is repeated so long as the circuit to the bell is closed. There is little or no sparking with a differential bell; hence it is used on circuits of relatively high voltage.

286. A continuous ringing bell (Fig. 216) is so arranged that when the button is pressed and the circuit closed through the bell, the armature is drawn over and the latch released and pulled down against its contact point by a spring or by gravity. This con-

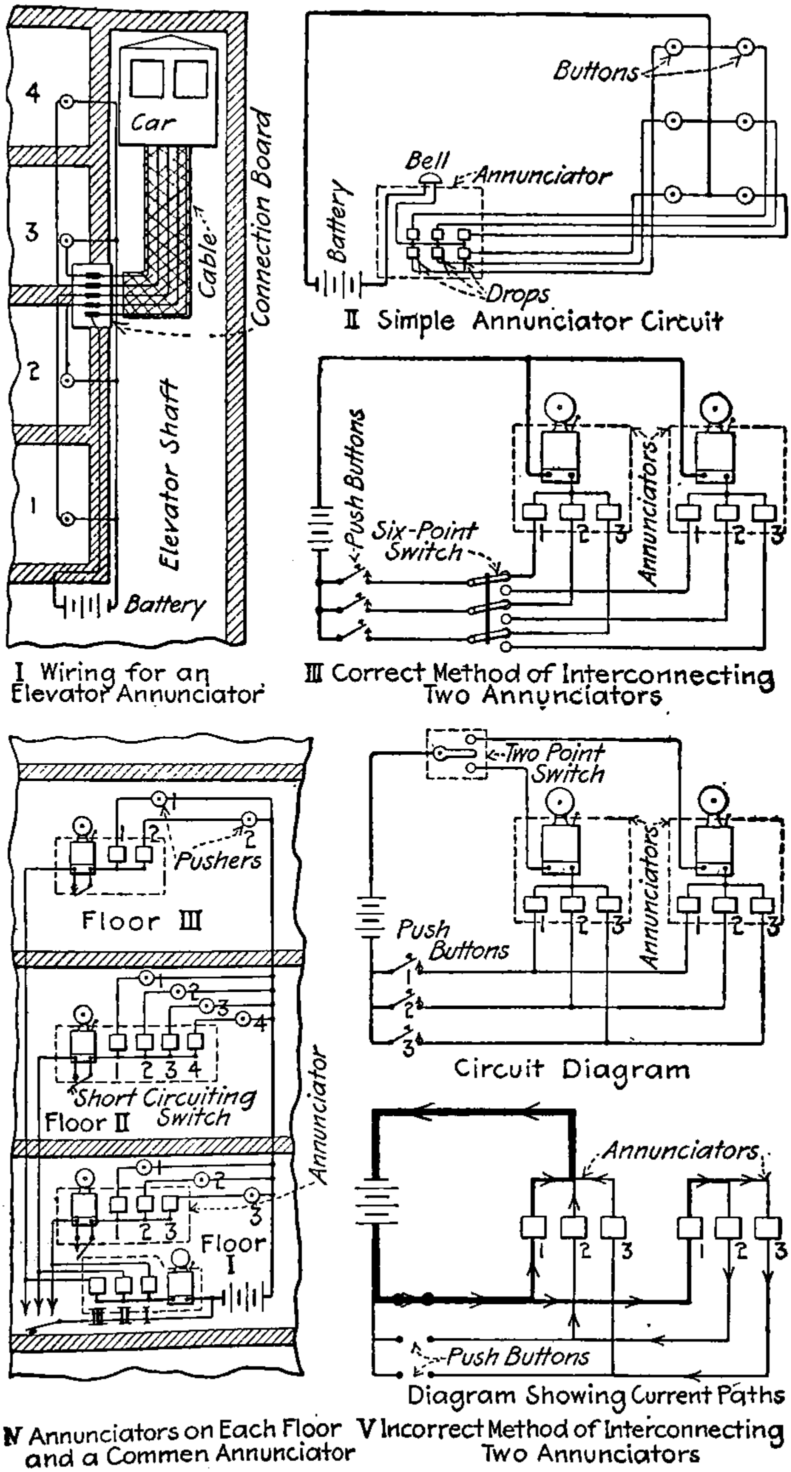


FIG. 218.—Annunciator circuits.

nects a shunt circuit around the button, and the bell continues to ring until the latch is restored by hand.

287. **A double-contact, three-point or return-call push button** (Fig. 217), is used in return-call bells and annunciator circuits. Applications of push buttons of this type are shown in the diagrams.

288. **Annunciator circuits** are shown in Figs. 218 and 219. With an elevator annunciator a cable having as many conductors as there are push buttons and one additional battery conductor is required. One end of this cable is attached to the car and the other is made fast midway up the elevator shaft and should be connected to the push-button wires with binding posts on a

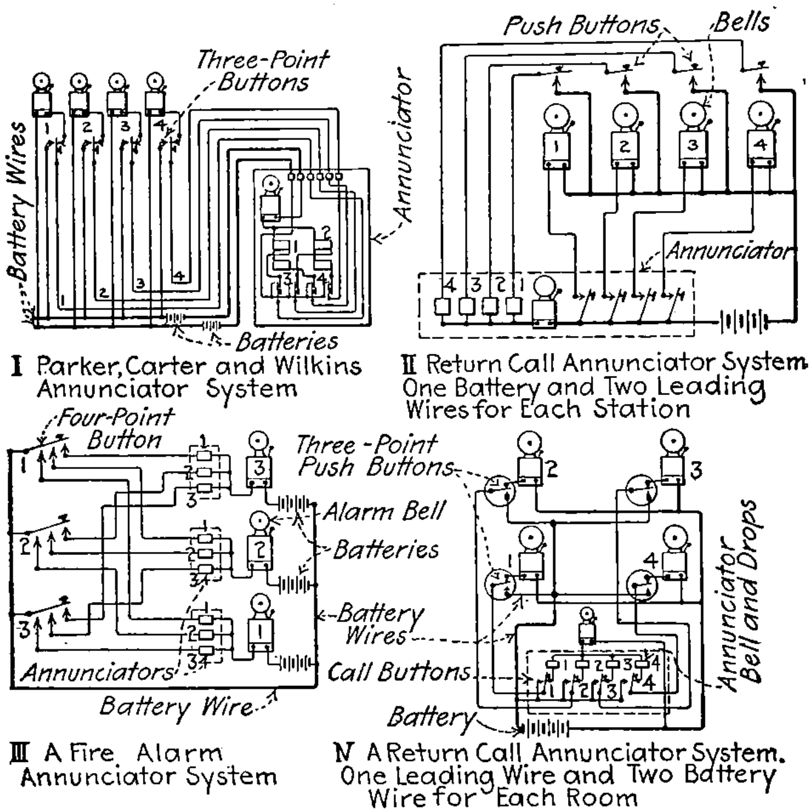


FIG. 219.—Fire alarm and return call annunciator circuits.

connection board. The connection board is of great convenience in locating trouble. It is a good plan to install a cable having one more conductor than is actually required so that a spare will be available in case of trouble.

Annunciators cannot be operated successfully in multiple because of the many paths that are afforded the signaling current through annunciators so connected. In Fig. 218 *III* is shown one correct method of connecting two annunciators installed at different locations and operated from the same buttons and battery. Either one or the other of the annunciators can be thrown into service with the six-point switch. If two annunciators are to operate simultaneously the drops of one must be connected in series with the drops of the other. In *V* is shown an incorrect method of connecting two annunciators. With it, when one button is pressed there are several paths for the current and it will divide and flow as shown in the lower diagram and may, unless the annunciator adjustments and battery strength are just right, throw all of the drops. Annunciators connected in accordance with this method will ultimately give trouble.

The method of connection of *IV* is used where attendants are signaled from annunciators located in different parts of the building during certain periods of the day and from a centrally located annunciator at other times. Either the local annunciator bells or the common annunciator can be shunted out when necessary with the short-circuiting switches shown. Fig. 219, *I* shows a diagram of a Parker, Carter & Wilkins return-call annunciator system. With this system there is a considerable saving in wire as only one direct wire is required from a room to the annunciator. Two common battery wires are around the house.

Fig. 219, *II* and *IV* show two methods of accomplishing the same end. That of *II* is probably preferable for the average installation because (1) the signaling current does not pass through any button except that being pressed, (2) single-contact, not double-contact push buttons are used and (3) only one battery wire is carried to the rooms.

With the fire alarm system, *III*, when any one of the switches is closed all of the annunciator stations are signaled.

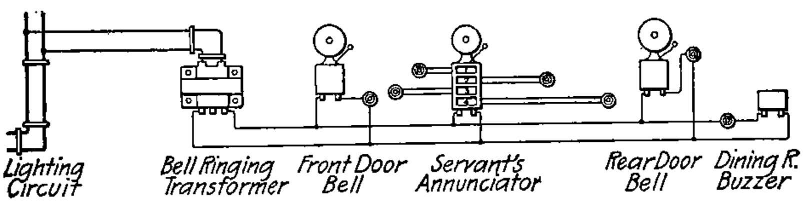


FIG. 220.—Application of a bell-ringing transformer.

289. Bell-ringing transformers (Fig. 220) should always, where there is alternating current, be used for operating signaling systems such as those for bell and annunciator service. A well-made bell-ringing transformer will last forever. Consult the local inspector as to his installation requirements before putting in a bell-ringing transformer, as there have been misunderstandings in regard to this matter. The Code Rules specify that the transformers shall be of special design and that the primary wiring shall be installed in accordance with the rules for light, power and heat wiring and that the secondary wiring shall be installed in accordance with the rules for signal system wiring. It is well to try out a bell-ringing transformer with any instrument that is to be operated by it, that has coils of many turns (such as an annunciator) before final connections are made, because the impedance of these coils to the alternating current sometimes "chokes" the current and renders operation less satisfactory than would be expected judging from the secondary voltage rating of the transformer. A well-designed bell-ringing transformer requires practically no energy for its operation and will not start an ordinary watt-hour meter either when it is idle or when it is furnishing ringing current for an electric bell such as is usually installed in residences.

290. **There are two systems of electric gas lighting: The multiple and the series.** Series systems may be further subdivided into those operating from induction coils and those operating from frictional or static electric machines. The multiple system is the most common. The series system, which is best adapted for large auditoriums where many lights are used in groups, is seldom now used because such places are almost invariably lighted by electricity.

291. **The operation of the multiple system** is evident from Fig. 221. One battery terminal is grounded, or preferably, connects to a common battery wire. The other battery terminal connects through the spark coil to the terminals on the burners. If a common battery wire is used each burner must be insulated from the gas fixture with a rubber nipple. To light the gas, it is either first turned on or is turned on automatically by the burner mechanism and then further movement of the burner mechanism draws a wire wiper, which connects to one side of the battery, across an insulated wire hook which is mounted on the burner tip and which connects to the other side of the circuit. When the wiper leaves the hook a spark is drawn which lights the gas.

292. **Burners of different forms** are shown in Fig. 221. With the stem burner, the gas is lighted by turning the stem which turns on the gas and also draws the spark. With the simple pull burner the gas must be turned on by hand and then pulling the pendant draws the spark and lights the gas. With the rachet burner, one pull of the pendant turns on the gas and lights it and when the pendant is released the wiper and ratchet-pawl are returned to their normal position by a spiral spring. A second pull of the pendant turns off the gas. Automatic burners are so arranged that with them the gas can be lighted or turned off by pressing a button at any one of one or more control stations which can be located at any reasonable distance from the burner. Two insulated wires are required with each automatic burner where the gas pipe is used as a return and three wires are necessary where a nongrounded return is used.

293. **Spark coils** are necessary in electric gas lighting systems to insure that the spark at the burner will be "fat" enough that it will light the gas. The "fat" spark is produced by reason of the self-induction of the coil which acts to momentarily increase the voltage of a circuit enormously, through the coil when the circuit is broken. A spark coil for gas lighting usually consists of about 6 layers of No. 14 or No. 16, double-braid cotton-covered wire wound on a core $\frac{3}{4}$ in. in diameter consisting of a bundle of soft iron wire. The coils are made in various lengths of from 8 in. to 12 in. An 8 in. or a 10 in. coil of No. 16 wire is about right for the average gas lighting installation. A spark coil can be either pur-

chased with or equipped with a relay attachment (Fig. 222). The relay closes a bell circuit when there is a short-circuit on the system and the bell rings and gives an alarm. The bell can be operated from the gas lighting battery as indicated by the dotted lines but it is better practice to use a separate battery, as shown in the full

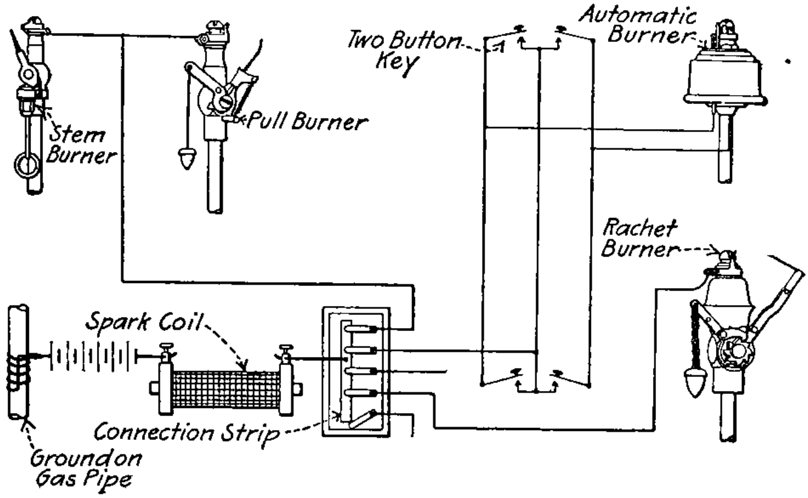


FIG. 221.—Multiple system of gas lighting.

lines, as the cells of the main battery used for such a purpose are liable to be exhausted much more rapidly than the others.

294. A connection strip (Figs. 221 and 222) whereby the leading wires running to the different burners or groups of burners can be disconnected from the battery for testing or in case of trouble should be provided in all gas lighting systems of any consequence.

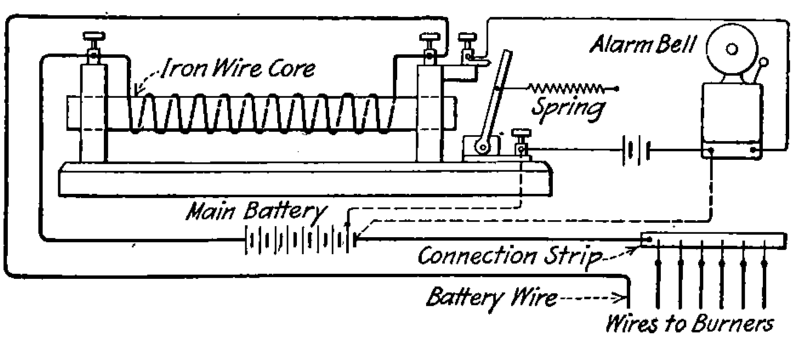


FIG. 222.—Spark coil with relay.

Such a strip may consist of a group of single-point switches or a strip of metal connected to the battery on which the ends of small metal straps normally bear. Each strap is pivoted at its outer end so it can be swung out of connection with the strip and the leading wires to the burners are connected to the pivoted ends.

295. **Batteries for gas lighting** should be of the open-circuit type and should have low internal resistance. Only cells of the very best grade should be used. A battery of 6 sal-ammoniac cells in combination with a spark coil will make a good spark.

296. **Wire for gas lighting systems,** from the battery to the fixture and for general wiring may be No. 16 weather-proof. On fixtures special wire, either No. 22 or 24, is used. These wires can be obtained with three windings of cotton, three windings of cotton and one of silk or with three windings of cotton soaked in a fire-proof compound and then served with an outer layer of silk. On fixtures the wire where possible may be carried within the tubing which covers the gas pipe stem. Care must be exercised that corners and edges do not cut the insulation. On fixture arms the wire is carried on the outside, held thereto with thread and then shellaced which holds it nicely. A helix or "pig-tail" should be formed in the wire at each joint in a bracket. Wire having an outer insulation of a color that matches the fixture should be used.

297. **In installing a multiple system of gas lighting** it is better to use a complete metallic circuit insulating the burners from the fixtures, but in small installations a ground (gas-pipe) return is satisfactory. Divide the burners into groups each served by one leading wire as illustrated in Fig. 221. There should not be more than 6 pull, stem or ratchet burners in any one group and each automatic burner should have its own leading wire direct from the battery. The National Electrical Code rules for installing gas lighting systems are the same as for other signal circuits operating at pressures of less than 10 volts. Electric gas lighting equipment cannot be installed on fixtures having both gas and electric lights.

298. **An automatic cut-out** should be installed in gas lighting systems of any consequence to protect the battery from grounds or short-circuits. In the cut-out the battery wire is connected to the coil of a relay which, when energized, permits a clockwork to operate. If the clockwork operates long enough it, through a mechanism, opens all of the circuits, leading to the burners, which terminate on the cut-out base or a connection strip. The relay is not energized for a sufficient length of time when a burner is operated to permit any great movement of the clockwork. However when a ground or short-circuit occurs on a circuit the clockwork soon opens the circuits. The clock movement must be wound occasionally.

299. **In the series system of gas lighting** (Fig. 223) a spark gap (Fig. 224) is installed at each burner. The spark gaps are connected in series by fine, bare copper wires (No. 26 gage) stretched between them. An induction coil, or sometimes a frictional electric machine, is used to produce the sparks or small arcs at the gaps. About 15 gaps may be allowed for every inch of spark or arc that the induction coil is capable of producing. The gaps are arranged in groups and each group is connected on a separate circuit after a method similar to that illustrated for multiple gas lighting. The gas is turned on and then the induction coil, it being in operation, is connected successively to the different groups, creates arcs at the gaps and lights the gas. Burners can often be arranged close

together so that one will light from another in which case a spark gap is required on only one burner of a group so arranged. The bare wires connecting burners should not be carried closer than $1\frac{1}{4}$ in. to metal work. Where this separation is impossible the wire should be encased in glass tubing. The voltage is very high and

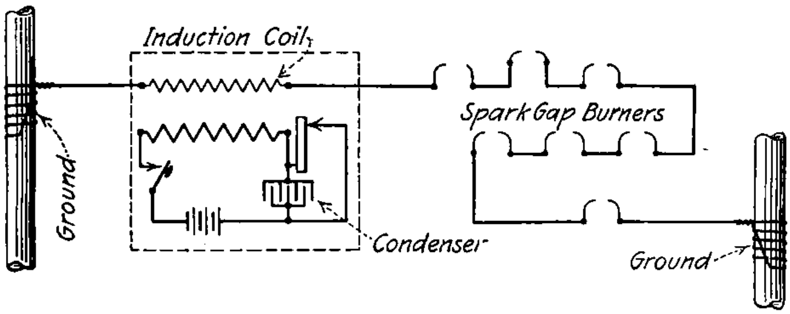


FIG. 223.—Diagram of series gas lighting system.

thorough insulation is essential. The condenser in the induction coil is for minimizing the spark at the vibrator.

300. **Burglar alarm systems** (*Standard Handbook*) are simply modifications of call bell systems; the bell circuit being closed whenever a door, window, transom or skylight, etc., is opened. More elaborate alarm systems entail the use of an annunciator indicating which window or door, etc., has been opened; a continuously ringing bell; a silent test switch to show that every window, door, etc., in the house has been properly closed; switch for testing bell and battery; a general switch for cutting out the alarm system during the day or whenever it is not required; lock switches for admitting persons with proper keys without sounding the alarm; attachments for lighting an incandescent lamp or gas-jet automatically when the alarm sounds so that the annunciator drop may be visible, and numerous other refinements.

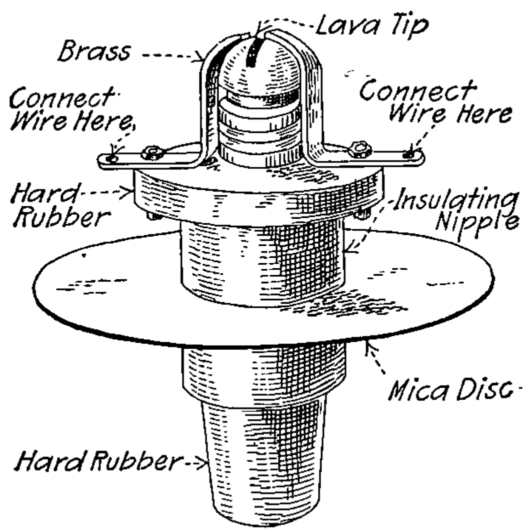


FIG. 224.—Spark gap burner for series gas lighting.

The chief requisite of an alarm system is the certainty of action of the apparatus and contacts. Since the apparatus may stand months and even years without being called into action, rubbing contacts, German silver springs, etc., are largely employed. Wires, contacts, etc., should be concealed and should be installed in a first class manner.

301. There are two classes of burglar alarm systems: open circuit and closed circuit. In open-circuit systems the circuit or circuits to doors and windows throughout the building are normally open and when the circuits are closed by a door or window being

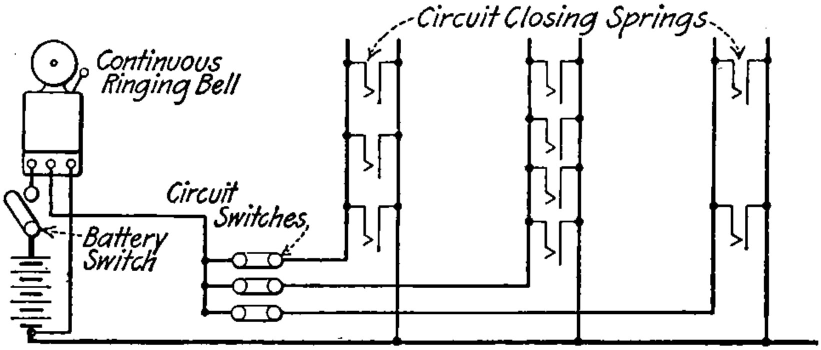


FIG. 225.—Simple open-circuit burglar-alarm system.

opened the alarm is sounded. In closed-circuit systems the circuit throughout the building is normally closed and current is flowing in it. When it is opened the alarm is sounded.

302. Open-circuit systems are shown in Figs. 225, 226 and 227. Some arrangement—a continuous ringing bell or drop—must be provided whereby the circuit through the alarm bell will remain continuously closed if a house circuit is closed instantaneously.

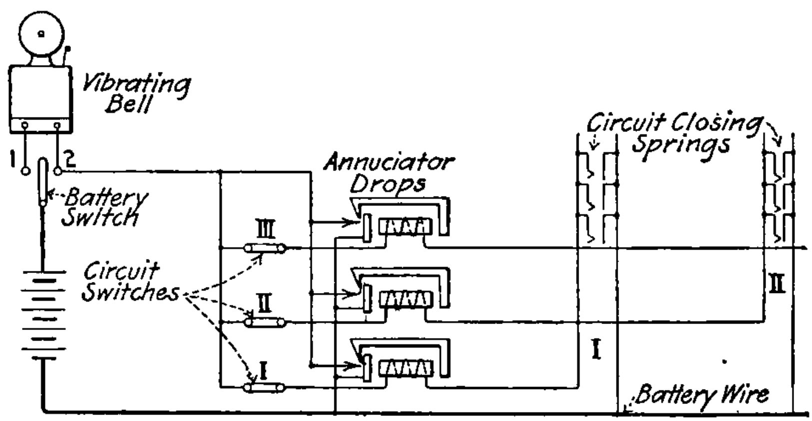


FIG. 226.—Open-circuit burglar-alarm system with alarm annunciator.

In setting the system for the night, the battery switch and the circuit switches are all opened. Then the battery switch is closed and the circuit switches are closed one at a time thereby locating any circuit on which there is trouble or on which a window may have been left open. Open-circuit systems are usually installed in preference to closed-circuit because of their simplicity.

303. One objection to the open-circuit system is that if the wires should be cut no protection is afforded, the alarm being then inoperative. When properly installed, however, the cutting of wires is a very rare occurrence. To guard against this possibility, a closed-circuit system may be installed in connection with the open-circuit system, the window, door and other contacts being arranged to open the circuit of a relay which thereby makes contact with the bell circuit. This system will give the alarm when the wires are cut, or when the closed-circuit battery is run down, or when a window, door, etc., has been opened. A straight closed-circuit system may also be installed.

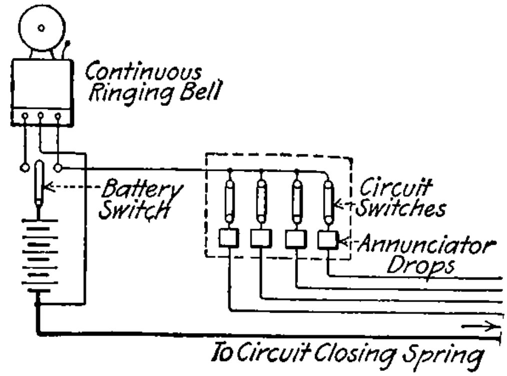


FIG. 227.—Open-circuit burglar-alarm system using an annunciator in combination with a continuous-ringing bell.

304. Closed-circuit systems are more sensitive than open circuit but are more liable to disarrangement. Fig. 228 shows an installation with two house circuits but usually one house circuit suffices. Fine bare copper wire (No. 24 gage) can be used for the house circuits and may be strung in front of doors, windows and objects to be protected so that its breakage will open the circuit and set off the alarm. Gravity cells are used for the closed-circuit battery and Le Clanche cells for the open-circuit battery.

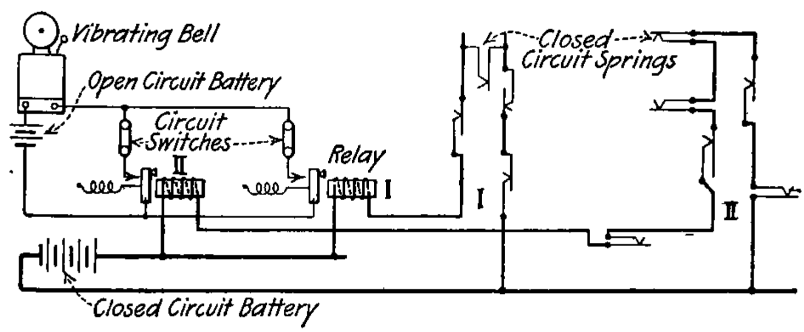


FIG. 228.—Closed circuit burglar alarm with two alarm circuits.

305. Burglar alarm fittings are shown in Fig. 229. Fig. V shows burglar alarm attachments for protecting windows, skylights, blinds, etc. A wire or string is attached to the ring and is drawn so as to break the contact. Further tension on the wire or string or its severance will establish the contact and give the alarm. Alarm springs for shades are shown in Fig. VI. The string of the shade is attached to the arm or hook so as to break the contact. Any interference with the setting makes contact and gives warning of intruders. A lock burglar alarm switch is shown in Fig. VIII. This is placed on the door frame so that persons with proper keys can enter without giving the alarm. Turning the key opens the bell circuit.

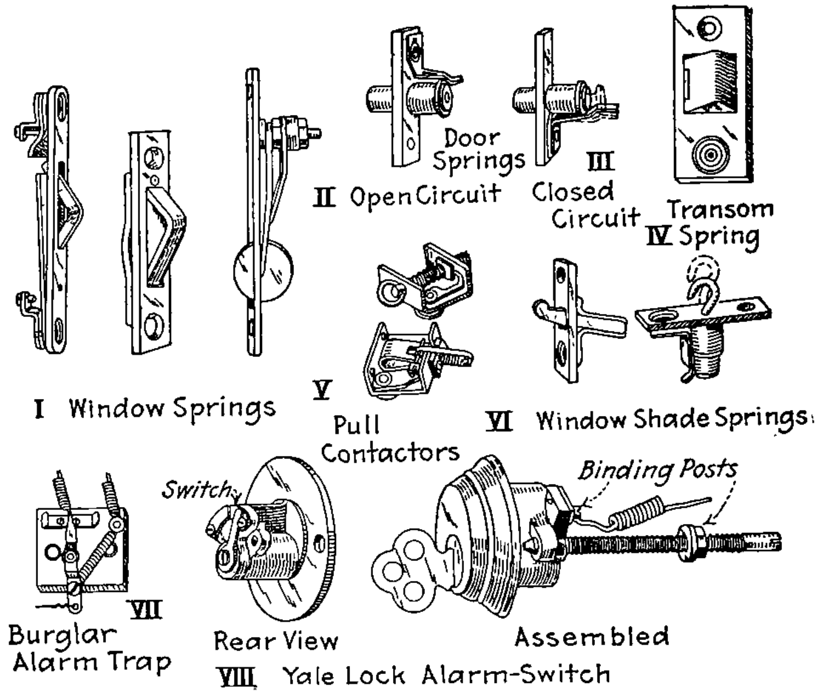


FIG. 229.—Burglar-alarm fittings.

A burglar alarm trap is shown in Fig. VII. This simple device has a great many applications. The illustration shows the trap in a balanced position, that is, the switch is not making contact. The string connected to the switch may be attached to a window, door, skylight, stretched across a hall, open doorway, etc., to be protected against intruders. The slightest disturbance of the string will draw the switch to one side and make contact and if the string is broken the spring will draw the switch to the opposite side and make contact so that in either case an alarm is given. An auto-drop or constant-ringing attachment is shown in Fig. 230. The bell circuit is closed automatically and is kept closed as long as desired. The drop is placed in the bell circuit and when the circuit is closed by a push button, door or window spring, the circuit-closer drop is operated by an electromagnet and keeps the circuit closed until the drop is raised again.

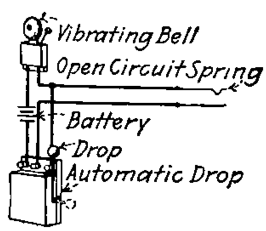


FIG. 230.—Constant ringing attachment.

Instead of contacts in windows, doors, etc., electric mats are sometimes used. An invisible electric mat is placed under the carpet or other floor covering and which when trod on or touched by the foot sounds an alarm or signal in any part of the house by closing the bell circuit By this means windows may be left open for ventilation and protection still obtained.

306. Clock burglar alarms (*Standard Handbook*) (Fig. 231) may be had which automatically disconnect sections at predetermined times. These may also be fitted with a constant ringing switch, a servants' call switch, an incandescent lamp or an attachment for automatically lighting the whole house in case of an alarm. Switches are provided for testing each circuit leaving the annunciator; for testing the bell and line, and for testing the battery.

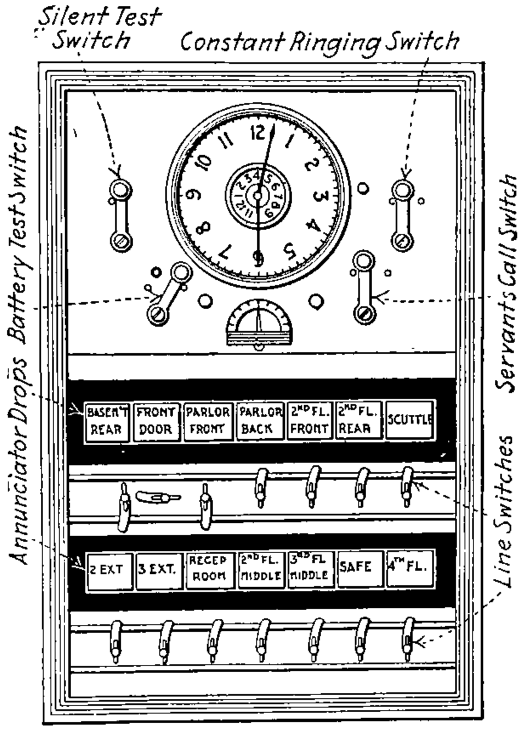


Fig. 231.—Burglar-alarm clock annunciator.

307. The installation of a burglar alarm system (open circuit) is shown in Fig. 232. It is to be understood that all the windows in one room are connected in multiple so that only one drop on the annunciator is required for each room. Fig. 233 shows the arrangement of a simple, closed-circuit, burglar-alarm system. All the contacts are arranged to open the closed-circuit when disturbed; this releases the armature of the relay which is instantly drawn by the spring to complete the bell circuit and give the alarm. This arrangement requires the use of both closed-circuit and open-circuit batteries, and while a trifle the more expensive is the most reliable system that can be installed. In

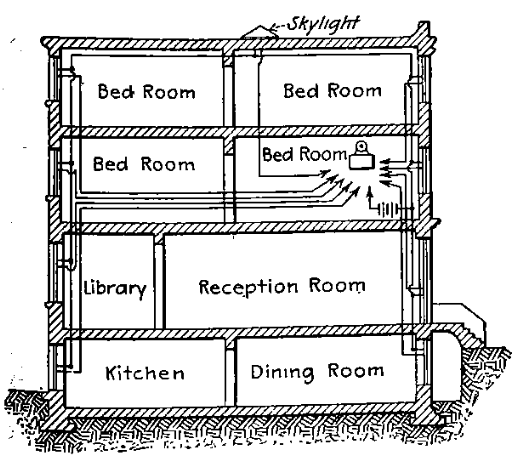


Fig. 232.—Open-circuit burglar-alarm system.

this system the alarm is given, the room indicated and the lamps throughout the building turned on whenever the circuit is opened. In closed-circuit systems a resistance should be placed in the circuit when the alarm is not set. (*Standard Handbook.*)

Circuit opening or closing springs are usually placed in window frames and door jambs. In installing springs be careful that the door or window fits snugly enough that the spring will lie in its normal position when the door or window is closed.

308. There are two general plans for installing interior telephone systems (*American Telephone Practice*). One is to install a switchboard at some central point to which all lines radiate and at which they are connected as desired by an operator. The switchboards and instruments are of the types made for small exchanges.

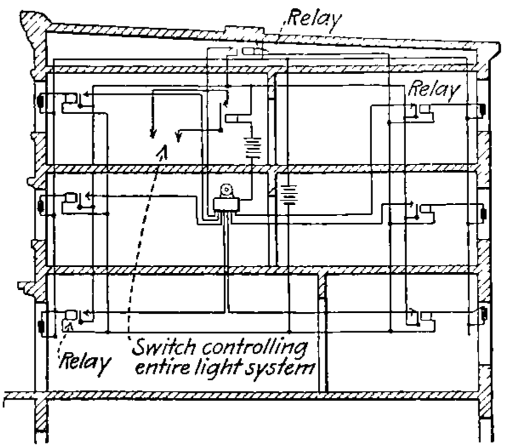


FIG. 233.—Closed-circuit burglar-alarm system. Annunciator indicator room and switch throws on all lights.

The second plan involves the use of an intercommunicating or house system in which the instrument at each station is placed on a separate line, the line belonging to each station passing through all of the other stations. By means of a switching device arranged at each station, the party at any station may, at will, connect his telephone with the line belonging to any other station and call the party at that station without the intervention of an operator. This plan involves the necessity of running at least one more wire than there are instruments in the exchange through each one of the stations and the simplest way to do this is to run a cable having the requisite number of conductors through each of the stations, all of the conductors in the cable being tapped off to the switch contact points on each telephone.

From 12 to 20 stations is considered a maximum for intercommunicating systems. Where there are more stations a switchboard should be installed.

309. Local battery telephones may be divided into two classes, series and bridging. The series instruments are adapted for use on single station lines in exchange work or on a line connecting only two instruments. This type is termed series because the generator and bell are connected in series with each other and further because it was formerly the practice on party lines to connect such instruments in series in the line. The bridging instruments are so called because the generator and ringer are separately bridged across the line and in party line work it is common to connect such instruments in multiple on the line.

310. **The circuit of a series instrument** is shown in Fig. 234, *I*. The switch hook is shown in its raised position so as to connect the receiver and the secondary of the induction coil in series in a circuit between the binding posts of the instrument. At the same time the transmitter, the primary of the induction coil and the battery are connected in a local circuit by themselves. This is the condition

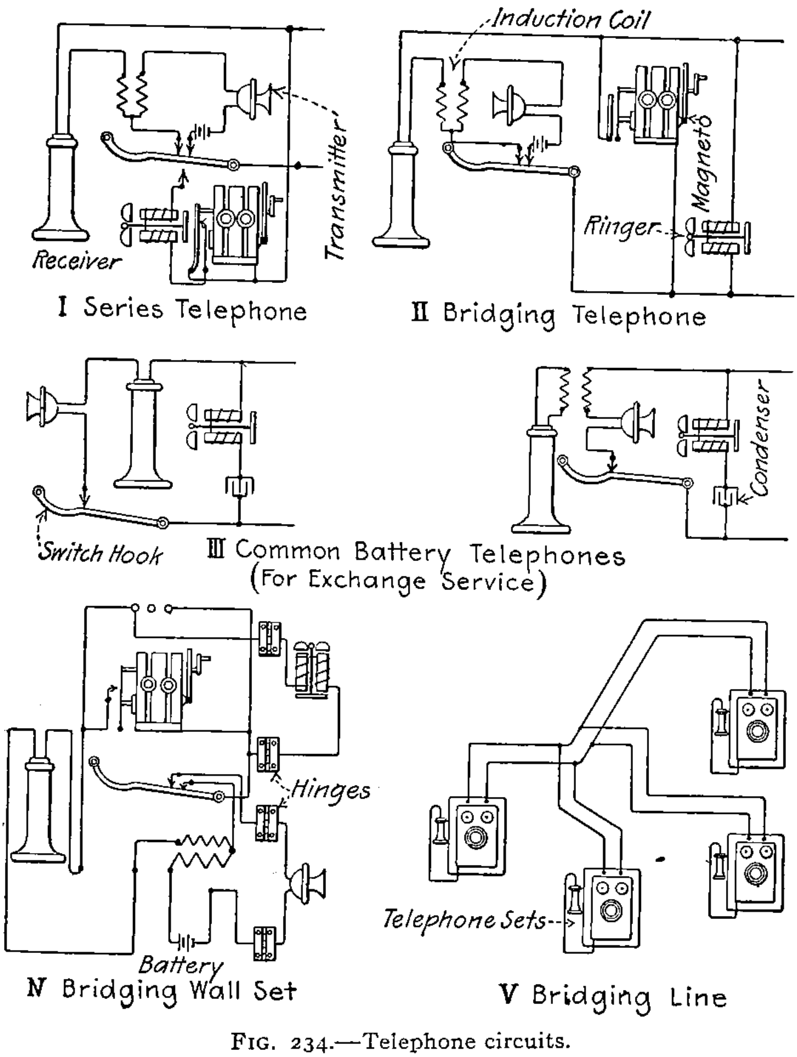


FIG. 234.—Telephone circuits.

for receiving or transmitting speech. When the hook is depressed, as when the telephone is not in use, the bell or ringer is connected across the terminal posts. This circuit would also include the generator but for the fact that it is normally shunted out by springs. The contact between these springs is automatically opened, however, when the generator is operated and then there is current from the generator to the line through the bell. The springs form what is called an "automatic shunt" for the generator, their function being to cut out the resistance of the generator armature from the circuit at all times except when the generator is in use.

311. **The circuit of the bridging telephone** is shown in Fig. 234, *II*. In this, the arrangement of the receiver, induction coil, transmitter and battery are identical with that in the series telephone. The ringer, however, is bridged permanently across the line and the generator is placed in a circuit across the line which is normally open but which is closed automatically by a spring when the generator is operated. The magnets of the ringer or bell are wound with many turns of fine wire. This gives them great impedance. The talking currents, which are high-frequency alternating currents, do not, therefore, pass through the ringer coils. The ringing currents can readily pass through the ringer coils and cause them to operate.

312. **The circuits of an assembled bridging telephone** are shown in Fig. 234, *IV*. As the ringer and the transmitter are mounted on the door of the instrument box the connection between them and the other parts of the apparatus is made through the hinges as shown. Note that the circuits are identical with those given for the elementary bridging instrument.

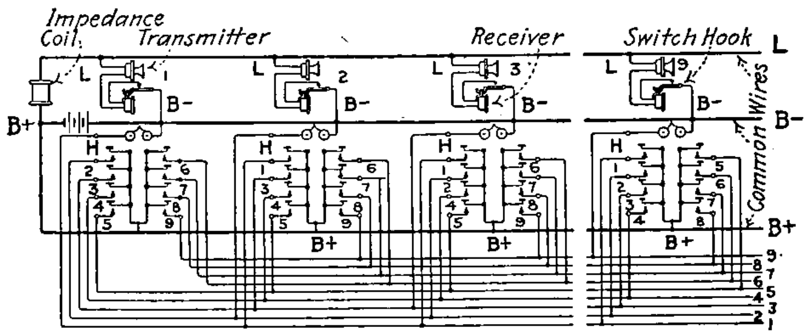


FIG. 235.—Selective-ringing, common-talking, private-line system.

313. **A simple intercommunicating system which permits of but two parties talking simultaneously** is shown in Fig. 235. As furnished by the Western Electric Company, the bells are wound to 10 ohms resistance insuring minimum draught of current from the battery and long battery life. The transmitter and receiver are of high resistance and the impedance of a coil through which battery is supplied to the transmission circuit prevents the shunting of talking currents through the battery. The use of high-resistance transmitters and receivers insures that the most distant instrument will receive practically as much as those near the batteries. The wall instruments are quite similar in external arrangement to that of Fig. 242, but are furnished in the surface type only. Desk instruments can also be supplied.

314. **The circuits of an ordinary lever switch intercommunicating system** are shown in Fig. 236. One station calls another by the turning of a magneto generator, the switch lever having first been moved into contact with the button corresponding to the

number of the station desired. The disadvantage of the system is that the switch lever must always be returned to the "home" button or endless confusion from cross signals will result.

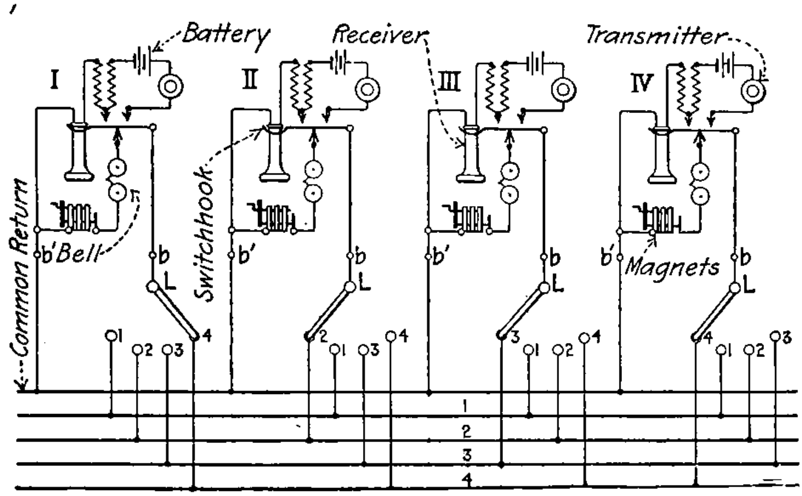


FIG. 236.—Circuit of lever switch intercommunicating system.

315. The circuits of a common-battery, common-return plug and jack intercommunicating system are shown in Fig. 237. The wiring for 10 stations is shown but only 5 of them are indicated. The plug is inserted in the jack corresponding to the station wanted

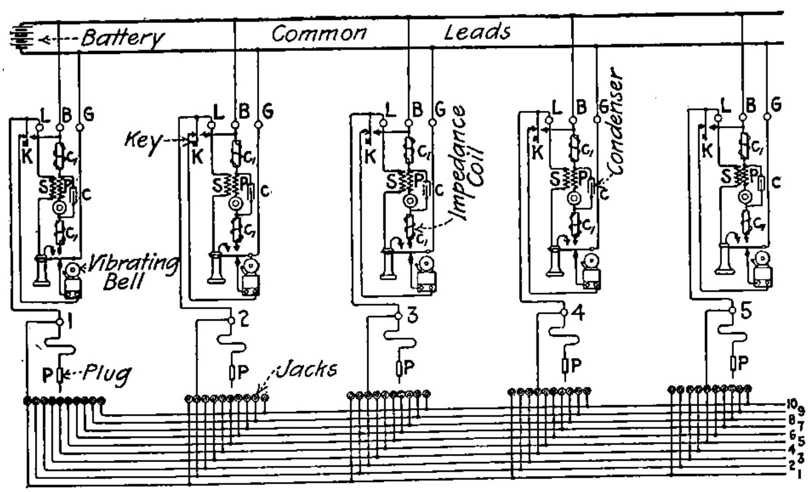


FIG. 237.—Common-battery, common-return, plug and jack, intercommunicating system.

and a pressure of the key rings the wanted station's bell. Impedance coils are inserted in the primary circuits to reduce cross talk and the transmitter is bridged by a condenser which provides a local circuit for the talking currents set up by the transmitter.

The plug must be removed after a conversation, or cross ringing will result.

316. **The circuits of the Holtzer-Cabot intercommunicating system** are shown in Fig. 238. The switch is so arranged with a ratchet wheel that it will be released and fly back to normal position through the action of a spring when, after a conversation is finished, the receiver is hung up. The switch lever at each station is arranged to slide over and make contact with the buttons. However, the curved contact piece is so arranged that the lever will not normally

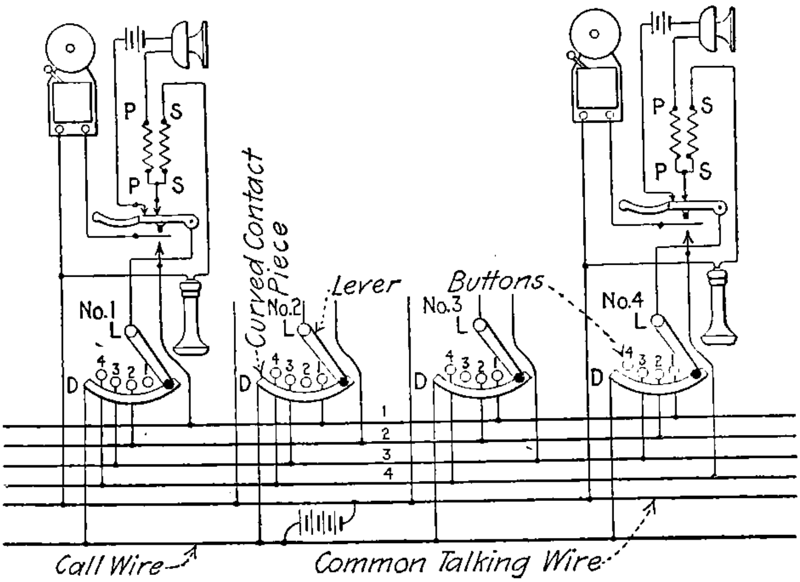


FIG. 238.—"Holtzer-Cabot" system circuits.

engage it but by pressing on the handle of the lever it may be brought into engagement and thereby complete the ringing circuits through the bells of both stations.

317. **The circuits of a metallic circuit intercommunicating system using plugs and jacks or keys instead of a switch** are shown in Fig. 239. In many systems the fault exists that if a person at one station fails to return his switch to normal after using his telephone, he cannot be called by others because his instrument is not connected with his own line. In the circuit shown this is avoided by permanently connecting the bell belonging to each station across the line of that station.

There are five lines running through five separate stations and the call-receiving bell *B* on each line is permanently bridged across the line at that station bearing the same number as the line. Two-point spring jacks are provided at each station for each line and the subscriber's telephone set and generator may be switched into the circuit of any line by inserting the plug in the proper jack. Thus if a party at Station No. 1 desires to call Station No. 5, the plug at station No. 1 would be inserted in jack No. 5 and the generator operated. This would ring the bell at Station No. 5 and the party at that station would respond by inserting the plug in his own home jack. When through talking, if the party at Station No. 1 left his plug in connection with line No. 5, no harm would be done

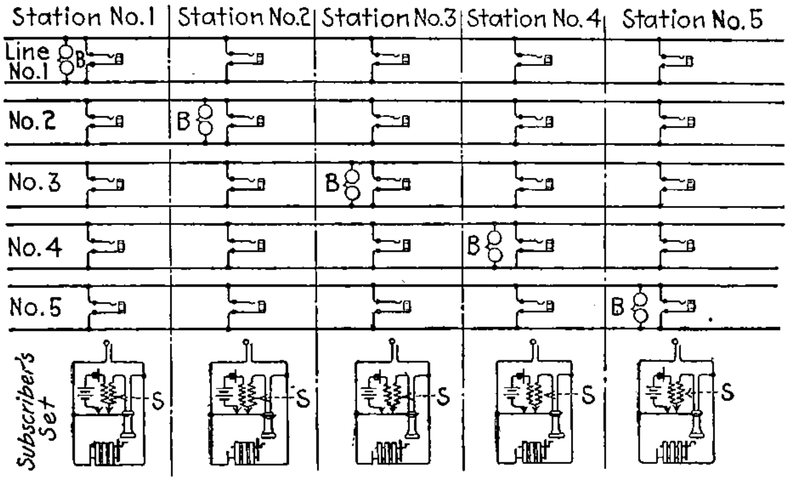


FIG. 239.—A plug-in intercommunicating system.

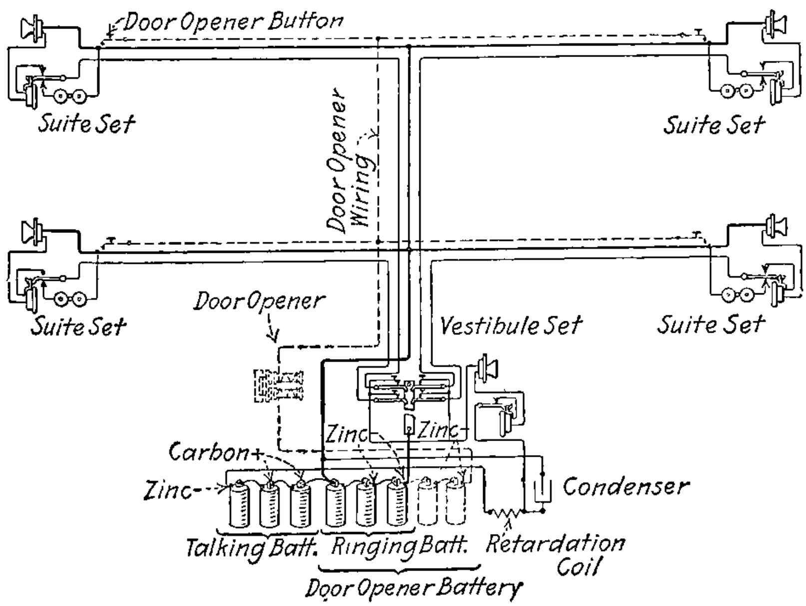


FIG. 240.—Apartment house system giving service between vestibule and apartments.

as other parties could operate the call bells of either line, No. 1 or No. 5, just as well with the plug inserted as with it out.

Instead of using plugs and jacks, as shown in Fig. 239, to effect the connection of the telephones with the various lines, a more

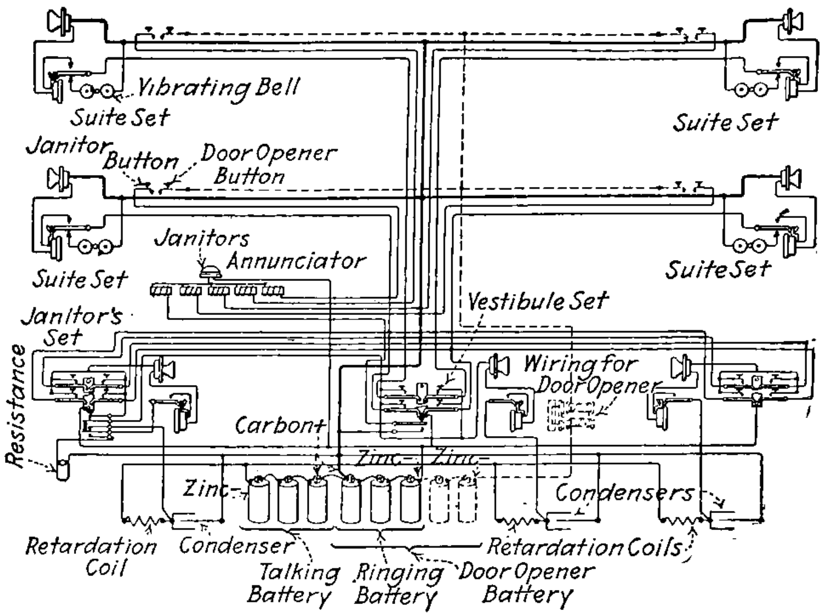


FIG. 241.—System giving service between vestibule and apartments, vestibule and janitor and tradesmen and apartments.

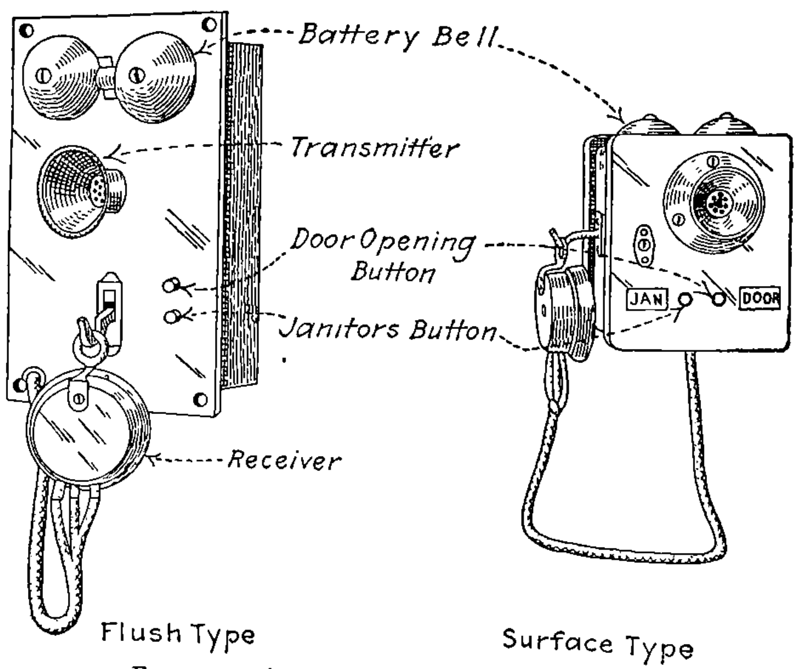


FIG. 242.—Apartment-house suite telephones.

convenient arrangement, described hereinafter, involving, however, the same principle, is to employ push buttons or keys. The proper connection with these is made by pushing a key instead of inserting a plug in a jack.

318. Apartment house telephone system circuits are shown in Figs. 240 and 241 which are recommended when the installation of a

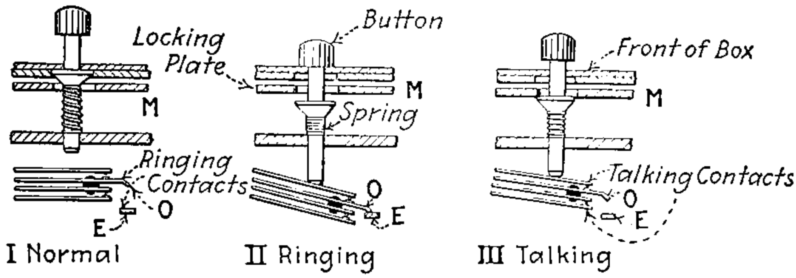


FIG. 243.—Positions of intercommunicating key.

private branch exchange is not justified. These illustrations show Western Electric Company's Interphone systems. The suite telephones (Fig. 242) may be of either the flush or surface types. The talking battery is fed through retardation coils, so in installation where there is provision for simultaneous conversation between two stations, there cannot be cross talk. The receiver and transmitter in the telephones are in series, an induction coil not being

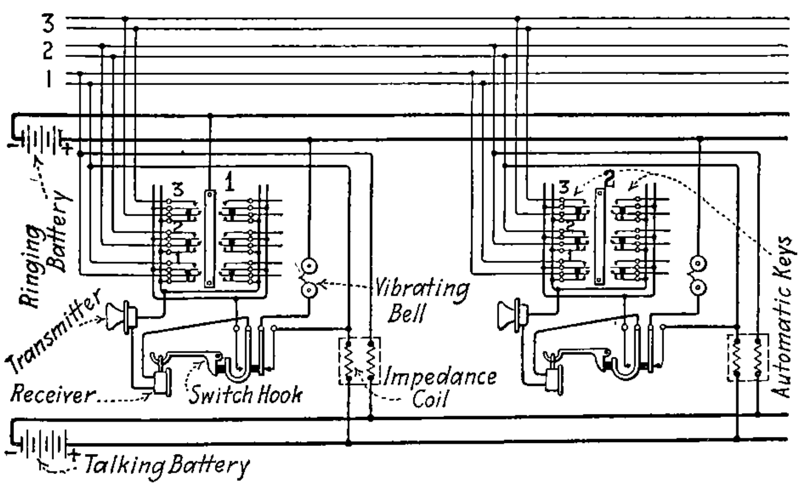


FIG. 244.—Automatic-key intercommunicating sets. Any two or more stations on the system can converse simultaneously.

necessary for the short distances involved. The calling buttons on the telephones make connections as described in paragraph 319. Where a janitor's set is installed, the annunciator for it is similar to ordinary annunciators. One janitor's equipment can be made to serve any reasonable number of vestibules and apartments by making proper modifications. The bells in the apartments are wound to 10 ohms and the resistance of the janitor's annunciator drop plus that of his bell is 10 ohms, which insures minimum draught of current from the battery and maximum battery life. Ordinary electric bells have about 2 or 3 ohms resistance.

319. The operation of the keys in an interphone instrument is shown in Fig. 243. When the button is pressed all the way down as at *II*, the ringing position of the key, contact is made with the line wires of the station called and ringing current is thrown out on that line. When the pressure on the button is released, it assumes an intermediate position, *III*, the talking position, and the ringing contacts *o* and *e* are open but contact with the line for talking purposes is maintained. The key is automatically held in this intermediate position by a locking plate *m* until this plate is actuated by the operation of any other button in the telephone which releases the key so that it assumes its normal position as shown at *I*.

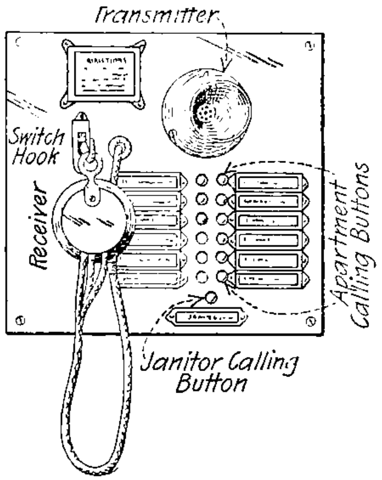


FIG. 245.—Flush-type vestibule, janitor's or tradesman's set.

320. An automatic key intercommunicating system which permits simultaneous communication between stations is shown in Fig. 244. This is a Western Electric Company Interphone circuit, but similar arrangements are furnished by other concerns. The instruments are quite similar in appearance to that of Fig. 245 and may be of either the flush or surface type, or desk sets can be used. The operation of the automatic keys is described in paragraph 319. Wiring between stations may be full metallic as shown or common return. Full metallic is recommended and instruments are arranged for it, but can be easily altered by the wireman for common return. Circuit arrangements can be provided insuring secret service between certain stations. Three or more parties can converse with each other at once by depressing the proper calling buttons.

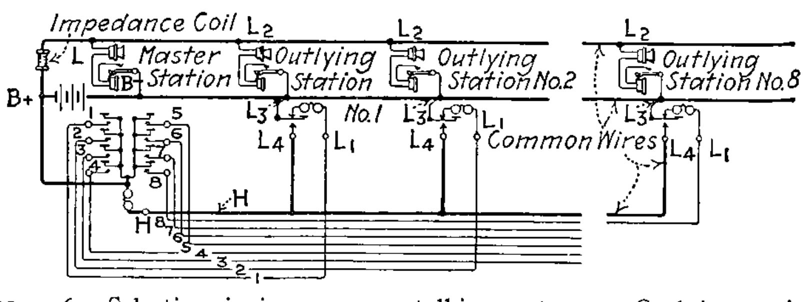


FIG. 246.—Selective-ringing, common-talking system Outlying stations cannot intercommunicate.

321. **An arrangement wherein the master station can call any outlying station but the outlying station can call only the master station** is shown in Fig. 246 which gives the Western Electric circuit. In general this is similar to the scheme of Fig. 235. The arrangement is used in schools, factories, stores, banks and offices where an executive communicates with subordinates and they with him, but where there is no occasion for the subordinates communicating with each other.

322. **Conductors for telephone wiring** (*Standard Handbook*) are usually of rubber-covered, twisted pair, copper wire, but the work may often be done much better and cheaper, particularly in large buildings, with lead-covered paper-insulated cable such as is used by telephone companies in the subways. These cables are smaller for the same number of wires and are less costly than cables containing the same number of wires rubber-insulated. Paper cables less than 3 in. in diameter and containing as many as 600 pairs can be obtained. Of course with this type of cable all the terminals of the cable or its branches must be made with lead-covered, silk-and-cotton insulated cables, as the paper insulation will not stand handling when exposed. Where the terminal is in a damp location the run should be made with rubber-covered wire. Shafts are preferable to iron conduit for carrying the main riser cables, as it is a difficult matter to make splices between the riser cables and the floor terminal cables if the former are run in conduit.

323. **In installing telephone cables** or conductors for a system a few spare pairs should always be included. Where this is done the installation of additional stations is inexpensive. Instruments having provision for more stations than required for the initial installation should be used to obviate the replacement of the instruments which is otherwise necessary when additional stations are put in.

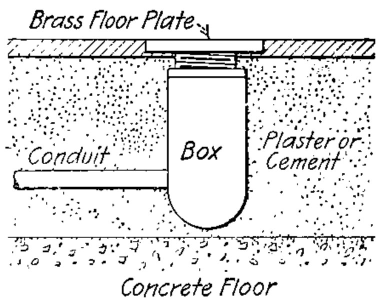


FIG. 247.—Signal-circuit, floor-outlet, box.

324. **In wiring for telephones and signaling systems in department stores** (*Standard Handbook*) or in other places where it is desirable to have outlets for counters or on desks, a very flexible system may be installed as follows: Lines of $\frac{1}{2}$-in. galvanized pipe may be laid under the floor from the riser shafts and arranged to checker the floor (Fig. 248) in such a manner that all parts of the floor are within short range of the outlet points. Connection boxes (Fig. 247) may be installed at intervals of 50 ft. into which the lines of conduit are bushed. These boxes should be large enough and square and should be fitted with tight-fitting brass cover-plates flush with the surface of the finished floor. Service outlets through which connections may be extended to telephones, bells, etc., may be located approximately 10 ft. apart throughout the entire system.

From these outlet-tees and the vacant sides of the connection boxes, wires may be fished under the floor to any desired point. The tees in the conduit may be entirely concealed beneath the floor and made accessible through removable sections of the flooring above them. The tees may be normally plugged, and may be fitted with outlet bushings when connections are to be made through them.

The connections for these low voltage circuits may be made through 2-in. conduit risers located in the same space as the lighting risers. Special interconnected panels (Fig. 249) should be provided at every floor through which branch connections to the underfloor conduit system may be easily made. The interchanging of connections may also be made at these panels. This system may be used for all telephone, bell and signal wires.

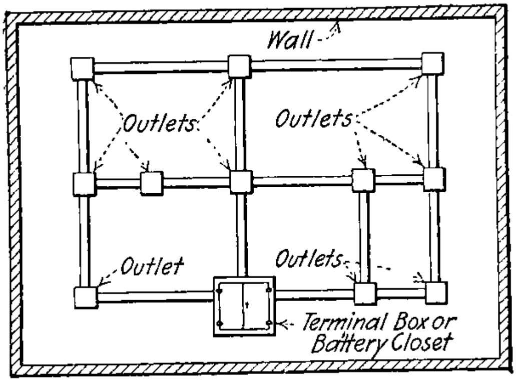


FIG. 248.—Conduit system for signalling installation.

325. For wiring large office buildings for telephones (*Standard Handbook*) a very economical and satisfactory system can be arranged as follows: One or more terminal boxes are provided on each floor at points adjacent to vertical pipe-shafts. Elevator shafts can frequently be used for this purpose. From the basement one or more cables are extended up through these shafts. Branch taps of sufficient size to provide for service on each floor are terminated in the terminal boxes. The riser cables and the service cables from the telephone exchange should terminate in a common main terminal in the basement so that connections can be easily made between the two sets of cables. The terminal boxes should be placed near the ceiling and wide shell molding should be provided in the halls for carrying the wires from the terminal boxes to the rooms. A smaller molding should also be provided for carrying the wires in the individual rooms.

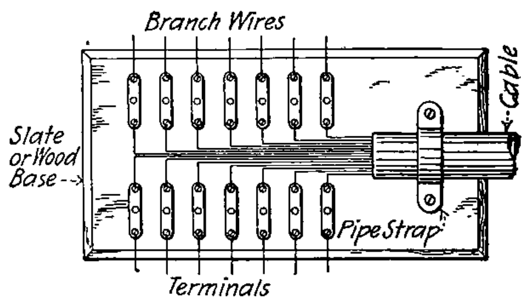


FIG. 249.—Interconnection board.

Where the wires enter the room from the hall, a piece of $\frac{3}{4}$-in. conduit should be furnished for carrying the wires through the partition. This conduit should be either lined with insulating material or the sharp edges around the inside of the pipe should be rounded off. Where it is necessary to run across the ceiling of a hall in order to avoid either carrying the exposed wires across the finished ceiling, or making a circuitous run around the hall to reach the rooms on the opposite side from the floor terminal, conduit should be installed across the ceiling before the plastering is completed for the purpose of carrying a small branch cable to provide for such lines.

326. **When wiring large hotels and apartment houses for telephones** (*Standard Handbook*) it may be taken for granted that one telephone will be required in each room of a hotel and one for each apartment in an apartment house. In office buildings, a number of telephones may be required in one room, and a very flexible system of wiring must be installed. In hotels the wiring involves the running of a pair of wires from each room to a common center near the switchboard which is usually located on the first floor. Provision should also be made so that the cable of the telephone company carrying the trunk lines may run from the switchboard to the outside of the building. A 2-in. conduit is usually large enough for this purpose, but the local telephone company which usually installs the wires after the race ways are in place should be consulted.

From the telephone switchboard a cable is run through the vertical pipe shaft. The size of this cable diminishes as it extends up through the building. At each box a tap is terminated of sufficient size to provide wires for all telephones on that floor. From the terminal boxes on each floor twisted pairs of rubber-insulated wires are run through the conduits to locations in each room.

A very simple manner of wiring apartment or hotel buildings for telephones is to place a terminal box on each floor convenient to a vertical pipe shaft. From this terminal box a ½-in. conduit is run to a designated location in the wall of each room. The height of the outlet should be 4 ft. 10 in. from the finished floor. This conduit should not be over 50 ft. long and should have not more than three bends with a minimum radius of five inches. Any conduit 100 ft. long should be not less than 1 in. in diameter; ½-in. conduit should be provided for a maximum of two pairs of wires; ¾-in. conduit for five pairs, and 1-in. conduit for ten pairs. In extending the conduit from the terminal box to rooms, it is possible to use one run of larger conduit to supply a number of rooms, rather than run small conduit to each room. Where the floor area is large and the number of telephones required is great, it may be found economical to install more than one terminal box on a floor.

327. **In relatively small apartment houses** where only one telephone is required in each apartment, it is an easy matter to run a vertical conduit up through each tier of apartments and provide an outlet in each apartment. Individual pairs of twisted rubber covered wire can then be pulled from the switchboard through the conduit for each telephone. The individual wires can be carried in a cable from the bottom of the risers to the switchboard.

328. **The number of telephone wires to be provided** in a building depends, of course, on the building and the class of business for which it is to be used. A rough average is one pair per 200 sq. ft. of floor space in financial buildings, and one pair for every 300 sq. ft. of floor space in commercial buildings.

DESIGN OF INTERIOR WIRING INSTALLATION

329. **Factors Affecting Wiring Lay-outs** (*Standard Handbook*).—In conduit work the space available often dictates that the feeders be split up into two or more feeder lines. Conduit larger than 2 in. in diameter is not easily handled, and even if the run were such that 2-in. conduit could be easily installed, it would be preferable to install smaller conduit and divide the feeders so as to guard against complete shut down should anything happen to the feeders. Very often the mistake is made of installing feeders just large enough to carry the present load, and when additions are called for the feeders are overloaded and additional feeders must be installed at great expense. The same is true of branch circuits. The maximum allowance of 660 watts on branch circuits should not be used up. Frequently a larger lamp may be substituted for a 16-c.p. lamp; in fact, this is very easily done because of the fact that the lamp socket will take any size of incandescent lamp up to 500 c.p. and circuits are thus easily overloaded. It is usual to connect up about 400 watts so that fans, etc., may be connected afterward without overloading the circuit.

330. **In selecting a system for wiring for light** one should be used whereby 110 volts or thereabouts can be impressed on the lamp terminals. Nominal 110-volt incandescent lamps, including those of voltages of from say 90 volts to 125 volts, are more efficient, cheaper and have longer lives than those for higher voltages. Lamps of nominal voltages of about 50 volts are seldom used now and require excessive expenditures for copper conductors. The three-wire system is much more economical of copper than a two-wire system, therefore should be used for feeders and mains in installations of any consequence; then the two-wire system is used for branches. Three-phase systems can be used for lighting as elsewhere described (see index) and can be used to advantage in industrial plants where the use of constant speed motors makes the use of the three-phase system desirable.

331. **The method to use for wiring a building** is determined by conditions. *For residences:* Exposed work on knobs and cleats is cheap and safe but seldom used because of its unsightliness. Molding work is sometimes used in old buildings but does not look well. The knob and tube method can be used when the building is being wired while under construction or in wiring an old building. It is a low-cost method and quite safe. Either rigid or flexible conduit or steel armored conductor wiring are best and also most expensive. In many communities, conduit or steel armored conductor wiring are the only methods permitted for concealed work. Flexible steel armored conductors provide the best and safest installation for wiring old buildings. *For business and public buildings* of frame or of brick and frame construction the above suggestions for residence wiring apply. For fire-proof buildings the rigid, wrought-iron conduit method is used almost exclusively.

332. **In planning the wiring for a residence** secure the floor plans of the building or, if it is a small one, inspect the building. Decide first where the meter is to be located, as the point of entrance

to the building should be as close to the meter as possible. Some central station companies specify where meters shall be located. Often the meter can be located and the service wires enter in the cellar, as in Fig. 250. A kitchen is a poor location for meters because they will get greasy and collect dirt. Where the service wires enter between the first and second floors a good location for the meter is in a rear hall or in the pantry. Meters should not be located in attics or where the readers must climb stairs to reach them. A basement or a first floor entrance is the best.

The meter location having been determined, ascertain how many lamp outlets there will be, the current taken at each, and where

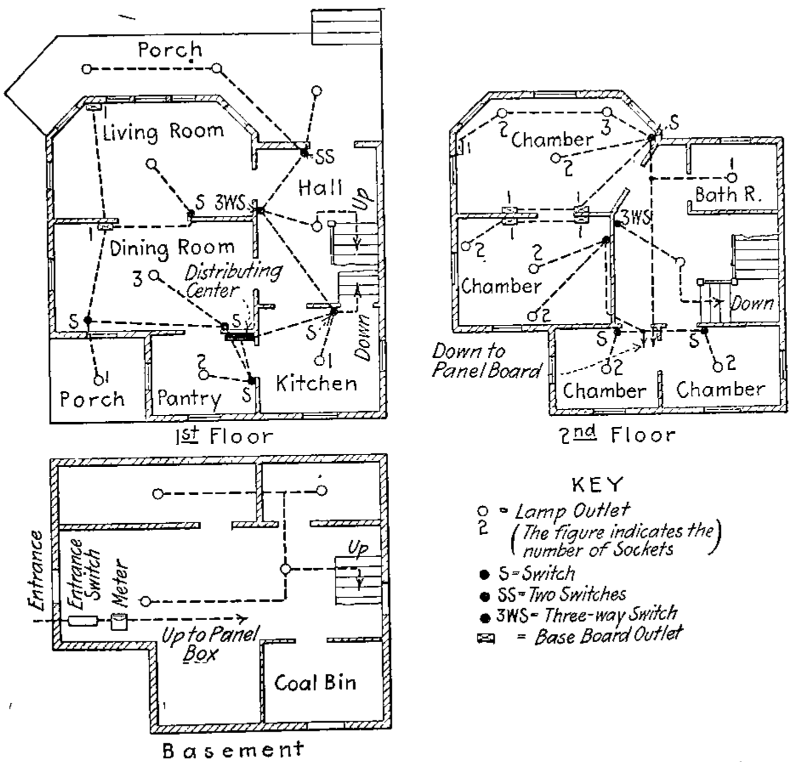


FIG. 250.—Wiring lay-out in a two-story house (Conduit Method).

the outlets will be located. Decide on the location of the distributing center as directed in another paragraph. Divide the outlets into groups requiring less than 660 watts, each group to be fed by a branch circuit from the distributing center. No branch circuit feeding incandescent lamps can have a load in excess of 660 watts connected to it and it is better to so subdivide the outlets that no branch circuit will have an initial load greater than about 440 watts which allows 220 watts for growth. Fig. 250 shows the subdivision of branch circuits radiating from a distributing center throughout a house. Locate the switches. Calculate the size of feeder that will be required in accordance with directions given elsewhere herein. If load exceeds 660 watts it is best to use a three-wire service. Incandescent lamp branch circuits are usually of No. 14 wire unless they are over 100 ft. long when wire at least as large as No. 12 should be used. No. 14 is the smallest size permitted by the *Code*. Figs. 250 and 252 show plans for conduit jobs, with non-conduit jobs the arrangement would be the same except that splices could be made elsewhere than in outlet boxes.

333. **The wiring in a residence between the entrance and the distributing center** is shown with a three-wire feeder in Fig. 251. A fused entrance switch is always inserted in the feeder circuit immediately inside of the building, then comes the meter and finally the branch blocks or panel box whereby the branch circuits are tapped from the feeder for distribution throughout the building. With a two-wire feeder the arrangement would be similar.

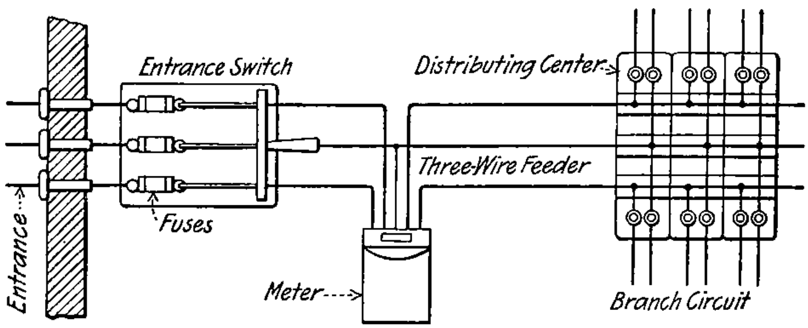


FIG. 251.—Wiring between entrance and distributing center.

334. **Distributing Centers in Residences.**—Often one panel or a group of cut-out blocks is sufficient for an entire house of three stories or less and not requiring more than 10 or 12 branch circuits. See other items in this section describing panel boxes and their construction. It is much better, if possible, to locate all cut-outs in one group than to distribute them all through a house. In a one-story house all branch cut-outs or panel boxes can usually be located near the meter at the entrance or in a hall. In a two-story house the best location is usually in the stairway to the cellar or in the rear hall. In a three-story house the best location for the distributing center is usually in the second floor hall. Where there are more than three stories, distributing centers can be effectively located on every third or second floor. Fig. 252 shows the wiring plan and distributing center in a one-story residence. Closets are considered very unsafe locations for distributing centers.

335. **Things to Consider when Laying Out Residence Wiring** (*National Electric Light Association Bulletin*).—*Three-way switches* should be used to control the hall lights on two or more floors from any floor. *A double-control switch* can be installed in any room whereby a portion or all of the lamps in the room can be lighted or extinguished with this same switch. *Wall switches* should be located so that the door which they are near will not cover them when they are open. *A master switch* for throwing on all of the lights in the

house in case of accident can be located in the owner's bed room. *A closet door switch* can be inserted in the jamb of a closet door whereby a lamp in the closet will be automatically lighted when the door is opened. Through the use of a chain pull socket for the closet lamp, waste of electricity can be avoided when the door is open. *Switches for front porch and lower hall lamps* should be located conveniently near the door so one can reach in from the outside, with the door partially open, and turn them on or can, when inside, open the door with one hand and turn the switch with

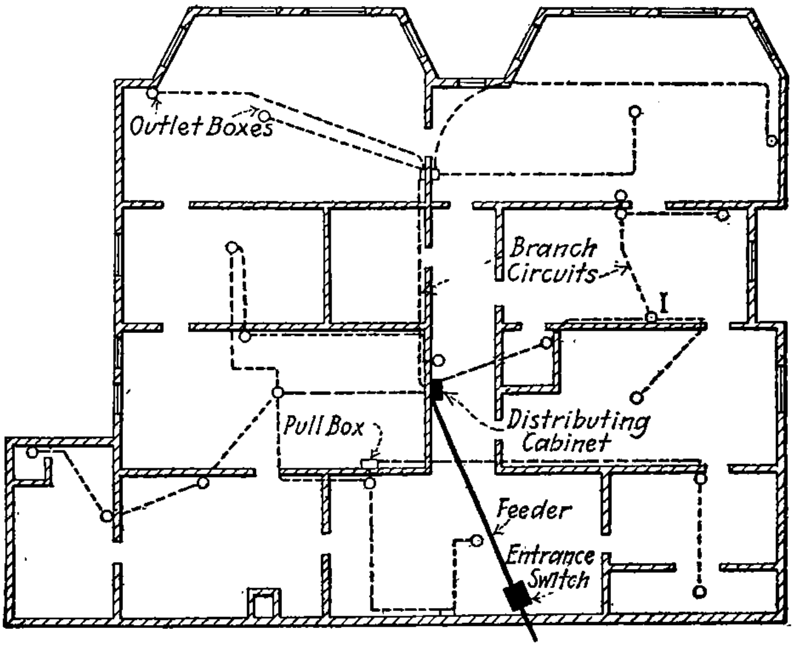


FIG. 252.—Conduit wiring in a one-story residence.

the other. *A cellar beacon light*, a small red lamp near the cellar lamp switch, can be arranged to remain lighted so long as the cellar lamps are burning. *Bathroom lamp outlets* should be so arranged that shadows will not be cast against windows.

336. There are five points that must be considered in designing the wiring lay-out for a large building (*Knox, Electric Light Wiring*) They are:

1. *Control of groups of receivers (other than hall or night lights) from the main switchboard.*
2. *Control of hall lights from the main switchboard.*
3. *Maximum load that should be served by one feeder.*
4. *The best maximum limit for the size of the feeder conductors.*
5. *The proportion of the total voltage drop that can be allowed in feeders and mains.*

Each of these items will be separately considered in the following paragraphs. By a receiver is meant any device that consumes electrical energy.

337. **Control of groups of receivers** (other than hall or night lights) **from the main switchboard.** Where it is desirable to control a group of receivers from the main switchboard in the basement, a separate feeder must be carried from it to each group to be so controlled. Usually the feeder system can be laid out without regard to the control of the room lights, because, as a rule, they do not have to be controlled from the switchboard. It is usually advisable to have each of the lower floors, up to and including the ground floor, on a separate switch as these floors often require light when the others do not. Special lighting appliances such as sign, clock dial and outside dome lights require separate feeders from the switchboard because they are turned on and off at set times from the switchboard. Certain motors may require similar control. In hotels the feeder switches are never opened except in case of accident so, from a control standpoint only, it is not necessary to subdivide hotel feeders. Where tenants of portions of buildings pay for the light they use it is often desirable to carry a separate feeder from the switchboard to each tenant's suite so that all meters can be located together at the switchboard. Suites can be metered separately by cutting meters in the mains at the suites but this may be undesirable.

338. **The control of hall lights from the main switchboard** is an important consideration. In private dwellings it does not usually pay to install a separate feeder for the hall lights, and it may not be necessary in a hotel where attendants are constantly passing in the halls. In a majority of public buildings, however, separate control of the hall lights is very desirable if not necessary. The usual problem is, then, whether there shall be one or two sets of hall light feeders. With two sets of feeders for hall lights local switches may be eliminated and control effected entirely from the main switchboard. Two sets of hall feeders increase the cost of installation but the saving in energy usually justifies them. By arranging two sets of feeders, one set serving say, one-third the hall lights and the other the remaining two-thirds, the smaller group can be used for dark days and for an all-night circuit and a saving in energy will result. Where there are two sets of hall lights thus controlled the wiring of outlets should be such that there will be a uniform distribution of light whichever set is lighted. Where tenants pay for the energy used in their suites a separate feeder for the hall lights is indispensable.

339. **Maximum Load that Should be Served by One Feeder.**—It is impossible to give a hard and fast rule covering this feature. The total load in the building, the available space for the switchboard, the method of control desired and the cost all influence a decision. The load should always be somewhat subdivided to localize trouble and so that, in an isolated plant, the engineer can disconnect portions of the load, while he is getting another machine on the line, when the load comes on suddenly.

340. **Best Maximum Limit for the Size of Feeder Conductors.**—On a basis of cost alone it is usually cheaper to run a few large conductors than a great number of small ones. It does not pay, however, to use conductors larger than 1,000,000 cir. mils. When

greater capacity is required it is cheaper to subdivide, so that several conductors will have the aggregate capacity required. For alternating currents, conductors larger than 700,000 cir. mils are not desirable because of skin effect. Often the space available for conductor runs makes it necessary to use small conductors. Each case must be decided on its merits.

341. The Proportion of the Total Voltage Drop that can be allowed in Feeders and Mains.—Distribution of drop is discussed in another section and it is there stated that it is usual to confine certain proportions of the drop to the feeders, certain proportions to the mains and certain proportions to the branches. As the allowable voltage drop determines the size of a feeder or main it is evident that the lay-out of feeders and mains for any given job will in a measure depend on the drop distribution. Where the load on an incandescent lighting feeder exceeds 660 to 1000 watts, a three-wire feeder should be used to insure good voltage regulation and maximum economy of copper.

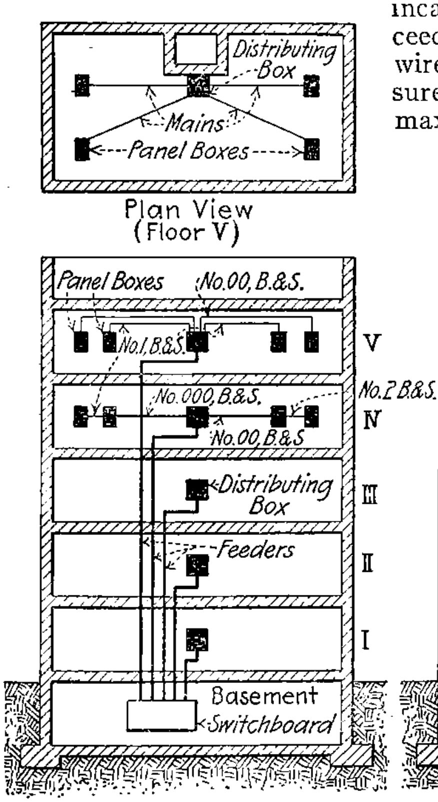


FIG. 253.—Individual feeder to each floor.

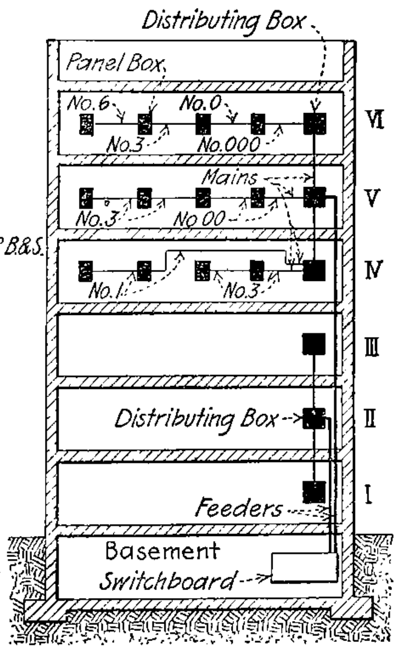


FIG. 254.—One feeder serving three floors.

342. To design the wiring lay-out for a large building make a sectional-elevation drawing of the structure and a plan drawing of each floor. Indicate the receivers (lamps and motors) on the plans and then locate panel boxes so that, in general, no lighting branch circuit will be much over 100 ft. long or have a load much greater than 400 watts. While 660 watts is allowable it is well to provide the 220 watts spare capacity. Panel boxes should be placed so that they can be readily reached and so that the branch circuits, mains and feeders can be run to them. Compute the load on each panel box and indicate it on the drawing at the box.

Now lay out the mains and feeders. First decide whether the hall or public lights will be controlled separately, or together with the private lights from the main switchboard because this feature affects the arrangement of the feeders and possibly that of the mains. Next decide (note conditions outlined above affecting this matter) whether there should be a separate feeder to each floor as in Fig. 253, or whether several floors or portions thereof will be served by

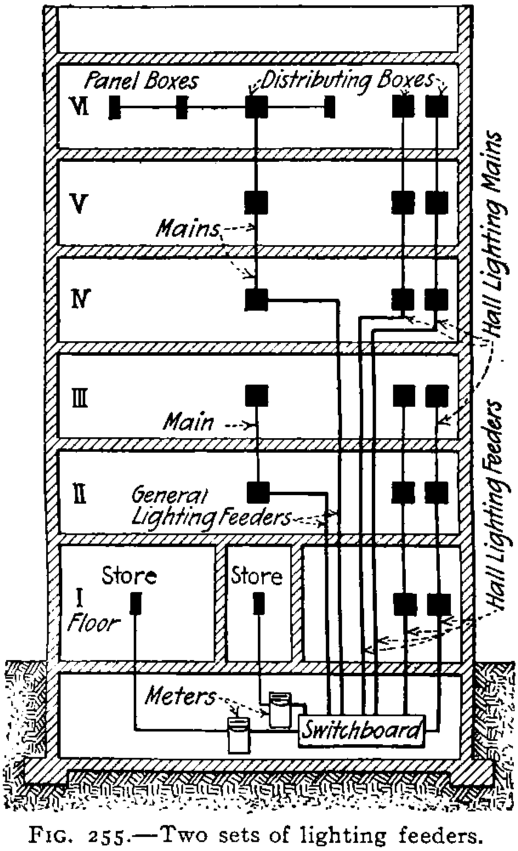


FIG. 255.—Two sets of lighting feeders.

one feeder (Figs. 254 and 255). Where it is not necessary to separately control the loads on the different floors and where the conductor size will not be prohibitively large, the cheapest and probably the best arrangement is to serve several or possibly all floors with one feeder. Usually the only limit to the number of floors that may be served with one feeder is the refinement of control that is required from the main switchboard. It is frequently necessary to make several tentative lay-outs and computations before the most desirable arrangement is found. Make a tentative arrangement of mains and feeders and compute the conductor sizes by rules given elsewhere. If the tentative scheme does not prove satisfactory lay out another and try that. Motors, and groups of motors, unless very small, should be served by independent feeders.

343. Examples of feeder, main and panel-box lay-outs in large buildings are shown in Figs. 253 to 257. These are shown to illustrate principles rather than actual installations but each method shown could be effectively applied in some certain case. Elevator shafts often provide excellent runways for vertical, conduit-encased feeders. Mains and feeders should be installed of a size 25 per cent. larger than actually necessary to provide for growth. It is good practice to arrange to install feeders and mains in conduit even if the other conductors are run open.

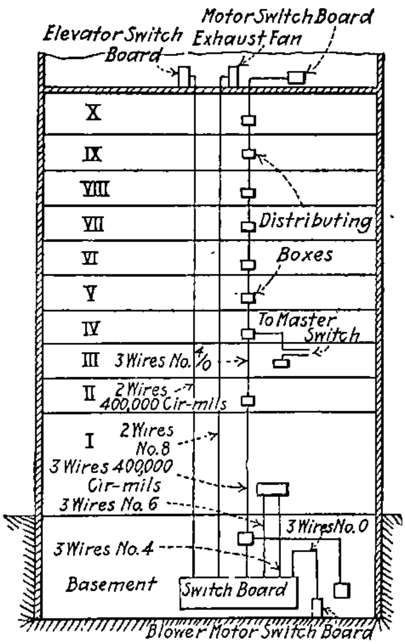


FIG. 256.—An actual feeder lay-out.

344. Feeders and Mains to the Floors of Buildings.—In buildings covering large areas, several panel boxes per floor may be required. These panel boxes may each be served by a separate riser if vertical wire ways are convenient (Fig. 257) or it may be better to install but one riser to each floor and distribute through horizontal mains to the panel boxes on the floor as in Fig. 254. In an installation where the feeders and mains are all vertical there need be no feeder runs in the floors. The construction of the building and the flexibility of control desired largely determine these points. An excellent arrangement is one with a feeder to each floor, Fig. 253, wherein flexibility of control and good voltage regulation are assured. The method of Fig. 254, one feeder serving three or more floors, is probably most often used. It costs somewhat less than the feeder-per-floor method, but does not provide equal flexibility of control nor quite as good voltage regulation. The feeder and main arrangement of Fig. 255 will also give good results if the main connecting the distribution boxes is made of the same size wire throughout, thus avoiding the installation of fuses in series. (See a discussion of this matter, as applied to the mains connecting a number of panel boxes on the same floor, which is given in a following paragraph.) Sometimes a single main is made to serve all the panel boxes in a building as in Fig. 256, but as a general proposition this places "too many eggs in one basket" and results in inflexible control. Any particular case must be decided on the basis of cost and merit.

345 Distribution to Panel Boxes on Floors.—(See above paragraph.) Often in buildings covering a small area one panel box per floor for general lighting is sufficient. Fig. 253, floors *V* and *IV* show an arrangement of mains from the distributing box to the panel boxes that may be used where the distributing box is located at about the center of the building. The lay-out on floor *V* is the best because with it trouble is localized, and very uniform pressure at panel boxes is assured. Where, as shown in *V*, subdivided mains are used the conduit for them will be small and can be readily installed within the floors. The method of *IV* is cheaper than that of *V* but the disadvantage is that fuses are required in series in the mains at each point where the wire size changes. The mains can be made the same size throughout at increased cost and fuses thereby avoided. (See information on mains and tapered mains in Sect. II of this book.)

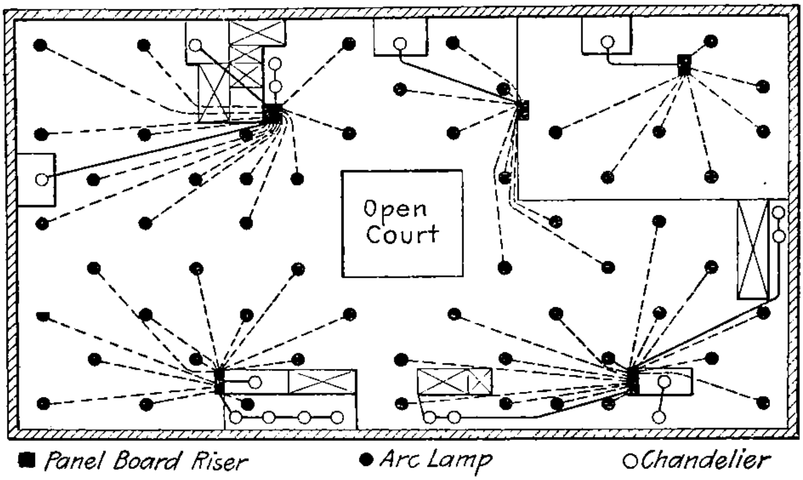


FIG. 257.—Arrangement of panel boxes on one floor.

Where the feeder to a floor rises at one side of the building the mains from the distributing box to the panel boxes may be arranged as in Fig. 254, floors *IV*, *V* and *VI*. The lay-out of *VI* is objectionable because there must be a fuse in series with the main in every panel box. By using two-wire sizes as in *V* instead of four the number of series fuses is reduced to two. The best arrangement is that of *IV* because with it there are no series fuses and troubles are localized. Fig. 257 shows a lay-out on a floor that is served by four panel boxes, each fed by a vertical riser.

346. Shop Wiring Design.—The design of the conductor system between the generating station and the shop buildings of an industrial plant that generates its own power is treated in another section and a general comparison of the distribution methods that may be involved is there given. The wiring for the lighting circuits within the shop is laid out on the same general basis as for other buildings as herein outlined. The lighting, feeder, main, distribution center and panel box lay-outs are about the same as for other buildings. For groups of motors, circuits independent of the lighting circuits should be provided unless the motors are very small. These independent circuits should extend preferably from the generating station or at least from the entrance through the building to points wherever there are motors.

In general, the factors affecting the design of interior feeder and main lay-outs for power circuits are the same as given in Paragraph 336. Often in a one-story shop or on each of the floors of a several story shop the best method of serving the motors is to carry a single main the entire length of the shop. The motors can then, through fuses and switches, be connected to this main. A single main on each floor suffices for a narrow shop. Where the shop is wide, several parallel mains so located that no motor is very far from some one of them may be installed. Often a ring main running around just inside of the shop walls (see Fig. 124 Par. 233) provides a good arrangement. The branches from the main can be carried down the walls and under the floor to the motors. In a shop of several stories, unless the motor load is very small, it is a good plan to run separate power mains from the entrance to the building to each floor but any of the feeder and main arrangements shown for lighting circuits in Figs. 253 to 256 can be used. However the lay-outs for power conductors should be, and usually are, much more simple than those for lighting conductors. A simple arrangement is usually possible because a close voltage regulation is not so important with power as with lighting circuits.

347. Wiring for Electrical Distribution in Industrial Plants.—Standard practice of one large concern is described by Geo. R. Terry, in *Electrical World*, June 23, 1912. With large motors, each of which takes a considerable percentage of the energy transmitted over a main, separate motor and lighting mains are preferable. But with many small and mixed sizes of motors which are liable to removal and which consume a relatively small proportion of the power of the mains, one system of feeders and mains for motors and lamps appears to work out to greater advantage as any one motor is seldom large enough to cause interruption of service on the mains.

The feeders are carried through buildings on roof trusses supported on porcelain cleats, strain insulators being used at turns and ends. The cleats merely hold the conductors in line and out of contact with the trusses. When circuits pass through the yards from building to building they are carried on glass insulators supported on steel bents attached to the building side walls or roofs. The general rule for work inside of buildings is to run all circuits of wires larger than No. 8 B. & S. gage open above the roof truss line and in conduit below. All circuits of No. 8 and smaller wire are always in conduit.

INTERIOR WIRING COSTS

348. Cost of Interior Wiring (*Lectures on Illuminating Engineering*, Johns Hopkins University, October and November, 1910).—Prices of labor and material differ in different localities and at different times. It is, therefore, difficult to state even approximately what the cost of interior wiring for lighting should be. In large cities, these variations are not extreme and it is possible to state the limits within which the cost, expressed in terms of the usual contractor's price per outlet, should lie. The figures given below apply to interior wiring of all classes, from the small residence up to the large hotel or office building. They cover the portion of the work from the main source of supply, assumed to be at the building line. In case the building is lighted from its own plant these figures will apply to the portion of the installation lying between the lamps and the plant switchboard. No lamps, fixtures or reflectors are included in these prices which are for work installed as building is being constructed:

Exposed wiring, $1.50 to $1.60 per outlet.

Wire in wooden molding, $2.00 to $2.50 per outlet.

Concealed knob and tube wiring, $2.50 to $3.00 per outlet, with $1.00 added per switch outlet.

Wiring in iron conduit, $4.50 to $5.00 per outlet.

Wiring in iron conduit in concrete buildings, $5.00 to $6.00 per outlet.

In the above, switches and base-board plugs are considered as outlets when the iron box is included. If the switch and plate are also to be furnished, approximately $1.00 per outlet of this nature should be added. For the larger installations in modern buildings the price of $7.00 per outlet, including all wiring and feeders up to the lighting fixture, has been found to be a fairly close figure.

348A. Knob and Tube Wiring In Finished Buildings

PRICES TO CONSUMER FOR DIFFERENT NUMBERS OF OUTLETS, SINGLE FLOOR CONSTRUCTION

No.	Cost	No.	Cost	No.	Cost	No.	Cost	No.	Cost
5	$15.85	17	$37.40	29	$57.20	41	$77.82	53	$100.82
6	17.85	18	39.05	30	58.85	42	79.75	54	102.85
7	19.85	19	40.70	31	60.50	43	81.75	55	104.77
8	21.85	20	42.35	32	62.15	44	83.60	56	106.70
9	23.85	21	44.00	33	63.80	45	85.50	57	108.62
10	25.85	22	45.65	34	65.45	46	87.45	58	110.55
11	27.50	23	47.30	35	67.10	47	89.37	59	112.47
12	29.15	24	48.95	36	68.75	48	91.30	60	114.40
13	30.80	25	50.60	37	70.40	49	93.22	....	....
14	32.45	26	52.25	38	72.08	50	95.15	....	....
15	34.10	27	53.90	39	73.97	51	97.07	....	....
16	35.75	28	55.55	40	75.90	52	99.00	....	....

Add as per following for outlets under other than single floors and for hardware and drop cords.

Under double flooring otherwise than hardwood. Second or third story.

Ceiling outlet.................................... $1.00 extra.

Switch outlet for any center outlet.................... 1.00 extra.

Under hardwood flooring, single, double or triple. Second and third story.

Ceiling outlet.................................... $3.00 extra.

One switch outlet for any center outlet................. 3.00 extra.

Additional on same gang for same center outlet......... 1.50 extra.

Switches, hardware and drop cords as per following:

Push button switches, each	$1.00 extra.
Push button 3-way switches, per set of two switches	2.75 extra.
Porcelain base switches, each	.35 extra.
Porcelain base Edison receptacles, each	.35 extra.
Baseboard flush plate receptacles, each	1.15 extra.
Drop cord, key sockets each	.60 extra.
Drop cord, chain sockets, each	.75 extra.

Above from tables prepared for use of new business solicitors by the Central Station Development Company, of Cleveland, Ohio.

349. Prices of Wiring Old Buildings—Cottages.—(Commonwealth Edison Co., Chicago. From *Data*, November, 1911.) The prices are those charged the customer. This list is called special schedule "E" and is for 1-story cottages with open attic.

Seven to twelve lights	$35.00
Thirteen lights	39.00
Fourteen lights	41.00
Fifteen lights	43.00
Sixteen lights	45.00
Seventeen lights	47.00

Prices of wiring for switches and receptacles as given in **352** must be added. Prices of fixtures not included. The prices are based on concealed flexible conduit work, except in basement where rigid conduit is used.

350. Prices of Wiring Medium Grade Old Buildings.—The following prices are those charged the customer by the Commonwealth Edison Co., Chicago, and published in *Data*, October, 1911. The prices are for lamp outlets in flats of semi-fire-proof construction, renting for from $25.00 to $40.00 per month and in houses renting for from $20.00 to $50.00 per month. Schedule applies only to old houses having double floors of hardwood on pine. Prices of wiring for switches and receptacles from **352** to be added to the list prices. Prices are based on concealed flexible conduit work, except in basement where conduit is installed exposed on the ceiling.

Lights	Cost		Lights	Cost		Lights	Cost	
	Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story		Class "A" building 2 story	Class "B" building 3 story
10	$50.00	$70.00	28	$92.00	$116.00	46	$138.00	$173.50
11	52.00	72.00	29	94.00	118.00	47	140.00	176.50
12	54.00	74.00	30	96.00	120.00	48	143.00	179.50
13	59.00	81.00	31	98.00	122.00	49	148.00	186.50
14	**61.00**	**83.00**	**32**	**100.00**	**124.00**	**50**	**151.00**	**190.00**
15	63.00	85.00	33	102.00	126.00	51	154.00	193.50
16	65.00	87.00	34	104.00	128.00	52	157.00	197.00
17	67.00	89.00	35	106.00	130.00	53	160.00	200.00
18	69.00	91.00	36	108.00	132.00	54	163.00	203.00
19	**71.00**	**93.00**	**37**	**113.00**	**143.00**	**55**	**166.00**	**206.00**
20	73.00	95.00	38	116.00	146.50	56	169.00	209.00
21	75.00	97.00	39	119.00	150.00	57	172.00	212.00
22	77.00	99.00	40	122.00	153.00	58	175.00	215.00
23	79.00	101.00	41	125.00	156.50	59	178.00	218.00
24	**81.00**	**103.00**	**42**	**128.00**	**159.50**	**60**	**181.00**	**221.00**
25	86.00	110.00	43	130.50	162.50	61	186.00	226.00
26	88.00	112.00	44	133.00	165.50	62	189.00	229.00
27	90.00	114.00	45	135.50	168.50	....	....	....

351. Cost of Wiring High-grade Old Buildings.—Prices charged the customer by the Commonwealth Edison Co., Chicago. From *Data*, November, 1911. The prices are for lamp outlets in high-class apartments and medium-sized residences with hardwood finish throughout, renting for $50.00 per month. Prices of fixtures not included. Prices of wiring for switches and receptacles from **352** must be added. Prices are based on concealed flexible conduit work in buildings with a hardwood floor over one of pine.

Lights	Cost		Lights	Cost	
	Class "C" building 2 floors	Class "D" building 3 floors		Class "C" building 2 floors	Class "D" building 3 floors
10	$ 75.00	$ 88.00	36	$161.00	$182.00
11	78.00	91.00	37	166.00	189.00
12	81.00	94.00	38	169.50	193.50
13	89.00	99.00	39	173.00	198.00
14	92.00	102.00	40	176.50	202.50
15	95.00	105.00	41	180.00	207.00
16	98.00	108.00	42	183.00	211.00
17	101.00	111.00	43	186.00	215.00
18	104.00	114.00	44	189.00	219.00
19	107.00	117.00	45	192.00	223.00
20	110.00	120.00	46	195.00	227.00
21	113.00	123.50	47	198.00	231.00
22	116.00	127.00	48	201.00	235.00
23	119.00	130.50	49	206.00	242.00
24	121.00	134.00	50	210.00	246.50
25	126.00	141.00	51	214.00	251.00
26	129.50	145.00	52	218.00	255.50
27	133.00	149.00	53	222.00	260.00
28	136.50	153.00	54	226.00	264.50
29	140.00	157.00	55	229.50	268.50
30	143.00	161.00	56	233.00	272.50
31	146.00	164.50	57	236.50	276.50
32	149.00	168.00	58	240.00	280.50
33	152.00	171.50	59	243.50	284.50
34	155.00	175.00	60	247.00	288.50
35	158.00	178.50	......	....	....

352. Cost of Wiring Old Buildings—Switch Outlets, Switches and Extras.—The following prices to the customer are those of the Commonwealth Edison Co., Chicago (*Data*, Nov., 1911) and are to be added to the price given for outlets in the three preceding tables. Wiring is concealed and in flexible conduit.

Cost of wiring for switch outlets

Class	A	B	C	D	E
Single pole.	$3.00	$3.50	$4.25	$4.50	$2.50
3-way..............	4.50	5.00	5.75	6.00	4.00

In addition to the above prices for wiring switches, additional prices for switches, etc., will be as follows:

Flush push button single pole	$1.00	Drop cord (without canopy)..	.75
Standard snap single pole....	.50	Water-proof floor receptacle.	3.00
Automatic door switch......	1.50	Flush baseboard receptacle...	1.50
3-way flush switch..........	1.00	Standard wall socket........	.50
3-way snap switch..........	.50		
Drop cords, including spun brass canopy cord, and socket	1.00		

353. Cost of Knob-and-Tube and Conduit Work.—Work done in St. Paul, Minn. Costs are those to the customer and are for new work. (*Electrical World*, Jan. 28, 1909.)

Job number	Knob-and-tube			Iron conduit	
	Number of outlets	Total cost	Cost per outlet	Total cost	Cost per outlet
1	120	$247.00	$2.06	$423.00	$3.53
2	80	147.00	1.84	251.00	3.14
3	72	158.00	2.19	248.00	3.44
4	66	136.00	2.06	213.00	3.23
Average	....	....	2.04	....	3.26

Average excess cost of conduit above knob-and-tube work is 60 per cent.

354. A day's work for a wireman and helper in erecting molding, on surfaces where holes must be drilled and plugged to support it, is the running of 100 ft. (Auerbacher).

355. The division of cost of a conduit job will be approximately as follows: Labor, 40 per cent.; conduit, 22 per cent.; wire, 18 per cent., and incidentals, switches, outlets, etc., 20 per cent. (*Electrical World*).

356. Cost of double-braided rubber-insulated wire in place in conduit. (*Nelson S. Thompson, Electrical World*, Sept. 9, 1911.) Costs do not include conduit.

Single conductors			
Size A.W.G.	Cost per 1,000 ft.	Size A.W.G. & cir. mils	Cost per 1,000 ft.
Solid		Stranded	
16	$15.00	1	$101.30
14	18.60	0	128.00
12	21.70	00	156.00
10	25.85	000	184.25
Stranded		0000	217.00
8	35.40	250,000	275.00
6	48.25	300,000	327.00
4	62.65	400,000	405.00
3	75.25	500,000	500.00
2	82.00		
Duplex conductors			
14	$30.00	10	$40.25
12	34.00	8	49.25

357. Cost of Conduit in Place (New Building)

½ in. size	$ 8.50 per 100 ft.
¾ in. size	10.25 per 100 ft.
1 in. size	13.75 per 100 ft.
1¼ in. size	18.25 per 100 ft.
1½ in. size	22.00 per 100 ft.
2 in. size	30.60 per 100 ft.
2½ in. size	47.00 per 100 ft.
3 in. size	60.00 per 100 ft.

358. Cost of Conduit Elbows in Place

2 in. size	$ 1.00 each
2½ in. size	1.25 each
3 in. size	4.00 each
4 in. size	10.00 each

359. Estimating Costs of Conduit Installations.—The Treasury Department of the United States uses the following methods and values for computing the costs of conduit wiring in federal buildings. (*Nelson S. Thompson, Electrical World,* Sept. 9, 1911.) The figures are for high grade work in fire-proof buildings. The material is taken off accurately from the drawings. The total amounts of conduit and wire are the lengths scaled from the plan plus the following: Number of ceiling outlets×2 ft.; number of bracket outlets×10 ft.; number of switch outlets×10 ft.; number of baseboard outlets×4 ft.; number of two-gang switches×15 ft., and number of three-gang switches×20 ft. Table 357 shows the cost of conduit in place. For the cost of underground service connections in place and for work in old buildings where walls and ceilings are cut and plaster must be replaced, 50 per cent. should be added to the tabulated values.

The cost of all kinds of outlet boxes in place is 25 cents each in new buildings and is 50 cents in old buildings where plaster must be repaired. The cost of large junction boxes in place is 5 cents per pound. Plug receptacles in place cost $1.30 each. Single pole snap switches in place cost $1 each. Fixture studs cost 5 cents each in place; outlet bushings 5 cents each in place; lock-nuts 1 cent each in place. One should estimate 3 bushings and 3 lock-nuts per outlet.

The average total cost of lighting systems complete in place in eastern sections of the country is about $12 per outlet; in the West and South the cost will be about $15 per outlet, and in the extreme West the cost per outlet will be $20. The number of outlets upon which these figures are based does not include switch outlets, but only the actual lamp outlets. In old buildings the cost of the conduit and wiring work is $20 to $25 per outlet and $30 in the extreme West.

360. Miscellaneous wiring costs for first class conduit work in fire-proof buildings. (*Nelson S. Thompson, Electrical World,* Sept. 9, 1911.) Busbars for switchboards, in place 50 cents per pound; structural steel work, in place, for switchboards, 10 cents per pound; blue Vermont marble, 2 in. thick, $2 per square foot; slate panels, 1¼ in. thick, 50 cents per square foot; drilling holes, slate and marble, 25 cents each; labor on switchboard panels in shop, \$25, and on the job, \$12 each; tablets and cabinets, complete in place, \$5 per switch. One should ascertain if possible the actual cost of cabinets and tablets and add \$1 per circuit for installation. Standard floor outlet boxes (such as are used in United States federal buildings) cost \$3 each in place; telephone cabinets in place (such as are used in federal buildings) cost \$20 each.

Motor connections, 5 h.p. and under, \$2 per horse-power; motor connections, 10 h.p. up, \$1 per horse-power; freight and drayage, 3 per cent. of total cost of material and labor; railroad fare, depending on location of the job; board and lodging, depending on location of the job; superintendence, 1 per cent. of total cost of materials and labor, and profit, 20 per cent. of total cost of materials and labor.

ELECTRIC SIGN WIRING

361. Methods of Wiring Electric Signs (*Data on Electric Signs*, The National Electric Light Association).—Lamps burning in multiple may be connected either two-wire or three-wire, as shown in Fig. 258. In series wiring, lamps may be connected either in straight series or multiple-series, as shown. Where transformers

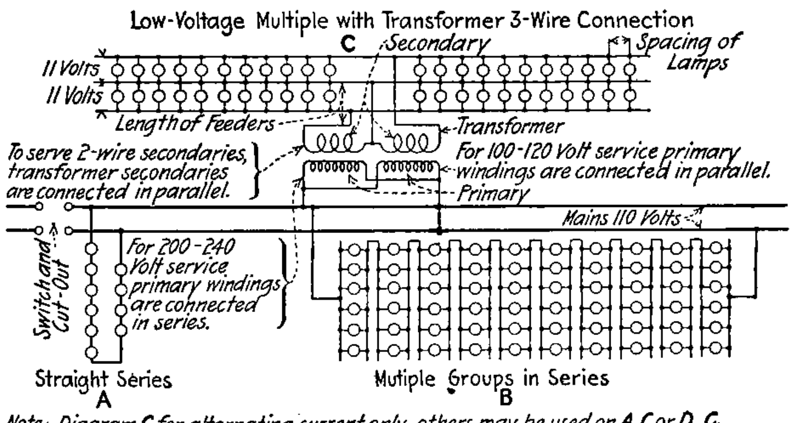


FIG. 258.—Methods of connecting sign lamps.

(see section on Transformers for information on sign transformers) are used to obtain low voltage, lamps may be connected either two-wire or three-wire as in standard multiple wiring, the transformer reducing the voltage from the regular 110- or 220-volt circuits to the voltage required by the lamp. The ordinary multiple wiring can be changed to straight series wiring by merely clipping the alternate connections between lamps (Fig. 259).

In a large sign any combination of series or multiple-series may be used. With straight series wiring, should one lamp in the series burn out, all the lamps in that series will be out. If the lamps are connected in multiple-series, the failure of one lamp does not cause any of the other lamps to go out. However, there should be not less than eight to ten lamps in each multiple group or the failure of one lamp will cause too much current to flow through the other lamps of the same group, thus shortening their lives.

362. Sockets for Electric Signs.—Any standard weather-proof socket manufactured for sign use is satisfactory providing it has been approved by the Underwriters and has been shown to be thoroughly weather-proof. A socket with an extending porcelain cap which protects the base of the lamp from water is desirable

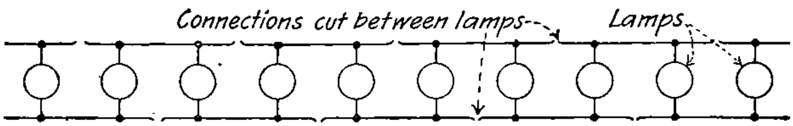


FIG. 259.—Method of changing sign wiring from multiple to series.

in that it gives a longer life to the lamp. A removable copper shell is desirable inasmuch as there is a certain amount of wear from the taking of the lamps out of the sign for cleaning or renewing, and as the workmen are in the air, they cannot be as careful as they would be under ordinary conditions and the copper shell is often torn. If the copper shell cannot be removed from the front of the socket, it is necessary to open up the sign to make repairs, while if the shell can be removed, a new one can be put in at small expense.

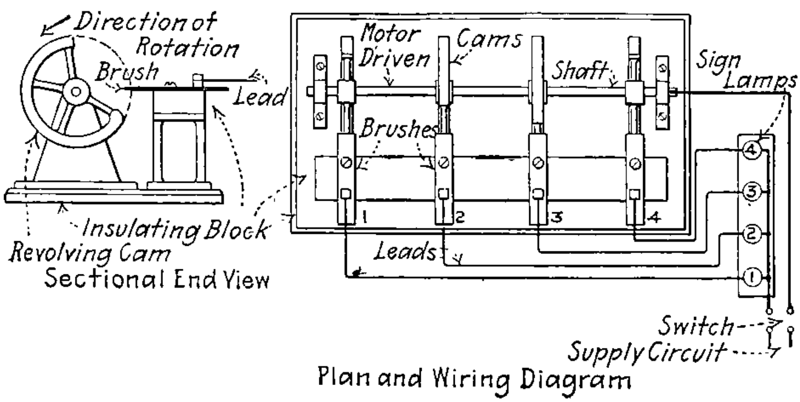


FIG. 260.—The elementary sign flasher.

363. The principle of the sign flasher is illustrated in Fig. 260. Cams or a drum are mounted on a shaft that is rotated by a small electric motor. The circumferences of the cams or of the drums are so cut that, in the brush-type flashers, the brushes will make contact only during certain predetermined portions of a revolution and thereby complete the electric circuit through the sign lamps only during that period. In the carbon-type flashers the cams, instead of carrying current and making and breaking the contacts directly, operate to open and close carbon-break knife switches which control the sign lamps. The possible variations in arrangement of cams and drums for producing different effects are almost numberless.

364. Current Carrying Capacities of Flashers.—Double-pole flashers are made in four sizes that will carry respectively 15, 30, 45 or 60 amp. per switch. Single-pole carbon flashers are made that will carry 5 amp. per switch. Brush type flashers are rated at from 2 to 5 amp. on each brush and are not reliable for greater currents. Non-carbon, double-pole-switch flashers are made for currents of 15 amp. and greater but it is claimed by some manufacturers that 15 amp. should be the maximum because no knife switch can successfully break greater currents continuously.

365. Wiring and Installing Brush Type Flasher.—Fig. 261 shows the wiring for a sign for "spelling" out. The neutral wire

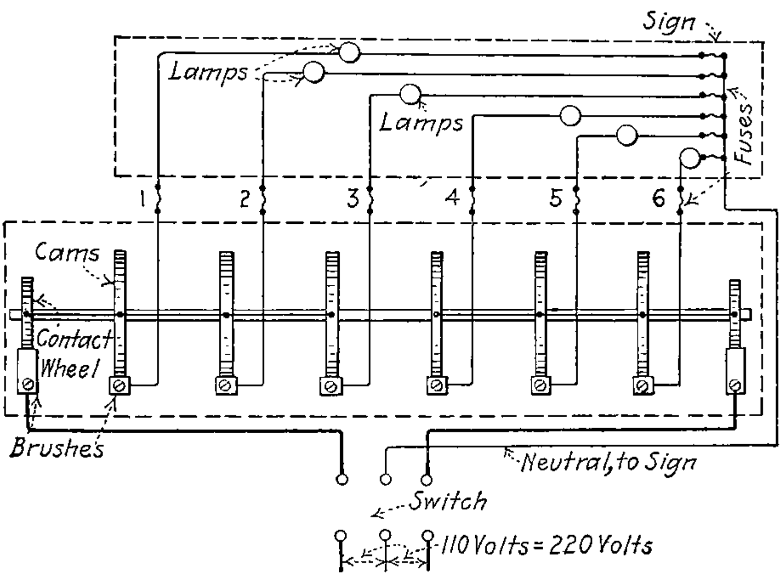


FIG. 261.—Wiring of three-wire brush-type flasher.

(or one main on a two-wire system) runs direct to the sign through the customary cut-outs, and the outside "legs" (or remaining main on a two-wire system) run to the flasher as a common feed. From the flasher one wire is run to each individual letter through the customary cut-outs. In the case of a double face sign, two like letters can be connected in multiple and regarded as one circuit, provided the load which one switch of the flasher is designed to carry is not exceeded.

Always install so that the copper brushes are at the front of the flasher. Follow the general installation directions given for carbon flashers in another paragraph.

366. Wiring diagrams for carbon sign flashers (*Reynolds Dull Flasher Co.*, Chicago) are given in Fig. 262. Unless otherwise ordered flashers are furnished requiring a wiring arrangement like that at *III*. The load is balanced by running the neutral around the machine, to the cut-outs, breaking only the outside "legs" on a 220–110-volt system. While this method of wiring is entirely feasible, is no harder on the contacts, and permits the use of a cheaper flasher, it is technically a violation of the insurance rules, which specify that all circuits of more than 660 watts must be broken double pole. If the load is absolutely balanced it would break double pole at 220 volts, and the lamps would be in series, but if the load is not exactly balanced there would be single-pole breaking. In other words, it is a double break and again it is not, according to circumstances. The use of this machine wired in this way should be taken up with the local inspector. If he is disposed to take a broad view of the matter he will undoubtedly permit

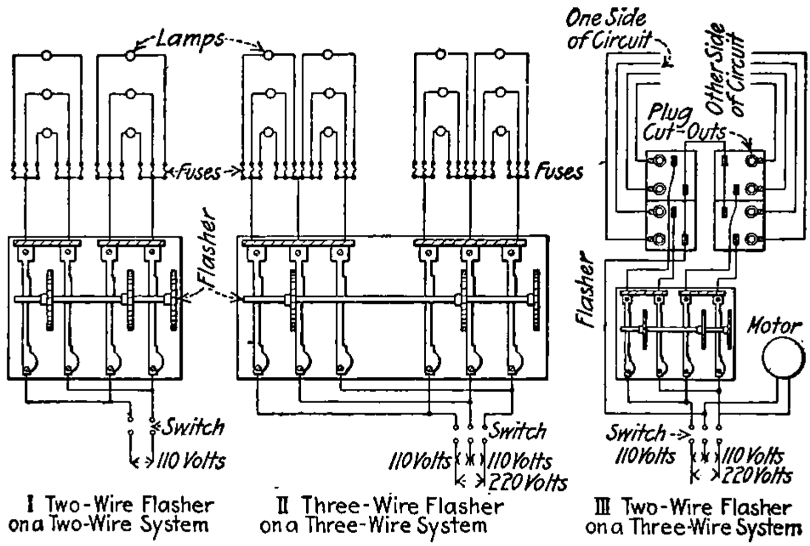


FIG. 262.—Wiring diagrams for carbon sign flashers.

its use, as it is just as safe as any other way, but if he should insist on an absolute observance of the code, it is probable that he would not permit it.

367. In installing and wiring a carbon flasher (*Reynolds Dull Flasher Co.*, Chicago) run the mains to the upper bridge of the flasher, and run the sub-mains to the sign and to the terminals on the base of the machine. The sub-mains are divided into the small circuits either in the sign or as close thereto as possible to save the cost of wiring. Each small circuit into which the sub-mains are divided should be protected with fuses and some inspectors may require that the sub-mains also be protected with fuses where they leave the flasher.

Place the flasher on a wood shelf, 15 in. wide and 10 in. longer than the slate base, in such manner that the carbons are in the front, the motor at the left with the commutator side to the front. The shelf should be covered with asbestos and if the machine is in a basement or out of sight, cover it with an iron or fire-proof box and if to be run in plain view, it should be covered with a glass case. Run all wires through bushings in the shelf close to the base of the machine.

Do not screw either flasher or motor down tight but leave an eighth of an inch clearance under the heads of the screws. The top of a show window, a board partition, or anything that acts as a sounding board will increase the noise three-fold and when it is necessary to install in such places, arrange an extra set of rubbers under the shelf also.

368. Some "Dont's" to Observe in Installing Sign Flashers (*Reynolds Dull Flasher Co.).*—DON'T start the flasher without examining it for damage in transit. Give a few turns by hand and see that everything works perfectly free and easy and that the blades fit into the forks properly.

DON'T install the flasher in the bottom of a box where it is not accessible. Place it on a shelf, run the wires down through the shelf close to the base and turn a cover upside down over it.

DON'T install hind-side foremost. The carbons should always be to the front.

DON'T run with a tight belt. Practically no power is required. Run the belt just as loose as it will stay on.

DON'T run your flasher backward. Looking at it from the switch side, the main shaft should run from you on the top.

DON'T run the flasher over ten revolutions per minute nor less than six.

DON'T fail to instruct your customer about oiling.

DON'T connect up a carbon machine single pole.

DON'T overload any switch on a flasher.

369. Wiring for the so-called "high-speed" effects (*Reynolds Dull Flasher Co.*, Chicago) such as running fountains, rising smoke,

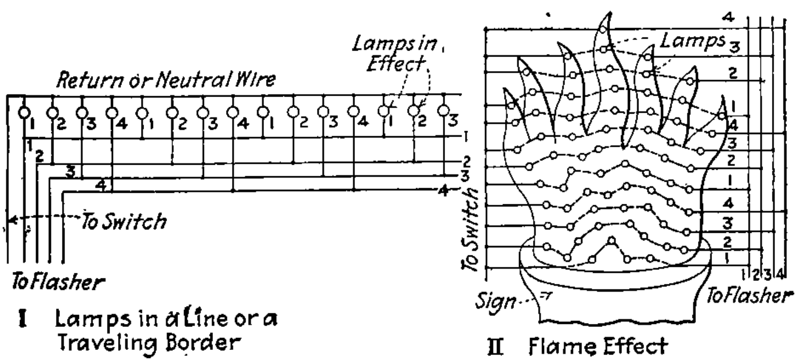


FIG. 263.—Wiring of "High-speed" effect signs.

flames, traveling borders and revolving wheels are wired as indicated in Fig. 263. The diagram at *I* is for the effect where the sign lamps are in a single line and the same general arrangement is used for a traveling border. For a fountain effect number the lamps at the beginning of each stream and so continue to the end of the stream and where several streams run parallel all the lamps in one horizontal row can be connected to the same branch as though they were one lamp. Traveling borders on an ordinary 3 ft. × 10 ft. sign should have lamps spaced about 6 in. apart. In a fountain 15 ft. high the lamps should be about 9 in. apart. Fig. 263, *II*, shows the wiring diagram for smoke, flame, steam, dust and running water effects. Avoid a "straight-across" arrangement of lamps as the resulting effect will be unnatural.

370. The wiring for a flashing illuminated sign, that is, a painted sign which is successively illuminated (by lamps carried in a reflector trough above it) and darkened by the lamps being extinguished is shown in Fig. 264. Lamps should be 16 c-p. and mounted not more than 12 in. apart in the reflector which should preferably be of the silver backed type. For flashing in colors but three can be used, namely: red, clear and amber. Other colors such as green, blue, etc., are too dense to produce a good effect and little light will throw down more than 8 ft. A carbon type flasher should be used.

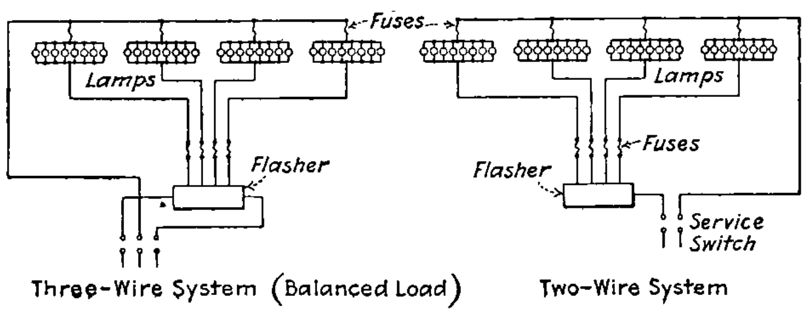


FIG. 264.—Wiring for flashing sign.

371. Regulations for the erection of electric signs as given in the *Rules and Regulations of the Commonwealth Edison Company*, Chicago, are as follows:

Accessibility.—Signs which are to be cleaned or re-lamped from a ladder must not be hung higher than 30 ft. above the sidewalk. All signs placed at a greater height must be so located and hung that they may be swung in toward the building both ways and reached from the windows. Such signs shall be so placed that the bottom of the sign shall not be below the window sills from which it is to be cleaned, and the top of the sign shall not be more than 6 ft. above the window sill.

Guy Lines.—Any sign which must be cleaned or re-lamped from a ladder, and whose top is more than 18 ft. above the sidewalk, shall be provided with two sets of guy lines having separate attachments on sign and on building. All guy lines, whether of chain or cable, shall be hot galvanized. Sectional signs, provided with two sets of guy lines, shall have one set attached to the bottom of the sign and the other set attached to the top of the sign. Guy lines shall be placed at such an angle with the horizontal that the signs will not be raised up and the weight taken from the main supporting chain by strong wind.

Strong Backs.—In case it is not convenient to provide a sign with guy lines on each side, the sign shall be held rigid from swinging by means of a stiff rod or strong back connected to the top of the sign.

Expansion bolts shall be of the lead wedge expansion type, $\frac{3}{8}$ in. in diameter by 3 in. long, and shall be firmly set in holes drilled into a masonry wall. If the wall is of brick, the hole shall be in the center of a hard, firm brick. All soft or loose bricks must be avoided. If a solid brick cannot be found, the guy line must be attached to a bolt passing through the building wall.

Turnbuckles.—Eye bolts and hooks which screw into turnbuckles shall have holes drilled through their ends and shall be provided with a split pin to prevent unscrewing.

Hinge Bolts.—Hinge bolts shall be provided with lock nuts or split pins.

Bushings and Collars.—Swaying signs shall be attached to their cranes by hangers passing over iron collars placed on the crane and provided with an aluminum lining. A bearing for these aluminum-lined collars shall be placed upon the crane, and shall consist of solid aluminum collars with flanges at one end. The aluminum collars shall be placed upon the crane with the unflanged ends facing each other, and shall be rigidly attached to the crane and be of such size that the aluminum-lined iron collars shall have a snug fit, but be free enough to permit the sign to oscillate.

Cross Plates.—Cross plates to which guy lines are attached shall be bolted to the sign with two short, snug fitting bolts, which shall be riveted over after nuts are put on. These bolts shall be large enough to support the sign without danger of breaking or shearing, and shall not be smaller in diameter than $\frac{3}{8}$ in. The plates shall be of such a width that the distance between bolts shall not be less than one-third the distance between the holes where the guy lines are attached.

Feed Wires.—Swaying signs supported from a crane shall have stranded feed wires between building and sign. Feed wires which are not run through the crane shall be attached to insulated support on the crane near its base, and from this support connect to the sign with a drip loop extending 3 in. below the sign outlet. Wherever feed wires pass through an iron plate or through the side of an iron pipe the opening shall be protected by a porcelain enameled bushing.

ELECTRIC HEATING DEVICE INSTALLATION

372. **Special outlets for heating devices** are frequently required. Outlet plates, similar to that of Fig. 265, provided with receptacle, switch and indicating lamp socket are regularly manufactured for currents as great as 20 amp. Keyless brass sockets have a maximum rating of 6 amp. The ordinary pull-chain and key sockets have a maximum rating of $2\frac{1}{2}$ amp. Standard separable attachment plugs are approved for 660 watts at 250 volts, or 10 amp. on a 110-volt circuit. Where ordinary key sockets are used for switching on and off heating devices they soon wear out under the action of the arcs formed in breaking the relatively heavy currents. Snap or knife switches should always be used for heating devices. Specially constructed, asbestos-covered, flexible cords are specified for all heating devices requiring more than 250 watts.

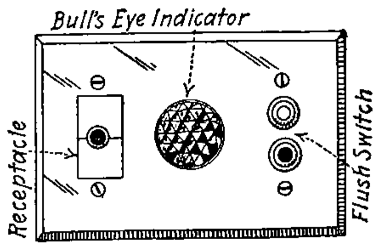


FIG. 265.—Indicating heater receptacle.

373. **An approximate rule for the wattage of an electric heater to heat a room** is to allow $1\frac{1}{2}$ watts of heater input (maximum) per cubic foot of air space for shops, factories, halls, churches and central stations and 2 watts per cubic foot of air space for average rooms. The direction of exposure, the number of windows and the quality of building construction, and other things, all have a bearing on the matter so the values given are approximate only for average conditions of building and climate.

374. Power and Current Taken by Heating Devices (*Electrical Solicitor's Handbook*)

Domestic devices

Device	Watts consumed	Amperes taken at 110 volts
Broilers, 3 ht.	300 to 1,200	2.7 to 10.9
Chafing dishes, 3 ht.	200 to 500	1.8 to 4.6
Cigar lighters	75	0.7
Coffee percolators for 6-in. stove	100 to 440	0.9 to 4.0
Corn poppers	300	2.7
Curling-iron heaters	60	0.6
Double boilers for 6-in., 3 ht. stove	100 to 440	0.9 to 4.0
Flatiron (domestic size), 3 lb.	275	2.5
Flatiron (domestic size), 5 lb.	400	3.6
Flatiron (domestic size), 6 lb.	475	4.3
Flatiron (domestic size), 7.5 lb.	540	4.9
Flatiron (domestic size), 9 lb.	610	5.6
Frying kettles, 8 in. diameter	825	7.5
Griddle-cake cookers, 9 in. by 12 in., 3 ht.	330 to 880	3.0 to 8.0
Griddle-cake cookers, 12 in. by 18 in., 3 ht.	500 to 1,500	4.6 to 13.7
Heating pads	50	0.5
Instantaneous flow water heaters	2,000	18.2
Nursery milk warmers	450	4.1
Ovens	1,200 to 1,500	10.9 to 13.7
Plate warmers	300	2.7
Radiators	700 to 6,000	6.4 to 5.5
Ranges: 3 heats, 4 to 6 people	1,000 to 4,515	9.1 to 40.1
Ranges: 3 heats, 6 to 12 people	1,100 to 5,250	10.0 to 47.5
Ranges: 3 heats, 12 to 20 people	2,000 to 7,200	18.2 to 65.5
Shaving mugs	150	1.4
Stoves (plain), 4.5 in., 3 ht.	50 to 220	0.5 to 2.0
Stoves (plain), 6 in., 3 ht.	100 to 440	0.9 to 4.0

Commercial devices

Device	Watts consumed	Amperes taken at 110 volts
Annealing furnaces	200	1.8
Bar or barber's urns, 1 to 5 gals., 3 ht.	200 to 1,700	1.8 to 15.5
Baker's ovens, 30 to 80 loaves	6,000 to 10,000	54.5 to 91.0
Cigar lighting	75	7
Dental furnaces	450	4.1
Glue pots	110 to 880	1.0 to 8.0
Hat irons (small)	200	1.8
Hatter's iron, 9 to 15 lb.	450	4.1
Instrument sterilizers	350 to 500	3.2 to 4.6
Laboratory apparatus flask heaters	500	4.6
Machine irons, 12 to 18 lb.	770	7.0
Pitch kettles, 12 and 15 in., 3 ht.	300 to 1,500	2.7 to 13.7
Polishing irons, 3.5 to 5.5 lb.	330 to 450	3.0 to 4.0
Radiators (various sizes)	700 to 6,000	6.4 to 54.6
Sealing-wax pots, 0.5 and 1.5 pt.	175 to 300	1.6 to 2.7
Shoe irons	200	1.8
Soldering irons (various sizes)	100 to 450	1.8
Soldering pots, 4 to 10 lb. capacity	200 to 440	0.9 to 4.0
Tailor's iron, 12 to 25 lb.	660 to 880	6.0 to 8.0
Vulcanizers for automobile tires	100 to 450	0.9 to 4.0

375. Luminous radiators or air heaters, which are sometimes called convectors, can be used for room heating. From the standpoint of energy utilization a heater of one type is as efficient as a heater as the other since in any electrical heating device all of the electrical energy put into it is transformed into heat. Luminous radiators, which throw off radiant heat, are suitable for quickly warming any portion of one's body. The radiant heat rays will warm only a material which is opaque to them. They pass through air without heating it and are not affected by air currents. They may heat air indirectly by heating objects in contact with air, the objects transmitting the heat to the air. As a general proposition luminous radiators are not suitable for warming large spaces.

Air heaters or convectors heat the air passing over the heated surfaces of the convector. Convectors should be so arranged that there is an effective circulation of air through and around them. A single, large capacity heater in a room will not heat it as effectively as several small capacity heaters having the same aggregate capacity. Heaters should be preferably placed under or near windows.

376. To estimate the wattage of an electric heater to heat a room the following approximate formula has been used. It is based on the assumption that the inside temperature is to be 70 deg. fahr. and the outside temperature is about 12 deg. fahr. below zero.

$$\text{Watts required} = 5S + 50W + 0.5A$$

Wherein, $S =$ sq. ft. of wall surface exposed exclusive of window surface, $W =$ sq. ft. of window or glass surface exposed, and $A =$ cu. ft. of air space in the room. Where the inside and outside temperatures vary much from those above assumed, the wattage required will be (approximately) correspondingly more or less in proportion to the difference between the inside and outside temperatures.

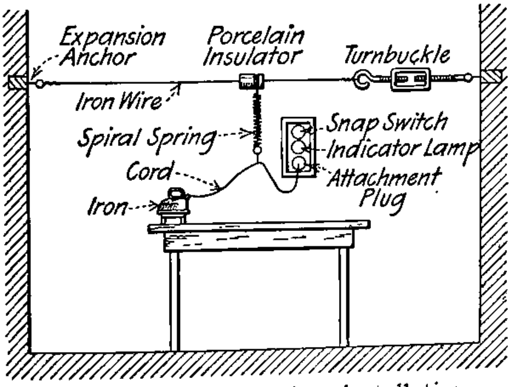


FIG. 266.—An electric iron installation.

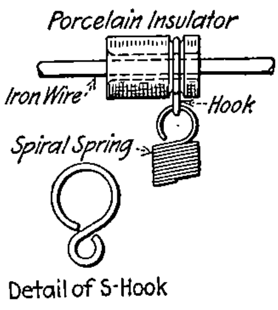


FIG. 267.—Method of supporting spring.

377. A method of supporting the conducting cord of an electrically heated iron (*Electrical World*, May 4, 1911) is shown in Fig. 266. The spring is fastened with an "S" hook (see Fig. 267) to a porcelain insulator which is arranged to slide back and forth on a wire. As the iron is pushed to and fro the porcelain insulator follows its movements and, as the spring will stretch, ironing can be done over a considerable area. The conducting cord is supported well out of the way of the operator. Spiral springs are usually furnished by the manufacturers with all sadirons.

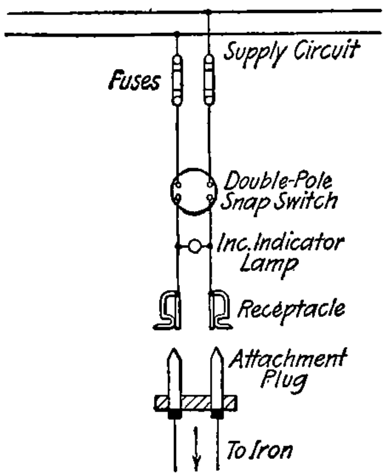


FIG. 268.—Wiring diagram.

The iron wire is made up in a screw eye, inserted in the wall at one end and into one eye of a small turnbuckle at the other end which provides means for keeping the wire tight. The hook end of the turnbuckle engages with a screw eye inserted in the wall. It is well to arrange the iron wire somewhat to the rear of the line along which the iron will be used. This is done to prevent the cord from striking the hand of the ironer.

378. **A method of wiring an electric iron** is shown in Figs. 266 and 268. An incandescent lamp of small candle-power is connected across the branch circuit to the iron on the iron side of the double-pole switch. So long as the switch is closed and the iron connected to the supply source the lamp will glow and indicate the fact that the iron is "alive." This device not only tends to make the operator careful in his use of energy, but it assists in preventing the fires that are sometimes caused by an electric iron being left on a wooden ironing board while connected to a supply source.

WIRING OLD BUILDINGS

379. **Information on Wiring Old Buildings.**—The information herein given on this subject is taken, for the most part, from a paper "*The Wiring of Old Houses*" read before the Pennsylvania Electric Association Convention, Bedford Springs, Pa., Sept. 3, 1912, by Howard H. Wood of the Allegheny County Light Company.

380. **In laying out old house wiring installations,** the first things to be considered are the location of the meter and the tablet board, and the point where the wires are to enter. The meter loop should generally be located in either the kitchen, pantry or cellar. In the smaller houses, the tablet board should be located near the meter, and in the larger houses, where there are a number of branch circuits, at the central point of distribution, *i.e.*, at some point on the second floor, preferably the hall. The point of entry should be located with reference to the accessibility of the service connection.

381. **Typical Wiring Plan of an Old Building.**—Fig. 269 shows the routes taken by the wires, to chandeliers and switches, within

walls and under floors. The point of entry for the mains in this case is the kitchen, on the outer wall of which is located the main switch, the fuse block, and the meter. The connected load being less than

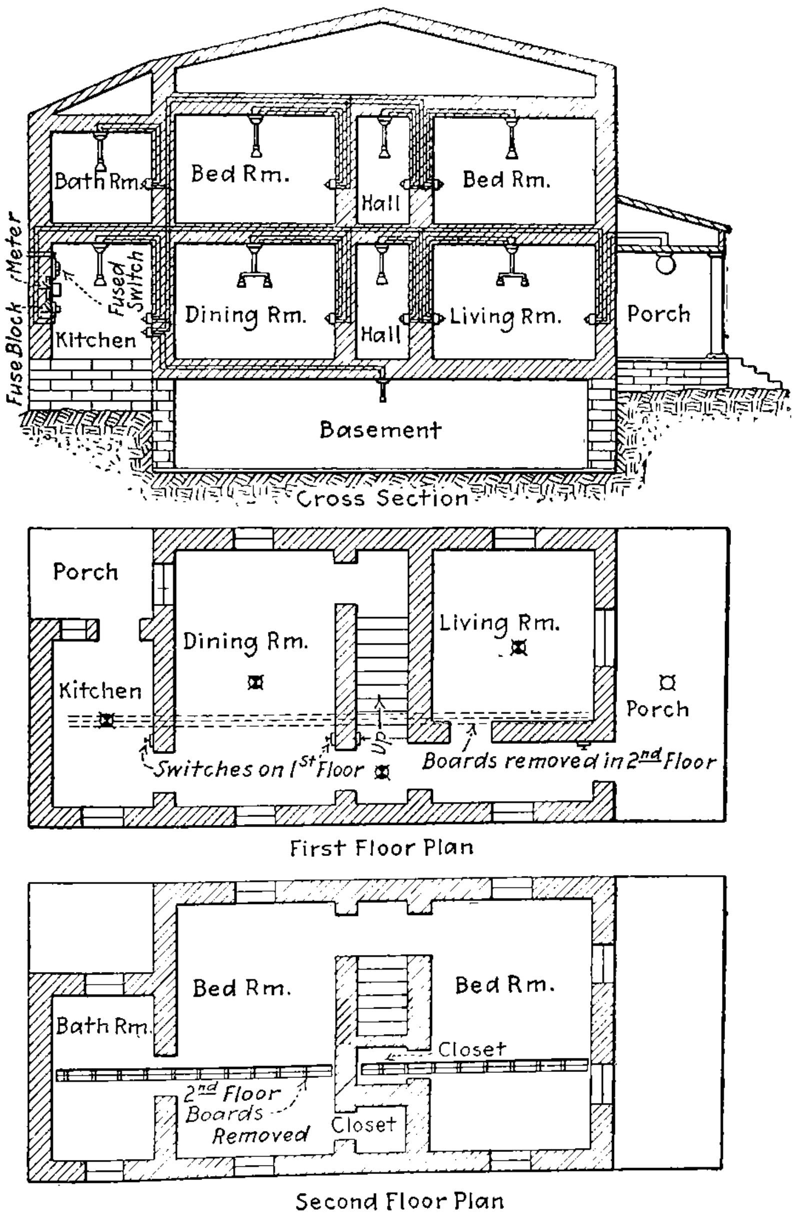


FIG. 269.—Wiring of a five-room house.

660 watts, or the equivalent of 12 lamp outlets, only one circuit is necessary. Double-pole switches are shown, as they are required in certain cities in installations where combination gas and electric

fixtures are used. Single-pole switches, installed in accordance with Code rules, are practically as good for the average installation. The methods of carrying conductors to single-pole switches will be obvious from a study of the illustration.

The dotted lines show the flooring boards taken up on the second floor, and the fixture and switch locations on the first floor are indicated. The switch locations are within easy fishing distance.

The flooring boards are removed on the second floor in such locations as to pass under one partition only, and with regard to accessibility of the outlet and switch openings below.

In many houses of the type shown, the space between roof and second floor ceiling is sealed, in which case a hole is cut in the ceiling of a closet, and the opening is provided with a trap door.

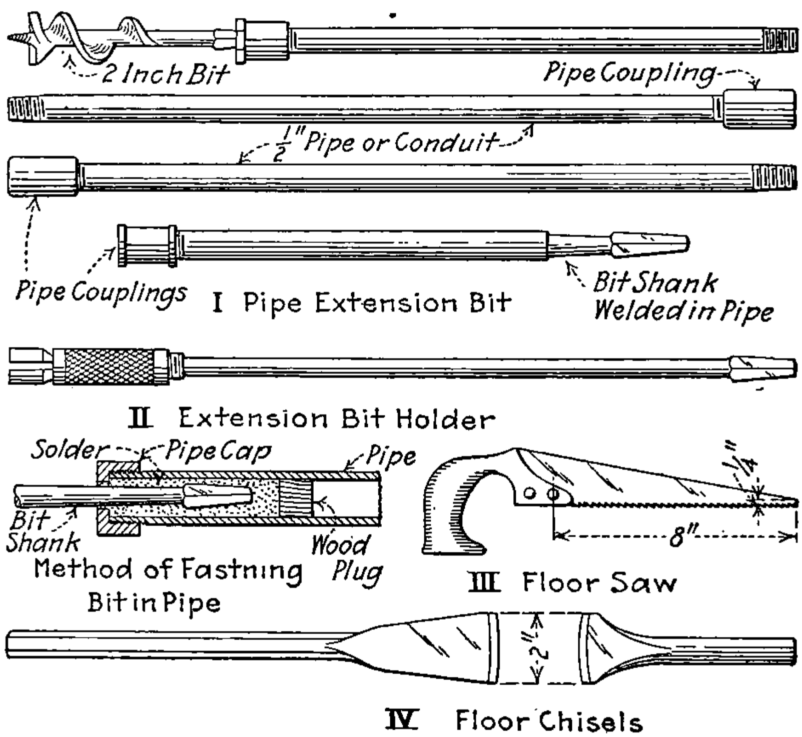


FIG. 270.—Tools used in wiring old buildings.

382. **Special Tools Used in Wiring Old Buildings.** (See Fig. 270.) (*a*) *Pipe Extension Bit.*—Used to drill through cross pieces or headers in a partition where it is impossible to get over or under them, as from the cellar up, and from the third floor down. A 2-in. bit is used, making a hole large enough to take four pieces of flexible tubing. Cases are known where boring has been done from the cellar to the third floor successfully, although the necessity for this is very rare. Fig. 271 illustrates the application of this device. A bit brace can be used for turning it or if the space is restricted a pipe wrench can be used.

(*b*) *Floor Saw.*—Used in removing flooring boards, made short enough so that it cannot be pushed through the plaster of the ceiling below. The blade is $\frac{1}{4}$ in. wide at the point and approximately 8 in. long with a handle similar to a key hole saw.

(*c*) *Floor Chisels.*—Used in removing the flooring boards. The chisels are from 12 to 24 in. long and 2 in. wide at the point.

(*d*) *Extension Bit Holder.*—Used in a bit brace for drilling holes in joist. They are 2 to 3 ft. long, and enable wireman to drill holes in a recess, or in places where a long bit would be needed. By coupling two of the holders together, the wireman can drill circuit holes in joist while standing, which renders the work much easier, where there are a number of holes to be drilled.

Mouse.—Used in locating cross pieces, and finding clear spaces in partitions. Is made up of a length of twine with a piece of lead or other heavy material on its end.

Snake.—Used in fishing wires through partitions or under floors; made of rectangular or round steel wire.

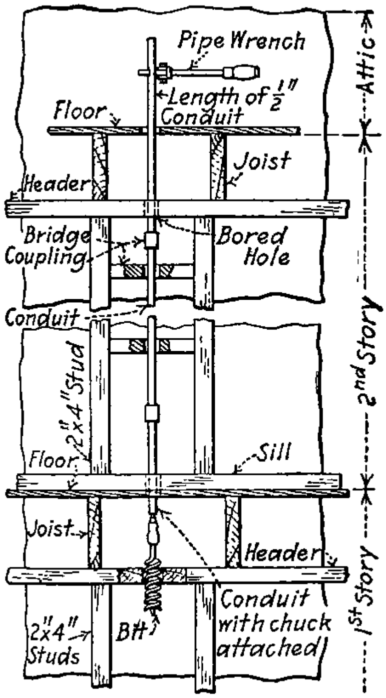


FIG. 271.—Illustrating use of the pipe extension bit.

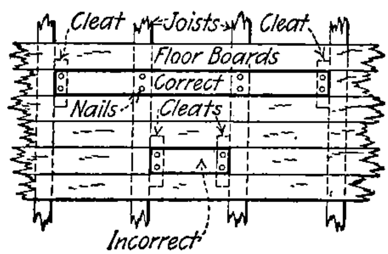


FIG. 272.—Methods of locating cleats to support floor boards that have been removed.

383. Removing Flooring Boards.—First a slot must be made in the seam between flooring boards of sufficient size to enable the floor saw blade (Fig. 270) to be inserted. This is best done with a sharp, narrow chisel having a $\frac{5}{8}$-in. blade. Then the saw blade is inserted, and the tongue at the junction of the flooring boards is sawed off the full length of board to be removed. The wireman can tell when he reaches the joist at which he wishes to end his cut. At this point the chisel blade is placed, with the flat part across the board at edge of the joist, and another small slot made. Then the board is sawed off even with the joist, and can be easily removed with a floor chisel (Fig. 270). When the board is replaced, a cleat is nailed to joist (Fig. 272) for the board to rest on, and then the board is nailed down, or better yet, screwed down, so that, if it is necessary to get at the wires again, it can be done with little trouble. When fastening down the flooring, two nails or screws should be put in each joist. When only one nail is used, the board is liable to squeak when walked over. To insure a substantial job, any floor board that is removed should be long enough to bridge at least two joists.

384. **Fishing to Center Outlets.**—A great deal depends on the layout of the house. Almost invariably the joists are run parallel to the street. If the house is one with a side or center hall on the second floor, the circuits can be run the length of the hall, necessitating the removal of two boards for that distance. Wires can then be fished from the center of the room by cutting a small hole at the chandelier location, or by cutting a pocket in the floor directly above the location of the outlet. If it is necessary to take up the boards in the floor at some distance from the partitions, another pocket will have to be taken up close to the partition in order to drop the switch loops, and to go through to the other side. This is necessary when the hall is in the center, with the rooms to be wired on each side.

If, as is the case with some of the smaller houses, there is no hall on the second floor, and the rooms are directly in the rear of each other, the boards can be taken up through the door-ways, and the wires dropped to the switches, outlets, and to the tablet board in the kitchen very readily. (See Fig. 269.) Where there are hardwood floors, the wires must be fished from the center of the room to a closet, or to a point where the baseboard can be removed, so as to get into a partition going either up or down. In a great many cases, it is necessary to drop to the cellar, and then come up again in another location for the switch loop. Where this is necessary, the most convenient place for the tablet board is in the cellar.

384 A. **When plaster-of-Paris molding or center pieces are to be drilled,** the Syracuse bit is the best. In many cases it is necessary to first saw off the lower portion of the center decoration to provide a flat surface to front the drill. Use very little pressure, and have the drill very sharp.

385. **Wiring for Switch Loops.**—In a great many cases, the bringing out of the switch loops at outlets at a proper distance from floor is the most difficult part of wiring old houses, on account of the cross pieces or bridges sometimes found in partitions. The method to be used must be determined by the wireman on the job, according to the conditions found. Following are some of the methods used:

First, with his mouse, he finds if the runway is clear; if so, the rest is easy. But, if he finds there are cross pieces, he locates their position by measurement with the mouse, and marks the location on the wall. If the cross pieces are above the proper positions for the switch, he will probably use one of the following methods of getting around it:

(*a*) Remove the door stop strip from the frame of the doorway (Fig. 273), bore through on each side of the cross piece, and cut a recess in the inside of the frame, then fish the wires around.

(*b*) If on the second floor, and there is no partition directly above, the wireman can use a pipe extension bit (Fig. 270, *I*), drilling one hole large enough to fish the switch loop through.

(*c*) If the cross piece is not too far above the proposed location of the switch, holes can be drilled on a slant from switch opening.

(*d*) Remove the wall paper directly over the cross piece, which can easily be done, especially in an old house where there are several thicknesses of paper, either dry or by dampening it. This can be done by cutting an X through the paper at the point over which the opening is to be made, and bending the paper back, but taking care not to bend it enough to crease it. Then cut a hole smaller than the paper removed, and bore holes or cut away the cross piece

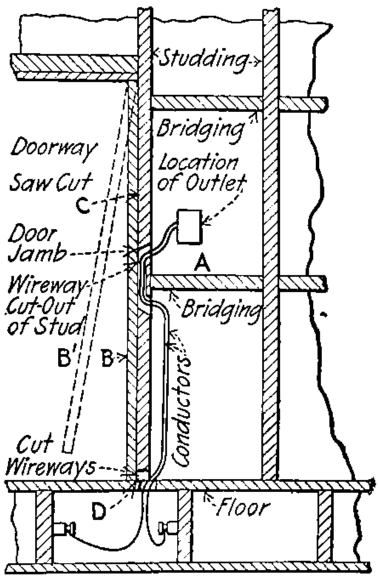


FIG. 273.—Carrying wires around a bridge.

enough so that the wires will pass. If there is a figure or flower where the cross piece is located, the same can be cut out with a sharp knife, and, after the hole is plastered up with plaster of Paris, the paper can be replaced very neatly. A careful man usually performs this operation very successfully.

(*e*) Sometimes a wireman will attempt to remove these cross pieces, when he can get at them from above, by putting a piece of pipe down between the partition, and hitting with a heavy hammer. This method is liable to cause damage to the plaster by bulging or breaking it out, and is not recommended.

(*f*) When a switch must be located on a brick wall, it is necessary to run wires in rigid or flexible steel conduit. The wall must be channeled, and the conductor buried in it, and the groove replastered. At the point where the metal terminates under the floor a suitable outlet fitting must be provided.

386. Examining Partition Interiors.—With a pocket flashlamp and a little mirror the interior of a wall or partition which would ordinarily be inaccessible can be inspected (Fig. 274). The mirror is introduced in the outlet hole and the flashlamp and eye are held behind it as illustrated. The mirror reflects the light of the lamp onto the place to be illuminated, at the same time reflecting the image back to the eye. (William Sprunt, *Electrical World*, Mar. 2, 1912.)

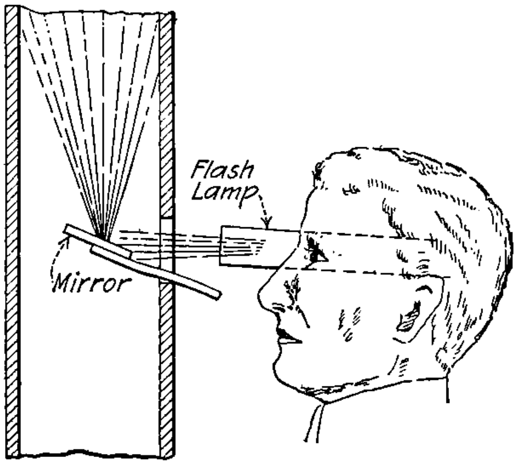


FIG. 274.—Examining partition interior.

SECTION V

TRANSFORMERS

GENERAL

1. The term stationary or static transformer (*Standard Handbook*) as ordinarily applied, refers to an apparatus for changing the voltage or current in an alternating system from one value to another with an inverse change respectively in the value of the current or voltage.

1 A. A step-up transformer is a constant potential transformer so connected that the delivered voltage is greater than the supplied voltage.

1 B. A step-down transformer is one so connected that the delivered voltage is less than the supplied; the actual transformer may be the same in one case as in the other, the terms step-up and step-down relating merely to the application of the apparatus.

1 C. A constant-potential transformer (Fig. 1) consists essentially of three parts: the primary coil which carries the alternating current from the supply lines; the core of magnetic material in which is produced an alternating magnetic flux; and the secondary coil in which is generated an e.m.f. by the change of magnetism in the core which it surrounds.

Generally the primary is the high-tension winding and it is composed of many turns of relatively fine copper wire, well insulated to withstand the voltage impressed on it. The secondary winding is composed of few turns of heavy copper wire capable of carrying considerable current at a low voltage.

2. The most important application of constant-potential transformers is for raising the voltage of an electric transmission circuit so that energy can be transmitted for considerable distances with small voltage drop and small energy loss. (See Sections I and II for a more complete discussion of this matter.)

3. The Theory of Operation of the Constant-potential Transformer.—(See Fig. 1.) It has been shown in Section I that turns of wire wound on an iron core have self-induction. When an alternating voltage is applied to such turns a current flows through them that generates a counter voltage or e.m.f. that opposes the applied voltage. From formulas, the transformer designer can compute just how many turns are necessary for a transformer of a given size so that it will generate a counter voltage equal to the applied voltage. So, in designing the primary winding of the transformer of Fig. 1, the designer would select such a number of turns for the primary winding that the counter voltage generated by it would be 2,200 volts. Hence, when the primary winding is connected to a 2,200-volt circuit, it generates a counter voltage of practically 2,200 and no appreciable current flows. A small current, the exciting current, just enough to magnetize the core, does flow but it is so small that it can be disregarded in this discussion.

Since the primary and secondary windings are on the same core, the magnetic flux generated by the magnetizing or exciting current flowing in the primary winding also cuts the turns of the secondary winding and generates in them an e.m.f. This e.m.f. will be, in accordance with a well-known law, opposite in direction to that impressed on the primary. If the secondary circuit is open no current can flow in it but if it is closed a certain current, proportional to the impedance of the secondary circuit, will flow. This current, because of the direction of the e.m.f. generated in the secondary, will be in such a direction that the magnetic flux produced in the core by it will oppose the flux due to the primary winding. It will therefore decrease the effective or resultant flux in the core by a small amount which will decrease the counter e.m.f. of the

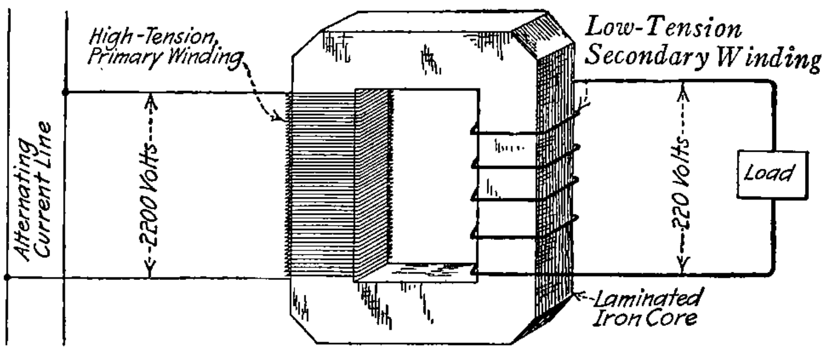


FIG. 1.—The elementary transformer.

primary winding and permit more current to flow into the primary winding. As noted elsewhere, the ratio of the number of turns in the primary winding to the number of turns in the secondary winding determines the ratio of the primary to the secondary voltage.

If the voltage impressed on the transformer is maintained constant the voltage of the secondary will be nearly constant also. When more current flows in the secondary there will be a corresponding increase in primary current. As the load on a transformer increases, the impressed voltage remaining constant, there is actually a slight drop from the no-load voltage of the secondary due to certain inherent characteristics of the transformer, but in a properly designed device this drop will be very small. Although the construction and elementary theory of the transformer are very simple, a theoretical explanation of all of the phenomena involved in its operation is very complicated. Only the principal features have been described. Some minor, though very important, considerations that would complicate things have not been treated.

4. **The ratio of the primary to the secondary turns determines the ratio of the primary to the secondary voltage.** For example, for transforming or "stepping-down" from 2,000 volts to 100 volts the ratio of the turns in the windings will be 20 to 1. The currents

in the primary and the secondary windings will be, very closely, inversely proportional to the ratio of the primary and secondary voltages because, disregarding the small losses of transformation, the power put into a transformer will equal the power delivered by it. For example, considering a transformer with windings having a ratio of 20 to 1, if its secondary winding delivers 100 amp. at 50 volts the input to its primary winding must receive almost exactly 5 amp. at 1,000 volts. The imput and output are each (practically) equal and each would equal (almost exactly) 5,000 watts.

5. The terms "high-tension winding" and "low-tension winding" are preferable to the terms "primary winding" and "secondary winding" because a high-tension winding may be the primary in one case and the secondary in another. But if the names "high-tension" and "low-tension" are used there can be no confusion.

6. The efficiency of a transformer is, as with any other device, the ratio of the output to input or, in other words, the ratio of the output to the output plus the losses. As a formula it may be expressed thus:

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Output}}{\text{Output} + \text{Copper loss} + \text{Iron loss}}$$

7. The copper loss of a transformer is determined by the resistances of the high-tension and low-tension windings and of the leads. It is equal to sum of the watts, I^2R losses in these components at normal load.

8. Performance of Distributing Transformers.—The table shows about average values for 2,200 to 220–110-volt, 60-cycle transformers and is not particularly representative of any certain manufacturer's line.

Kva.	Watts loss		Per cent. efficiency				Per cent. regulation				Per cent. exciting current
	Iron	Copper	Full load	¾ load	½ load	¼ load	100% P.F.	90% P.F.	80% P.F.	70% P.F.	
½	15	13	94.7	94.4	93.2	88.8	2.6	2.73	2.62	2.5	8.0
1	20	24	95.8	95.7	95.0	92.0	2.4	2.51	2.41	2.25	5.5
1½	24	33	96.4	96.4	95.8	93.5	2.2	2.4	2.35	2.3	4.0
2	29	40	96.7	96.7	96.2	94.1	2.0	2.25	2.23	2.2	3.6
2½	32	51	96.8	96.9	96.5	94.7	2.05	2.42	2.45	2.4	3.3
3	33	57	97.1	97.2	96.9	95.4	1.92	2.31	2.38	2.35	3.0
4	37	70	97.4	97.5	97.4	96.0	1.81	2.55	2.75	2.85	1.9
5	43	82	97.5	97.6	97.5	96.3	1.7	2.35	2.51	2.6	1.8
7½	57	110	97.8	97.9	97.7	96.7	1.55	2.4	2.6	2.8	1.7
10	70	140	97.9	98.0	97.9	96.9	1.47	2.32	2.6	2.7	1.65
15	95	192	98.1	98.2	98.1	97.2	1.35	2.2	2.42	2.58	1.5
20	123	255	98.1	98.2	98.1	97.3	1.35	2.6	3.0	3.25	1.3
25	138	305	98.2	98.3	98.3	97.5	1.3	2.6	3.0	3.3	1.25
30	158	370	98.3	98.4	98.3	97.6	1.29	2.75	3.2	3.5	1.15
37½	175	415	98.4	98.5	98.5	97.9	1.18	2.9	3.43	3.8	1.05
50	239	520	98.5	98.6	98.5	97.8	1.14	2.7	3.22	3.57	1.0

9. **The iron loss of a transformer** is equal to the sum of the losses in the iron core. These losses consist of Eddy or Foucault current losses and hysteresis current losses. Eddy current losses are due to currents generated by the alternating flux circulating within each lamination composing the core and they are minimized by using thin laminations and by insulating adjacent laminations with paint. Hysteresis losses are due to the power required to reverse the magnetism of the iron core at each alternation and are determined by the amount and the grade of iron used for the laminations for the core.

10. **Transformer Ratings.**—Transformers are rated at their kilovolt-ampere (kva.) outputs. If the load to be supplied by a transformer is at 100 per cent. power factor the kilowatt (kw.) output will be the same as the kva. output. If the load has a lesser power factor, the kw. output will be less than the kva. output proportionally as the load power factor is less than 100 per cent.

For example: A transformer having a full load rating of 100 kva. will safely carry 100 kw., if the 100 kw. is at 100 per cent. power factor or 90 kw. at 90 per cent. power factor or 80 kw. at 80 per cent. power factor.

11. **Capacities of Transformers for Operating Motors** (*General Electric Company*).—For the larger motors the capacity of the transformers in kilovolt-amperes should equal the output of the motor in horse-power. Thus a 50-h.p. motor requires 50 kva. in transformers. Small motors should be supplied with a somewhat larger transformer capacity, especially if, as is desirable, they are expected to run most of the time near full-load, or even at slight overload. Transformers of less capacity than those noted in table 12 should not be used even when a motor is to be run at only partial load.

12. **Capacities of Transformers for Induction Motors.**
(*General Electric Company*)

Size of motor horse-power	Kilovolt-amperes per transformer		
	Two single-phase transformers	Three single-phase transformers	One three-phase transformer
1	0.6	0.6	....
2	1.5	1.0	2.0
3	2.0	1.5	3.0
5	3.0	2.0	5.0
7½	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

13. **Regulation on Inductive and Non-inductive Load** (*General Electric Company*).—While with a non-inductive load such as incan-

descent lamps the regulation of transformers is within about 3 per cent., with an inductive load, the drop in potential between no-load and full-load increases to, possibly, about 5 per cent. If the motor load is large and fluctuating, and close lamp regulation is important, it is desirable to use separate transformers for the motors.

14. **The oil used in transformers** (*Standard Handbook*) performs two important functions. It serves to insulate the various coils from each other and from the core, and it conducts the heat from the coils and core to some cooler surfaces where it is either dissipated in the surrounding air or transferred to some cooling medium. It is evident that the oil should be free from any conducting material, it should be sufficiently thin to circulate rapidly when subjected to differences of temperature at different places, and it should not be ignitable until its temperature is raised to a very high value.

Although numerous kinds of oils have been tried in transformers, at the present time mineral oil is used almost exclusively. This oil is obtained by fractional distillation of petroleum unmixed with any other substances and without subsequent chemical treatment. A good grade of transformer oil should show very little evaporation at 100 deg. Cent. and it should not give off gases at such a rate as to produce an explosive mixture with the surrounding air at a temperature below 180 deg. cent. It should not contain moisture, acid, alkali or sulphur compounds.

It has been shown by Mr. C. E. Skinner that the deteriorating effect of moisture on the insulating qualities of an oil is very marked; moisture to the extent of 0.06 per cent. reduces the dielectric strength of the oil to about 50 per cent. of the value when it is free from moisture; but there is very little further decrease in the dielectric strength with an increase in the amount of moisture in the oil.

Dry oil will stand an e.m.f. of 25,000 volts between two 0.5-in. knobs separated by 0.15 in. The presence of moisture can be detected by thrusting a red hot nail in the oil; if the oil "crackles" water is present. Moisture may be removed by raising the temperature slightly above the boiling point of water, but the time consumed (several days) is excessive. The oil is subsequently passed through a dry-sand filter to remove any traces of the lime or other foreign materials.

15. **Bell-ringing transformers** are referred to in the section on *Interior Wiring* under *Bell Wiring*.

SINGLE-PHASE CONNECTIONS

16. **Connections for standard distributing transformers** are shown in Figs. 2 and 3. Distributing transformers of medium and small capacity are almost invariably arranged, as shown, with two primary and two secondary coils. By making the necessary changes in the primary-coil connections they may be used on primary circuits of either 1,100 or 2,200 volts and their secondary windings can be so connected as to deliver 110 or 220 volts or for a 110–220-volt, three-wire circuit. For changing the connections

of the primary coils a block is provided within the transformer case. The connections of the secondary coils are made, either by splicing the secondary leads or with connectors, outside of the transformer case. Distributing transformers are also made for primary voltages of 1,040 or 2,080 and corresponding secondary voltages

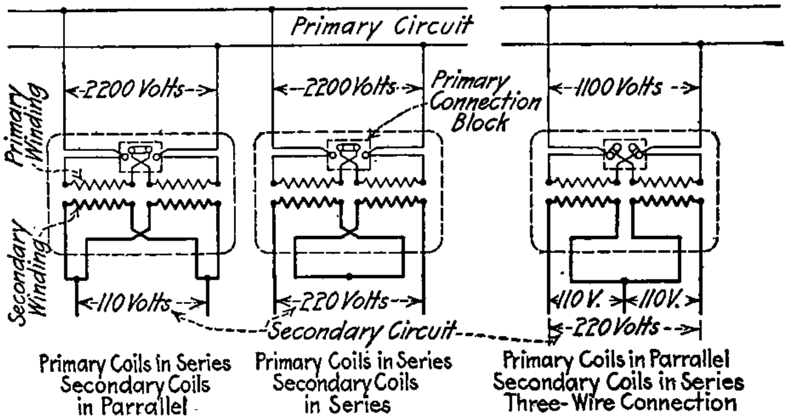


FIG. 2.—Connections of standard distributing transformers.

of 115 and 230 and have an approximate ratio of 9 or 18 to 1. Front and rear views of a Westinghouse distributing transformer are shown in Fig. 3 *A*.

17. **Transformer connections for three-wire secondary service** are shown in Figs. 2, 3 and 4. In the arrangement Figs. 2 and 3

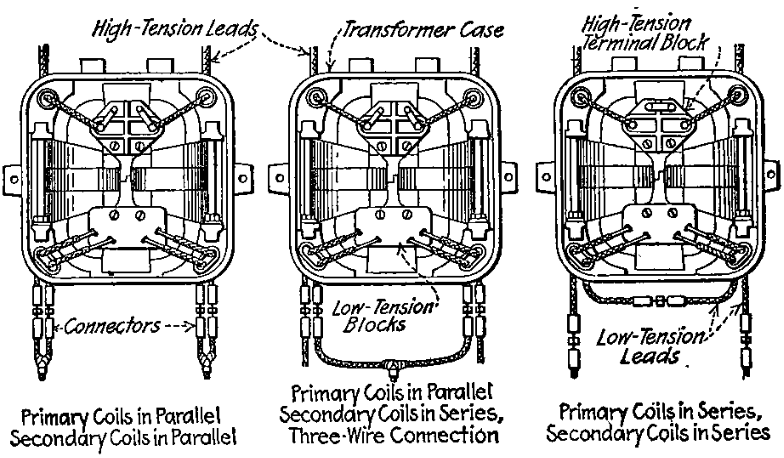


FIG. 3.—Method of interconnecting transformer secondaries with connectors.

one transformer only is used. Its secondary windings are connected in series and a tap is made to the point of connection between the two windings, providing 220 volts between the two outside wires and 110 volts on each of the side circuits. The transformer should have a capacity equal to the load to be supplied and the three-wire circuits should be carefully balanced. If the three-wire circuits are decidedly unbalanced, the transformer should have a capacity equal to twice the load on the most heavily loaded of the two side circuits.

In Fig. 4 two transformers are shown connected to serve a three-wire circuit. The three-wire load should be balanced as nearly

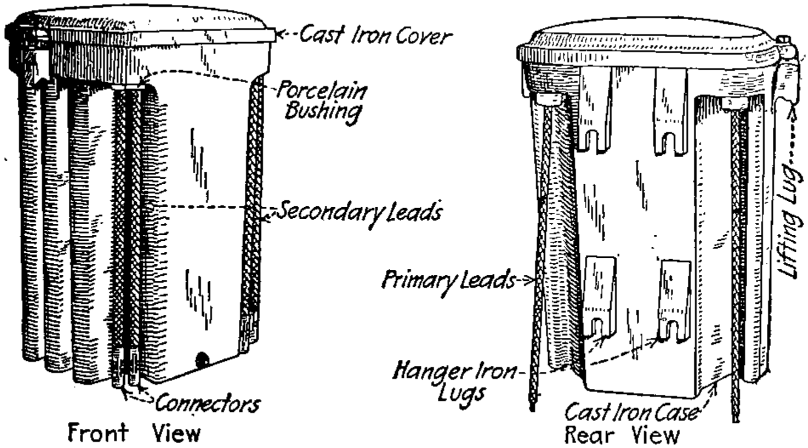


FIG. 3A.—Standard distributing transformer.

as possible and where it is very nearly balanced each transformer should have a capacity equal to one-half of the total load. If the load is badly unbalanced, each transformer should have a sufficient capacity equal to the load on its side of the circuit. See discussion of "Parallel Operation."

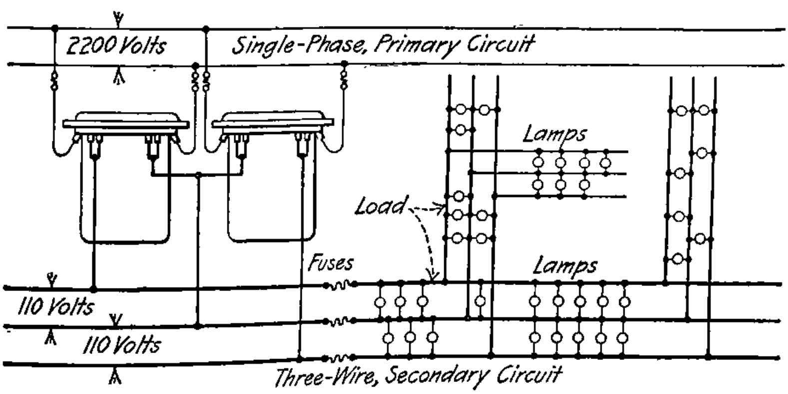


FIG. 4.—Two transformers serving a three-wire circuit.

TWO-PHASE CONNECTIONS

18. Transformers connected to four-wire, two-phase circuits are shown in Fig. 5. As a rule two-phase primary lines are four-wire as shown and to such a four-wire line the transformers are

connected to each of the side circuits as if each side circuit were a single-phase circuit not having any connection with the other. The total load should be so divided between the phases that the loads on each will be equal as nearly as possible. Each trans-

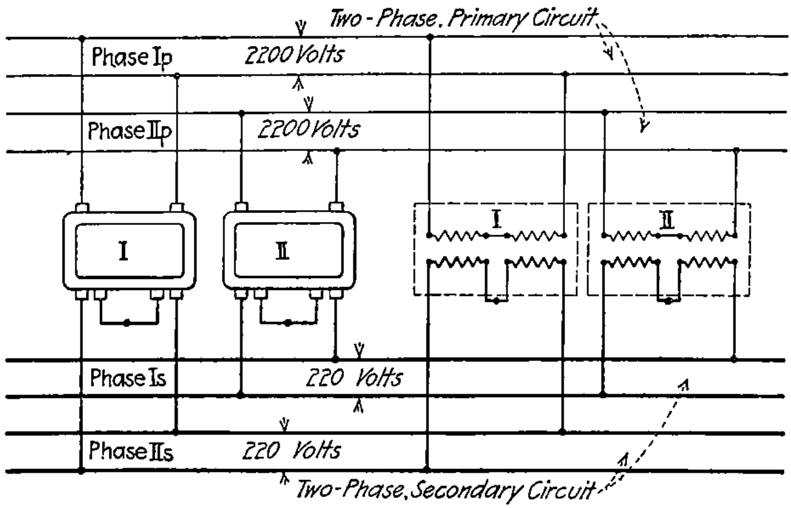


FIG. 5.—Transformers, two-phase to two-phase, four wire, connection.

former should be designed for line voltage and will carry line current. Each transformer should have a kva. capacity equal to one-half of the kva. load that is served by the two transformers.

18 A. **Transformers connected to three-wire, two-phase circuits** are shown in Fig. 5 *A*. The current in the center line wire (*AA*)

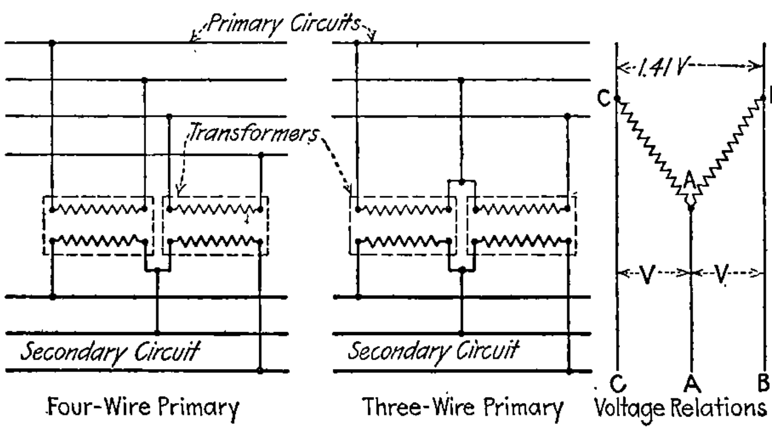


FIG. 5A.—Connections for transformers on three-wire, two-phase circuits.

is 1.41 the current in either of the outer wires. Each transformer has line voltage impressed on it and carries one-half the total load. A General Electric Co. publication comments thus: "Considerable unbalancing of voltage at the end of a transmission line or cable is experienced with the three-wire, two-phase system due to the mutual induction between phases. Where the power factor is low, a still worse regulation is obtained, making satisfactory operation difficult. Very few systems now operate on this plan and practically all of them could be improved by the use of some other system."

19. **Mixed connections are sometimes made with two-phase transformers** as shown in Fig. 6. With improper connections such as those shown, difficulty will be experienced in the operation of motors and they may not run at all.

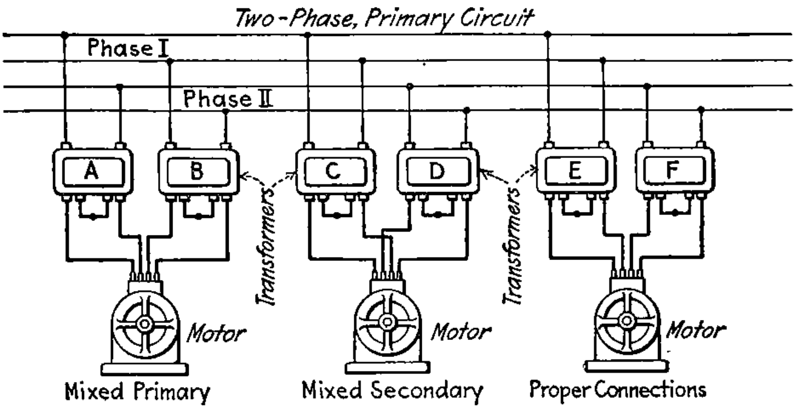


FIG. 6.—Correct and incorrect connections for transformers serving two-phase motors.

THREE-PHASE CONNECTIONS

20. **Comparison of one three-phase transformer as against a group of single-phase transformers** (*Standard Handbook*) that may be employed for obtaining the same service have been summed up by Mr. J. S. Peck as follows: Advantages of three-phase transformer: First, lower cost; second, higher efficiency; third, less floor space and less weight; fourth, simplification in outside wiring, and fifth, reduced transportation charges and reduced cost of installation. The disadvantages of the three-phase transformer are: First, greater cost of spare units; second, greater derangement of service in the event of break-down; third, greater cost of repair; fourth, reduced capacity obtainable in self-cooling units; and fifth, greater difficulties in bringing out taps for a large number of voltages. It is considered that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the event of break-down—an abnormal condition which occurs at rarer and rarer intervals as the art of transformer design and manufacture advances.

21. **Transformers with both primary and secondary coil delta (Δ) connected** are shown in Fig. 7. All three of the transformers are connected in series in a closed circuit and each line wire is connected

to the connection between two of the transformers. The voltage imposed on either the primary or secondary of the transformer is the primary or secondary line voltage, respectively. The current in either winding = line current $\div\sqrt{3}$, or line current $\times$ 0.58.

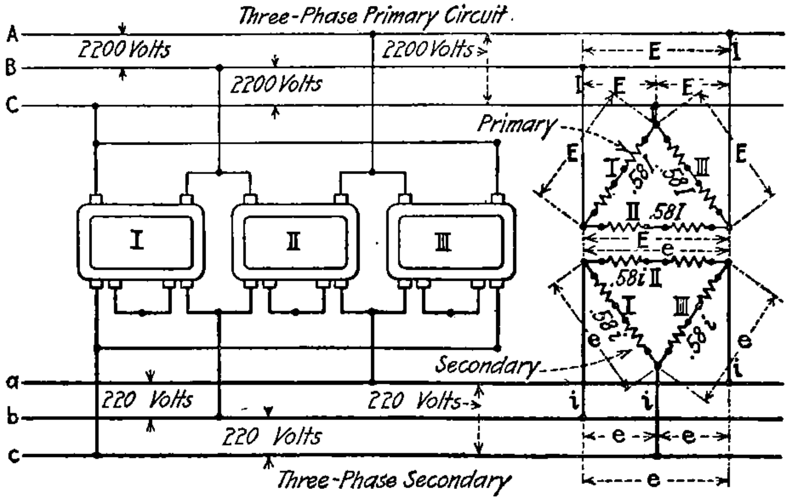


FIG. 7.—Transformers, delta-connected on both primary and secondary on three-phase circuits.

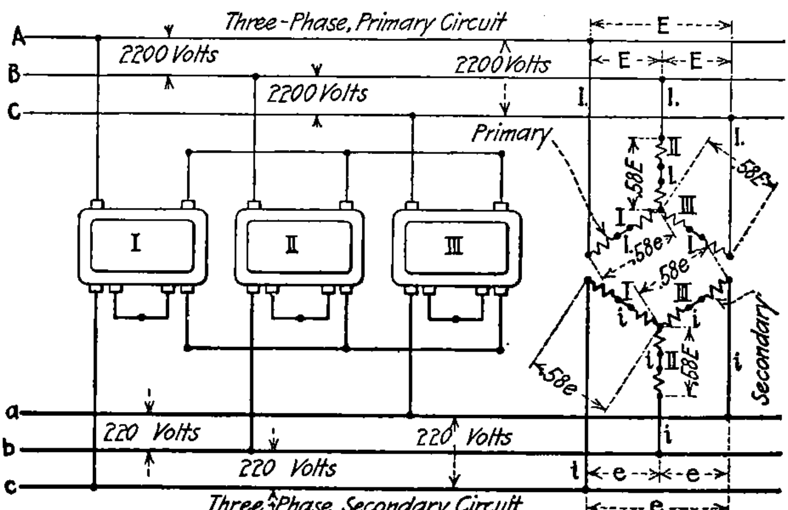


FIG. 8.—Transformers, star-connected on both primary and secondary on a three-phase circuit.

The kva. capacity of each transformer should be equal to one-third the total kva. of the load to be served. The total kva. load transmitted by a balanced three-phase line $=1.73\ IE$ (where I is the line current in each line wire and E is the voltage between wires). Therefore, the kva. capacity of each transformer should be $1.73\ IE \div 3 = 0.58\ IE$.

22. Transformers with both primary and secondary coils, star-connected, from a three-wire primary circuit, are shown in Fig. 8. The current in each transformer winding is the same as the line current and the voltage imposed on each winding = line voltage $\div \sqrt{3} =$ line voltage $\times$ 0.58. The kva. capacity of each transformer should be equal to one-third the total kva. of the load to be served. The total kva. load transmitted by a balanced three-phase line $= 1.73\ IE$ (where I is the line current in each line wire and E is the voltage between wires). Therefore, the kva. capacity of each transformer should be $1.73\ IE \div 3 = 0.58\ IE$.

The star-star connection is seldom used.

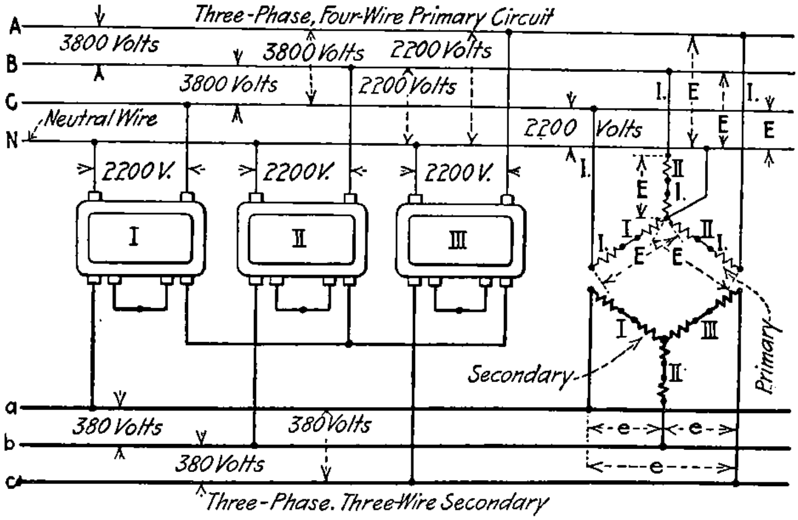


FIG. 9.—Transformers, star-connected on both primary and secondary on three-phase circuits (four-wire primary circuit).

The same grouping except that the primary circuit is four-wire is shown in Fig. 9. In thus connecting transformers from a four-wire, primary circuit it should be remembered that each right-hand primary terminal connects with a line wire and each left-hand terminal connects with the neutral wire or the reverse, respectively. The voltage and current relations are shown in the illustration.

23. Transformers delta-connected to the primary circuit and star-connected to the secondary circuit are shown in Fig. 10. Any group of transformers can be connected with either their primary or secondary coils connected in either star or delta. With the primary delta-connected and the secondary star-connected as shown, the secondary voltage will be 1.73 times what it would be if it were delta-connected. For example, in the illustration (the transformers are assumed to have a 10 : 1 ratio) with a delta secondary connection the secondary line voltage would be $2{,}200 \div 10 = 220$ volts, but with a star or Y secondary connection the secondary voltage is $220 \times 1.73 = 380$ volts. It should be noted that with a delta-connected primary an increase of 15 per cent. in the primary voltage and a star secondary connection will make the secondary voltage twice what it would be with delta-connection and normal primary voltage.

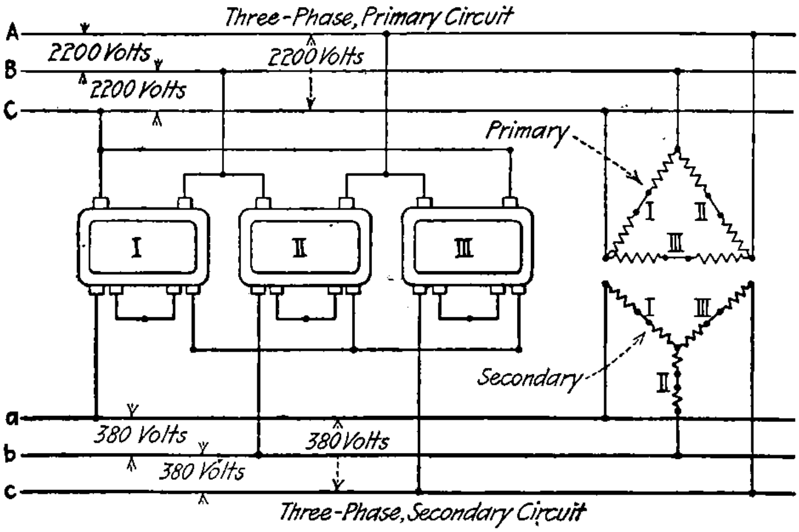


FIG. 10.—Transformers, delta-connected, primary and star-connected secondary.

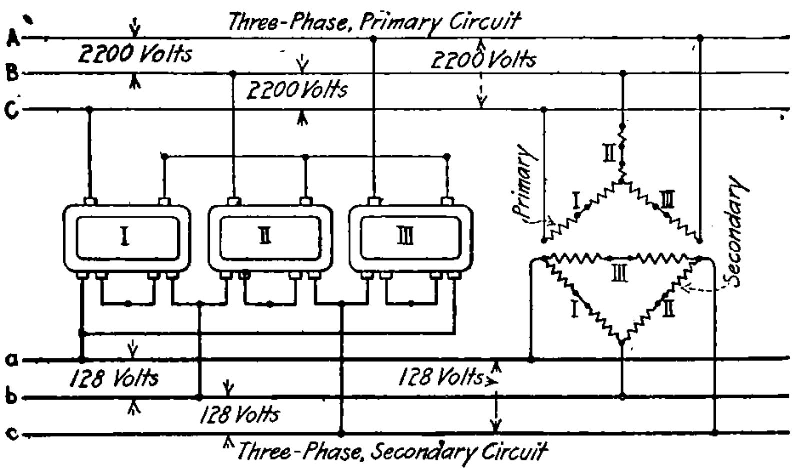


FIG. 11.—Transformers, star-connected primary and delta-connected secondary.

24. **Transformers star-connected primary and delta-connected secondary** are shown in Fig. 11. This is the reverse of the grouping described in **23** and the secondary voltage will be but 0.58 times as great as if both secondary and primary were star-connected.

25. The Three-phase V- or Open-delta Connection (Figs. 12 and 13).—Line voltage is impressed on each transformer and line current flows in each transformer coil. This method is considerably used for motors but has the objection that if one of the transformers becomes inoperative the three-phase circuit served will be fed by but one transformer and hence will be inoperative. (The *Reversed-V- connection* is indicated at the primary side in Fig. 13.)

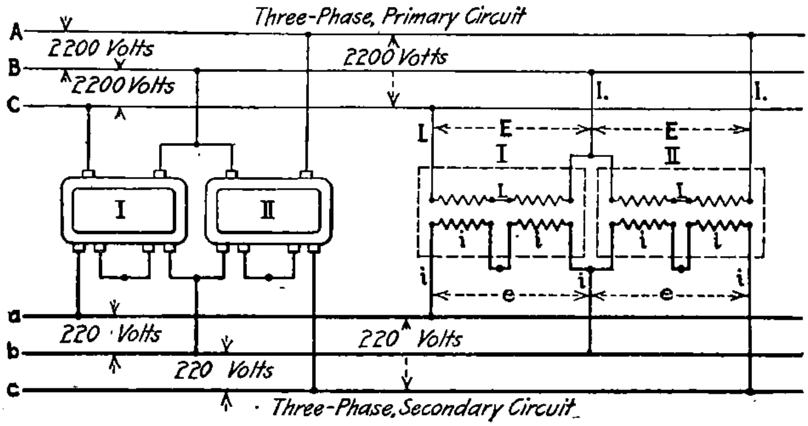


FIG. 12.—Transformers, V- or open-delta primary and secondary (three-wire, three-phase primary circuit and three-wire, three-phase secondary circuit).

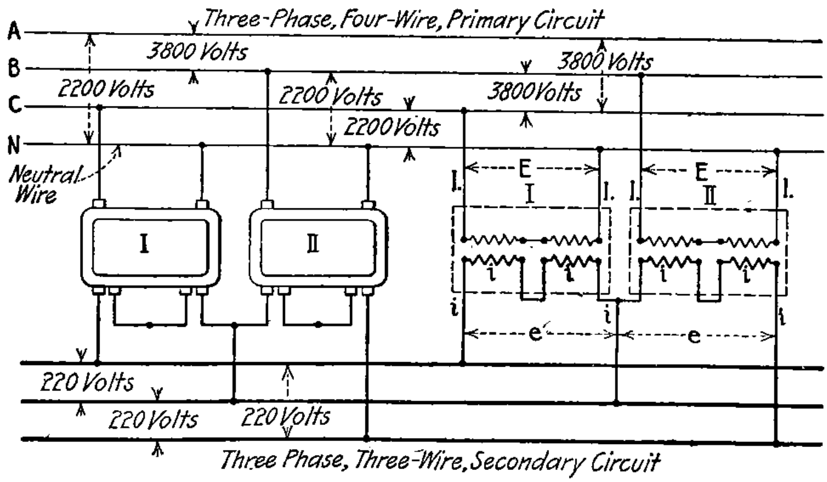


FIG. 13.—Transformers, primary connected in reversed- V and secondary V- connected (four-wire, three-phase primary circuit and three wire, three-phase secondary circuit).

The combined capacity of two transformers (*Gear and Williams*), connected by this method and serving a given load should be 15.5 per cent. greater than the combined capacity of three transformers, delta- or star-connected and serving the same load. For instance if three 5-kva. transformers (total capacity 15 kva.) are required for a certain installation and they are replaced by two $7\frac{1}{2}$-kva. transformers (total capacity 15 kva.) the two transformers will be overloaded by 15.5 per cent. at a full load of 15 kw. at 100 per cent. power factor.

For example, assume that in a three-transformer installation the current in the secondary line is 17.3 amp. This imposes a load of 10 amp. on the transformer secondary coils. At 200 volts this is 2 kw. per transformer or 6 kw. in all. If, now, two 3-kw. transformers are put in to replace the three 2-kw. units the capacity of the secondary coils would be 15 amp. But, as above noted, with the open-delta connection the current in the secondary coil is the same as the current in the line and the 15-amp. winding must carry 17.3 amp. or 15.5 per cent. overload.

In the grouping of Fig. 12, to reverse the direction of a motor served by the group, interchange any two of the primary phase wires or reverse any two of the secondary wires.

Usually two transformers for open-delta grouping of proper aggregate capacity to serve a given load will be cheaper than three transformers for star or delta grouping to serve the same load, but this is not always the case.

26. Disadvantages of the V- or Open-delta Connection (*Standard Handbook*).—For normal operation not only must each of the V-connected transformers be larger than each of the delta-connected transformers, but the two transformers must have a combined rating 15.5 per cent. greater than the three transformers. This fact taken alone does not represent a disadvantage of the V-connection, because the two larger transformers are exactly equal in constructive material and operating efficiency to the three smaller transformers. The real objection to the V-connection for serious work resides in the tendency for the local impedance of the transformers to produce an enormous unbalance of the secondary voltages and of the primary currents. In spite of this disadvantage (which is really of little consequence in 2,200-volt primary, distribution work) many V-connected groupings are in satisfactory operation.

27. Comparison between the Delta, the Star and the Open-delta Methods of Connection (*Standard Handbook*).—The choice between the methods would be governed largely by the service requirements. When the three transformers are delta-connected one may be removed without interrupting the performance of the circuit—the two remaining transformers, in a manner, acting in series to carry the load of the missing transformer. The desire to obtain immunity from a shut-down due to the disabling of one transformer has led to the extensive use of the delta connection of transformers, especially on the low-potential delivery side. It is to be noted that in case one transformer is crippled the other two will be subjected to greatly increased losses.

Thus, if three delta-connected transformers be equally loaded until each carries 100 amp., there will be 173 amp. in each external circuit wire. If one transformer be now removed and 173 amp. continues to be supplied to each external circuit wire, each of the remaining transformers must carry 173 amp., since it is now in series with an external circuit. Therefore, each transformer must now show three times as much copper loss as when all three transformers were active, or the total copper loss is now increased to a value of six relative to its former value of three.

A change from delta to Y in the secondary circuit alters the ratio of the transmission e.m.f. to the receiver e.m.f. from 1 to $\sqrt{3}$. On account of this fact, when the e.m.f. of the transmission circuit is so high that the successful insulation of transformer coils becomes of constructive and pecuniary importance, the three-phase line sides of the transformers are connected in "star" and the neutral is grounded. However, most of the circuits operating at 100,000 volts or more are not grounded and the transformers are joined in "delta" and insulated for the full e.m.f.

See also **26** regarding properties of an open-delta connected group.

28. Comparative Cost of Transformers for Different Groupings for Three-phase Service.—The following table shows the costs of the single-phase transformers, of proper capacities for either a delta or an open-delta grouping and of a three-phase transformer to serve a 75-kva. installation.

Method of connection or grouping	Number of transformers required	Capacity of each transformer, kva.	Aggregate capacity	Cost per transformer	Aggregate cost
Delta (Δ)	3	25	75	$213	$639
[1]Open Delta (V)	2	40	80	312	624
Three-phase transformer	1	75	75	546	546

[1] The theoretical aggregate capacity of two single-phase transformers for open-delta grouping for a 75-kva. three-phase load would be (see 25) $75 \times 1.15 = 86.3$ kva. or $86.3 \div 2 = 43.2$ kva. per transformer. The nearest commercial capacity to 43.2 kva. was 40 kva., which gives an aggregate capacity of 80 kva. which is sufficiently close to the theoretical requirement for practical work.

SPECIAL TRANSFORMER CONNECTIONS

29. Transformers connected for transforming from three-phase to two-phase or the reverse are illustrated in Fig. 14 which shows what is known as the Scott connection. The transformers required are special and each has a lead brought out from the middle point of the high-tension winding and a special voltage tap is arranged giving 86.6 per cent. of the high-tension winding. Usually two transformers just alike are purchased so that they will be interchangeable. These special transformers can be purchased from any of the large manufacturers. Those shown are Westinghouse transformers. Two standard single-phase transformers for such service should have an aggregate kva. rating $15\frac{1}{2}$ per cent. greater than their group or nominal rating.

30. T-Connected Transformers for Transforming from Three-phase to Three-phase (*Standard Handbook*).—A method of employing two transformers in three-phase transformation which practically overcomes the disadvantages of the V-connection, and possesses considerable merit, is found in the T-connection. As indicated in Fig. 16, one transformer is connected across between two of the line wires while the other is joined between the third line wire and the middle point of the first transformer. The current in the primary coil of each transformer is the same in value as that in the primary coil of the other, and the secondary currents in the two transformers are likewise equal in value. The voltage impressed across one transformer is only 86.6 per cent. of that across the other so that if each transformer is designed especially

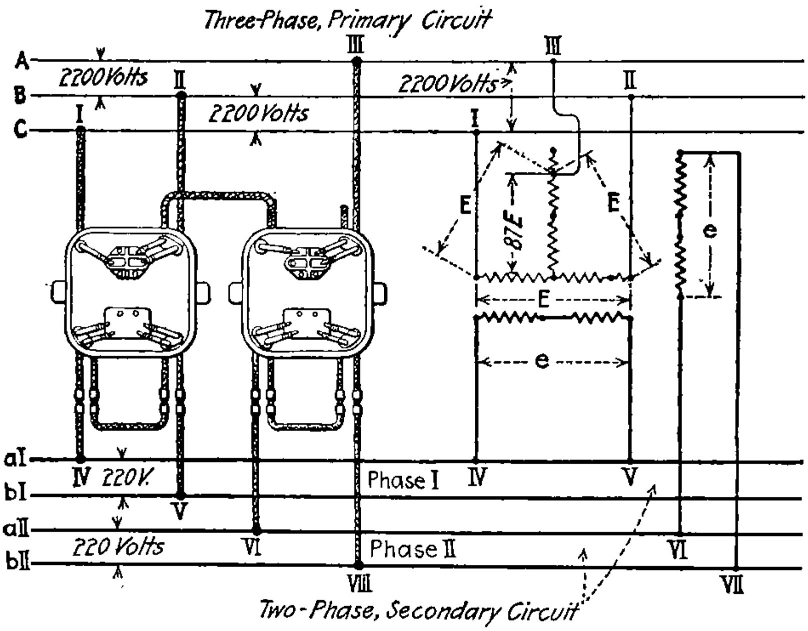


FIG. 14.—Transformers connected for three-phase to two-phase transformation.

for its work one will have a rating of EI and the other a rating of 0.866 EI, where I is the current in each line wire and E is the e.m.f. between lines. The combined rating will therefore be 1.866 as compared with 1.732 EI for three one-phase transformers connected either Δ or Y, or with 2,000 EI for two V-connected transformers.

30 A. Requisites for Transformers for T-Connection.—The two transformers should possess the same ratio of primary to secondary turns and a tap is brought out from the central point of one of the transformers. It is not essential that the former transformer be designed for exactly 86.6 per cent. of the voltage of the latter; the normal voltage of one can be 90 per cent. of the other, without producing detrimental results. Moreover, transformers designed for the same normal e.m.f. and intended for V-connection can be T-connected with considerable improvement in service.

30 B. In comparing the T-connection with the Δ- or the Y-connection (*Standard Handbook*), it is to be noted that each connection accomplishes the transformation without sensible distortion of phase relations. The T-connection allows the neutral point to be reached equally as well as does the Y-connection. The Δ-connection, however, is the only one capable of transforming in emergencies with one disabled transformer. With reference to its ability to maintain balanced phase relations, the T-connection is much better than the V-connection.

The aggregate kva. rating of two T-connected transformers should be $15\frac{1}{2}$ per cent. greater than the nominal kva. rating of the group.

31. Explanation of the Transformation from Three Phase to Two Phase (*Standard Handbook*).—Assume the simple case of a total value of power of 30,000 watts at 100 volts, three phase, to be transformed (without loss) to 30,000 watts 100 volts, two phase, see Fig. 15. Assuming now that the load is balanced on the two-phase side, there will be 15,000 watts per phase, or 150 amp. at 100 volts. Since the three-phase power is represented as $\sqrt{3}\,IE = 30{,}000$, where I is the current per line wire and E is the e.m.f. between line wires, I must equal 173.2 amp. because E has been taken as 100 volts.

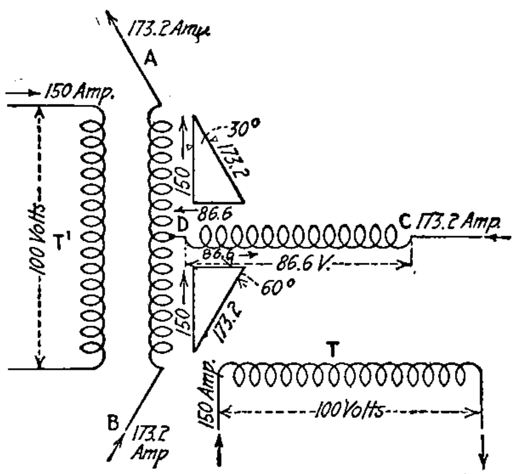


FIG. 15.—Three-phase to two-phase transformation.

As shown in Fig. 15, the three-phase coils of one transformer must be designed for 100 volts and 173.2 amp. while the three-phase coils of the other transformer must be designed for 86.6 volts and 173.2 amp. The current through the coil, *CD*, divides equally, a part (86.6 amp.) goes through *DA* and an equal part (86.6 amp.) passes differentially through *DB;* thus the magneto-motive force of these two currents has a resultant of zero, and it has no effect upon the core flux so far as transformer T′ is concerned. The coil, *A D B*, carries a total value of current of 173.2 amp. throughout all of its turns, but the current in one-half is 60 time-degrees out of phase with that in the other half.

That is to say the 173.2 amp. in one half is made up of a load current of 150 amp. in leading time-quadrature with which is 86.6 amp., while that in the other half is made up of a load current of 150 amp. in lagging time-quadrature with which is a superposed current of 86.6 amp. The magnetizing effect of the 173.2 amp. is, therefore, 150 amp. and the current in the two-phase side of transformer T′ is 150 amp. In the *T*-transformer the magnetomotive force of 173.2 amp. in 86.6 per cent. turns is just equal to that of 150 amp. in 100 per cent. turns; these two currents are directly in time-phase opposition, and the apparatus operates in all respects like a one-phase transformer. The phase relations and the relative values of the several components of currents are shown in the vector diagram of Fig. 15.

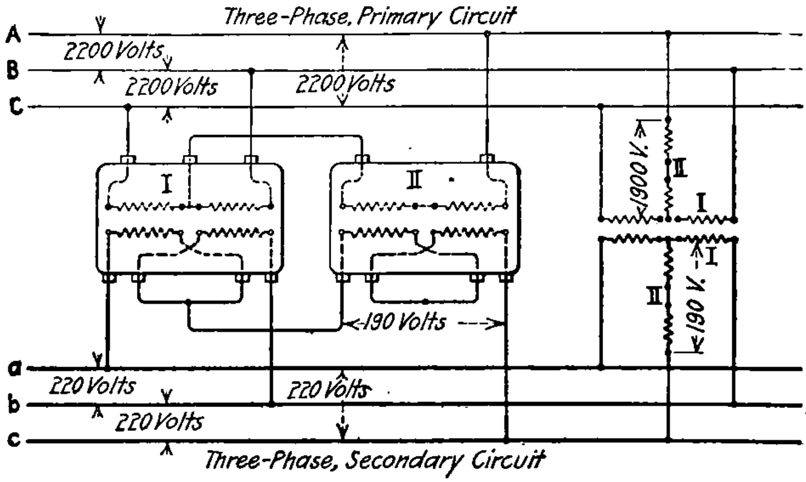


FIG. 16.—Transformers, T-connected for three-phase transformation.

32. Kilovolt Ampere Ratings of Transformers for Scott Connection (Three-phase to Two-phase) for Serving a Given Horsepower Load.—The following table gives the ratings recommended by the Westinghouse Company for transformers serving squirrel-cage induction motors and indicates the efficiency of the installation. The temperature guarantee with performances as shown is a 50 deg. Cent. rise.

Horse-power of motor	Number of transformers	Kilovolt-ampere capacity of each transformer	Total kilovolt-ampere load imposed on the group of two transformers when motor is operating at full load	Efficiency of bank of transformers with full-load on motor
½	2	½	0.75	92.8
1	2	½	1.35	94.5
2	2	1	2.40	95.2
3	2	1½	3.4	95.9
5	2	2½	5.5	96.4
7½	2	4	8.1	97.0
10	2	5	10.7	97.2
15	2	7½	15.7	97.4
20	2	10	20.9	97.6
30	2	15	31.5	97.8
40	2	20	42.0	98.0
50	2	25	51.0	98.0
75	2	37½	77.0	98.3

$$\text{Kva. on each transformer} = \frac{\text{h.p.} \times 746 \times 1.08}{(\text{eff} \times \text{P. F. of motor})}$$

$$\text{Efficiency} = \frac{\text{kva. on transformer}}{\text{kva. transformer loss} + \text{kva. on transformer}}$$

33. Booster transformers (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Ordinary distributing transformers applied as illustrated (Fig. 17), are used where it is necessary to raise by a fixed percentage, the voltage delivered by a line, as is necessary when transformer ratios do not give quite the right voltage or when line drop is excessive. A booster raises the voltage of any primary circuit in which it may be inserted by the amount of the secondary voltage of the booster. (See Fig. 17.)

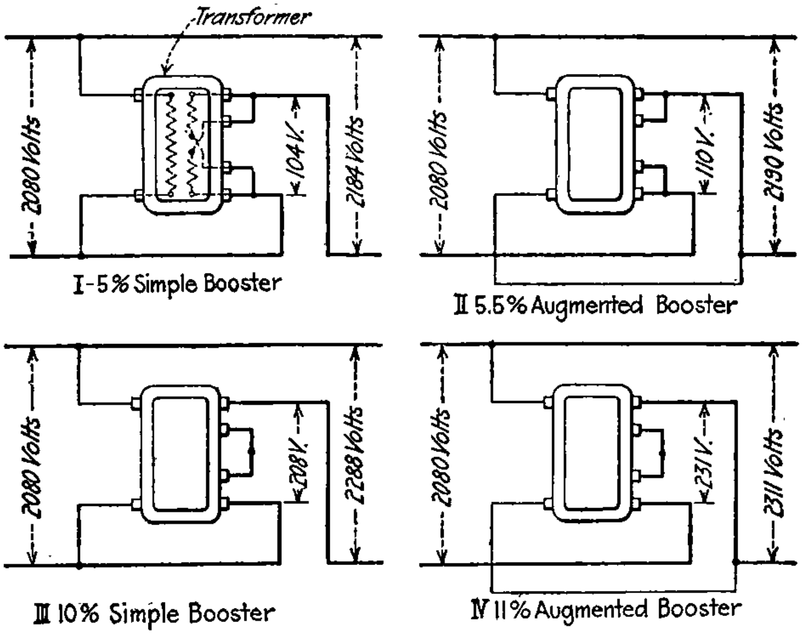


FIG. 17.—Transformers used as boosters.

Examples.—On a long, single-phase, 2,080-volt lighting branch so heavily loaded that the pressure drops more than the amount for which the normal regulation of the feeder will compensate, a 110-volt transformer inserted in the line as a booster will raise the pressure of the primary branch on the load side of the booster by 110 volts. This raises the secondary pressure 5.5 volts on all of the transformers beyond the booster.

With 440-volt service supplied by star-connected, 230-volt transformers, a 10 per cent. booster in each phase raises the normal pressure of 230–400 volts to 253–440 volts.

The connections for a simple booster are shown in Fig. 17 *I*, the line pressure being raised from 2,080 to 2,184 volts or 5 per cent. The connection at *II* is that for an augmented booster in which the line pressure is raised from 2,080 to 2,190 volts, because the primary of the booster is connected across the line on the far side and the boost r is boosted as well as the line. This gives an increase of 5.5 per cent. in the line pressure.

Fig. 17 *III*, shows a 10 per cent. simple booster and *IV* an augmented 11.1 per cent. booster.

The transformers shown in Fig. 17 have a 10 or 20 to 1 ratio and the percentages shown apply only to transformers of this ratio. If boosters having a ratio of 2,080 to 115–230 are used the percentages are increased about 10 per cent. Fig. 17 *I* would then become 5.5 per cent.; *II*, 6.05 per cent.; *III*, 11.1 per cent.; *IV*, 12.2 per cent.

34. **The proper connection of the secondary for a booster or choke transformer** must usually be determined by trial for a transformer of any given type, but once determined, any transformer of the same type may be connected in the same manner. The connections shown in Figs. 17 and 18 are correct for transformers of the principal makers.

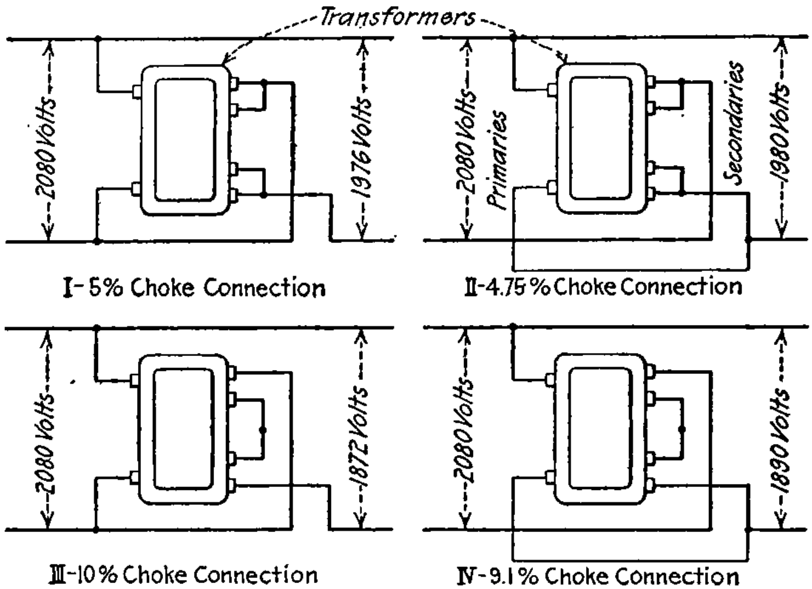


FIG. 18.—Choking transformers.

35. **Boosters are connected in a two-phase circuit** in a manner similar to that shown in Fig. 17 for a single-phase circuit. In three-wire, two-phase feeders the boosters (secondary windings) are cut into the outer wires and the primary windings are connected between the middle and the outside wires.

36. **Booster transformers in three-phase circuits are connected** as shown in Fig. 19 (*Gear and Williams, Van Nostrand Co.*).—The insertion in any phase wire of the booster voltage affects two phases. The boosting and choking effects, with transformers of various ratios, with the boosting transformers used in one, two or three phases are expressed in percentage of the primary voltage in the table of 37.

37. **Voltage Boosting and Choking Effect of Transformers Connected in Three-phase Circuits** (*Electric Central Station Distributing Systems*, Gear and Williams, *Van Nostrand Co.*).—Values in the body of the tables are the percentages that the voltages will be increased or decreased respectively by the insertion of booster or choking transformers, of different ratios, in one, two

or three, of the phase wires. Transformers are connected for boosting as shown in Fig. 19. The letters *AB*, *BC* and *CA* refer to the three phases of Fig. 19.

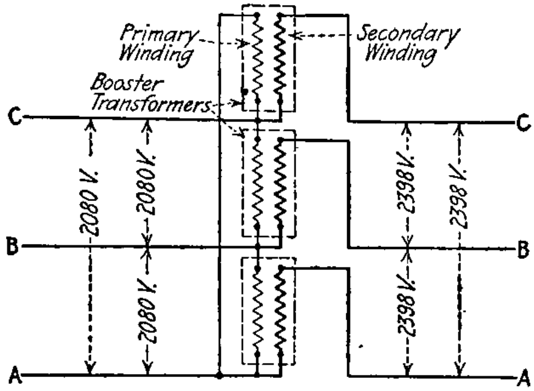


FIG. 19.—Booster transformers in a three-wire, three-phase circuit.

	Boosting											
Ratios	10 to 1			20 to 1			9 to 1			18 to 1		
Booster in	AB	BC	CA	AB	BC	CA	AB	BC	CA	AB	BC	CA
A phase	10.0	10.0	5.3	5.00	0.00	2.65	11.0	0.0	5.8	5.5	0.00	2.9
A and B	15.3	10.0	5.3	7.65	7.65	2.65	16.8	5.5	5.8	8.4	2.75	2.9
A, B and C	15.3	15.3	15.3	7.65	7.65	7.65	16.8	16.8	16.8	8.4	8.40	8.4
	Choking											
A phase	10.0	0.0	4.6	5.0	0.0	2.3	11.00	0.00	5.06	5.5	0.00	2.53
A and B	14.6	10.0	4.6	7.3	5.0	2.3	16.06	11.00	5.06	8.3	5.50	2.53
A, B and C	14.6	14.6	14.6	7.3	7.3	7.3	16.06	16.06	16.08	8.03	8.03	8.03

38. An arrangement of standard transformers, connected as auto-transformers, and boosters to provide 2,080 volts from a four-wire, three-phase system is shown in Fig. 20. This is taken from Gear and Williams' "*Central Station Distributing Systems*" (*Van Nostrand Co.*). The installation served was a 300-kw., 2,080-volt, three-phase motor and the source of energy was a four-wire, Y-connected system operated at about 2,160 volts between each phase wire and neutral or 3,740 between phases.

The only transformers available were six, 50 kw., units, having primary coils wound for 1,040 or 2,080 volts and secondary coils for 115 or 230 volts. By connecting these transformers for 1,040 volts on the primary and arranging two in series from each phase wire to neutral with secondaries in parallel, it was possible to tap the motor circuit off at half the line pressure. The line pressure being but 3,740, the additional voltage required to provide 4,160 volts was secured through the use of a 9 to 1 booster in each phase.

39. Choking Transformers (Gear and Williams in *Electric Central Station Distributing Systems, Van Nostrand Co.*).—When the secondary is connected in reverse order the transformer becomes a "choke," depressing the line pressure instead of raising it. This method of connection is useful where less pressure is desired.

Examples.—A 5 per cent. choke connection is shown in Fig. 18 *I*, a 4.75 per cent. choke in *II*, a 10 per cent. choke in *III* and a 9.1 per cent. choke in *IV*.

The transformers shown in Fig. 18 have a ratio of 10 or 20 to 1 and the percentages shown are only for transformers of that ratio. If choking transformers having a ratio of 2,080 to 115–230 are used, the choking percentages would be decreased to the following values: Fig. 18 *I*, 5.5 per cent.; *II*, 5.24 per cent.; *III*, 11 per cent.; and *IV*, 10 per cent.

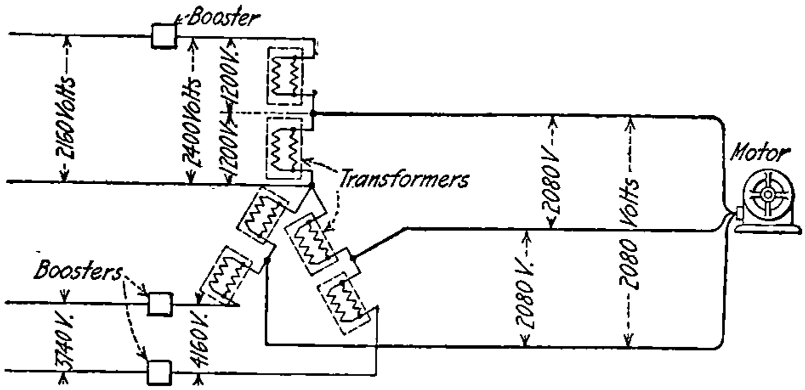


FIG. 20.—Arrangement of standard transformers, connected as auto-transformers and boosters to provide 2,080 volts from a four-wire, three-phase system.

40. There are certain precautions that should be observed in the installation of boosters (Gear and Williams, *Electric Central Station Distributing Systems*), to protect them from injury. The booster secondary is in series with the line and current is drawn through its primary windings in proportion to the load on the line. If the primary of the booster is opened while the secondary is carrying the line current the booster acts as a choke coil in the main circuit. This causes a large drop of pressure in the booster, imposing upon its secondary windings a difference of potential of two to five times normal. Under these conditions the insulation of a 2,000-volt transformer may be subjected to a pressure of 10,000 to 20,000 volts or more depending upon the load carried by the main circuit at the time.

If a fuse is used in the primary its blowing creates the above condition and the arc holds across the terminals of the fuse block until it burns itself clear. It has often been observed that where boosters have been "protected" by fuses in this way, the transformer has burned out shortly after the blowing of its primary fuses if not at the time.

41. Booster Cut-out (Gear and Williams).—In connecting or disconnecting a booster the main line should be opened before putting it in or out. If service on the line cannot be interrupted, or if it is desired to switch the booster in or out at certain times, it may be done with a series arc cut-out as in Fig. 21. The operation of the cut-out simultaneously opens the primary and short-circuits the secondary of the booster. The switch must be of a type having a positive action so that arcing will not damage its contacts at the moment the secondary is short-circuited. The arc cut-out must have sufficient carrying capacity to carry the main-line current when the booster is shunted out and standard series arc cut-outs should not be used where the line current is likely to exceed 20 to 25 amp.

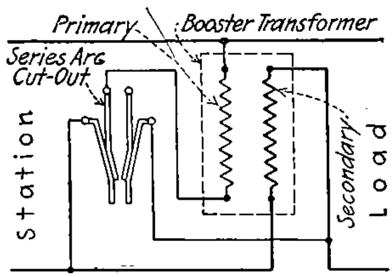


FIG. 21.—Series arc cut-out for a booster.

When the augmented booster is used the terminals of the primary winding of the transformer which goes to the cut-out should

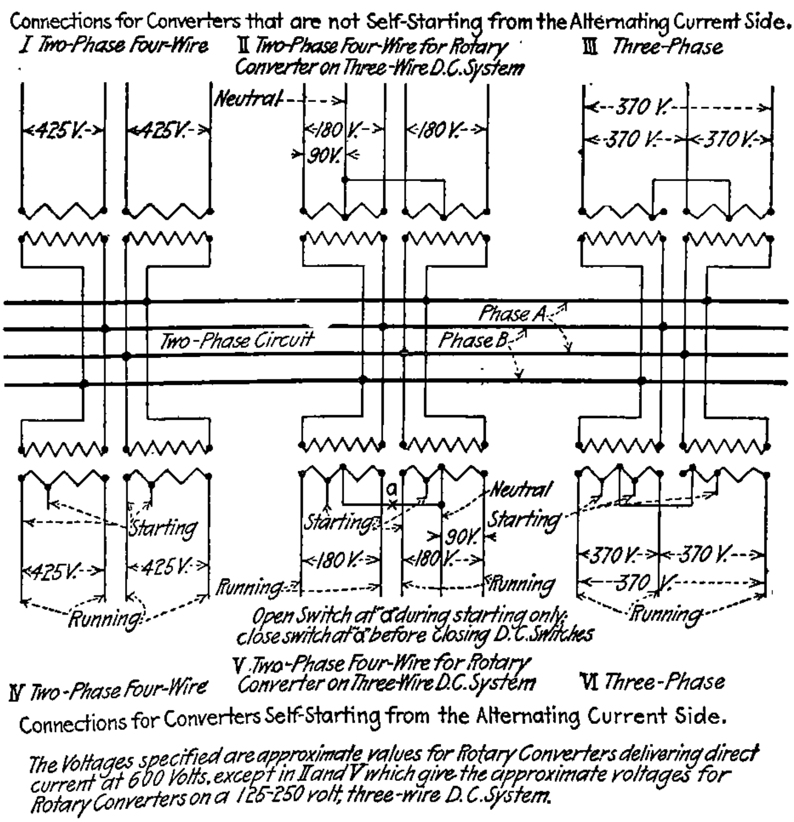


FIG. 22.—Connections for transformers serving rotary converters from a two-phase system. (*Westinghouse Electric & Manufacturing Co.*)

be connected to that terminal of the cut-out which is shown as not being in use in Fig. 21.

42. **Transformers for serving rotary converters** may be con-

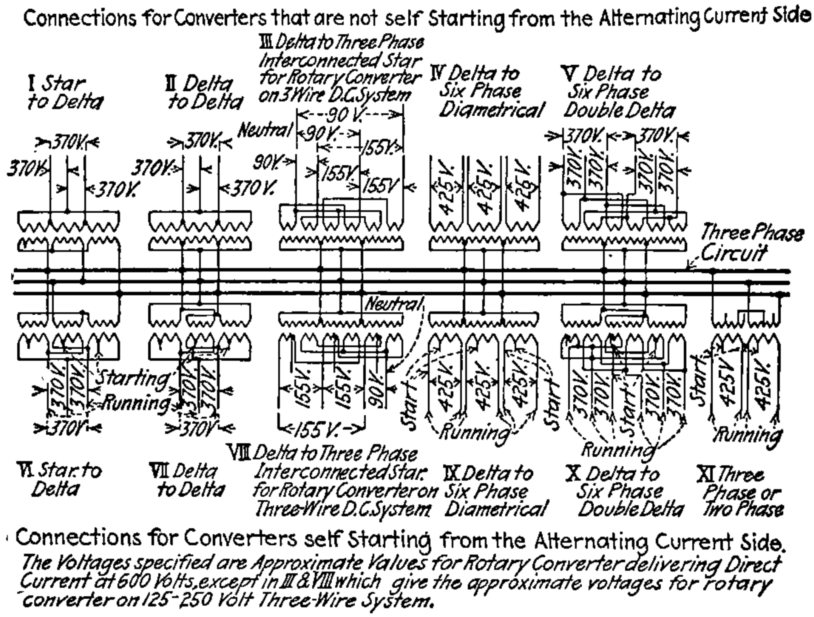


FIG. 23.—Connection for transformers serving rotary converters from a three-phase system. (*Westinghouse Electric & Manufacturing Co.*)

nected as indicated in Figs. 22 and 23 which show Westinghouse standard practice. The secondary voltages given are (with four exceptions) the ones that should be impressed on the alternating-current sides of converters so that the converters will produce a direct-current voltage of 600 for railway work. The four exceptions are noted in the illustrations.

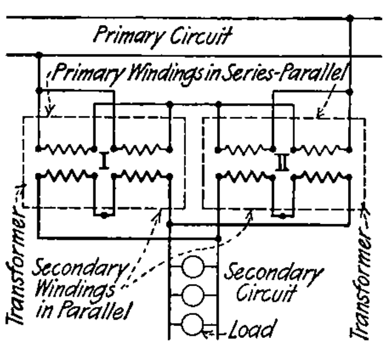


FIG. 24.—Connection for forcing parallel operation of transformers which have different impedance characteristics.

43. **A method of forcing equal division of load between transformers having considerably different impedance characteristics** (A. D. Fishel, *Distributing Transformers*) is shown in Fig. 24. Standard, 2,200-volt distributing transformers are usually provided with arrangements for the series-parallel connecting of both the high-tension and the low-tension windings and therefore the connections shown can be used. As the high-tension windings are in series the currents in the primary windings will be the same, hence the transformers will be equally loaded.

44. Transformer Connections for Obtaining 250 and 400 Volts from a 1,150-volt Line for Starting and Running a Motor (H. W. Young, *Electric Journal*).—The motor is a 20-h.p., 60-cycle machine. To supply 20 h.p. will require approximately 20 kw., which, in three transformers, corresponds to approximately three 7.5-kw. units. If these are connected to give a 5 to 1 ratio, 1,150 volts on the primary will give 230 volts for the secondary. If the transformers are connected with the high-tension windings in delta and the low-tension windings in star, as shown in Fig. 25 *I*, the ratio of the three-phase transformation will be 1,150 to 400 as desired, and by using the middle point of the low-tension windings, 200 volts will be available for starting the motor. Usually such motors will start very satisfactorily on one-half voltage.

As another solution: Two 15-kw. and two 3-kw. transformers may be connected in V with one 15-kw. and 1-kw. transformer on each leg, as shown in Fig. 25 *II*. With one of the 15-kw. transformers connected with a ratio of 2.5 to 1, 1,150 volts high tension

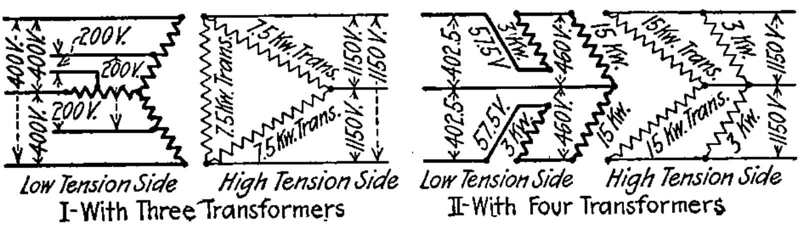


FIG. 25.—Connections for obtaining 250 and 400 volts from a 1150-volt line.

will give 460 volts low tension. The 3-kw. transformers should then be connected to give a ratio of 20 to 1, so that 1,150 volts will give 57.5 volts low tension. If the 15- and the 3-kw. transformers be connected in parallel on the high-tension side to the 1,150-volt line and in series on their low-tension windings, so that the 3-kw. transformer winding will oppose that of the 15-kw. transformer, the resultant voltage will be 460 minus 57.5 or practically 400 volts. The middle point of the 15-kw. low-tension transformer gives 230 volts, which is fairly close to that desired for starting the motor.

Note that the normal low-tension current of the 15-kw. transformer at 400 volts is 37.5 amp., and 30 amp. for the 3-kw. transformer at 100 volts, so that the current capacities of the transformers are sufficient for the three-phase load of 20 kw. at 400 volts, which correspond to approximately 29 amp. ($20{,}000 \div 1.73 \times 400$). Obviously, two 7.5-kw. or one 10-kw. transformer and one 5-kw. transformer might be substituted for the 15-kw. transformer and the 3-kw. transformer might be replaced by a 4-kw., a 5-kw., or two 1.5-kw. transformers, if any of these are available.

45. Obtaining 7.5 kw. at 500 Volts from a 60-cycle 1,000-volt Circuit with Standard Transformers (H. W. Young, *Electric Journal*).—As the high-tension voltage of the standard 1,050-volt transformer is substantially that required and the frequency normal the problem is one of determining a method for obtaining the secondary voltage of 500. The 500 volts may be secured by connecting two transformers in series (Fig. 26 *I*) the sum of the voltages of which will be that desired. If, then, a 5-kw. transformer connected as shown for 1,000 to 400 volts be used in combination with a 1.5-kw. transformer with a ratio of 1,000 to 100 the low-tension windings in series will yield 500 volts and the high-tension windings in parallel 1,000 volts as desired.

The current required on the low-tension side is 15 amp. ($500 \times 15 = 7.5$ kw.) which is the normal current for the 1.5-kw. unit but corresponds to a 600-kw. unit with a 400-volt secondary. That is, the 5-kw. unit will be overloaded 20 per cent. This is permissible as the iron loss is considerably reduced due to the lower voltage.

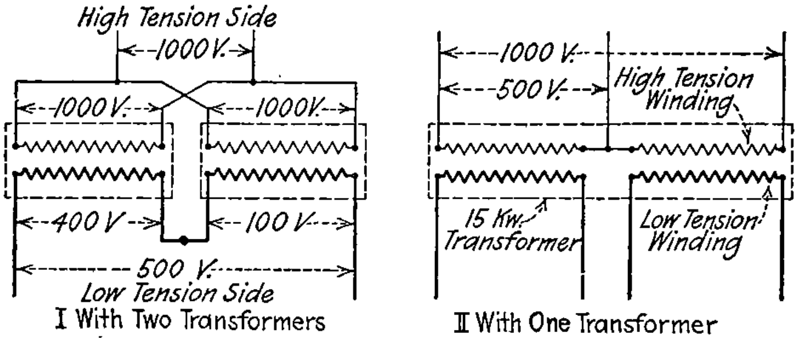


FIG. 26.—Connections for obtaining 500 volts from a 1000-volt circuit.

Instead of the 5-kw. unit, two 3-kw. units might be connected at a ratio of 1,000 to 400 with both high-tension and low-tension windings in parallel and these in turn might be connected in series on the low-tension side, with the 1.5-kw. transformer above referred to, and in parallel on the high-tension side.

Another method would be to employ a 15-kw. transformer as an auto-transformer (Fig. 27 *II*) using only the high-tension winding. In this case, 1,000 volts would be impressed over the high-tension winding when 500 volts could be taken from one-half of the winding as shown. With this arrangement the 1,000- and the 500-volt circuit are in electrical connection which may be undesirable.

46. Transforming from 360 Volts to 2,400 Volts with Standard Transformers (H. W. Young, *Electrical Journal*).—The arrangement described hereinafter (Fig. 27) was devised for the emergency supply, of a town four miles distant, from a 360-volt generator serving rotary converters. A standard transformer at 120 volts with a 20 to 1 ratio, or at 240 volts with a 10 to 1 ratio gives 2,400 volts high tension. (These voltages are considerably higher than normal although permissible in cases of emergency.) It is evident that $120+240=360$. That is, if two transformers are used with their high-tension windings in parallel for 2,400 volts and their low-tension windings in series, one connected for 240 and the other for 120 volts, the group will operate at a ratio of 360 volts to 2,400 volts. The transformers were thus connected and energy was efficiently transmitted the four miles at 2,400 volts. Note that full-load current for the 10-kw. transformer at 240 volts corresponds to the current of the 5-kw. transformer at 120 volts, thus permitting the operation of the transformers in series on the low-tension side as indicated.

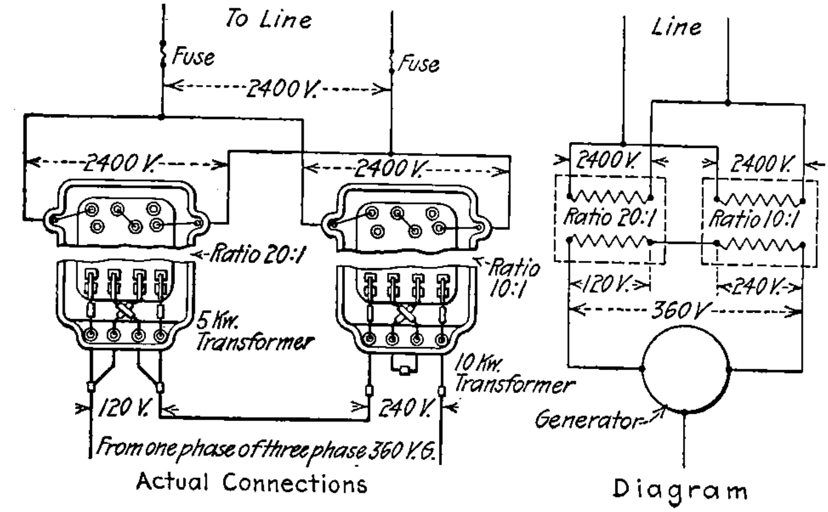


FIG. 27.—Feeding a 2,400-volt line with standard transformers from a 360-volt source.

PARALLEL OPERATION

47. Parallel Operation of Transformers.—Transformers will operate satisfactorily in parallel (Fig. 28), that is, with their

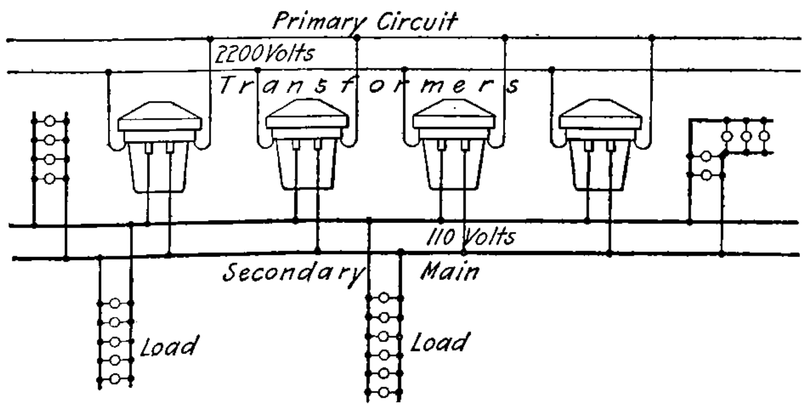


FIG. 28.—Transformers banked or operating in parallel.

high- and low-tension windings respectively connected directly to the same circuits provided—(1) they have the same ratio of transformation, (2) the same voltage ratings and (3) approximately the same regulation. If the low-tension voltages are different the transformer having the highest voltages will circulate current to those of lower voltage and cause a continuous loss. If transformers connected in parallel do not have the same regulation they will not share the total load in proportion to their ratings. The greater share of the load will be taken by the transformer having the best regulation.

In connecting large transformers in parallel, especially when one of the windings is for a comparatively low voltage, it is necessary that the resistance of the joints and interconnecting leads does not vary materially for the different transformers or it will cause an unequal division of load.

48. **With transformers of the same general voltage and capacity characteristics connected in multiple in a secondary network** (*Distributing Transformers*, A. D. Fishel) little trouble will be encountered as the impedance of the line between two transformers on separate poles spaced about 100 or 200 ft. apart will normally neutralize any difference in the transformer impedances. When transformers operated in multiple are placed on the same pole the question of equal sharing of the load may be of some importance. The standard transformers of reliable manufacturers do not differ very widely in impedance characteristics however, and it is usually practicable to operate transformers of the various standard types in parallel. Often the commercial desirability of paralleling transformers of different sizes will overbalance the undesirability of some inequality in the sharing of the load which might result.

49. **Polarity of Transformers.**—The windings of a transformer are usually so connected to the leads extending out through the case that the direction of flow of the alternating current or the polarity of the transformer at any given instant is the same in all the corresponding leads of transformers of the same type.

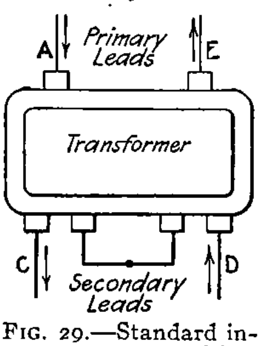


FIG. 29.—Standard instantaneous polarities.

For example: The transformer of Fig. 29 is so connected internally that at an instant when current is flowing inwardly through the primary lead *A* it flows outwardly through the secondary lead *C*. The polarities of the single-phase transformers of practically all of the large companies are as shown in Fig. 29. Where a transformer of a certain polarity is connected without transposing its leads, in parallel with one of a different polarity the effect is the same as that of a short-circuit on both units. Where such an incorrect connection has been made it can be corrected by reversing either the primary or the secondary leads.

50. **The Arrangement of the Windings of a Transformer does not Necessarily Determine its Polarity.**—Polarity—so called—has to do only with the plan or arrangement adopted in bringing the leads out of the case. Interchanging the positions of the leads that extend through the bushings in the case will change the polarity of the transformer.

51. **Tests for Polarity of Single-phase Transformers.**—Where a standard transformer of known correct polarity and of the same

ratio and voltage as the transformer to be tested is available the following simple method can be used:—Connect together (Fig. 30 *I*) the high-tension and the low-tension leads as if for parallel operation, inserting a fuse in one of the secondary leads. If both transformers are of the same polarity, no current will flow in the low-tension windings and the fuse will not blow. If the transformers are of opposite polarities the low-tension windings will short-circuit each other and the fuse will blow. The fuse should be sufficiently small that there can be no possibility of injuring the transformers.

A method of testing for polarity of single-phase transformers with a voltmeter is shown in Fig. 30, *II*. Connect the transformer as shown. Make successively voltmeter readings V, V_1, and V_2. If the transformer has standard polarity, $V+V_1$ will

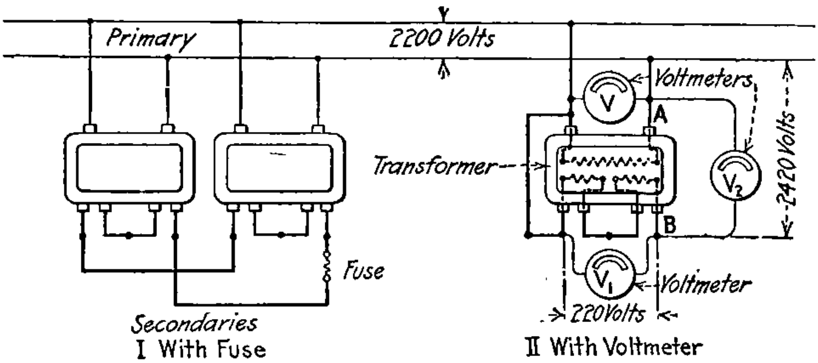


FIG. 30.—Testing transformers for polarity.

equal V_2. If the transformer is of non-standard polarity V_2 will equal $V-V_1$. For example, in Fig. 30, *II* the transformer is of standard polarity and the primary line voltage, V (2,200 volts) plus the secondary transformer voltage V_1 (220 volts) equals the voltage between A and B or 2,420 volts. With an incorrect polarity the voltmeter V_2 would read (2,200 − 220) 1,980 volts.

52. Polarity of Single-phase Transformers Connected in Banks on Three-phase Circuits (W. M. McConahey, *Electric Journal*, July, 1912).—A standard star-delta connection with six single-phase transformers is shown in Fig. 31. The polarity of *No.* 6 is the reverse of that of the other five. If the polarity of all six transformers were the same, *No.* 6 would be connected in a manner similar to that of *No.* 3 instead of having the connections of one winding reversed. If the polarity of all the transformers is the same, all banks should be connected to the line in exactly the same manner. It is possible to connect one bank differently from the others and still secure parallel operation but this is not advisable, because it is liable to lead to confusion and trouble. It is best to adopt one scheme of construction and to adhere to it.

53. Some Three-phase Transformers can be Paralleled and Some cannot (W. M. McConahey, *Electric Journal*, July, 1912).—A transformer having its coils connected in delta on both high-tension and low-tension sides cannot be made to parallel with one connected either in delta on the high-tension and star on the low-tension or in star on the high-tension and in delta on the low-tension side. However, a transformer connected in delta on the high-tension and in star on the low-tension can be made to parallel with

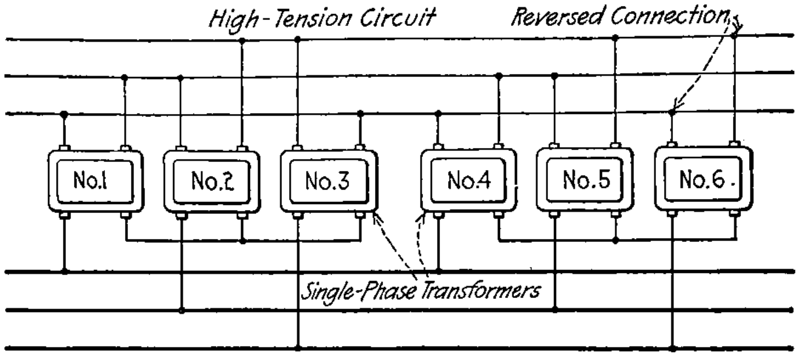


FIG. 31.—Single-phase transformers connected in a bank on a three-phase circuit.

transformers (having their coils joined in accordance with certain schemes) connected in star on the high-tension side and in delta on the low-tension side. Some three-phase transformers cannot be made to parallel (without changing the internal connection arrangement of their coils) with others using the same type of connections for the two windings. For example, a transformer connected delta to delta may have its coils so interconnected that it will not parallel with another transformer connected delta to delta. By changing the internal connections between the coils, however, it will be possible to bring out the terminals in such a way that parallel operation can be obtained.

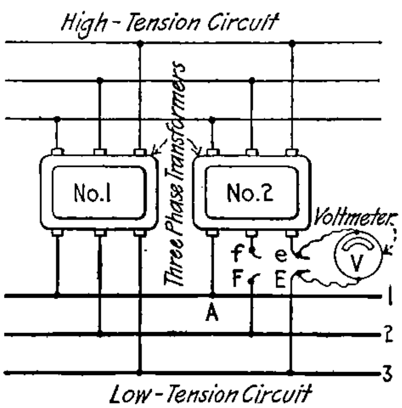


FIG. 32.—Testing three-phase transformers for parallel operation.

54. How to Determine whether or not Three-phase Transformers will Operate in Parallel.—If the transformers are available connect them as indicated in Fig. 32 leaving two leads on one of the transformers unjoined. Test with a voltmeter across the unjoined leads. If there is no-voltage between *E* and *e* or between *F* and *f* of transformer *No.* 2 the polarities of the transformers are the same and the connections can be completed and the transformers put in service.

If a voltage difference is found between *E* and *e* or between *F* and f or between both, the polarities of the transformers are not the same. Then connect transformer lead A successively to mains 1, 2 and 3 and at each connection test with the voltmeter between e and f and the legs of the main to which lead A is not connected. If with any trial connection the voltmeter readings between f and e and either of the two legs is found to be 0 (zero) the transformer will operate with leads f and e connected to those two legs. If no system of connections can be found that will satisfy this condition the transformer will not operate in parallel without changes in its internal connections and it may be that it will not operate in parallel at all. See another paragraph on this subject.

For a very complete discussion of this subject and the description of a method whereby it can be determined by voltmeter tests whether or not two three-phase transformers which cannot be brought together for a practical test will or can be made to operate in parallel, see article in *Electric Journal* for July, 1912, by W. M. McConahey. The above material is largely abstracted from this article.

THREE-PHASE TRANSFORMERS

55. Three-phase Transformers (*Standard Handbook*).—Although there are numerous possible arrangements of the coils and cores in constructing a polyphase transformer yet it may be stated that a polyphase transformer generally consists of several one-phase transformers with separate electric circuits but having certain magnetic circuits in common. A three-phase transformer is illustrated in Fig. 33 together with the component one-phase trans-

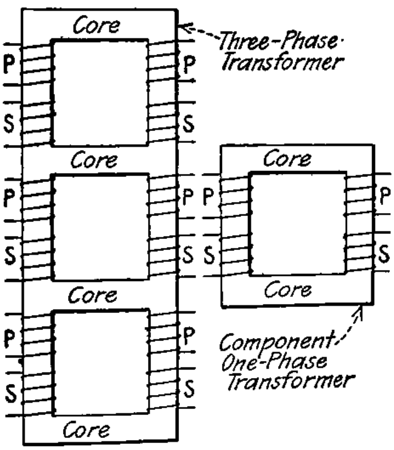


FIG. 33.—Three-phase core-type transformer.

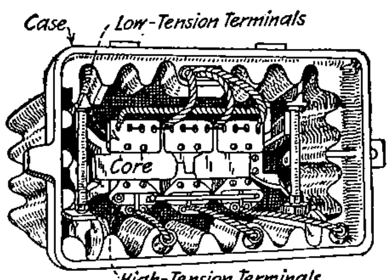


FIG. 34.—Interior view of a Westinghouse three-phase transformer.

former. It will be observed that a three-phase transformer requires three times as much copper as the one-phase component transformer, but less than three times as much iron. Thus in comparison with three individual transformers the three-phase unit is somewhat lighter and more efficient. Each component transformer operates as though the others were not present, the flux of one transformer combining with that of an adjacent transformer to produce a resultant flux exactly equal to that of each one alone. Fig. 34 shows the interior of a Westinghouse three-phase transformer.

56. Application of Three-phase Transformers (A. D. Fishel).—For central stations of medium sizes, three-phase transformers are rarely superior to single-phase except where the larger sizes can be applied in which cases the transformers are normally installed in sub-stations or central stations. The chief reason for this is the non-flexibility of a three-phase transformer. It is usually purchased for a particular size and type of load, and if that load should be changed, the transformer, representing a comparatively heavy investment, remains on the hands of the central station, whereas a single-phase transformer of one-third the size, could usually be adapted for some other service.

This feature becomes of less importance as the central station increases its size, and three-phase transformers for purely power service are now being used by a considerable number of the large central stations of this country. The three-phase transformer costs less to install and the connections are simpler, points that are of importance in connection with outdoor installations. The fact that a failure of a three-phase transformer would interrupt service more than the failure of one single-phase transformer in a bank of three, is of little importance because of the comparatively few failures of modern transformers. On the other hand, especially for 2,200 volt service, the single-phase transformer has been carried to a high degree of perfection, and is manufactured in much larger quantities, so that better performance is usual and in some cases, a lower initial cost. At present (1912) the three-phase distributing transformer is used by central stations in cities of 100,000 population or less only for special applications and not for standard power service.

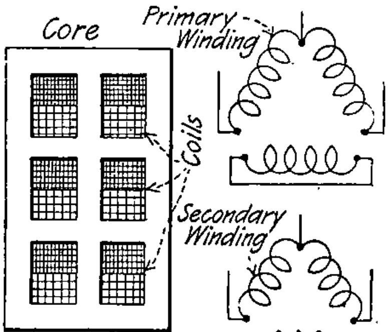


FIG. 35.—Operating a damaged three-phase transformer.

57. Methods of Connecting the Windings of Three-phase Transformers (*Standard Handbook*).—The windings of each component transformer are connected to the external circuits just as though this component were a one-phase unit; that is, the primaries may be connected either Y or delta. Moreover the relative advantages of the Y-connection and the delta-connection are quite the same with one three-phase transformer as with three one-phase transformers. The delta-connection is advantageous in some cases in that if the windings of one phase become damaged by short-circuiting, grounding or through any other defect it is possible to operate with the other phase windings V-connected.

58. In operating a damaged three-phase transformer on two coils it is necessary to separate the damaged transformer windings electrically from the other coils, as indicated in Fig. 35. The high-potential winding of the damaged phase should be short-circuited upon itself and the corresponding low-potential winding should also be short-circuited upon itself. The winding thus short-circuited will choke down the flux passing through the portion of the core surrounded by them without producing in any portion of the winding a current greater than a small fraction of the current which would normally exist in such portion at full load.

AUTO-TRANSFORMERS OR COMPENSATORS

59. The Auto-transformer (*Standard Handbook*).—The most efficient and effective method of operating a stationary transformer (when the ratio of transformation is not too large) is as an auto-transformer; that is with certain portions of the windings used simultaneously as the primary and the secondary circuit. The electrical circuits of a one-phase auto-transformer (sometimes called a "compensator" or a "balance coil") are indicated in Fig. 36. The auto-transformer has only one coil a certain portion of which is used for both the high-tension and the low-tension winding. The number of turns of this coil is the same as would be required if it were used exclusively for the high-tension winding and a separate additional coil were used for the low-tension winding. Moreover, when the ratio of transformation is 2 to 1 or 1 to 2, the amount of copper in the one coil is exactly the same whether it is used as an auto-transformer or as a high-tension coil of a two-coil transformer of the same rating. Not only is there less copper required for an auto-transformer than for a two-coil transformer but less iron is needed to surround the copper.

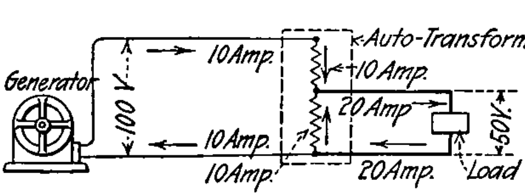


FIG. 36.

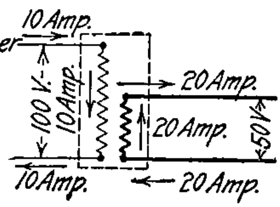


FIG. 37.

FIG. 36.—Electric circuits of a 1-kw., single-phase auto-transformer.
FIG. 37.—Electric circuits of a 1-kw., single-phase, two-coil transformer equivalent to the auto-transformer of Fig. 36.

Referring again to Fig. 36 it is to be noted that the one-coil is designed for 10 amp. throughout and for a total e.m.f. of 100 volts. Evidently the voltage per turn is uniform throughout, so that to obtain 50 volts it is necessary merely to select any two points on the continuous winding such that one-half of the total number of turns is included between them. The load current of 20 amp. (required for 1,000 watts at 50 volts) is opposed by the superposed 10 amp. of primary current, so that even in this section of the coil the resultant current is only 10 amp.

If an ordinary two-coil transformer had been used, the circuits would have been as noted in Fig. 37, while the required constructive material would have been approximately as indicated in Fig. 38 *I*. So far as concerns its constructive material, a 1-kw., 2 to 1 ratio auto-transformer is the equivalent of a 1 to 1 ratio 0.5 kw., two-coil transformer as shown in Fig. 38, *II*. The latter transformer requires about 14 lb. of copper and 28 lb. of iron as compared with about 22 lb. of copper and 34 lb. of iron for the transformer of Fig. 38, *I*. Moreover, the losses of the auto-transformer are correspondingly less than those of a two-coil transformer.

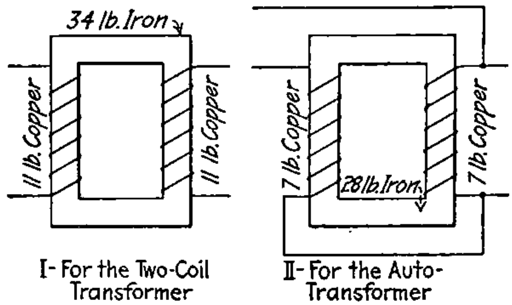


FIG. 38.—Comparison of constructive material required for a transformer and for an auto-transformer.

60. Standard Transformers used as Auto-transformers.—The applications shown in Figs. 39 and 40 are from Gear and William's *Central Station Distributing System*. The connections of Fig. 39, *I* are those for providing a 110-volt distribution on a 220-volt system. The load is assumed as 20 amp. The arrow-heads and figures indicate the distribution of current in the windings. Obviously a transformer of a wattage equal to that of the load, is

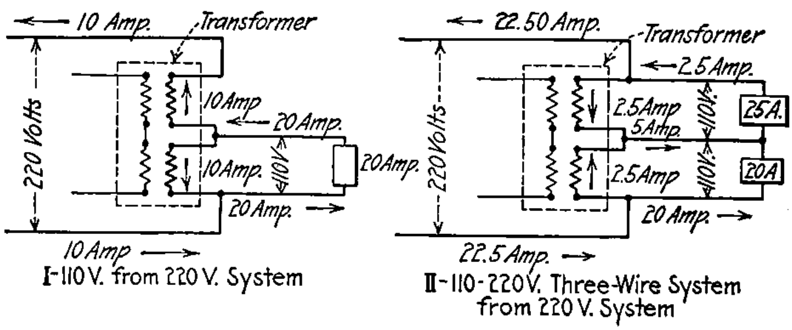


FIG. 39.—Standard transformers used as auto-transformers.

required. At *II* the connections for a 110–220-volt three-wire system are shown. The transformer winding carries only the unbalance of current in the two sides of the system. The transformer secondary winding need be only large enough to carry the largest unbalance that is likely to occur. In the methods of both *I* and *II* the transformer primaries are left open and are not used.

Figure 40 shows other arrangements. At *I* is a connection arrangement that can be used in a 440-volt plant where 110–220-volt lighting is required. Two transformers are connected in series with their secondary windings in series and their primary windings in parallel. It is important that the primaries be in parallel as the second transformer will, if the primaries are left open, act as a choke to the lighting current. For a 110–220-volt system as shown, transformers each of capacity equal to the load are required. A similar 110-volt distribution system requires that the

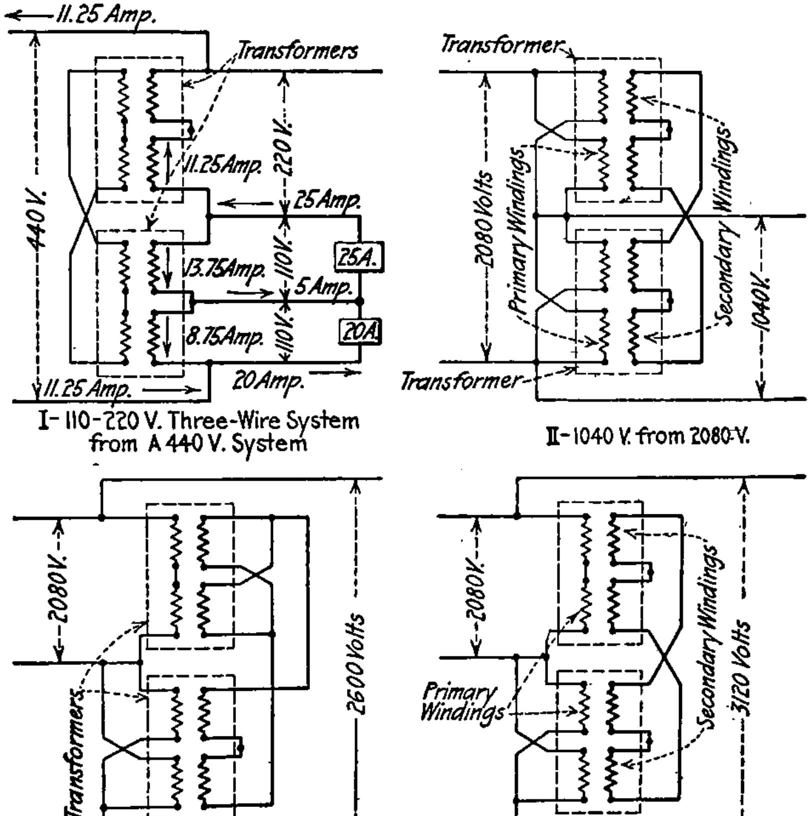


FIG. 40.—Standard transformers used as auto-transformers.

transformer on the side on which the lights are connected have a capacity of 1.5 times the load and the other one must carry half the load, making the total capacity twice the load.

Figures 40, *II*, *III* and *IV* show respectively methods whereby 1,040, 2,600 or 3,120 volts can be secured from a 2,080-volt system by the use of two transformers in series on the primary side and in multiple on the secondary side.

61. A common application of the auto-transformer is as a balance coil in a three-wire distribution from a two-wire supply as indicated in Fig. 41, *I*. In this diagram the supply is at 200 volts, two-wire and a 2 to 1 ratio auto-transformer allows the distribution to be at 100+100 volts, three-wire. In Fig. 41, *II* the supply is at 100 volts, two-wire, while a 1 to 2 ratio auto-transformer permits distribution at 100+100 volts, three wire.

When used on a 220-volt two-wire circuit to provide a three-wire, 110-volt system, the balance coil maintains balanced voltages between the two sides of the system regardless of load conditions provided its capacity is not greatly exceeded.

62. Capacity and Ratings of Balance Coils.—The capacity of a balance coil for three-wire service is determined by the unbalanced load or the difference in load between the two circuits. For example, if there are 50 lights on one side of the coil and 100 on the other, the actual load on the coil is 50 lights. If there are 200 lights on one side and 150 on the other, the load on the coil is, as before, 50 lights; *i.e.*, the difference between the loads on the two

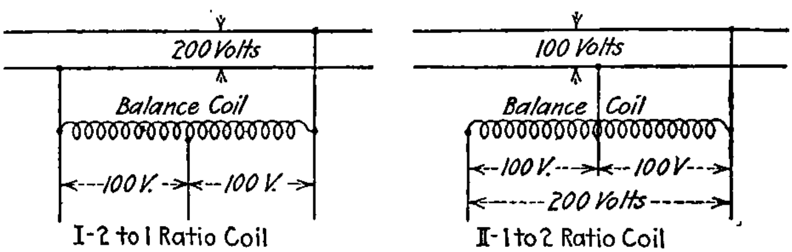


FIG. 41.—Auto-transformers used as balance coils.

circuits determines the load on the coil. Or stating it in another way: The kva. capacity of a coil represents the normal unbalancing allowable between the side circuits.

The reason for this is that only the unbalanced current flows through the coil, and on this account a balance coil may be placed on a circuit supplying any number of lights, provided that the difference between the loads on the two circuits does not exceed the capacity of the coil. In selecting a three-wire balance coil, one having a capacity sufficient for supplying one-half the total number of lights on the two circuits is sometimes chosen, so that all the lights on one circuit may be turned off without overloading the coil. This, however, is a very conservative rating and if accurate data regarding the operating conditions of the coil are obtainable, a smaller size may frequently be used. It is probably more frequent practice to consider that the unbalance will be 10 per cent. and for this condition a coil of a capacity equal to 10 per cent. of the total load on both side circuits is used. But even with the above conservative rating, the balance coil is lower in first cost, lighter in weight and much more efficient in operation than a transformer with separate primary and secondary windings. The kva. rating of a five-wire balance coil represents the maximum unbalancing allowable between any two side circuits.

The internal losses in the balance coil, both in the iron core and in the windings, are much less than in a two-coil transformer for equivalent service. This comparison between the two-coil transformer and the balance coil holds in a general way for all classes of service, regardless of the ratio of transformation.

63. Commercial balance coils are usually oil cooled and mounted in transformer cases (Fig. 42). The coil most in demand is one for supplying a 110–220 volt three-wire circuit from a 110- or a 220-volt main. Coils for 440 to 220 volts are frequently furnished. Balance coils for supplying five-wire circuits are occasionally made. They may be for use on 440-volt circuits and have two outside and three intermediate leads, a total of five in all.

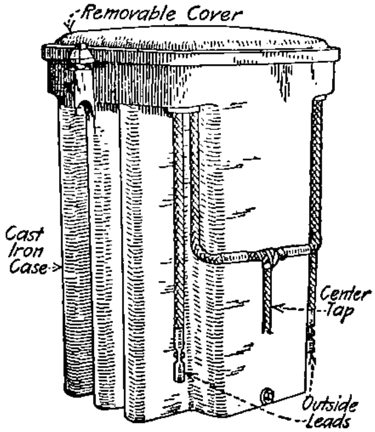


FIG. 42.—Westinghouse balance coil.

64. Another application of the auto-transformer is as a starting compensator for alternating-current motors. The compensator supplies a reduced voltage to the motor circuits while the machine is accelerating from rest. Ordinarily each auto-transformer is provided with several taps so that a number of low voltages may be obtained.

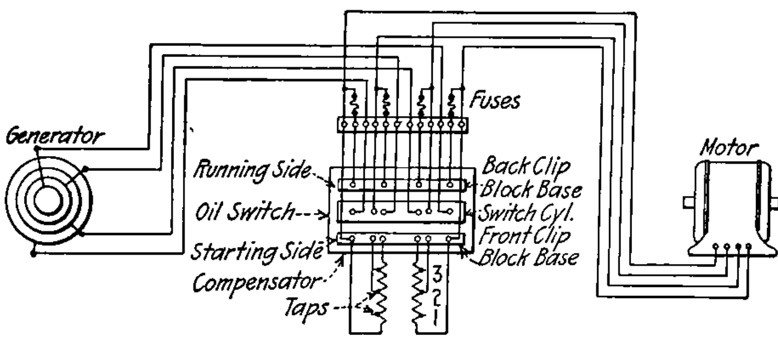


FIG. 43.—Two-phase starting compensator.

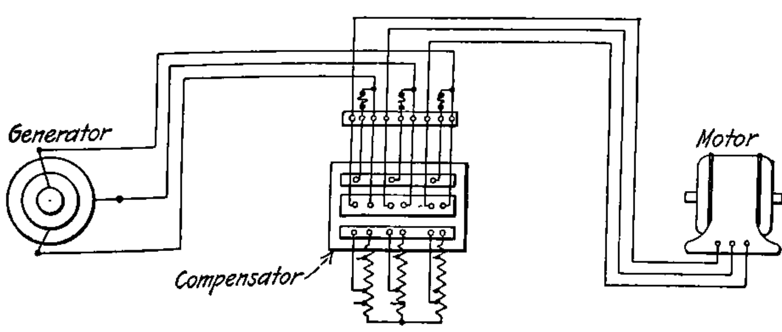


FIG. 44.—Three-phase starting compensator.

65. A starting compensator arrangement for a two-phase induction motor (*Standard Handbook*) is shown in Fig. 43. There are two auto-transformers, the two separate phase lines being connected to the ends of the separate auto-transformer windings.

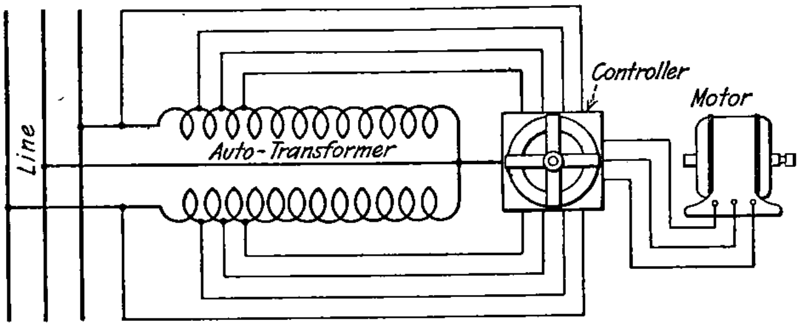


FIG. 45.—An auto-transformer, three-phase, starting compensator.

During the starting period the motor is connected between two of the ends and two intermediate taps. Fig. 44 shows a starting compensator arrangement for a three-phase induction motor. The three auto-transformer windings are Y-connected and low-voltage points are permanently selected along each leg of the Y. It is not necessary to employ three auto-transformers for starting a three-phase motor; two V-connected auto-transformers are quite satisfactory for this purpose. Fig. 45 shows two V-connected auto-transformers for starting a three-phase induction motor and operating it at four different voltages.

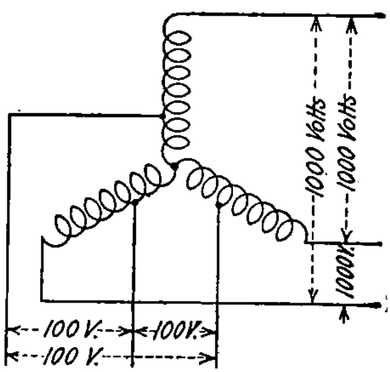


FIG. 46.—Y-connected, three-phase auto-transformer.

66. The coils of a three-phase transformer can be connected for operation as an auto-transformer, equally as well as can those of a one-phase transformer. The interconnections would ordinarily be by the Y-method although the delta-method or a combination of the Y- and delta-methods may be used. Fig. 46 represents a Y-connection for auto-transformer operation.

TRANSFORMERS OF SPECIAL FORMS

67. Transformers and Auto-transformers for Sign Lighting.—Low-voltage tungsten lamps cost less and have stronger filaments, consequently longer lives than have high voltage lamps. Hence lamps of a voltage of about 10 are widely used for signs. To produce this low voltage from ordinary 110- or 220-volt lighting circuits, small transformers or auto-transformers, especially made for the purpose by several manufacturers, are used. The transformers are sometimes called economy coils and the auto-transformers are sometimes called compensators. The transformer is, in general, to be preferred to the auto-transformer because with the transformer the secondary circuit is insulated from the primary which removes the liability of trouble from grounds on the secondary affecting the primary and largely removes the liability of shock from the high-voltage secondary circuit. See material on sign wiring in another section.

The transformers are made of capacities of from 250 to 2,000 watts. As the normal voltage on a low-voltage sign is relatively very low it is desirable that the length of conductor between a transformer and its lamps be maintained at a minimum. This is accomplished by using several small transformers mounted at different points on a sign rather than one large one. Slate bases are required by local rules in certain cities for sign transformers and auto-transformers.

68. The current transformer (*Standard Handbook*) sometimes incorrectly referred to as a "series transformer," considered electrically, and omitting any reference to the change in its design to accomplish its specific duty, differs from the shunt or potential transformer merely in the method of use. The latter transformer is ordinarily supplied with a constant impressed voltage, the load being changed by varying the impedance (load) of the total secondary circuit, while the total impedance of the secondary circuit of the former transformer is normally held constant and the change in load is due to a simultaneous change in the primary current and e.m.f. In the shunt transformer the actual ratio of the primary to the secondary current is of minor importance while every effort is made to so design the apparatus that the ratio of the secondary power to the primary power is as nearly unity as possible. In the design of a series transformer no thought whatsoever is given to the ratio of the primary and secondary watts but attention is concentrated on the endeavor to obtain a definite ratio of secondary to primary amperes.

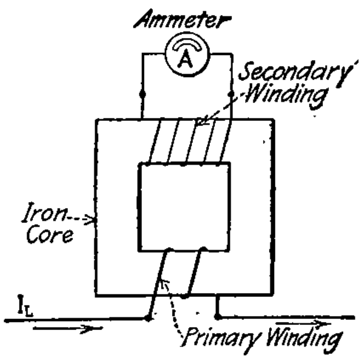


FIG. 47.—Elementary series transformer.

69. The electric and magnetic circuits of a series transformer can conveniently be represented by the diagram shown in Fig. 47, where it is used for reducing the line current to a value suitable for measurement by a low reading ammeter, which may be thoroughly insulated from the main circuit. Note that the current through the ammeter, *A*, is less than the line current *IL* by the core loss current and the exciting current, taken in proper phase relation.

70. Application of the Current Transformer.—When an alternating current is so large that to connect measuring or operating instruments directly in the circuit would be impracticable, or when the voltage is so high that to do so would be unsafe, the current transformer provides a means of reproducing the effect of the primary current on a scale suited to the instrument and of insulating the instrument from the main circuit. It is a special development of the transformer principle in which a constant ratio of primary to secondary current is the important consideration instead of the usual constant ratio of primary to secondary voltage.

Current transformers are used with alternating-current ammeters, wattmeters, power-factor meters, watthour meters, compensators, protective and regulating relays, and the trip coils of circuit-breakers. It is standard practice in this country to design current transformers (regardless of their capacity or ratios of transformation) to supply a full-load secondary current of 5 amp.

For example: A 600-amp. current transfomer has a ratio of 120 : 1, that is, when a current of 600 amp. flows in the primary circuit 600 ÷ 120 = 5 amp. will flow in the secondary circuit.

Measuring instruments for use with these transformers are so designed and are provided with scales such that they give a full scale deflection when 5 amp. flows through them and normally relays trip on a 5-amp. secondary current. One current transformer will supply three or four instruments with operating current without appreciably affecting accuracy.

71. It is Unsafe to Open the Secondary Circuit of a Current Transformer when there is any Current in the Primary.—When the secondary circuit is closed the current in this circuit creates a magnetomotive force which is in opposition to the magnetomotive force of the primary current and the core flux is thereby limited to the value necessary to generate in the secondary coil an e.m.f. sufficient to produce therein a current only slightly less than the primary current in magnetizing effect. When the secondary is open there is no opposing magnetomotive force for limiting the core flux which may reach a high value. Thus even a small value of primary current produces an excessive value of core flux and a correspondingly large secondary e.m.f. The secondary voltage under these conditions reaches a value which may both damage the insulation and prove dangerous to life. Absolutely no harm can come from short-circuiting the secondary terminals of the series transformer, and this method is used when it is necessary to insert or disconnect instruments in the secondary circuit.

72. The Constant-current Transformer (*Standard Handbook*).—The operation of low-voltage arc or incandescent lamps in parallel on a constant potential system necessitates a prohibitive expenditure for conducting material when the area to be lighted is extensive and the lamps are widely separated. For such service it is the common practice to operate the lamps which are connected in series with a constant current. The constant-current transformer is a special form of apparatus which converts alternating current at a constant potential of any value to a constant (alternating) current with a voltage varying with the load. It consists of a primary coil upon which the constant voltage is impressed, a secondary coil (or coils) movable with respect to the primary, and a core of low magnetic reluctance. It depends for its regulation upon the magnetic leakage between the primary and secondary coils.

Consider first the primary coil; with constant e.m.f. impressed upon this coil the total magnetism within the coil will be practically constant under all conditions. The e.m.f. generated in the secondary will depend upon the strength of the field which it surrounds. In all types of stationary transformers the secondary current is opposite in general time-direction to the primary, so that not only is there a repulsive thrust between the two coils but there exists a considerable tendency for the magnetic lines from the primary to be forced out into space without penetrating the secondary. In the ordinary constant potential transformer the repelling action between the two currents is prevented from producing motion of the coils by the rigid mechanical construction, while the proximity of the primary and secondary coils limits the magnetic leakage.

In the constant-current transformer, however, the repelling action is utilized to adjust the relative positions of the primary and secondary coils; when the coils are widely separated the paths for the leakage lines are increased and the lines which the secondary surrounds are fewer than when the coils are quite near together. The counter weights mechanically attached to the movable coil (or coils) are so arranged that when the desired current exists in the secondary coil (independent of its position along the core) the weights are just balanced. An increase in the current increases the repulsion and causes the coils to separate. With any current less than normal, the repelling force diminishes and the primary and secondary coils approach each other thereby restoring the current to normal. The primary can be wound for any reasonable potential (say as high as 10,000 volts) while the secondary can be wound for the voltage required for operating the arc lamps—from 15 to 200 or more lamps.

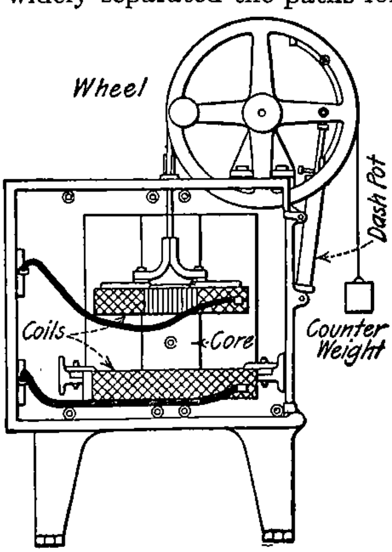


FIG. 48.—Constant-current transformer.

73. Mechanical Construction of the Constant-current Transformer.—The magnetic circuit of a constant-current transformer is usually of the "shell" type, the three limbs being placed vertically. In small sizes (Fig. 48) one of the coils is arranged in a fixed position while the other is movable. In some of the larger sizes there are two fixed primary coils and two movable secondary coils, while in others both the primary and secondary coils are movable. In any event the gravitational action on the movable coil or the gravitational action of one movable coil against another to which it is mechanically interconnected, is counter-balanced accurately with an excess or deficiency just equal to the repulsive thrust of the primary and secondary coils at the desired load current. By the use of cam mechanisms for the counter-weights, or of eccentrically placed extra weights, the excess force of the counter-weights may be arranged to be equal to the variable repulsive thrust corresponding to a constant value of current in the coils at all positions of the movable coils. In fact, the transformer may be adjusted to regulate for a current of constant value at all loads or for one which either increases or decreases with increase of loads, while both the real value of the load current and its rate of change with the variation in load may be adjusted at will. In order to prevent any "hunting" action of the movable coils each transformer is sometimes equipped with a dash-pot. (See Fig. 48.)

74. Commercial constant-current transformers are built for natural air cooling or for immersion in oil. Oil has proved an excellent medium for insulation, cooling and lubrication. This type of transformer is extensively used for series street-lighting service with either arc or incandescent lamps. It is frequently employed in connection with mercury-vapor rectifiers for operating series-connected direct-current lamps. The efficiency of a constant-current transformer is high, being about 96 per cent. at full-load for a 100-lamp transformer. The power factor which depends upon the magnetic leakage, is low at all loads; it reaches about 80 per cent. at full-load and decreases therefrom in almost direct proportion to the decrease in load.

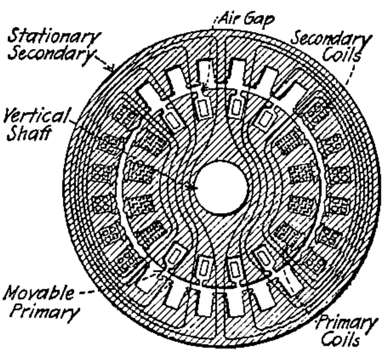


FIG. 49.—Section through a single-phase, induction-type, potential regulator.

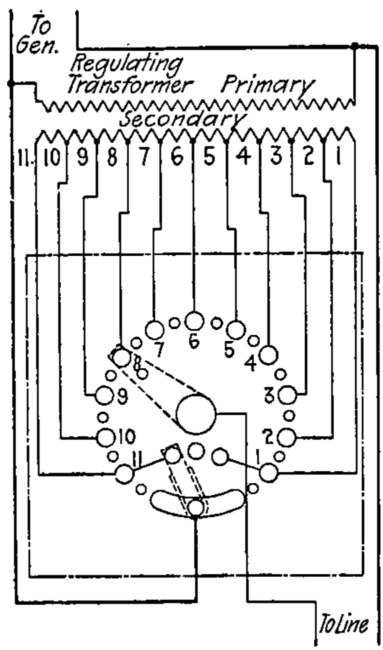


FIG. 50.—Single-phase, step-by-step type potential regulator.

75. The induction regulator (Fig. 49) is a special type of transformer, built like an induction motor with a coil-wound secondary.

which is used for varying the voltage delivered to a synchronous converter or alternating-current feeder system. In comparison with a variable-ratio transformer it possesses the advantage of being operated without opening the circuit and without short-circuiting any transformer coil. The primary of the induction regulator is subjected to the constant voltage of the supply system, the delivered voltage obtained from the secondary winding being varied by rotating the primary structure through a certain number of degrees with reference to the secondary structure. The primary structure is normally stationary, although it is movable either automatically or by hand for the purpose of varying the secondary voltage.

76. The step-by-step potential regulator is merely a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit according to the e.m.f. required. A diagram of the circuits of a regulator of this type is shown in Fig. 50. In comparison with the induction type of regulator the step-by-step type is less noisy in operation, requires less magnetizing current and is more rapid in action. However, it provides only a limited number of voltage steps and may give trouble from arcing at the switch contacts.

INSTALLATION OF TRANSFORMERS

77. Brief of Underwriters' Rules Covering the Installation of Transformers (*Factory Mutual Fire Insurance Companies' Wiring Rules*).—Where transformers are to be connected to high-voltage circuits, the local Inspection Department should always be consulted before work is begun or the apparatus is purchased, as it is necessary in many cases for best protection to life and property, that the secondary system be permanently grounded, and this cannot be done unless provision is made for it when the transformers are built.

Transformers should always be located outside of buildings, unless special permission is given to put them inside. In general, it is dangerous to locate transformers with oil-filled cases inside, as it is entirely possible for a break-down of insulation to ignite the oil, which may result in a very stubborn fire. For the same reason, the placing of these transformers on roofs is also objectionable.

Even transformers which are not oil cooled may contain a considerable amount of combustible material which, if ignited, would make a hot fire, especially if the cases are ventilated as is customary with these types of transformers. Moreover a burn-out in the windings may cause dense smoke, which might easily be mistaken for a fire and cause fire streams to be thrown into the building, with a resultant water damage. They can, therefore, be permitted inside of buildings only after the circumstances have been carefully considered and the necessary safeguards provided.

78. Size and Capacity of Transformer Fuse Wire

(Westinghouse Electric & Manufacturing Co.)

Capacity amperes	18 per cent. German silver wire	Capacity amperes	Aluminum wire
$\frac{1}{2}$ to $\frac{3}{4}$	No. 36	4 to 10	No. 24
$\frac{3}{4}$ to 1	No. 30	5 to 10	No. 24
1 to $1\frac{1}{4}$	No. 30	10 to 15	No. 23
$1\frac{1}{4}$ to $1\frac{1}{2}$	No. 30	15 to 20	No. 22
$1\frac{1}{2}$ to $1\frac{3}{4}$	No. 30	20 to 25	No. 21
$1\frac{3}{4}$ to $2\frac{1}{4}$	No. 26	25 to 30	No. 20
$2\frac{1}{4}$ to $2\frac{3}{4}$	No. 26	30 to 50	No. 19
$2\frac{3}{4}$ to 4	No. 26	....	....

79. Sizes of Primary Fuses Recommended for Transformers of Different Ratings

(General Electric Company)

Transformers kva. capacity	Primary volts	
	1,100–1,200 Amperes rating	2,200–2,400 Amperes rating
0.6	1	1
1.0	1	1
1.5	2	1
2.0	2	1
2.5	3	2
3.0	3	2
4.0	5	2
5.0	5	3
7.5	10	5
10.0	10	5
15.0	15	10
20.0	20	10
25.0	25	15
30.0	30	15
40.0	40	20
50.0	50	25

80. Mounting Distributing Transformers.—Units of the smaller capacities are supported on poles on cross-arms in accordance with instructions furnished by their manufacturers. Gear and Williams recommend that, for transformers of capacities larger than 20 kw., double-cross arms should be used at the top as the top arms carry most of the weight. "Where the installation consists of three 15-kw. or larger transformers it is advisable to use a larger-sized cross-arm than the standard. An arm having a cross-section of 4 in. by $5\frac{1}{2}$ in. has been found ample for installations aggregating 90 to 100 kw."

"Where a large amount of power is needed which requires a number of 50-kw. units which cannot be conveniently installed inside of the building, they can be safely and conveniently installed on a platform between two or more poles as shown in Fig. 51. The use of units larger than 50 kw. is usually not advisable as they are so heavy as to be inconvenient to handle and replacing them in case of a burn-out is a considerable task. A platform for supporting three 50-kw. units can be built by bolting in gains, between two poles, 2–3 in. × 10-in. planks and nailing to them a floor of 2-in. plank."

81. Methods of Hanging Transformers.—The methods of mounting transformers described and illustrated in the following paragraphs were taken from the *Report of the Committee on Overhead Line Construction* of the Pennsylvania Electric Association, Sept. 3, 1912. H. N. Müller of the Alleghany County Light Company of

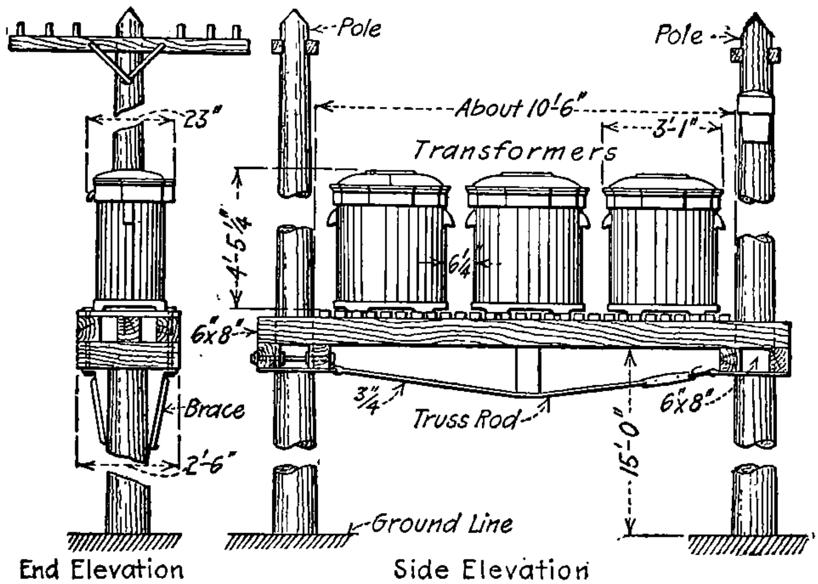


FIG. 51.—Platform for large transformers.

Pittsburgh was chairman of the committee and the practices outlined are those followed by the Alleghany Company. The methods provide ample clearances for linemen climbing the poles and assure that the wiring will remain in place and not give trouble from short circuits. Platforms are recommended for supporting the larger transformers because of the accessibility for repairs or replacements that they provide.

82. Method of Mounting Single Transformers of from 1- to 4-Kva. Capacity.—The transformer should be supported by the iron hangers furnished by the manufacturer and hung at the central point on the cross-arm and not out on the arm away from the pole. At the bottom of the hanger a section of an arm, not longer than the diameter of the pole, should be fastened to the pole with two lag bolts. The transformer can be hung on the bottom arm, if one is in place and supports lines, provided this arm is in the second gain or a lower one. The primary mains feeding the transformer should be on an upper arm.

In installations where the transformers are more than 4 ft.

below the arm supporting the primary mains, it is advisable to mount Western Union pins horizontally in the linearms. On these pins the primary wires can be tied to maintain them rigid. Iron pins should also be mounted in the transformer arm to take the stress imposed on the primary conductors by the fuse terminal screws.

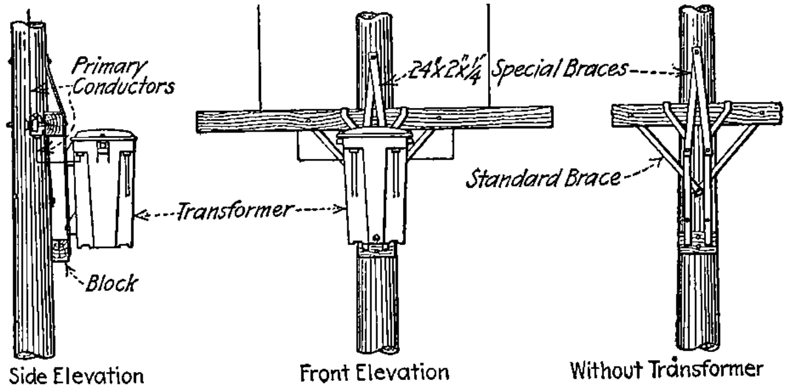


FIG. 52.—Method of supporting a 5- to 10-kw. transformer.

83. Method of Mounting Transformers of from 5- to 30-kva. Capacity. (Fig. 52.)—The same rules should be followed as outlined in the preceding paragraph with the following additions: The transformers, on account of their increased weight and dimensions, should not be hung on a linearm. A specially placed arm should be used underneath existing arms and other apparatus.

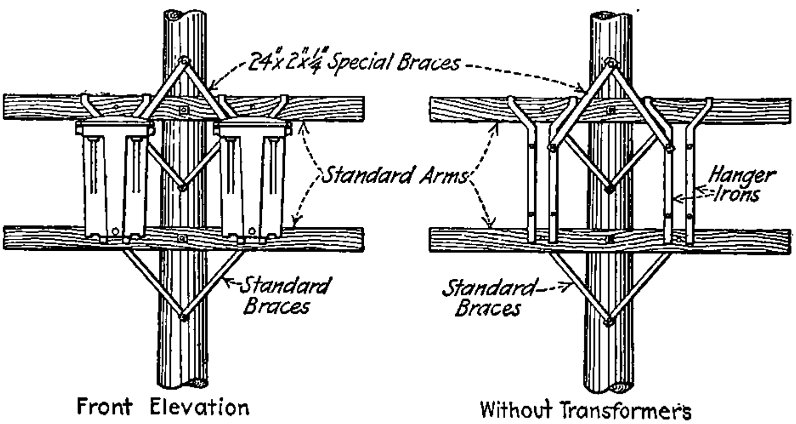


FIG. 53.—Method of supporting two 5-kva. or two 10-kva. transformers.

In addition to using the regular hangers which accompany transformers, a pair of iron braces $24 \times 2 \times \frac{1}{4}$ in. should be placed between the transformer lugs and the hanger with the hanger bolts passing through one of the holes in the braces. These braces are to be run in an upward direction and fastened to the pole with a standard through bolt. (See Fig. 52.) If the arm weakens or entirely rots away, these two braces are of sufficient strength to support the transformer and permit cross-arm replacement.

84. Method of Mounting Two 5-kva. or Two 10-kva. Transformers. (Fig. 53.)—Construction similar to that above described should be used except that a standard arm should be placed at the bottom on which the hanger irons can rest. Also only one special brace ($24 \times 2 \times \frac{1}{4}$ in.) per transformer, should be placed between the lug and hanger iron next to the pole.

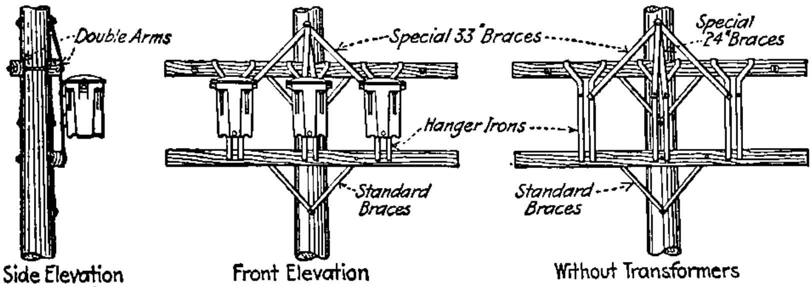


FIG. 54.—Method of supporting three 5-kva. transformers.

85. Method of Mounting Three 5-kva. Transformers. (Fig. 54.)—The construction should be similar to that outlined in the preceding paragraphs, excepting that the special braces supporting the outside transformers are 33 in. between centers of holes. It is also advisable to place an additional cross-arm on the rear side of the pole. This arm braces the front arm, and provides a place where fuse blocks can be mounted.

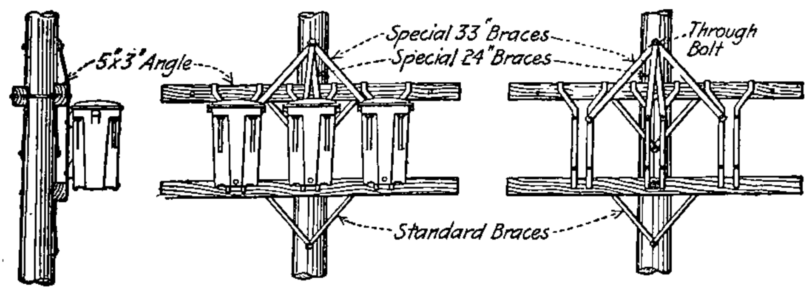


FIG. 55.—Method of supporting three 10-kva. transformers.

86. Method of Mounting Three 10-kva. Transformers. (Figs. 55 and 56.)—The construction is similar to that for three 5-kva. transformers with the following addition: The top arm supporting the transformers should be reinforced with a piece of angle iron 5×3 in. $\times$ the length of cross-arm, which should be placed with the 3-in. leg on the top of the arm.

The average life of long leaf yellow pine cross-arms has been found from observation to be from four to six years. When these arms are carrying unusually heavy loads, such as supporting heavy transformers, their useful life as such is considerably decreased. The braces are introduced so that the use of two or more cross-

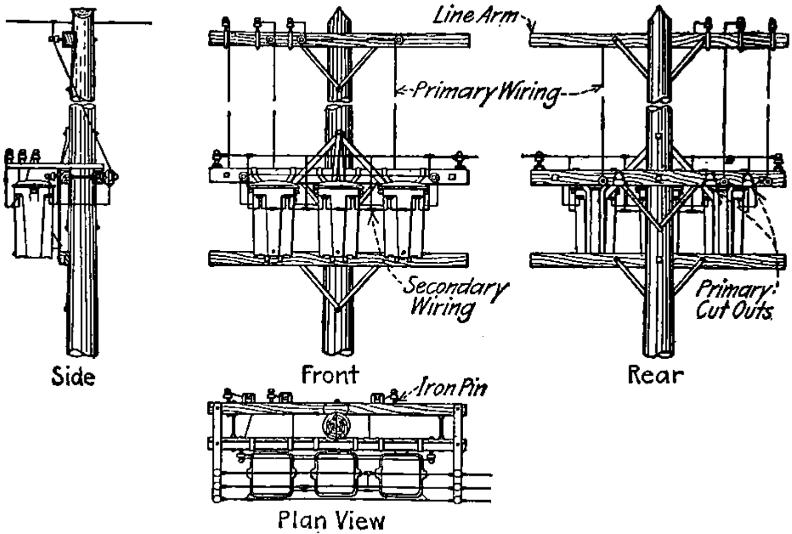


FIG. 56.—Wiring for three 5-kva. or for three 10-kva. transformers.

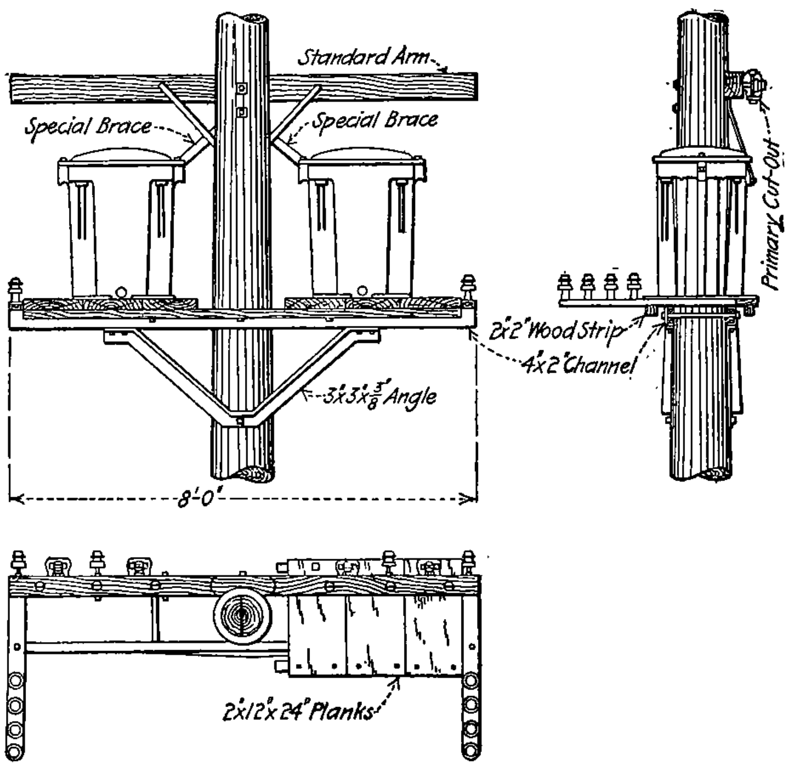


FIG. 57.—Single pole platform for two 20-kva., two 30-kva. or one 50-kva. transformer.

arms to provide equivalent mechanical strength will be unnecessary. They also insure against a transformer falling off.

87. Method of Mounting Two 20-kva., Two 30-kva. or One 50-kva. Transformer. (Fig. 57.)—For transformers of these capacities a single-pole platform is recommended. The beams for the platform should be 4 in. $\times$6 lb., channel iron 8 ft. long. The braces used are a single piece of angle iron $3\times3\times\frac{3}{8}$ in. bent in a

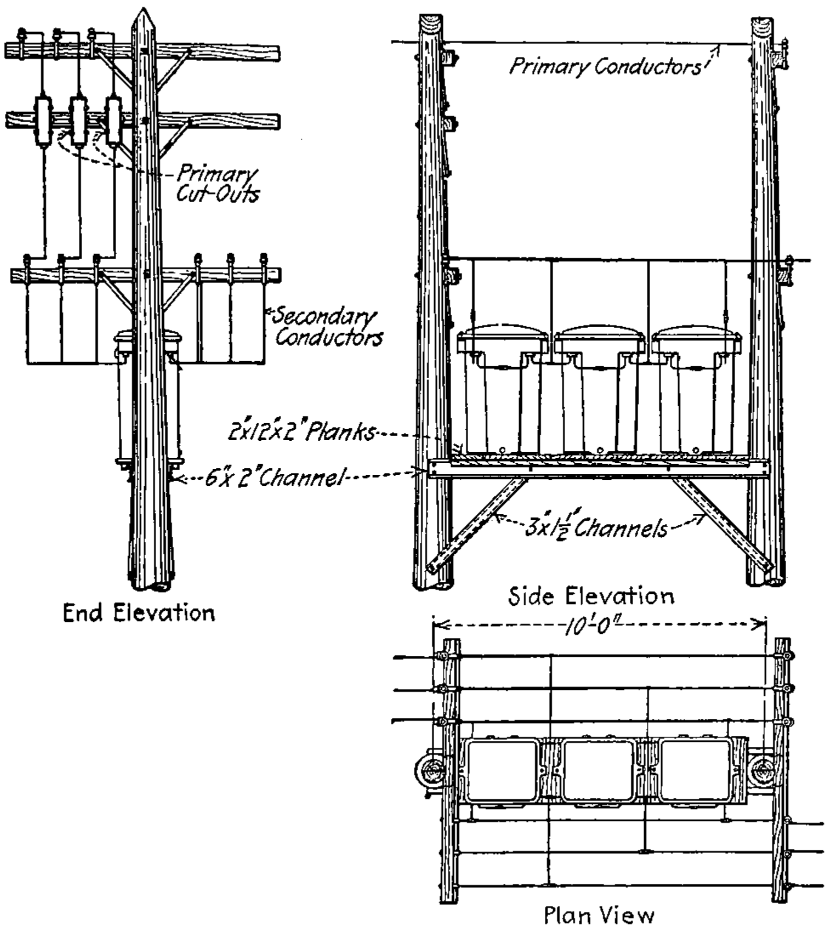


FIG. 58.—Double pole platform for three 20-kva., two 50-kva., or three 50-kva. transformers.

V shape. Pine or oak planks $2\times12\times24$ in. are to be laid across the channel irons for the transformers to rest upon. The wooden platform is to be held together by a 2×2 in. strip of wood running on the outside of the channel iron, to which the planks are secured by 4-in. wood screws or 20-penny nails.

88. Method of Mounting Three 20-kva., Three 30-kva., Two 50-kva. or One 50-kva. Transformer. (Fig. 58.)—The poles should be spaced 10 ft. apart on centers. The main channel irons are 6 in. $\times$10 lb. $\times$ 10 ft. 6 in. over all. Braces are of 3 in. $\times$4 lb. channel.

SECTION VI

ILLUMINATION[1]

[1] The compiler acknowledges the assistance of Messrs. Chas. R. Riker and S. Sidney Neu in the preparation of this section.

1. Physiological Features of Illumination.—In order to understand the principles of scientific illumination, it is necessary to understand the mechanism of the eye.

Fig. 1 (From *Primer of Illumination* copyright by Illuminating Engineering Society) shows the parts of the eye as they would appear if it were cut through from back to front vertically. In the process of seeing, the light passes through the cornea, pupil, and lens of the eye to the retina, just as in a camera light passes through the lens to the sensitized film. The picture is formed on the retina, which is a layer made up of the ends of nerve fibers which gather into the optic nerve and go directly to the brain.

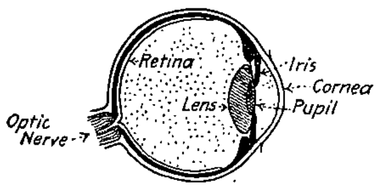


FIG. 1.—The eye—essential parts shown in section.

The optic nerve sends along the picture to the brain. The lens of the eye, unlike that of the camera, automatically changes in thickness to focus or make a clear image on the retina for seeing at different distances. This focusing action is called the accommodation of the eye, and when the light is dim or bad the focusing muscle vainly hunts for some focus which may make objects look

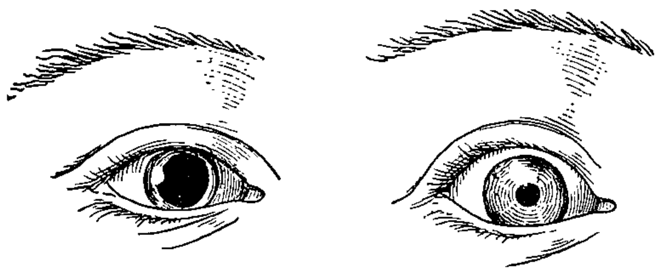


FIG. 2.—Expansion and contraction of the pupil of the eye.

clear and gets tired in trying to do it. The muscles which move the eye about also get tired in the same way and the result is eye-strain, which stirs up pain and headache just as any other over-tired muscles of the body may set up an ache.

The iris (which gives the eye its color) serves to regulate the amount of light which reaches the eye. In very dim light it opens out making the pupil big, as shown in Fig. 2, and in very bright light it shuts up as shown, and thus keeps out a flood of brilliant light which might hurt the retina. The protective action of the pupil is pretty good, but by no means complete, for it seldom gets smaller than shown in the illustration, however bright the light. From a study of Fig. 2 we may deduce:

(a) When trying to see any object, do not allow a light to shine into the eyes, nor face a brightly lighted area. In addition to tiring the retina, the superfluous light causes the pupil to contract, so that less light from the illuminated object reaches the retina. An object which would seem well lighted in a room with dark walls, and no light shining in the eyes, will appear poorly lighted in a bright room with light walls, or when a light is shining in the eyes, simply because the pupil is smaller. This also explains why a higher light intensity is necessary in the day time than at night. It is generally easier to read with the same light source in a room having dark walls than if the walls are light in color—though the total illumination on the page will probably be less. Reflected light from glossy paper produces the same effect as light surroundings. The effect produced by a light shining directly into the eyes is termed *glare.*

(b) A fluctuating light causes the pupil to be constantly changing. This is very tiring to the muscles which control the iris, and if long continued may even work a permanent injury.

(c) The lens of the eye is not corrected, as is a photographic lens, for color variations. It cannot focus sharply red and blue light from the same object simultaneously, although this is ordinarily not noticed. As white light is composed of all colors, it follows that we can see more clearly, *i.e.*, objects appear sharper and more distinct, by a monochromatic light (light of only one color) than by even daylight. The light from the mercury vapor lamps closely approximates this condition.

(d) Illumination should be uniform; otherwise the eye, in continually attempting to adapt itself to the unequal conditions, becomes tired in the same way as with a fluctuating light.

Correct illumination enables one to see clearly with minimum tiring of the eyes. To secure this, all the above conditions must be satisfied.

2. **A line of vision** is a line drawn from a given point to an assumed natural position of the eye of an observer. When a lamp is concealed from the eye of an observer by a reflector the lamp is out of the line of vision of the observer, but if the observer changes his position until he can see the lamp then it is in his line of vision.

3. **Visual Acuity.**—Experiments have shown that if the intensity of illumination is gradually increased the following facts are noticeable: *First*, that a certain definite intensity of illumination is required before the object can be distinguished; *second*, that as the intensity of illumination is increased, the visual acuity is increased in proportion, that is, the object becomes more easily seen, up to a certain intensity of illumination; *third*, that beyond a certain point, increasing the intensity of illumination does not result in a proportional increase in visual acuity. This is shown graphically in Fig. 3. It is therefore apparent that more than a certain amount

of illumination, depending on conditions and purpose, is wasteful, in that it does not make things any more clearly seen.

4. **Effect of Daylight on Illumination.**—Daylight is so much more intense than artificial illumination that it makes artificial lighting appear dim by contrast. Experiments show that when some daylight is present, from 50 to 100 per cent. greater intensity of illumination is required. This is because the eye gets used to the high intensity of illumination on all objects by daylight, and there are no deep shadows to relieve the monotony.

5. **The intensities of natural illumination** (Bell, *Standard Handbook*) vary very greatly, ranging up or down according to relation of the point considered to windows and sunlight. The intensity of the diffuse illumination near a south window may rise to 20 ft-c. or more; with less brilliant exposure it may be 10, or 5 or 3 ft-c., and so on down as one passes to less favorable positions and gets down to fractions of a foot-candle. The illumination, for example, where this paragraph is being written near a west window on a rainy day is about 3 ft-c., while 10 ft. further within the room it has fallen to less than 0.5 ft-c. by which it is difficult to read coarse print. So far as ordinary work goes any illumination above say 2 ft-c. is about equally good. When daylight drops materially below this, one has to resort to artificial light, and there is a strong tendency to use much more than is necessary to the detriment of the eyes. Under a desk lamp an illumination of 10 ft-c. is not an exceptional amount, but it is more than double that which can generally be advantageously utilized by the eye.

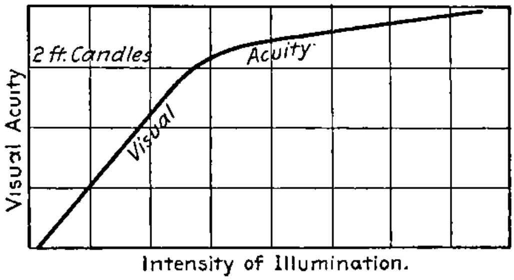


FIG. 3.—Characteristic curve of visual acuity.

6. **Direct lighting** is that wherein the light source is visible and the light is distributed directly from it.

7. **Indirect lighting** is that form wherein the light source is entirely hidden. The light is projected to the ceiling and walls from which it is reflected downward.

7a. **Indirect Compared with Direct Lighting** (H. W. Shalling).—Obtaining a large portion of the illumination indirectly has the following disadvantages as compared with direct lighting.

(1) Lower efficiency; to produce a given illumination requires about twice as much light with indirect lighting as with efficient direct lighting.

(2) More rapid depreciation due to the collection of dirt.

(3) A lower degree of perspective, since sharp shadows are largely eliminated.

(4) An unduly bright ceiling which often gives an unpleasant psychological effect, especially when the opaque unit of the indirect lighting forms a contrast with the brightly lighted ceiling.

8. The three fundamental quantities upon which the art of illumination is based are:

1. *Intensity*, or luminous intensity, which defines the light-giving power of a source and which is measured in candle-power.

2. *Illumination*, or light-flux density, which is measured in foot-candles.

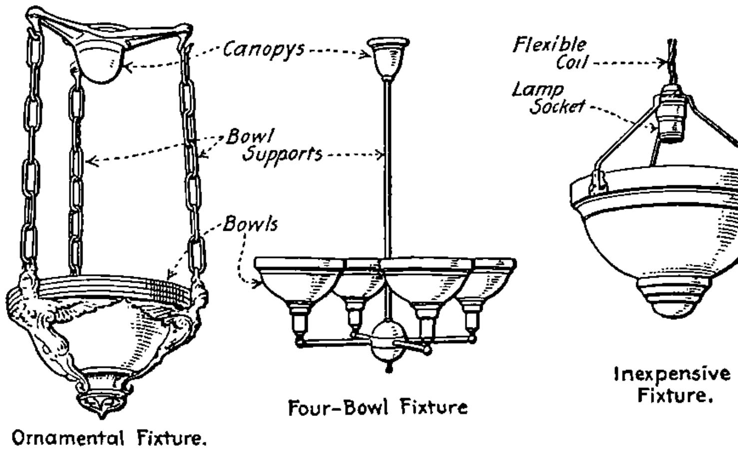


FIG. 4.—Examples of fixtures for indirect lighting.

3. *Intrinsic brilliancy*, which is measured by the luminous intensity per unit of area and in candle-power per square inch.

9. Candle-power.—The light-giving power of a luminous source is expressed in candle-power. It is determined by comparing the lamp either with a standard maintained by the National Bureau of Standards at Washington, D.C., or with a well-seasoned lamp that has been accurately measured to this standard and thus serves as a secondary standard. A light source generally gives more light in one direction than it does in another. (See Fig. 5.) Thus a direct-current arc lamp gives more light at an angle 45 degrees below the horizontal than in any other direction. The candle-power of a lamp therefore means nothing unless the direction is also specified. The candle-power generally is different in different directions.

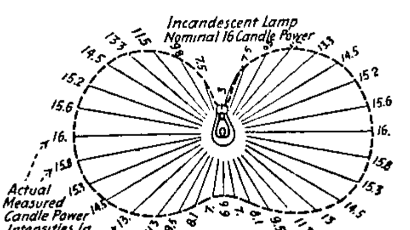


FIG. 5.—Actual candle-power intensities in different directions from a 16-c.p. carbon-filament incandescent lamp.

10. Mean Horizontal Candle-power.—The average of the candle-powers of a lamp in all directions in a horizontal plane is called the mean horizontal candle-power. Incandescent lamps were formerly rated by their mean horizontal candle-power. Two lamps rated the same (mean horizontal) candle-power may thus differ widely in their light-giving powers above and below the horizontal.

11. Mean Lower Hemispherical Candle-power.—The average of the candle-power of a lamp in all directions in the lower hemisphere is called the mean lower hemispherical candle-power of the lamp. As applied to incandescent lamps, the lamp is assumed to have the bulb down, base up. This term is of little importance where lamps are to be used with reflectors.

12. Mean Spherical Candle-power.—The average of the candle-power of a lamp in all directions is called the mean spherical candle-power. This term is of most importance as it is an index to the total light-giving power of the lamp in all directions.

13. Foot-candles—Candle-feet—Lux.—The unit of intensity of illumination is the foot-candle or candle-foot. It can be defined in two ways, both of which mean the same: 1 ft-c. is

(1) The intensity of illumination produced by a 1 c-p. source at a distance of 1 ft.

(2) The intensity of illumination produced by one lumen when spread over 1 sq. ft. of surface. The illumination on the interior surface of the sphere of Fig. 6 is 1 ft-c.

The lux is a unit of intensity of illumination employed when using the metric system. It is the intensity of illumination produced by a 1 c-p. source at a distance of 1 m., or that produced by one lumen when spread over 1 sq. m., 1 lux = .0929 ft-c., 1 ft-c. = 10.76 lux.

13A. The efficiency of an electric light source is ordinarily given in *watts per candle*, which means watts per mean horizontal candle-power. However, this method is unsatisfactory in that candle-power is not a true measure of the total light produced by the lamp. Furthermore, as the efficiency, on the above basis, increases, the figure expressing it decreases. A better method of expressing efficiency is in *lumens per watt*.

14. The reduction factor of a light source is the ratio of the mean spherical candle-power to the mean horizontal candle-power. Few sources radiate uniformly in all directions, and since most incandescent lamps have their maximum intensity in the horizontal direction, it is seen that the reduction factor must usually be less than one. According to this definition, the mean spherical candle-power can be obtained by multiplying the mean horizontal candle-power by the reduction factor.

15. Factors for Obtaining Mean Spherical Candle-power

Type of incandescent-lamp light source	Reduction factor
Carbon, oval anchored filament	0.825
Gem 50 watt, 20 c-p. filament	0.825
Gem 100, 125, 187, 250 watt filament	0.820
Tantalum filament	0.790
Tungsten (*Mazda*), multiple, vacuum, 105–125 volts	0.780
Tungsten (*Mazda*), multiple, vacuum, 220–250 volts	0.790
Tungsten (*Mazda C*), multiple, gas filled, nitrogen, 105–125 volts	0.800
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 60, 80, 100 c-p.	0.760
Tungsten (*Mazda C*), series, gas filled, for ordinary circuits, 250, 400, 600 c-p.	0.800
Tungsten (*Mazda C*), series, gas filled, 20-amp. circuits, 600 and 1000 c-p.	0.780

16. Economical Intensities of Illumination in Foot-candles

(National Electric Lamp Association)

Application	Foot-candles	Application	Foot-candles
Armory or drill hall	3.0	Library—	
Art Gallery		Stock room	1.5
White statuary	2.5	Reading room (with no local illumination supplied)	3.5
Bronze statuary	7.0	Reading room (with local illumination supplied)	0.7
Paintings	5.0	Machine shop—	
Assembly Room	3.5	Rough work	6.0
Auditorium	2.0	Average work	2.0
Automobile showroom	5.0	Fine work	4.0
Automobile (interior)	1.0	Market	3.0
Ball room	3.0	Moving-picture theater	1.5
Bank	3.0	Museum	3.0
Bar room	3.0	Office (no local lights)	4.0
Barber shop	2.5	Pattern shops	4.0
Blacksmith shop	3.0	Power house	3.0
Billboard	8.0	Postal service	7.0
Billiard room (general)	0.8	Public square	0.8
Billiard table	5.0	Reading (ordinary print)	2.0
Bowling alley—		Reading (fine print)	2.5
Alley	1.5	Residence—	
Pins	4.0	Porch	0.2
Cafe (see saloon)	2.5	Hall (entrance)	0.7
Carpenter shop	4.0	Reception room	1.5
Court room	2.5	Sitting room	1.5
Church	2.0	Library	2.0
Club—		Dining room	1.5
See Hotel, Residence, etc.		Kitchen	2.0
Dance hall	2.0	Laundry	1.5
Depot waiting room	1.5	Hall (upstairs)	0.5
Desk	4.0	Bed room	1.5
Draughting room	8.0	Bath room	2.0
Engraving	10.0	Cellar	0.6
Factory—		Store room	0.7
General illumination only, where additional special illumination of each machine or bench is provided	1.5	Rug rack	15.0
Local bench illumination	4.0	School—	
Complete (no local) illumination	4.0	Class room	2.5
Fire Stations—		Assembly room	2.0
When an alarm is turned in	3.0	Cloak room	0.8
At other times	1.0	Corridor	0.8
Foundry	3.0	Manual training	3.0
Garage	2.0	Drawing	5.0
Gymnasium	2.5	Sewing (light goods)	4.0
Hospital—		(dark goods)	8.0
Corridors	0.5	Shipping room	2.0
Wards (with no local illumination supplied)	1.5	Show window[1]—	
Wards (with local illumination supplied)	0.5	Light goods	7.0
Operating-table	12.5	Medium goods	15.0
Hotels—		Dark goods	20.0
Corridor	0.6	Sign	8.0
Bed room	1.5	Stable	1.0
Lobby	2.0	Station (railroad)	2.0
Dining room	2.0	Stenographer	5.0
Writing room	2.0	Stereotyping	4.0
Laundry	2.0	Stock room	1.5
		Store—	
		Art	4.0
		Baker	3.0

[1] Depends largely on character of street and other features of location.

17. Economical Intensities of Illumination—(*Continued*)

Application	Foot-candles	Application	Foot-candles
Store—		Store—	
Book	3.5	Piano	4.0
Butcher	3.5	Shoe	3.5
China	2.5	Stationery	3.5
Cigar	3.0	Tailor	4.0
Clothing	5.0	Tobacco	3.0
Cloak and suit	5.0	Street—	
Confectionery	3.0	Business (not including light from show windows and signs)	0.5
Decorator	3.0	Residence	0.1
Drug	4.0	Prominent residence districts	0.2
Dry goods	4.0	Country roads	0.05
Florist	3.0	Studio	4.0
Furniture	4.5	Swimming pool	2.0
Furrier	5.0	Telephone exchange (general)	3.0
Grocery	3.0	Theater—	
Hardware	4.5	Lobby	3.0
Hat	4.0	Auditorium	2.0
Jewelry	4.5	Train sheds	1.0
Lace	3.0	Typesetting	8.0
Leather	3.5	Warehouse	1.5
Meat	3.5	Wharf	1.0
Men's furnishings	3.5		
Millinery	4.0		
Music	3.5		
Notions	3.0		

18. Economical Intensities.—The above intensities of illumination are recommended for various purposes. These intensities enable objects to be seen with all the clearness generally necessary in the places mentioned. Thus, in draughting rooms greater intensity is required than in swimming-pool buildings, because more detail must be brought out. On billboards greater intensity is required than in a library reading room to enable the signs to be read at a great distance.

19. Average Intrinsic Brilliancy of Various Illuminants

Light source	Candle-power per sq. in.	Light source	Candle-power per sq. in.
Moore tube	0.3–1.75	Incandescent lamps:	
Opal-shaded incandescent lamp	0.5–3.0	Tantalum, 2.0 watts per candle	700–800
Frosted electric incandescent lamp	2–8	Tungsten, 1.25 watts per candle	850–1000
Candle	3–4	Tungsten, 1.0 watts per candle	950–1050
Gas flame	3–8	Nernst, 1.5 watts per candle	2200
Oil lamp	3–8	Sun, on horizon	2000
Cooper-Hewitt lamp	10–20	Flaming arc lamp	5000
Welsbach gas mantle	20–50	Calcium light	5000
Acetylene burner	60–100	Open arc lamp	10,000 / 50,000
Enclosed a-c. arc lamp	75–200	Open arc crater	200,000
Enclosed d-c. arc lamp	100–500	Sun, 30 degrees above horizon	500,000
Incandescent lamps:		Sun, at zenith	600,000
Carbon, 3.5 watts per candle	350–400		
Carbon, 3.1 watts per candle	450–500		
Gem, 2.5 watts per candle	625		

20. Intrinsic Brilliancy.—Lights of greater intrinsic brilliancy than 4 to 6 c-p. per sq. in. produce glare; that is, they tire the muscles and retina of the eye and prevent it from seeing objects clearly. It is well to avoid placing sources of light of greater intrinsic brilliancy than 1 c-p. per sq. in. in the field of vision. Intrinsic brilliancy is total candle-power per unit area of the source of light. Brilliant light sources in the line of vision should be protected by frosted or translucent shades.

21. Flux of Light. Lumen.—For purposes of calculation it is convenient to consider the light given out by any source as a flow, stream or flux from the source outward. The flux generated by a point source of 1 c-p. in a unit solid angle is called one lumen. In Fig. 6, if we assume the square to measure 1 in. on each side and to lie on the surface of a sphere 1 in. in radius, the light of 1 c-p. at the center would generate one lumen in the solid angle enclosed by the lines *abcd*. As the total surface of this sphere is 4π times $1 = 4 \times 3.1416 \times 1 = 12.56$ sq. in., the total flux emitted by a point source of 1 c-p. is 12.56 lumens. A source of 2 mean spherical c-p. would emit $2 \times 12.56 = 25.12$ lumens, and so on.

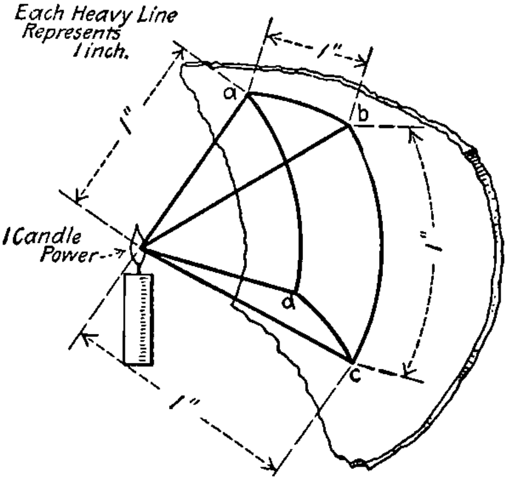


FIG. 6.—Flux of light in unit solid angle.

22. Intensity of Normal Illumination.—The inverse square law can probably be best understood by referring to Figs. 7 and 8. Consider first Fig. 7, in which the light from a light source is directed by a theoretically perfect parabolic reflector. A reflector of this type has, when the light source is properly placed within it, the property of projecting all of the light in perfectly parallel rays or in a beam. With a theoretically perfect reflector and with the light projected through an absolutely transparent medium the quantity of light at any point in the beam, as for instance at A, Fig. 7, would be the same as at any other point in the beam, as B (Fig. 7). Hence the intensity of illumination, or the brightness of the light, would be the same on A as on B. Parabolic reflectors that are used for automobile head lights give a result that approximates this condition. Obviously a perfect parabolic reflector and a perfectly transparent medium are impossible. The brightness of the beam of light projected by an automobile lamp diminishes as the distance from the lamp increases due to the imperfectness of the reflector, to the dirt and smoke in the air and to the reflection and absorption caused by the particles in suspension in the air.

This property of a parabolic reflector is noted merely to show that light is a perfectly tangible thing just as water is and that the amount or volume of light produced by a source is a perfectly definite quantity. The beam of light, projected from a source in a perfect parabolic reflector, through a perfectly transparent medium would extend out an infinite distance and the intensity of light at any point in the beam would be the same.

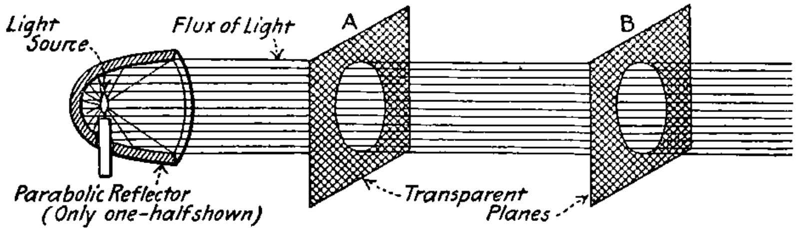


FIG. 7.—Light projected by a parabolic reflector.

Now consider the natural tendency of light (undirected by a reflector) which is to radiate from its source in all directions. It spreads out as it were. Therefore the greater the distance of any point from such a source the lower will be the intensity or brightness at that point. Consider Fig. 8. If the light from source L falls normally or at right angles on a surface A at a distance LA from the source it will illuminate A to a certain intensity or brightness. If instead it falls on a surface B, distant LB (LB being twice LA)

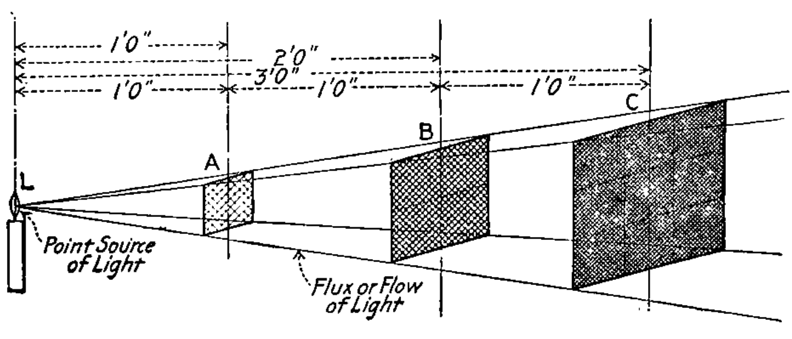


FIG. 8.—The radiation of light.

the same total number of lumens or quantity of light will illuminate a surface twice as wide and twice as high or of four times the area. As the same quantity of light is thus spread out over four times the area the average illumination on B will be but $\frac{1}{4}$ of that on A. If the same quantity of light from the same source falls on surface C (distant LC from L) the flux or beam of light will be spread out over a surface nine times the area of A and the average illumination will be but $\frac{1}{9}$ that on A.

In every case where light is radiated from a point-source to some point the intensity of illumination at the point is inversely propor-

tional to the square of the distance of the point from the source. This law can be expressed as a formula thus:

$$I = \frac{cp}{D^2} \text{ or } D = \sqrt{\frac{cp}{I}} \text{ or } cp = ID^2$$

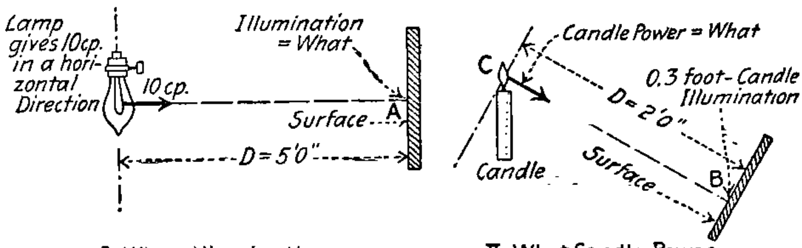


FIG. 9.—Illustrating the inverse square law.

wherein $I =$ the intensity of illumination in foot-candles on a surface normal (at right angles) to the direction of the light rays; cp = candle-power of the light source in the given direction and D is the distance from the source to the surface in feet.

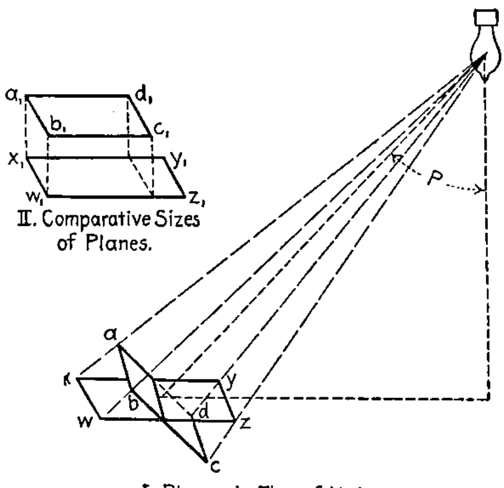


FIG. 10.—Illustrating the theory of the cosine law.

Example.—In Fig. 9, *I*, what is the intensity of illumination at the point *A* on the surface? The lamp produces an intensity of 10 c-p. in a horizontal direction and the surface is 5 ft. from the lamp.

Solution.—Substitute the values in the formula:

$$I = \frac{cp}{D^2} = \frac{10}{5 \times 5} = \frac{10}{25} = 0.4 \text{ ft-c.}$$

Therefore there is an illumination at the point *A* of 0.4 ft-c.

Example.—In Fig. 9, *II*, the illumination at point *B* is 0.3 ft-c. and the surface is 2 ft. from the light source, what is the candle-power of the light source in the direction *CB*?

Solution.—Substitute the values in the formula:

$$cp = ID^2 = 0.3 \times 2 \times 2 = 1.2 \text{ c-p.}$$

Therefore the candle produces 1.2 c-p in the direction *CB*.

23. Limitations of the Inverse Square Law.—Although the inverse square law applies with absolute accuracy only to light emitted from a source so small that it may be considered as a mere point, in practice results are sufficiently accurate if the distance from the source to the point at which the light is measured is ten to fifteen times as great as the apparent size of the light source.

24. Intensity of Illumination on Horizontal Surfaces. The Cosine Law.—(See Fig. 10.) The inverse square law and formula

(Par. 22) indicate how the intensity of illumination, on a surface normal or at right angles to the rays from the source of light, may be computed. Such a surface is indicated by *abcd*, Fig. 10, *I*. The intensity at the center of this surface (*abcd*) would be computed with the formula of 22.

$$I = \frac{cp}{D^2}$$

Now consider the surface *wxyz* which lies in a horizontal plane but which is inclined in relation to the direction of the light from the source. However, the same quantity of light or the same number of lumens (the beam of light included within the pyramid is formed by the dashed lines) illuminates *abcd* as illuminates *wxyz*. *Wxyz* is actually larger than *abcd* as shown at *II*. Since the same

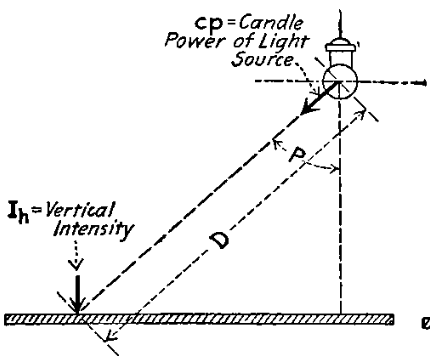


FIG. 11.—Notation for the first cosine law formula.

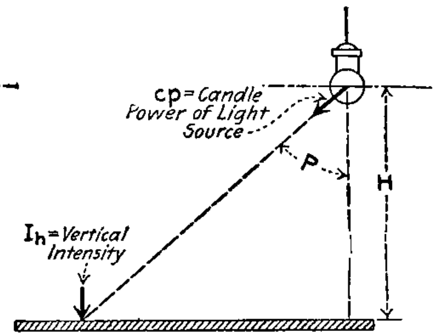


FIG. 12.—Notation for the second cosine law formula.

quantity of light illuminates a larger area in one case than in the other it is evident that the average intensity on the larger area must be less than the smaller one. The reduction in intensity on the area *wxyz* below that of *abcd* is obtained by multiplying the intensity of *abcd* by a factor, the cosine of angle *P*. A table of cosines is given in the first section of this book.

Expressing this statement as a formula using the notation of Fig. 11.

$$I_h = \frac{cp}{D^2} \times \cos P \quad \text{or} \quad D = \sqrt{\frac{cp \times \cos P}{I_h}} \quad \text{or} \quad cp = \frac{I_h \times D^2}{\cos P}$$

wherein I_h = vertical intensity in foot-candles of the illumination on the horizontal surface; cp = the candle-power of the light source in the given direction, D = distance in feet from the point under consideration to the light source and *cos* P = the cosine of the angle P as taken from a table of cosines. (Such a table, condensed, is given in the first section of this book.)

The above formula can be converted into this more convenient form (Fig. 12).

$$I_h = \frac{cp}{H^2} \times (\cos P)^3$$

Wherein the letters all have the same meanings as above except that H = the vertical height in feet of the light source above the horizontal surface illuminated.

25. The value for candle-power (cp) for use in the above formulas should not be taken as the nominal rated candle-power of the light source but should be taken from a photometric curve or from manufacturers' data as the candle-power in the particular direction under considerations as illustrated in following examples.

Example.—A lamp is located 12 ft. above a table (Fig. 13, *I*) and in such a position that the angle P is 60 degrees. Assume the candle-power of the lamp is 40 in this direction (30 degrees below the horizontal). What is the vertical intensity at the table or in other words what is the intensity of illumination on the table?

Solution.—From the table of cosines in the first section of this book it will be found that cosine (or cos) of 60 degrees = 0.5. Substitute the values from Fig. 13, *I*, in the formula:

$$Ih = \frac{cp}{H^2} \times (\cos P)^3 = \frac{40}{12 \times 12} \times 0.5 \times 0.5 \times 0.5 = \frac{40 \times 0.125}{144} = 0.035 \text{ ft-c.}$$

Therefore the vertical illumination at point Ih is 0.035 ft-c.

Example.—What would be the illumination on a book held at right angles to the beam of light as in Fig. 13, *II*? The distance from the book to the light source would be 24 ft.

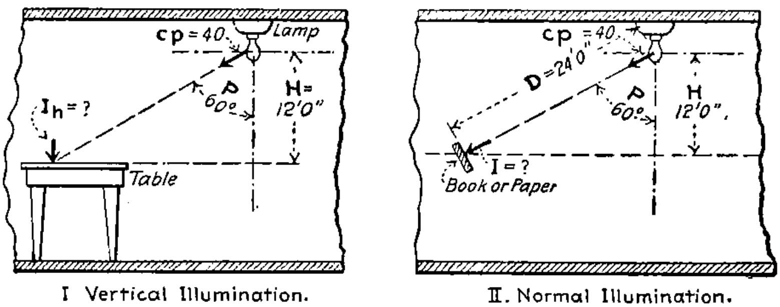


FIG. 13.—Example of computing vertical illumination.

Solution.—Substitute in the formula of 24:

$$I = \frac{cp}{D^2} = \frac{40}{24 \times 24} = \frac{40}{576} = 0.070 \text{ ft-c.}$$

Therefore the illumination at the point I on a book held at right angles to the beam of light would be 0.070 ft-c.

26. The calculation for intensity of illumination on a vertical surface is quite similar to that for a horizontal surface. (See 24.) The formula is (see Fig. 14):

$$Iv = \frac{cp}{D^2} \times \sin P \text{ or } \frac{cp}{S^2} \times (\sin P)^3$$

Wherein Iv = the intensity of illumination in foot-candles on the vertical surface; cp = the candle-power of the light source in the given direction; S = horizontal distance in feet from the lamp to the surface and P = angle between the direction of light and the vertical.

27. Caution Regarding the Use of the Preceding Formulas.—It must be understood that illumination intensities derived with the above formulas give the intensity of illumination due to direct light from the light unit, and in practice this derived value is always increased a certain amount by diffusely reflected light. This increase may be relatively large if the ceiling, walls and other objects in the room are light in color and have a high coefficient of reflection, but it is almost negligible in industrial plants, for instance, where the walls may be of dark brick, the roof and girder construction very dark in color, with the space filled with machinery of various sorts.

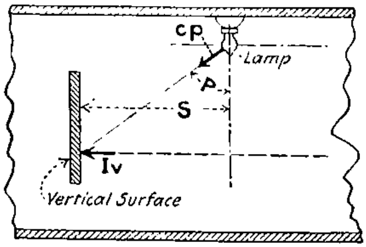


FIG. 14.—Notation for "Illumination on vertical surface" formula.

28. A photometric curve consists of lines, plotted on a polar diagram, which show graphically the distribution of the light about a light source and the candle-power intensities at various directions about the lamp or lamp and reflector. See Fig. 5 and other following illustrations for examples.

29. How to Read a Photometric Curve.—In the photometric curve of Fig. 15, *I*, the luminous intensity directly downward is indicated by measuring off this intensity on the vertical to a given scale. Thus, *XA* represents the candle-power intensity directly below the light. Similarly distances *XB*, *XC*, *XD*, *XE*, *XF*, and *XG* represent candle-power intensities given off all around

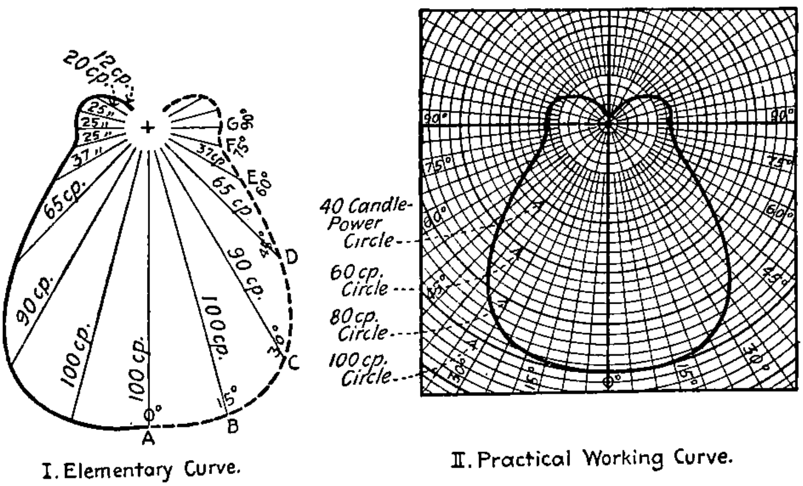


FIG. 15.—Photometric curves.

the light at angles above the vertical of 15 degrees, 30 degrees, 45 degrees, 60 degress, 75 degrees, and 90 degrees. Similarly the candle-power intensities above 90 degrees can be measured off to the given scale along their respective angles. These points are then joined by a continuous line, *G*, *F*, *E*, *D*, etc., and this line, completed for the 360 degrees, is called the photometric distribution curve of the light.

Fig. 15, *I*, shows such a completed photometric curve, but in practice it is customary to use circular lines, as indicated on Fig. 15, *II*, to show the scale to which the candle-powers are plotted.

The candle-power intensity of the light-unit can be measured along as few or as many angles as necessary, the accuracy of the resultant curve being largely determined by the number of angles taken.

REFLECTORS

30. **Reflection of light** is the redirecting of light rays by a reflecting surface. Whenever light energy strikes an opaque object or surface part is absorbed by the surface and part is reflected. Light colored surfaces reflect a larger part of the light thrown on them than do dark colored surfaces, whereas dark surfaces absorb a larger part of the light, black surfaces absorb nearly all the light which reaches them. Consider first a smooth surface *AB*, Fig. 16, on which a ray of light *L* falls. This ray will be so reflected in the direction *R*, that the angle *a* is exactly equal to the angle *b*. Consider now the effect of a number of rays falling on a smooth surface *CD*, Fig. 17. Each ray will be reflected in such a way that it leaves the surface at the same angle at which it strikes it. The eye if held as shown would perceive only the light reflected into it.

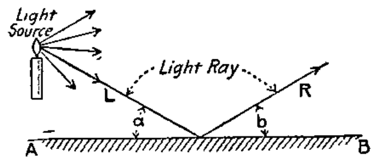


FIG. 16.—Reflection of light from a smooth surface.

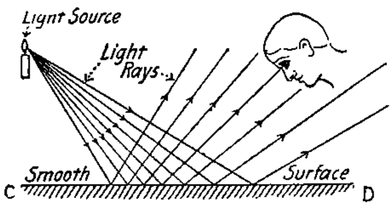


FIG. 17.—Reflection of light from a smooth surface.

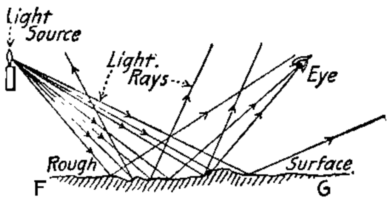


FIG. 18.—Reflection of light from a broken surface.

Consider now a broken surface such as *FG*, Fig. 18. Each ray of light is reflected from that portion of the surface on which it falls just as though that point were on a smooth surface. The result is that the light is scattered, and if the surface is irregular enough, the eye placed at any point will receive reflections from many points of the surface. All opaque surfaces except polished surfaces have innumerable minute irregularities like the surface in Fig. 18. This fact alone enables them to be seen.

31. **Reflecting Power of Surfaces.**—Different surfaces reflect different percentages of the light falling upon them. The illumination of a small room having poorly reflecting walls can often be improved by changing the wall coverings, particularly if bare lamps are used. If the room is large or if reflectors are used to throw the light downward so that not much light reaches the walls to be

reflected, a change in the wall covering will have little effect on the general illumination.

32. The following table of reflection coefficients (*Art of Illumination, Bell*) is useful in showing the relative reflective value of wall coverings in rooms.

Material	Per cent. reflection	Material	Per cent. reflection
Highly polished silver....	92	Chrome yellow paper....	62
Optical mirrors silvered on surface	70 to 85	Yellow wall paper.......	40
		Light pink paper........	36
Highly polished brass...	70 to 75	Blue wall paper.........	25
Highly polished copper..	60 to 70	Dark brown paper	13
Highly polished steel.....	60	Vermilion paper.........	12
Speculum metal.........	60 to 80	Blue green paper........	12
Polished gold...........	50 to 55	Cobalt blue.............	12
Burnished copper........	40 to 50	Glossy black paper......	5
White blotting paper.....	82	Deep chocolate paper....	4
White cartridge paper....	80	Black cloth.............	1.2
Ordinary foolscap.......	70	Black velvet............	0.4

33. Absorption is the loss of intensity or of volume of light that occurs when it passes through a reflecting or a translucent material, or when it is reflected by a reflecting surface.

34. Absorption of Light by Globes and Reflectors.—If globes are used on lamps, account must be taken of the light absorbed by the globes in calculating the total candle-power or lumens required. Table 35 gives average values (*Electrical Equipment of the Home—N. E. L. A.*).

35. Coefficients (per cent.) of Absorption of Globes and Shades

Material	Per cent. absorption	Material	Per cent. absorption
Clear glass globes.......	5 to 12	Opaline glass globes.....	15 to 40
Light sand blasted globes	10 to 20	Ground glass globes.....	20 to 30
Alabaster globes........	10 to 20	Medium opalescent globes	25 to 40
Canary-colored globes....	15 to 20		
Light blue alabaster globes.	15 to 25	Heavy opalescent globes	30 to 60
		Flame glass globes......	30 to 60
Heavy blue alabaster globes	15 to 30	Signal green globes.....	80 to 90
		Ruby glass globes......	85 to 90
Ribbed glass globes.....	15 to 30	Cobalt blue globes......	90 to 95

36. Refraction is the changing from the straight line, which a light ray normally assumes, that occurs when the ray passes from one medium into another of different density.

37. An unshaded incandescent lamp should never be tolerated under any circumstances, unless the bulb is completely frosted, and even then only in such locations as store rooms, etc., where it is desirable to light the entire wall surface, and where the eyes are normally directed away from the location of the lamps. This is because the lamp filament has a high intrinsic brilliancy; hence looking at it continually with the unprotected eye is apt to permanently injure the eye.

38. Distribution Curves of Reflectors.—The effect of a reflector in changing the direction of light given out by a light source is best expressed in the form of a distribution curve. Fig. 19 shows such a curve for a bare lamp and for the same lamp with a reflector. The curve represents the light in a single vertical plane through the center of the light unit, and it is assumed that the light in all similar vertical planes is similarly distributed. See 29 "How to read a photometric curve."

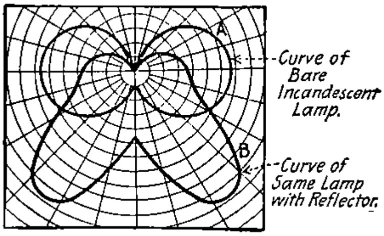


FIG. 19.—Comparison between distribution curve of a bare incandescent lamp with that of the same lamp equipped with a suitable reflector.

39. The area of the distribution curve is not proportional to the amount of light given off. Curve B, Fig. 19, represents a smaller total flux, by an amount equal to the absorption in the reflector, than does curve A, though it has a larger area. Such a curve as B is useful only for determining the intensity of light at any given angle below the horizontal.

40. Extensive, Intensive and Concentrating Reflectors (Fig. 20).—The Holophane Company first classified their reflectors into extensive, intensive and concentrating types, to which was later added the focussing type, the name designating the broadness

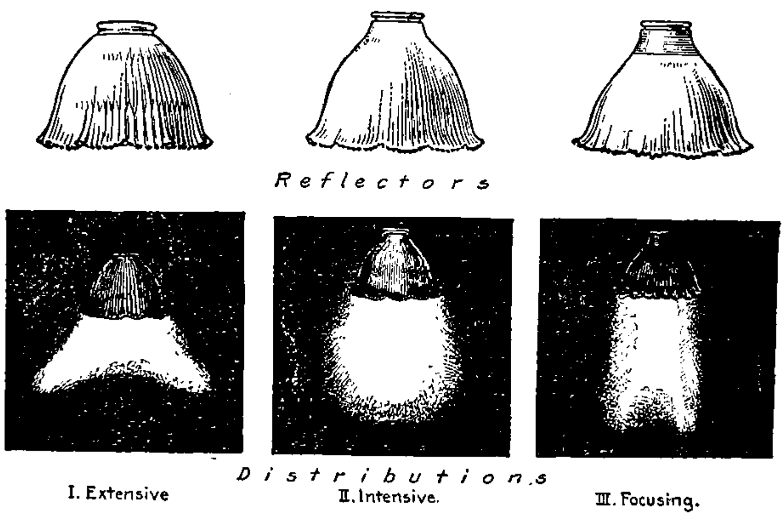


FIG. 20.—Typical prismatic glass reflectors.

of distribution as indicated by the distribution curve. These type names have since been adopted by other reflector manufacturers who make reflectors having definite and in general somewhat similar distribution curves, adapted for different mounting heights and spacing distances.

41. Application of Extensive, Intensive, Focussing and Concentrating Reflectors.—In general, focussing reflectors should be used when the distance between lamps is ¾ the mounting height; intensive reflectors should be used where the distance between lamps is about 1½ times the mounting height; extensive reflectors should be used where the distance between lamps is twice the mounting height. These figures are averages and may not apply to all makes of reflectors. If the best results as to uniformity of illumination are desired, lamps should be suspended from ceilings at such a distance as to give proper ratio of lamp spacing to mounting height, as advised by the reflector manufacturer or as determined by plotting illumination curves.

The different types (extensive, intensive, etc.) of Holophane reflector are not, in general, designed to give different illumination results. They are designed to give the same result, each type being suitable for a different condition of height and spacing of lamps.

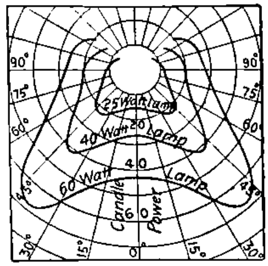


FIG. 21.—Typical photometric curves of lamps with "extensive" reflectors.

42. Extensive globes and reflectors (Fig. 20, *I*) distribute the reflected light over a wide angle below the horizontal (see Fig. 21). They are primarily for lighting moderately small rooms (say 12 ft. square) with single units or chandeliers on which the lamps hang pendant. The "extensive" type of distribution will meet the requirements of the following classes of rooms (*National Electric Lamp Association*):

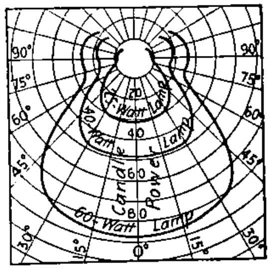


FIG. 22.—Typical photometric curves of lamps with "intensive" reflectors.

1. Rooms in residences where a single light or group of lights centrally located is employed (the distribution of several units hung vertically being approximately the same as that of a single unit).

2. Small offices, waiting rooms, alcoves, etc., where the conditions are substantially as above.

3. Wide hallways having moderate height of ceiling, stock-rooms, workrooms or other cases where even, general illumination is desired from a single line of outlets.

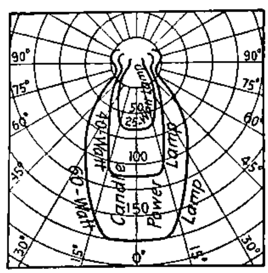


FIG. 23.—Typical photometric curves of lamps with "focussing" reflectors.

Extensive reflectors of the Holophane line give a distribution with the maximum candle-power at about 45 to 50 degrees up from the vertical.

43. Intensive globes and reflectors (Fig. 20, *II*) throw the light downward in a rather narrow angle (see Fig. 22). The primary purpose for which the "intensive" type of distribution was designed is that of evenly illuminating large rooms by means of distributed units placed close to the ceiling in the form of squares. This system is used commonly in department and other large stores, in dining halls and restaurants, hotel and club lobbies, large offices, assembly rooms, lodge rooms, halls of moderate dimensions, council chambers, court rooms, etc., where the lights are hung high above the plane of illumination. This method of lighting is seldom used in residences.

Intensive reflectors of the Holophane type have their maximum candle-power at and below 45 degrees.

44. **Focussing globes and reflectors** (Fig. 20, *III*) concentrate the light to a small area, producing greatest intensity of illumination along the axis of the reflector (see Fig. 23). The classes of lighting for which "focussing" reflectors are designed, include the illumination of tables, desks, display windows, store counters (by means of a row of lights placed high and directly over the same) and very high rooms (where they are used in the same manner as the "intensive" type). "Focussing" reflectors give an end-on candle-power approximately $3\frac{1}{2}$ times as great as the lamp's rated horizontal candle-power. The area intensely illuminated is a circle, the diameter of which should be one-half the height of the lamp above the plane of illumination; outside this limit the intensity falls rapidly, but not so abruptly as to give the effect of a spot of light.

Holophane "focussing" reflectors give their maximum candle-powers at about 10 degrees from the vertical.

45. **Concentrating reflectors** throw the light more strongly downward than those of the focussing type, giving in some cases an end-on candle-power of eight times the rated horizontal candle-power of the bare lamp. Higher concentration can easily be obtained but is not generally required commercially.

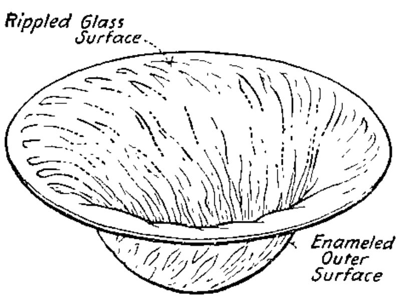


FIG. 24.—Silvered reflector for indirect lighting.

45A. **Asymmetric Reflectors** are those by which most of the light rays are thrown toward one side of the reflector. This is effected by interior vertical prisms which redirect the light from the side where it is not needed.

46. **Reflectors for Indirect Lighting.**—As manufactured by the National X-ray Reflector Company, a reflector, pointed upward, is placed under the lamp, and all of the light is directed to a light-colored ceiling. The room is illuminated by a reflected light from the ceiling. The result is a widely diffused illumination which resembles daylight; that is, shadows and general effects are similar to diffused daylight coming through a skylight or window. The decoration of the room, especially of the ceiling in which the system is to be used, should be of some light color. For best results the

ceiling should be a light cream or ivory, although somewhat darker shades give very satisfactory results. The walls of the room may be given darker tints, such as light brown, buff or tan. In all cases the lamps used with the system should be clear bulb tungsten. Each lamp has its individual reflector, especially designed, thus insuring the highest possible efficiency.

Many different types of reflectors are used, each adapted to particular conditions. One of these, a distributing type of reflector, is illustrated. Before attempting to suggest fixtures for any particular interior it is well to determine exactly what the conditions are under which the system is to be used, since the size and height of the room, color of walls and ceilings, as well as the location of the electric outlets, all affect the style of equipment that is to be specified. Styles of fixtures employed with this system are shown in Fig. 4. These fixtures are installed in exactly the same way as other electric-lighting fixtures. Some are designed for single lamps, others for multiple units, some types are made of metal, while others are constructed of "Compone" and composition. Special adaptables which may be added to the ordinary arm fixture can be procured. These adaptables hold the reflector in the correct relation to the filament of the lamp and can be readily fitted to arm fixtures that are already in place.

INCANDESCENT LAMPS

47. **Electric incandescent lamps** consist of a filament which is a highly refractory conductor mounted in a transparent glass bulb and provided with a suitable electrically connecting base. In incandescent lamps of the older types the air was, in so far as practicable, exhausted from the space within the bulb and surrounding the conductor (filament), leaving there a vacuum. But in many of the modern lamps this space is filled with an inert transparent gas—like nitrogen, for example. The conductor must have a high melting point or high vaporizing temperature and a high resistance; it must be hard and not become plastic when heated. In vacuum-type lamps the vacuum must be good, not only to prevent the oxidation of the filament, but also to prevent the loss of heat, which would reduce the efficiency. In non-vacuum-type lamps (gas-filled lamps) the gas used must be inert so as not to combine chemically with the filament material. The bulb must be transparent to permit the passage of light, not porous, so that it will retain the vacuum or inert gas, and strong to withstand handling and use.

48. **Classes or Types of Incandescent Lamps.**—There are now June, 1915) but three classes of incandescent lamps on the market, viz.: (1) *Carbon* filament, (2) *Metalized* filament or Gem, and (3) *Tungsten* filament or "Mazda." Several years ago the *tantalum* lamp was quite popular because it was then economical; this was prior to the perfection of the tungsten lamp. The demand for and manufacture of tantalum lamps has practically ceased because of the materially higher efficiency of the tungsten (or Mazda) lamp.

THE CARBON LAMP contains a filament made by carbonizing a cellulose thread, forming a filament of pure carbon. Its efficiency averages about 3.1 watts per candle. THE METALIZED FILAMENT OR GEM LAMP contains a carbon filament which has been treated in an electric furnace. This treatment imparts certain metallic properties to the carbon, thus permitting its operation at higher efficiencies than are feasible with ordinary carbon-filament lamps. Its efficiency is about 2.5 watts per candle. THE TUNGSTEN OR MAZDA LAMP has a filament of pure, drawn tungsten wire; see Art. 52.

48A. **Voltage and Wattage Ratings of Incandescent Lamps.**—All incandescent lamps for standard lighting circuits are now rated in watts. The watts rating of every lamp is indicated on its label. On the label is also specified the voltage at which the lamp is designed to operate. *The Three-Voltage-Rating* was formerly used, but the present practice is to show only one voltage. During the pioneer days of tungsten lamps their performances were somewhat uncertain and their first cost was high. Under these conditions the three-voltage-rating was justified inasmuch as it provided a means whereby light could be readily obtained at minimum cost with different power rates. Now, however, the lamps are low in price and their performance is uniform, hence, it appears, the three-voltage-rating is undesirable.

49. **The life of an incandescent lamp** (that is, the *useful* life) is always understood to mean the total hours of burning before the candle-power drops to 80 per cent. of the initial, unless the lamp becomes useless because of broken filament, or other cause prior to this. THE TOTAL OR BURNOUT LIFE of a lamp is the hours burning before failure of the filament.

50. Effect of Voltage Variation on Carbon Lamps
(All values in per cent.)

Volts	Candle-power	Watt per candle	Life
110	169	72.0	15.0
109	161	74.0	18.0
108	153	76.5	21.0
107	145	79.0	24.5
106	138	81.5	29.0
105	131	84.0	34.0
104	124	87.0	40.0
103	118	90.0	48.0
102	111	93.0	60.0
101	106	96.5	80.0
100	100	100.0	100.0
99	95	103.0	120.0
98	90	106.0	147.0
97	85	109.5	175.0
96	80	113.5	200.0
95	75	118.5	270.0
94	71	123.5	355.0
93	67	128.0	450.0
92	63	134.0	545.0
91	59	140.5	650.0
90	55	147.5	760.0

51. 220-volt vs. 110-volt Incandescent Lamps.—A number of 220–440-volt 3-wire direct-current systems have been installed with the idea of saving copper over that required for the 110–220-volt system. A comparison of lamp ratings shows that the 220-volt lamp—whether carbon, metallized or tungsten—has a much lower efficiency than the 110-volt lamp, costs more, and cannot be secured at all in the smaller sizes. Unless the load is composed so largely of motors that the lamp efficiencies and costs are over-balanced—which is not usually the case in these installations—it will be found that the saving effected by the use of 110-volt lamps will overbalance the saving in copper or the convenience effected by the higher voltage system.

52. Tungsten or Mazda Lamps.—The filament of the tungsten lamp is composed of pure metallic tungsten. When the lamps were first manufactured, the finely divided metal was mixed with a binder and squirted through a die, the binder afterward being burned away. As so made, the filaments were hairpin shape, and a number of them were connected in series in each lamp. At present the metal is drawn through dies, the same as any other wire, the final drawings being through diamond dies. The filament has a high tensile strength, is quite elastic and reasonably flexible, and the filament in each lamp is continuous, producing much better efficiency and greatly improved life. The modern lamps are capable of standing the abuse that may be accorded carbon or metallized lamps, and are very greatly superior to those originally produced, standing any reasonable amount of vibration without breakage. Unless accidentally broken, the lamps will easily average 1,000 hr. useful life. In fact, the efficiency ratings have been increased repeatedly (*i.e.*, the watts per candle decreased) in order to keep the average lamp from exceeding the rated life too greatly. The useful life of vacuum lamps has also been greatly increased by the addition of certain elements which absolutely prevent, except in case of impaired vacuum, the blackening of the globes, which was formerly so common.

It is possible to substitute tungsten lamps for either the obsolete carbon or the metallized filament lamps to give an equivalent candle-power with a saving of at least 60 per cent. in the energy consumed, or to consume an equivalent amount of energy with an increase of at least 60 per cent. in the light produced. The saving effected by the use of tungsten lamps, especially by substituting the larger size lamps for many smaller lamps, is of great importance.

The efficiencies of modern vacuum tungsten lamps range from about 1.3 watts per candle for the 10-watt lamps up to 0.9 watt per candle for the 250-watt lamps. The average for all sizes is about 1.3 or 1.4 watts per candle.

53. Tungsten Lamp Characteristics.—The positive temperature characteristic of the metallic filament makes the tungsten lamp much less sensitive to voltage variation than the carbon or even the metallized carbon filament. The resistance of the filament is very much lower when cold than at its operating temperature. This causes it to take an abnormal current when first turned on, causing the light intensity to increase very rapidly, producing the well-known "overshooting" of tungsten lamps. This is especially noticeable when both carbon and tungsten lamps are controlled from the same switch, the white light from the tungsten lamps appearing an appreciable interval of time before the yellower light of the carbon lamps. The changes produced by this characteristic of the tungsten lamp by changes in voltage are given in **56.**

53A. Gas-filled, Tungsten Incandescent Lamps.—Until recently it has been the practice of lamp manufacturers to exhaust the bulbs of incandescent lamps to an almost perfect vacuum. It has, however, been demonstrated that it is possible to operate tungsten wire filaments at higher temperatures in a bulb containing an inert gas. The presence of this inert gas in the bulb retards the evaporation of the filament. The convection currents—hot-gas currents—carry any particles evaporated to the upper portion of the bulb where they are deposited but where they absorb very little useful light. The filaments of these lamps are coiled and mounted in a compact manner to prevent their being cooled appreciably by the passage of the rising gas. These gas-filled tungsten lamps are referred to by some manufacturers as *Mazda C* lamps to distinguish them from the vacuum tungsten lamps which are now called *Mazda B*. The gas-filled lamps operate at considerably higher efficiencies than do the vacuum lamps but are so designed as to give the same useful life, viz., 1,000 hr. It is the usual practice to make the gas-filled lamps with pear-shaped bulbs having long glass necks. The efficiencies range from 0.80 watt per candle for the 100-watt multiple lamp to 0.45 watt per candle for the 1,000-c-p., 450-watt street series lamp.

53B. Mazda or Tungsten Lamp Illumination Data
(Multiple Lamps)

Watts	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
Straight-side type (vacuum), 105–125 volts						
10	1.30	7.7	0.60	7.54	75	78
15	1.15	13.0	0.68	8.52	128	78
20	1.10	18.2	0.71	8.91	178	78
25	1.05	23.8	0.74	9.34	234	78
40	1.03	38.8	0.76	9.52	381	78
60	1.00	60.0	0.78	9.80	588	78
100	0.95	105.0	0.82	10.32	1,032	78
150	0.90	167.0	0.87	10.89	1,634	78
250	0.90	278.0	0.87	10.89	2,723	78
Straight-side type (vacuum), 220–250 volts						
25	1.20	20.8	0.66	8.27	207	79
40	1.12	35.7	0.71	8.86	354	79
60	1.10	54.5	0.72	9.02	541	79
100	1.06	94.3	0.75	9.37	937	79
150	1.00	150.0	0.79	9.93	1,490	79
250	0.95	263.0	0.83	10.45	2,613	79

53B. Mazda or Tungsten Lamp Illumination Data
(Multiple Lamps).—(Continued)

Watts	Efficiency watts per candle	Mean horizontal candle-power	Efficiency spherical candle-power per watt	Efficiency lumens per watt	Total lumens	Reduction factor per cent.
Pear-shape type (gas filled), 105–125 volts						
100	0.80	125.0	1.00	12.57	1,257	80
200	0.75	267.0	1.07	13.40	2,680	80
300	0.70	429.0	1.14	14.36	4,310	80
400	0.70	571.0	1.14	14.36	5,745	80
500	0.70	714.0	1.14	14 36	7,180	80
750	0.65	1,154.0	1.23	15.47	11,600	80
1,000	0.60	1,667.0	1.33	16.76	16,760	80

54. **The tantalum lamp** had a filament composed of metallic tantalum. It had an efficiency of about 2 watts per candle. This lamp is not satisfactory for use on alternating current as the filament becomes beady and breaks after a short life. The demand for this lamp has practically ceased, it having been superseded by the more efficient and rugged tungsten lamp.

55. Characteristics of Metallized Filament or Gem Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volts	95.0	96.0	97.0	98.0	99.0	100
Amperes	95.8	96.7	97.5	98.4	99.2	100
Watts	91.0	92.8	94.6	96.4	98.2	100
C.P.	75.1	79.6	84.4	89.4	94.8	100
W.P.C.	121.0	116.6	112.2	108.0	103.7	100
Life	265.0	217.0	176.0	147.0	120.0	100
Volts		101.0	102.0	103.0	104.0	105.0
Amperes		100.8	101.6	102.4	103.2	104.1
Watts		101.8	103.6	105.5	107.3	109.3
C.P.		105.3	110.3	114.9	120.4	126.2
W.P.C.		96.5	94.0	92.0	89.0	86.5
Life		83.0	68.0	59.0	50.0	43.0

56. Characteristics of Tungsten (Mazda) Lamps
(All values in per cent.)

Per cent., change in	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Volts	95.0	96.0	97.0	98.0	99.0	100
Amperes	97.1	97.7	98.3	98.9	99.4	100
Watts	92.4	93.9	95.5	97.1	98.5	100
C.P.	83.6	86.7	90.0	93.3	96.6	100
W.P.C.	110.3	107.9	105.7	103.7	101.8	100
Life	212.0	181.0	154.0	132.0	115.0	100
Volts		101.0	102.0	103.0	104.0	105.0
Amperes		106.6	101.1	101.7	102.2	102.8
Watts		100.6	103.2	104.6	106.1	107.5
C.P.		103.4	107.0	110.0	114.4	118.2
W.P.C.		98.1	96.3	94.5	92.8	91.1
Life		86.0	74.0	64.0	56.0	48.0

57. Bases for Incandescent Lamps (See Fig. 28).—Standard nomenclature in this respect has been changed recently. One of the important changes is the substitution of the term "Screw" for "Edison" as applied to bases. The term "Bayonet" base has been adopted in place of the term "Ediswan" base. The classifying adjectives, "Medium" and "Mogul" have been adopted in place of the words "Large" and "Street Series" which were formerly

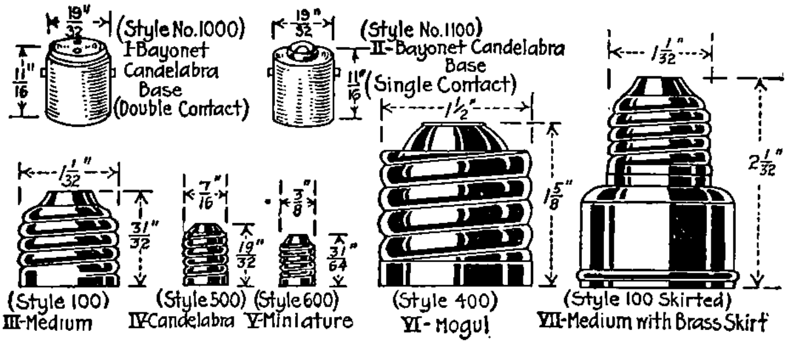


FIG. 28.—Different sizes of "screw" lamp bases.

used. Lamp bases may be divided into three general classes, as the base in a general way determines to which of the three styles the lamp belongs. 1. *Medium bases*, generally used with large lamps. 2. *Small bases*, generally used with candelabra and miniature lamps. 3. *Mogul bases*, generally used with street series lamps.

ARC LAMPS

58. Carbon Arc Lamps.—If two pieces of carbon are connected to an electric circuit and brought together, current flows through them. As the contact between the two pieces is poor, due to the nature of the materials, considerable heat is developed at that point. If the two carbons are now slowly separated, the resistance of the contact increases until the heat developed becomes sufficient to vaporize the end of one or of both of the carbons. This vapor forms a conducting path for the current after the carbons are separated and the current flows through this vapor, forming an electric "arc."

59. Open and Enclosed Electric Arc Lamps.—When the air can come freely in contact with the arc, the carbons are burned away very rapidly. This is the case with open arcs, which term includes those having a large globe into which air can enter freely. To prevent the rapid oxidation of the carbons and also to make the arc more steady, an inner globe, almost air tight, is provided on all modern carbon arc lamps. This globe and the "gas check" or cap are so designed that just enough air is admitted to burn up the carbon vapor so that it will not deposit on the globe. The increase in life of carbons that results from enclosing the arc is indicated in 60.

60. Representative Arc Lamp Data.—(*Wickenden*)

NOTE.—Values of watts per mean lower hemispherical candle-power approximate for open carbon arcs and magnetite arcs with clear globes, enclosed carbon arcs with opalescent inner globes and for flame and regenerative arcs with opal globes.

Type of lamps	Open or enclosed	Electrodes	Hours per trim	Amperes	Terminal volts	Arc volts	Terminal watts	Arc watts	Terminal power factor.	Watts per m.l.h. c-p.
D.-c series carbon arcs.	Open.....	+Upper, solid or cored. −Lower, solid.	9 to 12	9.6	50	47	480	450	....	0.6
	Open.....	+ Upper, solid or cored. − Lower, solid.	9 to 12	6.6	49.5	47	325	310	....	0.7
	Enclosed..	+ Upper, solid or cored. − Lower, solid	100 to 150	6.6	72.0	68	475	450	....	0.9
A.-c. series carbon arcs.	Enclosed..	One solid. One cored...	70 to 100	7.5	75.0	72	480	450	0.85	1.8
	Enclosed..	One solid. One cored...	70 to 100	6.6	77.0	72	425	400	0.85	2.0
D.-c. multiple carbon arcs.	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	5.0	110.0	80	550	400	....	2.25
	Enclosed..	+ Upper, solid. − Lower, solid.	100 to 150	3.5	110.0	80	385	280	....	2.35
A.-c. multiple carbon arcs.	Enclosed..	One solid One cored...	70 to 100	6.0	110.0	72	430	375	0.65	2.40
	Enclosed..	One solid. One cored...	70 to 100	4.0	110.0	72	285	250	0.65	2.60
D.-c. flame arcs.	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	45	440	360	....	0.45
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	45	550	450	....	0.40
	Open.....	Mineralized vertical....	10 to 16	8.0	55.0	38	440	304	....	0.45
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	38	550	380	....	0.40
Regenerative...	Semi-enclosed.	− Upper carbon. + Lower carbon, mineralized.	70	5.0	....	70	....	350	....	0.26
A.-c. flame arcs	Open.....	Mineralized inclined....	10 to 16	8.0	55.0	47	374	338	0.85	0.60
	Open.....	Mineralized inclined....	10 to 16	10.0	55.0	47	467	423	0.85	0.55
	Open.....	Mineralized vertical....	10 to 16	10.0	55.0	40	467	360	0.85	0.55
Magnetite......	Open.....	+ Copper. − Metallic oxide.	150 to 180	4.0	80.0	78	320	312	....	0.70
	Open.....	+ Copper. − Metallic oxide.	70 to 100	6.6	80.0	78	528	515	....	0.45

The carbons of an enclosed carbon arc lamp should burn 100 hr. on alternating current and 150 to 180 hr. on direct current if properly operated. Also as the air is excluded the carbons can be burned farther apart, resulting in better light distribution.

To secure satisfactory operation of an enclosed arc, however, care is necessary in the selection of carbons, both as to exact size and quality. Sufficient air must be admitted to unite with the carbon vapor as it is given off or it will deposit on the globe; too much air will greatly decrease the life per trim. If the diameter is not right, either too great or too small, air will be admitted through the gas check. If the quality of the carbon is poor, a deposit will form on the inner globe and discolor it.

61. **Flame Arc Lamps.**—Any of the ordinary carbon arcs can be made to flame by increasing the arc length or the current density. Such a flame gives off little or no light and hence is disadvantageous. By feeding into the arc certain metallic salts the arc flame can be made to produce light—the color varying with the metal used. Calcium—especially calcium fluoride—produces a yellow-colored light of very high efficiency. Strontium salts produce a reddish color and barium and titanium salts a brilliant white, at a somewhat reduced efficiency. The metallic salts are introduced into the flame by using either carbons cored with a mixture of soft carbon with the desired salt or salts or an electrode impregnated throughout with the desired compound. The carbons may be vertical, and co-axial as in the ordinary arc, but in most open-flame lamps they are inclined in a V-shape. There is thus no obstruction to the light below the horizontal. The arc burns in a cup-shaped economizer of a refractory material, which serves as a reflector, to shield the arc from air currents, and to prevent it from running up the carbons. A small magnet just above the economizer serves to "blow" the arc downward into a bow shape.

62. **The open-flame carbon arc** is dirty, giving off offensive fumes, and is very costly to maintain on account of the short life of the carbons, which are quite expensive. These defects have been overcome by enclosing the arc in an air-tight chamber.

63. **Candle-power of Inclined Electrode Flame Arc Lamps.**—The light from this type of lamp is given off at its greatest intensity in a direction nearly under the lamp. This is excellent for display lighting but not so satisfactory for street illumination and for this purpose the light distribution from the lamp is modified with a suitable reflector.

64. **Long-burning or Enclosed Flame-carbon Arc Lamps.**—Several manufacturers have recently placed on the market flame arc lamps constructed on the principle of the enclosed carbon lamp, *i.e.*, having an enclosed arc chamber from which free access of air is prevented. Some of these lamps have a burning life of as much as 100 hr. per trim. The globe is kept free from the deposit of soot by arranging the air circulation and condensing chambers in which the fumes deposit. These lamps preserve the advantage of the flame arc lamp—high light efficiency—and do not have most of its objectionable features.

65. **The enclosed flame arc lamp,** the arc of which is essentially that of the ordinary open flame arc lamps, has a burning life per trim of 100 hr. and compares favorably in candle-power and efficiency with the short-burning open-flame arc lamp. To secure long burning life of the carbons, the arc is enclosed in a chamber to which the supply of air is limited, as in the case of the standard enclosed arc lamp. In the flame-carbon lamp, however, the efficiency is reduced very little by the enclosure.

66. **Magnetite, Luminous, or Metallic Flame Arc Lamps.**—There are several makes of lamps on the market using one electrode of metal, that requires very infrequent renewal, and one of metallic oxides. These lamps combine the principles of the carbon arc and the flame arc, in that both the arc stream and the electrodes are highly luminous. These lamps have the peculiarity that the negative electrode burns away while the positive electrode is consumed very slowly. This limits these lamps to direct-current circuits. The negative electrode of these lamps is a very poor conductor when cold and therefore a conducting wire is generally run through its center to carry current to the arc, the electrode serving principally as a supply of substance to be burned in the arc. In one make of this lamp the negative is placed at the bottom and in another at the top.

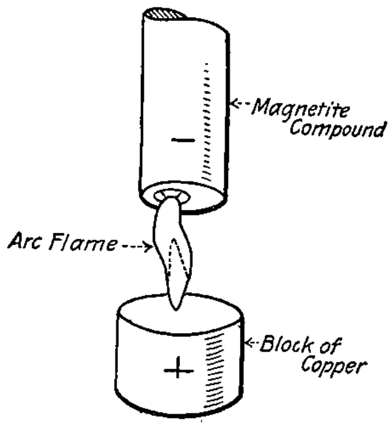


FIG. 29.—Electrodes of metallic flame lamp.

The negative electrode (Fig. 29) or cathode has a life of 160 to 200 hours. The arc flame is brightest near the negative electrode and decreases in brilliancy and volume as it nears the positive electrode. Mechanisms in these luminous lamps feed the negative electrode intermittently by restriking the arc. When the current is thrown on the feeding magnets are energized, bringing the electrodes together and striking the arc. A shunt magnet connected around the arc acts when the voltage caused by lengthening of the arc is sufficiently increased. This closes a contact which short-circuits the arc, causing the feeding magnets to strike the arc again with sufficient force to dislodge any drops of slag which may have accumulated.

The magnetite arc is well adapted for series operation with low currents. (Wickenden.) The four-ampere lamp, designed for series operation at 80 volts per lamp, has been widely used for street illumination. The 6.6-amp. lamp has a much higher efficiency and a somewhat shorter life per trim.

67. **Intensified Arc Lamps.**—By using special, small diameter carbons and a high-current density in these lamps, the temperature of the arc is considerably increased, and the ends of both carbons become incandescent, giving an increased light efficiency

with a shorter life. On account of the increased temperature the light is nearly white in color, closely approaching daylight in appearance. In general these lamps are quite similar to ordinary enclosed arcs, except in one type, in which two small upper carbons, arranged in V-shape, are connected in parallel, burning, however, one at a time. When adjusted for 5 amp., and 80 volts at the arc, and equipped with two 12 in. $\times \frac{1}{4}$ in. positive and one $3\frac{1}{2}$ in. $\times \frac{3}{8}$ in. negative carbon, a life of 75 hr. is secured with an efficiency of about 1 watt per candle with clear globes.

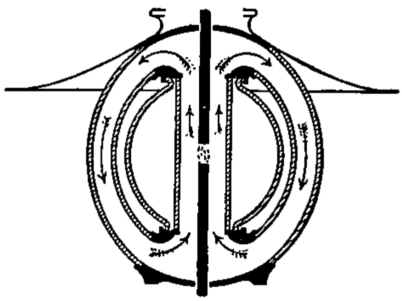


FIG. 30.—Carbon and globe arrangement in the regenerative arc lamp.

68. Regenerative Arc Lamps.—The so-called "regenerative" arc lamp (Fig. 30) is a flame arc lamp with its air currents so arranged that the fumes from the arc are returned to the arc chamber and there used over again and burned up. The arc is semi-enclosed in a glass globe, having two auxiliary glass-tubes opening into it both above and below. A circulation of the vapor is effected by the arc, the heated vapor passing around the circulating tubes from top to bottom and used in the arc many times before condensing. A specific consumption as low as 0.25 watts per mean lower hemispherical candle-power and a life per trim of 70 hr. with the advantage of a wide distribution of light is claimed.

MERCURY VAPOR LAMPS

69. The Cooper-Hewitt mercury vapor lamp consists essentially of two separate elements, the tube or light-giving part, and the operating mechanism. The tube (Fig. 31) is of clear glass of varying length, from 21 to 55 in., with electrodes at each end and containing a small quantity of metallic mercury. The air is

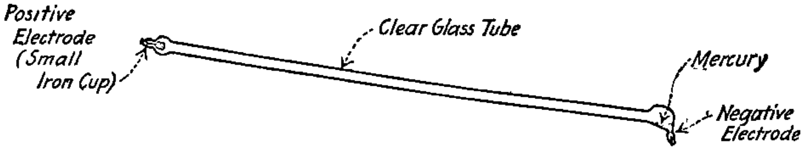


FIG. 31.—Cooper-Hewitt tubes removed from lamp.

exhausted and the tube then sealed. The mercury is held in the large bulb at one end of the tube, and serves as the negative electrode, the tube being always so suspended that this bulb is the lowest part of the tube. The positive electrode is a small iron cup at the other end of the tube. The current is conveyed to the electrodes through platinum wires sealed in the glass. The current, passing from the positive electrode to the negative, vaporizes some of the mercury and causes the vapor to become luminous.

70. The Arc.—It being practically impossible to pass an alternating current through a mercury arc, the mercury vapor lamp is therefore essentially a direct-current lamp, and gives its best results when operating on direct current. By providing two anodes, and an auto-transformer, the lamp can be operated, however, on alternating current, using the principle of the mercury rectifier, and alternating-current lamps are regularly marketed and satisfactory in operation.

71. **Quality of light** from a mercury vapor lamp is peculiar. It contains no red rays, and has a peculiar bluish-green color, which greatly distorts the color values of objects viewed by it. For work in which it is not necessary to distinguish color values, two advantages are claimed by the maker. *First*, due to the absence of red rays, it is easy on the eyes, since these rays are the least effective in producing vision, and, owing to their heating power, are irritating and fatiguing to the retina. This is offset by the great preponderance of ultra-violet rays which are claimed by some to be harmful, although this has not been established experimentally. *Second*, the approximately monochromatic nature of the light promotes acuity of vision, *i.e.*, objects are seen more sharply and details are more easily discernible than by white light. The lamps are chiefly useful for drafting, photography, and for lighting large manufacturing areas.

PRINCIPLES OF ILLUMINATION DESIGN

72. **General Principles of Illumination.**—The general purpose of illumination is to enable things to be easily seen. As things are seen by the light reflected from them into the eye, it is necessary to have the lighting units of such number and intensity and so arranged as to make the things it is desired to see most easily seen. To do this, account must be taken of the effect of illumination on the eye. Before attempting to lay out an illumination scheme one should be familiar with the facts outlined under *Physiological Features of Illumination*, Paragraph 1.

73. **Location of Lights.**—No general rule can be given for location of lights for general illumination. It is always desirable to so distribute the units that uniform illumination will result. Where the number and location of lighting outlets is not determined by architectural considerations, or by the arrangement of the furniture and fixtures, it is desirable to arrange the lighting outlets in the form of squares or rectangles. It is important that the units be placed at the centers of the squares and not at the corners. Fig. 32 shows this method of locating outlets which is bad because it gives a very low intensity of illumination near the walls, as compared with that at the center of the room. Fig. 33 shows the correct way of locating outlets in the centers of the squares. In certain cases, notably in office lighting, it may be desirable to place

the outer rows of outlets somewhat nearer the side walls of the room than would be the case if symmetrically arranged as shown in the diagram, to avoid shadows.

For a given ceiling height, the smaller the squares, the less intense will be any shadows produced. The higher the ceiling, the larger the squares can be. As a general rule the side of each square should about equal the height of the ceiling. For offices that have no desk lighting the squares should be smaller, say $\frac{3}{4}$ the height of the ceiling, to reduce shadows; for stores the squares can be a little larger.

If the room is divided by partitions, each enclosure should be treated as a separate room.

Where the ceiling is divided into panels or broken up by girders, the size and location of these often determine the spacing of the lights. In such cases it is advisable to space the lighting units symmetrically according to the decorations and girders and select lamp sizes and reflectors adaptable to such spacing.

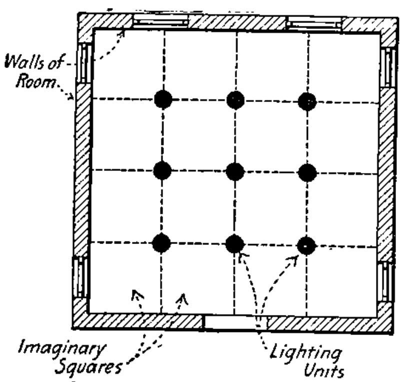


FIG. 32.—Wrong arrangement of lighting units.

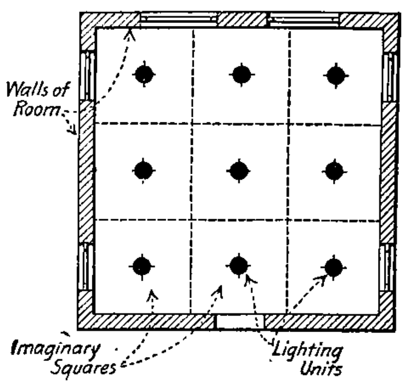


FIG. 33.—Correct arrangement of lighting units.

74. Desirable Sizes of Squares.—In lighting large offices, where individual desk lights are not employed, the squares should be comparatively small in order to have the light on any one desk coming from many units, thus merging the shadows and decreasing the glare due to regular reflections from the desk. In stores, the squares need not be so small. The size of the squares bears no relation to the intensity of illumination, but only to the evenness of illumination and depth of shadows. The following table gives the sizes of squares desirable for various spaces for direct lighting. The table cannot be strictly adhered to in all cases, and it is better not to use with the smallest ceiling height in each line the largest size square available for that height. In office lighting with no desk lights, the squares should never be made so large that extensive reflectors are necessary to obtain uniform illumination. (*Holophane Company.*)

Kind of room	Ceiling height	Desirable length of side of square
Armories	12 to 16 ft.	12 to 16 ft.
Auditoriums	12 to 16 ft.	12 to 16 ft.
Public halls	over 16 ft.	15 to 26 ft.
Rinks	over 16 ft.	15 to 26 ft.
Stores	8 to 11 ft.	8 to 11 ft.
Stores	11 to 15 ft.	10 to 16 ft.
Stores	over 15 ft.	14 to 22 ft.
Offices with individual desk lights	10 to 20 ft.	12 to 18 ft.
Offices without individual desk light	9 to 12 ft	7 to 11 ft.
Offices without individual desk light	12 to 16 ft.	9 to 14 ft.
Offices without individual desk light	over 16 ft.	11 to 18 ft.

75. A spacing chart for prismatic reflectors is shown in Fig. 34. Knowing either the spacing or mounting height, the correct reflector and its proper mounting height or spacing can be determined at a glance, or vice versa.

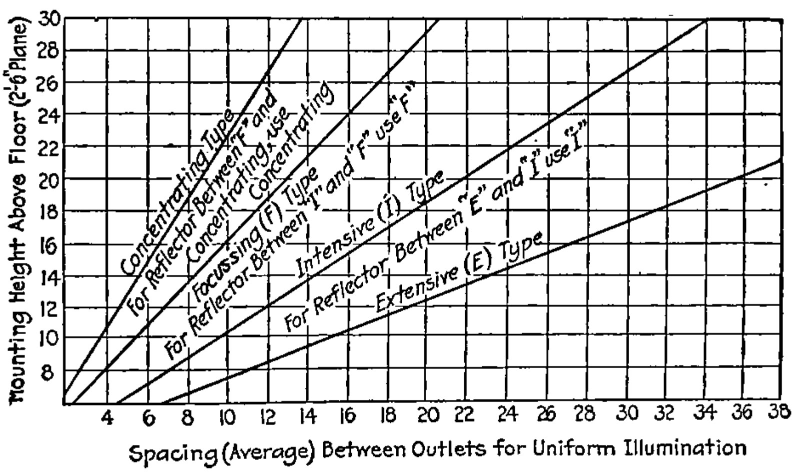


Fig. 34.—Spacing chart for reflectors. (*Holophane Company.*)

Example.—Consider an installation for which a spacing distance of 14 ft. has been selected. With this spacing distance extensive type reflectors call for a mounting height of about $9\frac{1}{2}$ ft. above the floor. This is obviously too low to secure the best diffusion and minimum shadows, so reference is made to the diagonal in Fig. 34 representing the intensive type, and a mounting height of $13\frac{1}{2}$ ft. is found. This gives a distance from ceiling to socket of about 1 ft. with a 15-ft. ceiling.

75A. Spacing for indirect and semi-indirect lighting is determined largely by the ceiling height. The distance between units should not, in general, exceed $1\frac{2}{3}$ times the height of the ceiling above the plane to be lighted, draughting rooms and offices where close work is performed should have closer spacings.

76. Mounting height usually means the distance from the center of the lamp to the plane of illumination, but it may mean the mounting height above the floor, that is, the height from the floor to the lamp.

77. Considerations Relating to the Height and Type of Ceiling or Roof of the Area Illuminated (*Electric Journal*).—In a manufacturing area, the direct system is almost invariably employed and the lamps mounted within a foot or two of the ceiling or on stringer boards which span the space between the lowest members of roof trusses at intervals where rows of lamps are deemed necessary. High mounting is desirable because then the lamps are out of the way of cranes, are less liable to be broken, the glare is reduced to a minimum and in the case of a light ceiling there is more reflection and better diffusion of light. The lamps should be lowered in locations where there is horizontal overhead belting, to the level of the bottom of the belting; otherwise a portion of the light is ineffective. It may be necessary, for the same reason, to install two or three units in an area where the conditions would otherwise warrant one unit.

In office lighting the direct, indirect, or semi-indirect system may be used. With the direct system the lower intensity lamps, such as the 60-watt unit, give most satisfactory results. This is due to the fact that the glare and inconvenience from shadows is reduced to a minimum. Ordinarily the lamps should be mounted near the ceiling.

78. Approx. Desirable Mounting Heights for Tungsten Lamps

Mounting height, ft.	Size of lamp, watts	Mounting height, ft.	Size of lamp, watts
7 to 10	40		
8 to 12	60	7 to 12	60
10 to 14	80		
12 to 16	100	11 to 16	100
14 to 20	150		
17 to 27	250	16 to 28	250
25 to 35	400		
30 to 40	500	28 to 40	500

78A. Mounting Height and Spacing for Reflectors

Type of reflectors	Ratio : $\frac{\text{spacing}}{\text{height}}$ (Multiply mounting height by following to obtain spacing of lamps)	Ratio : $\frac{\text{height}}{\text{spacing}}$ (Multiply spacing by following to obtain mounting height)
Extensive.........	2.00	0.50
Intensive.........	1.25	0.80
Focussing.........	0.75	1.30
Concentrating.....	0.50	2.00

DISTRIBUTING REFLECTORS are not designed for any particular spacing. Use them for spacings wider than *extensive* where uniform or even illumination is not necessary, as in stock-rooms, warehouses and the like.

NOTE.—Where conditions call for reflectors between any two of the above types, use the more concentrating of the two. For example: If a reflector midway between an *intensive* and a *focussing* is indicated by the computations, use the *focussing* type.

79. Total Lumens given by Clear, Regular Bulb Multiple Lamps (*Correct from Incandescent Manufacturers' Data Sheets, June, 1915*).—The amount of light radiated by any electric lamp is a perfectly definite and measurable quantity, the value of which depends upon the wattage of the lamp and the efficiency at which the lamp is burned. The unit in which quantity of light is measured is called the *lumen.*

In the following table are given the values of the total lumens radiated by each of the incandescent lamps in most common use for lighting purposes. The figures given in this table are correct for lamps operating at normal voltage with the efficiencies which are standard at this date. Use of table is explained in par. 85.

Rated watts	Mazda B or tungsten (vacuum)		Mazda C or tungsten (gas filled)		Tantalum		Gem	Carbon	
	105–125 volts	220–250 volts	105–125 volts	220–250 volts	100–130 volts	200–260 volts	100–130 volts	100–130 volts	200–275 volts
10	75	......	......	......	......	......	......	......	......
15	128	......	......	......	......	......	......	......	......
20	178	......	......	......	......	......	52	50	......
25	234	207	......	......	126	......	......	84	......
30	......	......	......	......	......	......	104	96	......
35	......	......	......	......	......	......	......	......	84
40	381	354	......	......	222	......	162	......	......
50	......	......	......	......	277	252	208	175	......
60	588	541	......	......	......	......	249	210	170
80	......	......	......	......	443	403	337	......	......
100	1,032	937	1,257	......	......	......	422	349	......
120	......	......	......	......	......	......	......	419	341
150	1,634	1,490	......	......	......	......	......	......	......
200	......	......	2,680	2,388	......	......	......	......	......
250	2,723	......	......	......	......	......	......	......	......
300	......	......	4,310	3,770	......	......	......	......	......
400	......	2,613	5,745	5,282	......	......	......	......	......
500	......	......	7,180	6,970	......	......	......	......	......
750	......	......	11,600	......	......	......	......	......	......
1,000	......	......	16,760	......	......	......	......	......	......

80. The three methods, in general use, of calculating illumination are:—(1) The Flux-Of-Light Method. (2) The Watts-Per-Square-Foot Method. (3) The Point-By-Point Method. Each has its applications and none is suitable for all problems. Only methods (1) and (2) will be discussed in this book. Method (2) is in reality a modification of method (1).

81. All of the methods of calculating illumination give approximate data. They really provide nothing more than reasonably accurate estimates which must be supplemented by the judgment of an experienced designer to afford dependable results. In laying out an illumination installation it is always a good plan to initially install in each outlet a lighting unit of a wattage somewhat larger than that the estimates indicate necessary. In case there is too much light, a lamp of smaller wattage can be used in each outlet.

82. Calculation by the "Flux of Light" Method.—The simplest method of laying out general illumination is by this method.

Knowing the intensity desired (16 and 17) on the surface to be illuminated and its area, the total flux or lumens required to produce that average illumination is readily computed:

$$lumens = \frac{Area\ (sq.\ ft.) \times Intensity\ (foot\text{-}candles)}{Constant}$$

or expressing the same thing in letters

$$F = \frac{S \times I}{c} \quad \text{and} \quad S = \frac{F \times C}{I} \quad \text{and} \quad I = \frac{F \times C}{S}$$

Wherein F = the total flux in lumens from all of the light sources that illuminate the area; S = the area illuminated in square feet; I = the average intensity in foot-candles over the entire area and C = constant from 84. Knowing the total lumens required, it is then possible to determine how many lighting units of a certain size or what size of lamps of a given number are required to provide the required flux (lumens). The lumens generated in a given lamp can be found from the table in par. 79.

83. **Illumination Constants.**—The "flux of light" method of calculation is based on the assumption that a certain proportion of the light generated in a room is thrown on the surfaces to be illuminated. Some of it is thrown on the walls and ceiling, and of this only a part is reflected to the illuminated plane. The following table indicates, approximately, the percentage of the light generated that reaches the illuminated plane under different conditions.

84. **Average Illumination Constants, Per Cent. Lumens Effective, or Efficiency of Utilization.**—If the number of total lumens produced by a light source be multiplied by the value (expressed as a decimal) for the conditions applying given below, the number of lumens effective in lighting the area will be the result. (See note.)

Ceiling	Light	Light	Medium	Light	Medium	Medium	Dark
Walls	Light	Medium	Light	Dark	Medium	Dark	Dark
[1] Prismatic, clear......	60	53	......	48	48	45	40
[1] Prismatic, V.F.......	53	50	......	45	45	42	38
[1] Holophane-realite ...	51	47	......	44	45	38	35
[1] Steel, porcelain, aluminum.	48	46	......	44	45	44	44
[1] Sudan..............	50	45	......	42	42	40	37
[1] Druid...............	48	43	......	39	38	34	31
[1] Druid, semi-indirect..	40	37	......	33	25	20	......
[1] Sudan, semi-indirect.	35	33	......	30	20	17	......
[1] Ivanhoe, indirect.....	31	28	......	25	18	15	......
Opal.................	50	45	44	42	42	40	37
White glass, light density.	48	44	43	40	40	36	33
Indirect and semi-indirect.	31	28	21	25	19	17	10
Bare lamps...........	41	35	34	30	30	25	21

NOTE that the above are average, and ordinarily safe, working constants. The actual constant to use in any case will be determined to some extent by the size of the room to be illuminated. For rooms of floor areas of less than 200 sq. ft., the constants used may be smaller than those above given by from 10 to 40 per cent. For rooms of areas larger than 1,000 sq. ft., constants greater than the above—by not more than 15 %—may be used, particularly where the walls are of medium or dark colors. [1] Holophane Works data.

85. Example, "Flux of Light" Method of Calculating Illumination.—Suppose we have a notions store to light, the dimensions of which are length, 80 ft.; width, 25 ft.; height, 12 ft. 6 in. The ceiling and walls are light. Tungsten lamps with prismatic velvet-finish reflectors are to be used.

Referring to the table in paragraph 17 we find that stores of this character should have an illumination of 3.0 ft-c. The area of the store is 80 × 25 or 2,000 sq. ft. The illumination constant for prismatic velvet-finish reflectors with tungsten lamps in rooms with light ceilings and light walls is 0.53 (paragraph 84). Substitute in the formula of 82 thus:

$$F = \frac{S \times I}{C} = \frac{2{,}000 \times 3.0}{0.53} = 11{,}300 \text{ lumens.}$$

Now determine the number and size of lamps necessary to supply this quantity of light. In 79 we find that a 25-watt tungsten lamp gives 234 lumens; a 60-watt lamp, 588 lumens; a 100-watt lamp, 1,032 lumens; and a 150-watt lamp, 1,634 lumens. (All of the data just given apply to vacuum lamps.)

The number of 25-watt lamps required would be, therefore, 11,300 ÷ 234 = 48; the number of 60-watt lamps, 11,300 ÷ 588 = 19; the number of 100-watt lamps, 11,300 ÷ 1,032 = 11; and the number of 150-watt lamps, 11,300 ÷ 1,634 = 7.

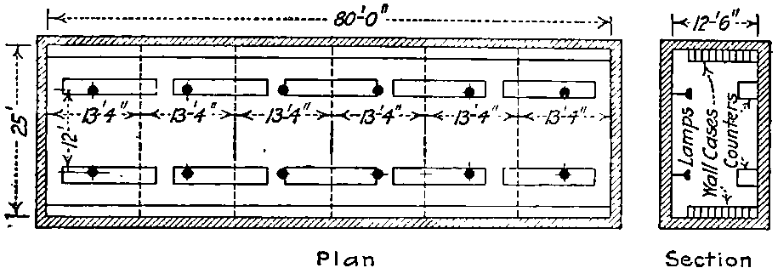


Fig. 35.—Illustrating the flux-of-light method of calculating illumination.

The lighting should be laid out in squares. (See paragraph **73.**) The room would then be 2 squares wide and 6 or 7 squares long, thus requiring 12 or 14 units. Twelve 100-watt lamps would therefore about satisfy the requirements, spaced as shown in Fig. 35. It will be even better to put the lights a litt e nearer the center of the room than the walls, because of the shelving along the walls. This has been done in Fig. 35.

The reflectors should be selected as indicated in paragraph **78A.** The lamps are spaced 12 ft. to 13 ft. 4 in. apart. The ceiling height is $12\frac{1}{2}$ ft., making the lamps about 10 ft. above the tops of tables and counters. The ratio of lamp spacing to height of lamps is $\frac{13}{10} = 1.3$. By suspending the lamps at the ceiling the ratio would be $\frac{13}{10} = 1.25$ (approx.), the correct ratio for average intensive reflectors.

86. Watts per sq. ft. Method of Designing Illumination Installations.—Where only one type of lighting unit, the tungsten lamp, for instance, is used and the mounting height of the units falls within the limits specified in 78, this method can be used. However, the *Flux of Light* is now usually considered the preferable method. The "*Watts Per Square Foot,*" of Table 87, is based on the fact that with a given type of lamp and given conditions, one foot-candle intensity will be produced on the working plane by a certain expenditure (in watts per sq. ft.) of energy.

Similar tables can be compiled for illuminants other than tungsten lamps.

In using the method, determine the size of lamp required from Table 78 and the watts per sq. ft. necessary to produce the desired intensity from Table 87. Then:

$$\frac{\textit{Wattage of lamp}}{\textit{Watts per sq. ft.}} = \textit{area of square of which lamp is the center.}$$

Taking the square root of the value representing the area of this square, the length of the side of the square, or the "ideal spacing distance" between lamps is obtained. It follows that

$$d = \sqrt{A} = \sqrt{\frac{W}{w}}$$

Wherein d = ideal spacing distance in feet; A = the area of the ideal square in square feet; W = wattage of each lamp and w = watts per square foot.

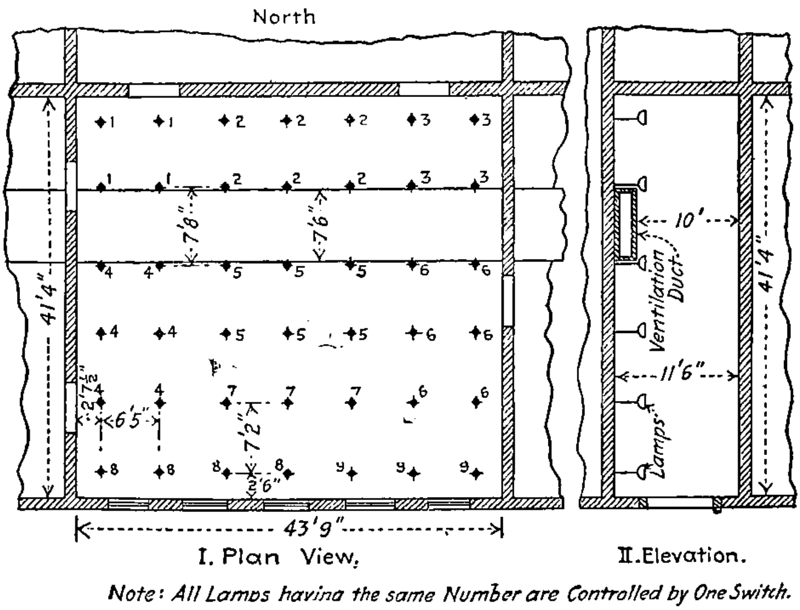


FIG. 36.—Example in laying out the illumination for an office room.

The spacing distance d having been ascertained, the designer should so lay out his area into squares or rectangles (Fig. 33) that the distance between lamps will be as nearly equal to the distance d as possible.

Where there are different ceiling heights in the same room, the size of lamp is finally decided by the relation of spacing distances to the dimensions of the room. For the sake of standardization, the number of sizes of lamps used may be reduced to four as shown in the right-hand half of Table 78.

Example of Application of the Watts per Square Foot Method.—A draughting room has a ceiling 11 ft. 6 in. high and both it and the walls are light colored. The area is 41 ft. 4 in. by 43 ft. 9 in., equalling 1,810 sq. ft. A ventilating duct causes an obstruction, as shown in Fig. 36, the bottom being 18 in. below the ceiling. An illumination of 7 ft-c. is desired. Tungsten lamps in prismatic reflectors are to be used.

The effect will be best if all the lamps are mounted with the top of the reflectors level with the bottom of the air duct. This gives a mounting height (which is always measured to the socket) of 10 ft. It is decided, upon referring to Table **78**, to use 60-watt lamps, the watts per square foot being (from Table 87) 0.19 *watts per sq. ft. per foot-candle* × 7 *ft-c.* = 1.3 *watts per sq. ft.* The ideal spacing distance, calculated out as explained, is 6 ft. 8½ in.

Laying out the lamps it is found that in a direction east to west, a spacing distance of 6 ft. 5 in. places them free from obstructions and leaves 2 ft. 7½ in. at each wall. In the other direction the width of air duct is 7 ft. 6 in., which makes 7 ft. 8 in. the minimum distance apart that the two rows of lamps can here be spaced.

Thus placing one row of lamps as near as possible to each side of the duct and laying out the rest of the system, a convenient spacing distance is found by trial to be 7 ft. 2 in., and this figure is adopted, the row of lamps nearest the walls being 2 ft. 6 in. distant therefrom. The general spacing distance is 7 ft. 2 in. by 6 ft. 5 in. = 46 sq. ft. (Fig. 36), giving $\frac{60}{46}$ = 1.3 watts per sq. ft. for each lamp and for the whole area the figure is found to be $\frac{42 \times 60}{1,810}$ = 1.4 watts per square foot.

87. Watts per Square Foot Necessary to Produce an Intensity of 1 ft-c. with Vacuum Tungsten Lamps. (*National Electric Light Association*).—Table is compiled on the assumption of an efficiency of 1 watt per candle. This is about the average efficiency for all of the commonly used sizes of vacuum tungsten lamps.

Lighting unit	Area 30 ft. × 30 ft. or larger		Small areas	
	Light ceiling		Light ceiling	
	Light walls	Dark walls	Light walls	Dark walls
Prismatic	0.19	0.21	0.27	0.30
Opal, heavy density	0.40	0.21	0.26	0.29
Opal, light density	0.24	0.27	0.34	0.37
Semi-indirect	0.29	0.35	0.43	0.53
Totally indirect	0.32	0.37	0.50	0.62

Where the efficiency of the lighting unit to be used is other than about 1 watt per candle, the watts per square foot required will vary proportionately with the efficiency. The watts required per sq. ft. varies directly as intensity in foot-candles.

88. Procedure in Designing a General Illumination Installation by the Watts per Square Foot Method (Alex. J. Airston, *Electric Journal*).—1. Measure the location, making a rough sketch of plan and elevation showing ceiling or roof trusses, positions of windows, obstacles which may affect the installation, present outlets and switching if any, and giving full dimensions.

2. Make a note of color and condition of walls, ceiling, fur-

niture, machinery and equipment as well as the class of work carried on and the closeness of application required.

3. a. Draw plans to scale.
b. Decide on the lamp size and mounting height.
c. Assume the watts per square foot to be used.
d. Deduce the ideal spacing distance—$d = \sqrt{\frac{\text{Wattage of lamp}}{\text{Watts per sq. ft.}}}$
e. Lay out positions of lamps on the plan, to give regular spacing distances, installing a row within 2 ft. 9 in. of each wall if an office, and approximating, as near as possible, to the ideal spacing distance in both directions.
f. Make a tracing, from the plans, showing boundaries of the area and positions of lamps and old outlets, if any, also switching.
g. Specify size of lamps and reflectors, mounting height and any other information deemed necessary for the assistance of the wiremen.
h. Show control of lamps by numbering all lamps on one switch with the same number.

4. Check up the design at the actual location to see that each lamp is effective and free from all possible obstacles.

89. Efficiencies of Utilization for Indirect Lighting
(*National X-ray Reflector Company*)

Minimum dimension of room divided by ceiling height	Efficiency of utilization	
	Dark walls	Light walls
1.0	0.20	0.24
1.5	0.22	0.26
2.0	0.24	0.28
2.5	0.28	0.30
3.0	0.30	0.32
3.5	0.32	0.34

NOTE.—The above values are 20 per cent. low, to provide for depreciation due to dust and aging of lamps. With lamps new and reflectors clean, the efficiencies of utilization will be correspondingly higher than given in the table.

INTERIOR ILLUMINATION

90. House Lighting.—The intensity generally required in each room of a residence is given in the table of paragraph **16.** Ceiling fixtures in which the lamps hang at an angle should be avoided. As shown in Fig. 37, such fixtures tend to throw a strong light around the walls, and into the eyes of persons in the room, although the angle shown in Fig. 37 is the correct one when an incandescent lamp is completely enclosed in a ground glass or opal globe—an inefficient arrangement, but considered by some to be artistic. Lamps hanging pendant as in Fig. 38 distribute the light in useful directions. Diffusing globes or shades should be used on all lamps which hang low enough to fall in the line of vision. Bowl-frosted lamps should be used unless the lamp itself is completely shaded.

91. **Lighting the Kitchen and the Bedroom.**—These are the two rooms in a house in which the arrangement of the lights is ordinarily most unsatisfactory. A single light or group of lights in the center of the kitchen usually compels the cook to work entirely in her own shadow, whether at the range, the sink or the kitchen cabinet or table. A couple of small bracket lights at the side of the room can usually be arranged to satisfactorily light all

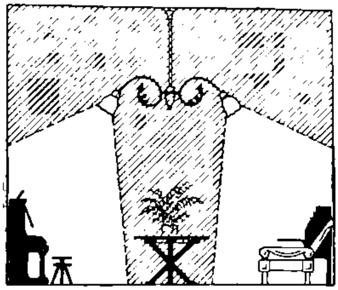


FIG. 37.—Effect of hanging residence lamps at an angle.

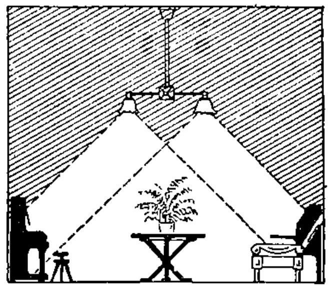


FIG. 38.—Effect of hanging residence lamps vertically.

three of these locations, and a third small light in the center of the room will give general illumination. The three need consume no more current than a single larger unit, and will give much more satisfactory service. Similarly in a bedroom, one or two bracket lights should be provided at the dressing table, with a small unit in the center of the room for general illumination. The ordinary arrangements are usually satisfactory for other rooms, except that a single ceiling or table light in a library requires that all readers shall sit with their backs toward one another to secure satisfactory reading light. This can be obviated by using scattered ceiling lights, four or more, depending on the size of the room, or by side brackets with reflectors of a type which will shade the light from the eyes of those sitting across the room.

92. **Living-rooms.**—The lighting of the living-rooms should in general be done with a view toward producing a comfortable and cheerful appearance rather than a high efficiency. The more highly efficient types of reflectors are generally out of place, as they do not allow sufficient general illumination to properly show the pictures and decorations, and therefore produce a gloomy effect.

93. **Store Lighting.**—The object of the illumination in a store is two-fold. Primarily, sufficient illumination must be provided to enable articles for sale to be seen plainly. But of almost equal importance is the advertising value. The lighting units must be so selected as to give a pleasing and cheerful appearance to the store as a whole, without glare. Stores may be divided into three classes: The small store, in which efficiency is of first importance; the large store, such as a department store, in which efficiency is neces-

sary on account of the large areas to be lighted, but must be balanced by artistic appearance, the result being a compromise between the two; and shops, large or small, in which the articles for sale are of a special type and the profits large enough that they can afford to have even the most inefficient system if it be sufficiently attractive or unique to attract customers. The general requirements which must be met are outlined in the following paragraphs:

94. General Features of Store Lighting.—The intensity of illumination must be varied with the articles which are to be sold. Furniture requires well-diffused lighting of relatively low intensity. Colored dress goods, men's clothing, rugs and carpets, etc., require

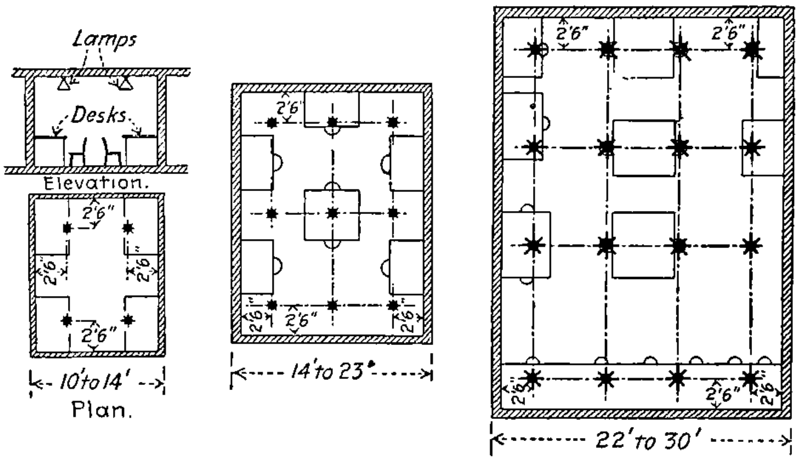


FIG. 39.—Good spacings of ceiling lights for offices (adapted from C. E. Clewell in *Electric Journal*).

a high intensity. In many installations side-light is very necessary and should be given especial attention in selecting types of units, and reflectors. Cut glass and jewelry should be so lighted as to sparkle and glitter. This requires bare lamps and mirrored reflectors. Glare is to a certain extent, in this case, unavoidable, but the light units can usually be so located as to be out of the customer's range of vision, when he is inspecting the ware. Pictures require a high intensity, with the light units at such an angle that light will not be reflected from the surface of the painting, or from the glass, directly into the observer's eyes. Individual units or mirrored trough reflectors, with linolite or tubular tungsten lamps are ordinarily used.

95. Office Lighting.—In general it is found more economical and more satisfactory to provide general rather than specific illumination in offices containing a number of desks. The lighting required can be found by the method given in a preceding paragraph. In locating the lights, the outer row should not be placed more than $2\frac{1}{2}$ ft. from the wall, to avoid shadows on desks placed about the walls. Fig. 39 shows good spacing of lamps for offices of various sizes and of ordinary height. Fig. 40 gives, in the form of a chart, spacing distances which have been found by experience to be satisfactory with different ceiling heights. As in industrial lighting, the cost of illumination is usually so small a percentage of the salaries of the men in an office that a very small increase in their efficiency, due to less eyestrain, fewer headaches, etc., will more than pay for even an extravagant lighting system (C. E. Clewell, *Electric Journal*).

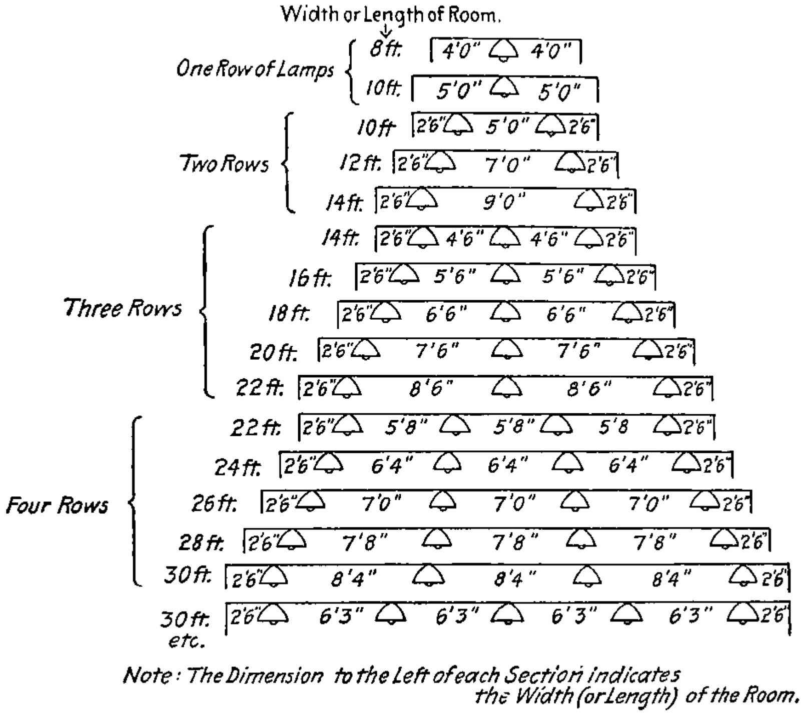


FIG. 40.—Chart showing spacing distances of lamps for offices of various sizes. (C. E. Clewell, *Electric Journal.*)

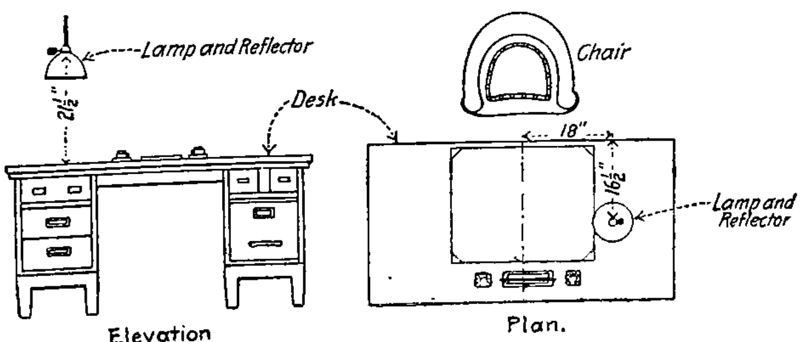
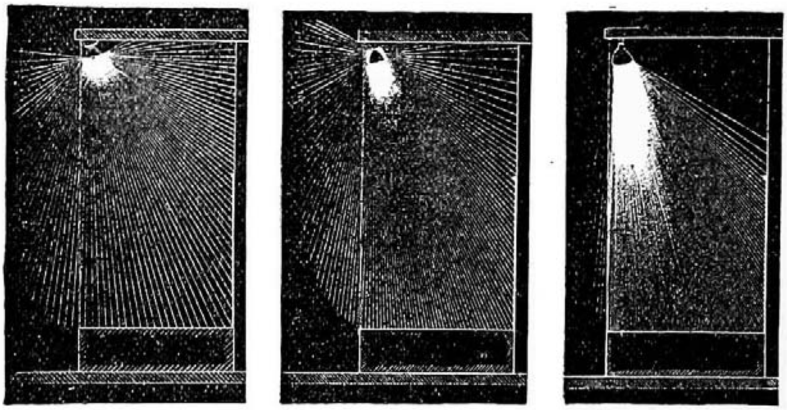


FIG. 41.—Proper method of hanging a desk lamp.

96. Specific desk lighting (Fig. 41) should as a general proposition be avoided. This is particularly true in large offices where a number of desks are located. A much better plan is to provide, as outlined under "Office Lighting," a general illumination sufficiently bright to render individual desk lighting unnecessary. Specific desk lighting should generally be restricted to cases where one or two desks are located in an office chiefly used for other purposes which permit of a comparatively low degree of illumination.

Do not locate the desk light too close to the work. The light unit for a desk should be hung 21 to 24 in. above the desk, about 16 to 18 in. from the front of the desk and about 18 in. to the left of the center. The lamp should be shaded from the line of vision by a bowl type of reflector—preferably one which is opaque. Too much light is as objectionable as too little. An 8-c-p. lamp provides ample light when located as suggested. A polished reflector is intolerable as the streaks produced are very trying to the eyes.

97. Some Common-sense Facts Regarding Window Lighting (see Fig. 42) (*National X-ray Reflector Co. Catalogue*).—A good way to blind your prospective customer, so he cannot see the goods



I. II. Effect with Improperly Selected Reflectors. III. Effect with Proper Reflectors.

FIG. 42.—Illustrating good and bad window lighting.

on display in your window, is to put exposed lamps around the window borders or suspend them from chandeliers or so install them in the top of the window that his eye cannot escape them.

The light must come from in front of the goods in order to avoid shadows. If the lamps are placed in the middle of the show-window ceiling, the front of goods displayed in the front of the window will be in darkness, because of the shadows. Strange to say, many do not consider this. If the display is altogether on the bottom of the window, as in the case of a jewelry store, this shadow effect is unimportant. In the clothing or drygoods store window, it is vital.

Carrying out this principle that light must be thrown on the goods from the front of the window in order that passers-by may see no shadows on the goods, practically means that the lamps must be placed high up in the window next to the window pane, because there is no other place where they can be put to throw the light in the proper direction and keep the lamps out of the ordinary range of vision.

98. **Show-window Lighting** (*I. P. Frink Catalogue*).—In the average sized window, linolite lamps will give excellent results when used with properly designed reflectors on account of their high efficiency and adaptability to limited space conditions. Reflectors with standard base lamps should be used in unusually high windows, and in windows unusually deep, such as found in furniture stores, as well as in some cases where the windows in question are situated next to a store front on which there is installed a mass of exposed lamps, the glare of which makes it necessary to use an excessive amount of illumination to make the adjoining window appear properly lighted. With correctly designed reflectors there are few windows that require more light than that given by 40-watt lamps spaced 8 in. apart. With this equipment, 8 to 12 ft-c. on the floor of the windows from 8 to 12 ft. high can be developed. If the window is not boxed in, the reflector should be provided with a shield to screen the lamps from the store. If the upper part of the window back is glass, or the window is backed with mirror, the reflector should also be designed with a shield to prevent back reflection.

99. **Watts and Number of Lamps Required per Front Foot for Window Lighting** (National X-ray Reflector Company).—The number of lamps per front foot of window or the watts per front foot required for good window illumination, depend very much on the location of the show window, whether it is on a brilliantly lighted street and in a city where a great deal of light is commonly used in show windows, or whether it is in a town where only a limited amount of show-window lighting is common. For example, in a small country town a single reflector may give a better illumination of a window with an 8-ft. frontage than is common among the other windows in the town. In large cities where dark dry-goods and men's clothing are displayed, some merchants consider that a window cannot be too brilliantly illuminated.

On account of the efficiency of properly designed reflectors (because of the fact that they confine and direct nearly all of the light where it is wanted) it is of course not necessary to use as many lamps where the reflectors are properly designed as where they are not. Where reflectors are designed for large lamps of 105 and 60 horizontal candle-power (100 and 60 watts) respectively, the lamps can be spaced some distance apart and still give good results. Some splendidly lighted show windows in large cities have 100-watt lamps spaced 18 and 24 in. apart. In the small towns where lower standards of illumination prevail, this spacing can be safely increased to 36 in. or more.

100. **In lighting counter and display cases** the same rule is followed as with show-window lighting, viz: Throw the light on the goods displayed and not into the eyes of the observer. If the glare from the lamps reaches the observer's eyes he is partially blinded and the result desired is not accomplished. Tube tungsten lamps are to be preferred and they should be equipped with proper —continuous if possible—reflectors. Ordinary pear-bulb lamps can be used with suitably designed reflectors but the tube lamps give more effective results and constitute a neater installation, and

furthermore the heating of the show-case glass work is equalized, minimizing its breakage.

101. Examples of Factory Tungsten Lighting Systems

(*Factory Lighting Systems*, Clewell) (See Note Below)

These installations do not in general have drop lamps, the lamps overhead providing for nearly every requirement.

Feet and inches			[1] Size of lamp, watts	[1] Watts per sq. ft.	Class of work and character of surroundings.[2] Opal or clear prismatic glass reflectors used
Ceiling or girder height	Mounting height above floor	Spacing distance			
8–1	7–6	8–0 × 8–0	60	0.94	Detail work—light ceiling, no walls
9–0	8–6	8–0 × 8–6	100	1.47	Bench work, flat—no ceiling, dark walls
11–1	10–3	8–0 × 8–9	100	1.43	Bench work—no ceiling, dark walls
11–9	11–0	8–0 × 9–6	100	1.32	Machining—dark ceiling, no walls
11–9	11–0	8–0 × 8–9	100	1.43	Machine work—dark ceiling and walls
12–0	11–3	8–0 × 8–0	100	1.56	Machine work—dark ceiling, no walls
12–0	11–3	8–0 × 8–0	100	1.78	Machine work—dark ceiling, no walls
12–0	11–3	7–0 × 8–0	100	1.78	Bench work—dark ceiling, no walls
12–6	12–0	8–0 × 10–0	100	1.25	Machine work—dark ceiling, no walls
13–8	12–10	8–0 × 8–6	100	1.47	Machine work—dark ceiling and walls
16–0	14–6	8–0 × 8–9	100	1.43	Detail work—no ceiling, dark walls
16–0	15–2	8–0 × 10–0	100	1.25	Rough work—no ceiling, light walls
16–0	15–2	11–6 × 16–0	250	1.36	Painting machines—no ceiling, light walls
16–0	15–2	10–0 × 12–0	250	2.08	Fine die work—no ceiling, dark walls
16–0	15–2	13–0 × 14–0	250	1.37	Bench work—no ceiling, dark walls
24–9	21–3	10–0 × 12–0	250	2.08	Fine assembly work—dark ceiling, no walls
24–9	21–3	10–0 × 12–0	250	2.08	Machine work—dark ceiling, no walls
24–9	21–3	10–0 × 12–0	250	2.08	Testing—dark ceiling, no walls
25–2	21–7	10–0 × 12–0	250	2.08	Testing—dark ceiling, no walls

[1] These data are based on the earlier tungsten lamp efficiencies. With the present (June, 1915) efficiencies, the new 40-, 60- and 200-watt lamps would give about the same illumination respectively as the old 60-, 100- and 250-watt lamps tabulated above, and the *watts per sq. ft.* consumptions shown would therefore be decreased accordingly—an average decrease in consumption of about 30 per cent.

[2] In factory construction, manufacturing spaces often occur where the girders and columns form the boundary lines without walls. Similarly open girder construction often occurs, where no ceiling exists.

102. **The wattage required to properly illuminate display and counter cases** varies with conditions. Experience provides the only rules for this work as conditions, such as reflection from the glass work and mirrors, render calculation useless. As a general proposition, the illumination in cases should be double that in the store (J. M. Johns-Manville Co.). In an 8- to 12-ft. show-case, 100 watts (ordinary show-case reflectors and tungsten lamps) will give excellent results with an average illumination of 7 to 8 ft.-c. With mirror-lined reflectors, the same intensity may be maintained, with the same wattage, in a 12-ft. case.

EXTERIOR ILLUMINATION

103. **General Requirements for Street Lighting.**—In all four classes of street lighting (see par. 104) it is desirable to have uniform intensity, good diffusion to prevent sharp shadows, and low intrinsic brilliancy to reduce glare. It is not usually feasible to attain all of these desirable conditions. It is their high intrinsic brilliancy, particularly when clear outer globes are used, that makes the older types of arc lamps objectionable as street illuminants.

104. **Classification of Street Intensities.**—City streets are generally grouped in four classes as to illumination requirements. *Class* 1, public squares, principal business streets, streets leading to railway stations, and sections of streets where crime is prevalent, should have an illumination intensity of 0.4 to 0.6 ft.-c. *Class* 2, comprising streets where night traffic is moderate, such as business streets having little traffic at night, and the outlying parts of main thoroughfares, require about 0.2 ft.-c. *Class* 3, comprising outlying residence streets, do not require more than 0.1 to 0.15 ft.-c. *Class* 4, comprising sections of the city not built up, or country roads, are sufficiently illuminated (beacon lighting) with 0.05 ft.-c. In addition to these there may be a "white way" where 1 or even 1.5 ft.-c., in addition to the illumination produced by the window and sign lights, is permissible. (From paper by C. E. Stephens.)

105. **Electric Light Sources Available for Street Lighting.**—Arc lamps and gas-filled tungsten incandescent lamps provide the most economical illumination for streets. Of the arc lamps, the open and enclosed carbon arcs have become practically obsolete as street illuminants. The metallic flame arc has largely replaced the older forms of lamp. The color of the light is white and the distribution curve shows a maximum candle-power from 15 to 25 degrees below the horizontal. Its maintenance cost is comparatively low. The efficiency of light production varies from 0.4 to 0.5 watt per m. l. h. c-p. The light from tungsten lamps can be refracted in any desirable angle.

The flame carbon lamp is the most recent arc-lighting development. The efficiency of light production varies from 0.25 to 0.35 watt per mean lower hemispherical candle-power. The light distribution curve shows a maximum candle-power from 20 to 30 degrees below the horizontal. The maximum candle-power varies from 1,600 to 2,500 c-p., depending upon the carbons used. (C. E. Stephens.)

Tungsten series incandescent lamps are available in sizes ranging from 60 to 1,000 c-p. The efficiency of light production varies approximately from 0.8 to 0.45 watt per candle. When properly equipped with a suitable reflector, they are well suited for street illumination.

106. **Number and Size of Units for Street Lighting.**—Using a small number of units of very high candle-power, mounted at considerable height and placed at great distances, requires a larger total light flux to secure the minimum allowable illumination midway between units than is required with closer spacing. There is some waste of energy where the sources are spaced at great distances from one another. On the other hand, increasing the number of units increases the installation and maintenance cost of the system. In general, if energy cost is low, large units at great distances apart are better; if energy cost is high, small units placed at frequent intervals are more economical.

On streets having trees, arc lamps cannot be used because the height at which they should be mounted will cause the trees to throw dense shadows on the streets. In such cases tungsten lighting is always most suitable.

In making calculations, the point-by-point method should be used, making calculations quarter and halfway between units, under each unit, and about 25 ft. from each unit. In making these calculations it is necessary to consider only the illumination caused by the two nearest units. (C. E. Stephens.)

107. **In residence street lighting the use of relatively small units is usually preferable** because with the smaller units the illumination is more uniform. Another feature that should be considered in this connection is that although large units are for a given installation preferable from the standpoint of installation and maintenance costs because a minimum number of units is necessary, considerable of the light from these large units will be wasted in lighting the yards facing the street. With small units spaced closer together, most of the light falls on the street and walks and little is wasted (Fig. 43). (C. E. Stephens.)

108. **Spacing and Height of Units.**—The uniformity of illumination with a given unit varies with the distance between units and their height. The very nature of the street area determines that the light units must be in a single or double row along the street. The number and size of units and their height are determined by the intensity requirements and cost of operation. In making a selection of units for a given condition it is necessary, therefore, to carefully consider the curve of light distribution of the available units. Increasing the height of the lamp decreases the intensity of illumination directly under the lamp quite rapidly and does not materially change the intensity at greater distances from the lamp. The height of a lamp is usually limited on account of the extremely high cost of installation, maintenance, tree obstruction, etc. (C. E. Stephens.)

109. **The actual amount of illumination to be tolerated as a minimum on the street** (Bell, *Standard Handbook*) is commonly

based in the United States on getting something like the effect of average moonlight say in the neighborhood of 0.02 ft-c.

110. **Distribution of Street Illumination.**—In the illumination of a sidewalk, for example, the required minimum being 0.04 ft-c., the specification could be better fitted by common candles placed 6 ft. high and 6 ft. apart along the curb than by powerful sources of light spaced 200 ft. apart, although the latter would give more than fifty times the total light of the former. (See Fig. 43.)

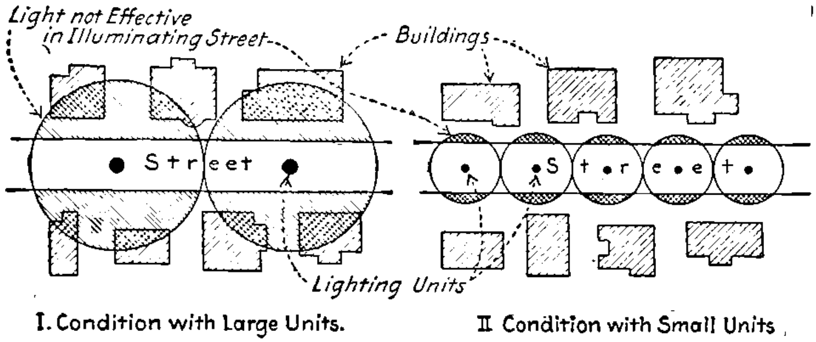


FIG. 43.—Illustrating how a considerable portion of light is ineffective in illuminating a street where high-power lighting units are used.

Some point between these extremes should evidently be chosen in the joint interest of economy and good average illumination, and a few trial computations will bring out the facts. In general, radiants of moderate power placed at moderate distances give the best illuminating effects, whether on the street or indoors.

111. **In locating arc lamps for outside illumination** one should be placed where possible at each street intersection so that the

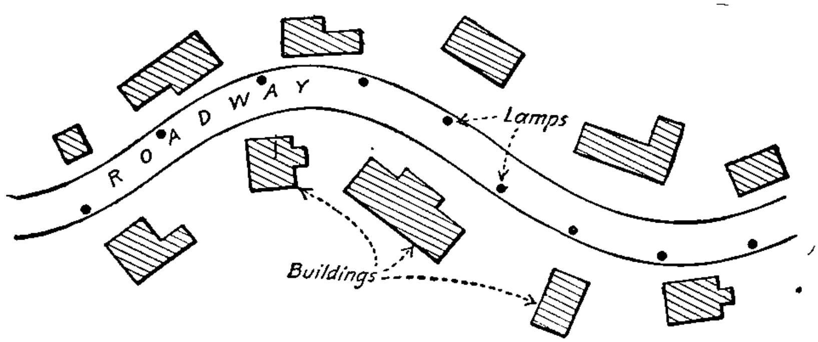


FIG. 44.—Preferable method of locating lighting units along a curved roadway.

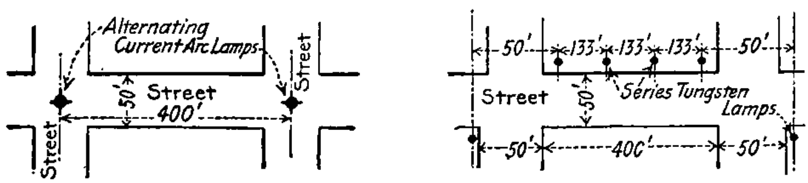
light will be useful in all four directions. Spacing distances between street intersection lamps is a thing that must be determined by local conditions. Where blocks are long, or strong illumination is required for display purposes, one, two or even more lamps can be equidistantly located between the street intersection lamps.

112. **In locating lamps along curved roadways** it is often considered preferable to place them as suggested in Fig. 44 rather

than all on the same side of the road. When arranged as shown more lamps can be seen at one time and it is claimed that distant moving objects in the road are more effectively revealed in that they will always lie between the observer and the lights.

113. **Height of Arc Lamps for Outdoor Illumination.**—Generally speaking the lamps should be hung as high as feasible. As a rule arc lamps are hung too low for best results. From 35 to 45 ft. from the ground is probably about right for average conditions, but it is seldom feasible to place lamps this high because of practical considerations such as cost, tree shadows and the like.

114. **Comparative Example of Alternating-current Arc and Series Tungsten Street Lighting** (H. A. Hussey, *Electric Journal*). —Consider a street (Fig. 45 *I*) 50 ft. wide and 400 ft. between intersecting streets, with one alternating-current enclosed arc at each intersection. Four 60-c-p. tungsten lamps (Fig. 45 *II*) would cost less to operate per year. The tungsten lamps are mounted 12 ft. above the ground on 4-ft. brackets and are equally



I. Alternating Current Arc Lamps.
II. Series Tungsten Lamps.

FIG. 45.—Street illuminated with enclosed arc and tungsten lamps.

spaced on one side of the street. Alternate blocks have the lamps on the opposite side of the street so that two lamps are provided at each street intersection on diagonally opposite corners, thus providing a higher illumination where most needed as well as distinctly marking street intersections. Along the center line of the street the comparative illumination on a horizontal plane at the street surface would be about as indicated in the following table. These figures show some of the advantages of series tungsten lamps. Horizontal intensity, is not the only criterion. When shadows, per cent. of light emitted reaching the working surface, uniform background, glare, etc., are considered, the advantages of the small unit become more pronounced. Unfortunately these factors cannot be stated numerically.

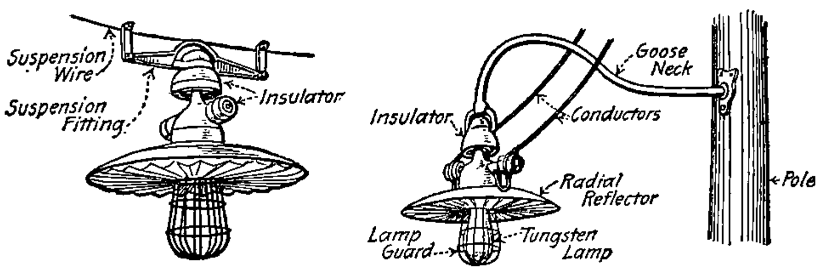
115. Comparative Values, A.C. Arcs and Series Tungstens

Quantities	Arc	[1] Tungsten
Maximum foot-candles	0.450	0.160
Minimum foot-candles	0.001	0.035
Average foot-candles	0.057	0.082
Ratio maximum to minimum	450.0	4.6
Ratio minimum tungsten to minimum arc	35	

[1] These data apply to tungsten lamps of the older and lower efficiencies.

116. Series Tungsten Street Lighting.—The adjuster socket system operates only on constant-potential circuits. It consists of a simple series of lamps connected across high-tension constant-potential alternating-current mains, or across the secondary terminals of a constant-potential transformer or auto-transformer. A reactance coil is connected in shunt across the terminals of each lamp. When the lamp is burning the reactance coil takes only 4 or 5 per cent. of the current. If the lamp filament is broken or the lamp removed the voltage forces the total current of the circuit through the reactance coil, magnetizing it to saturation, whereupon it produces a counter-electromotive force equal to the potential difference across the lamp when burning. This maintains the continuity of the circuit at all times.

117. Series Tungsten Street Lighting.—In the regulator system the series of lamps is supplied from a constant-current regulating transformer. (See Section on Transformers.) This automatically controls the current and voltage of the circuit, and maintains a constant current regardless of the number of lamps burning. A film cut-out device, consisting of a receptacle and socket located in the street hood, short-circuits the lamp and thus maintains the continuity of the circuit when a lamp burns out. The lamp cut-out, used in the regulator system for maintaining the continuity of the circuit, consists of a thin copper, aluminum or lead disc coated with an insulating enamel, placed between clips provided in the socket. If the lamp burns out, the increase of potential across the clips punctures the film between the socket clips and short-circuits the lamp.



I. Suspension Fixture. II. Bracket Fixture.

FIG. 46.—Street fixtures for tungsten lamps.

118. Fixtures for Street Tungstens.—Fig. 46 shows two of the most popular tungsten street-lighting fixtures. That of II is arranged for fastening to a pole, while that of I, when in service, hangs from a cable or span wire supported by two poles.

119. In locating single light series tungsten units, along the curb (see Fig. 46), the best results are obtained by allowing the lamps to hang from 1 to 1½ ft. outside of the curb line. In the case of single line lighting, a distance of from 3 to 5 ft. outside of the curb line is usually desirable. Lighting units may also be placed over the center of the street, either by suspension similar to that commonly employed for arc lamps, or on ornamental standards placed on "Islands of Safety."

120. Desirable Mounting Heights for Tungsten Street Series Lamps (*National Electric Lamp Association Publication*).—In general a height of from 12 to 16 ft. is desirable for single light units ranging from 25 to 80 c-p. This height is advisable from the fact that in the majority of smaller and in some of the larger towns or cities, the streets are heavily wooded, and it is necessary to place the illuminants beneath this natural canopy of foliage. In the case of higher candle-powers as, for example, the 200-c-p. tungsten lamp, a height of 20 to 25 ft. should be maintained unless the lamp is enclosed in a diffusing globe, in which case the above-mentioned height of from 12 to 16 ft. would hold. When ornamental standards with two or more lights are used, a height slightly greater than 12 ft. but not exceeding 16 ft. may effectively be employed. The height of lamps above the street, rather than the candle-power, determines the maximum spacing of units. When lamps are placed low and at exceptionally long intervals, an object in the roadway or unevenness of the pavement is greatly exaggerated and distorted. An increase in candle-power merely deepens the shadows and increases the distortion.

121. Tungsten, Gas-Filled or Mazda C Street Series Lamps

(*STRAIGHT SIDE AND PEAR-SHAPE BULBS—July* 1, 1917)

The following lamps are for use on constant current circuits. A small compensator made for each size of lamp, is used with the 15 and 20 ampere lamps to raise the current from 5.5, 6.6 or 7.5 amperes to the 15 or 20 amperes required. The price of lamps for rectifier service which are not included in the following may be obtained on application.

Amperes	Nominal rated candle-power	Total lumens	Average volts	Type and size bulb	Diam. bulb inches	Maximum over all length, inches	*Base regularly supplied	Standard package quantity	List price	
									Clear	Frosted
5.5	60	600	8.5	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	$1.00	$1.05
	80	800	10.8	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.20	1.25
	100	1000	13.0							
	250	2500	29.7	PS-35	$4\frac{3}{8}$	$9\frac{1}{4}$	Mog. screw	24	2.35	2.45
	400	4000	47.4	PS-40	5	10	Mog. screw	12	4.00	4.15
6.6	60	600	7.1	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.00	1.05
	80	800	9.1	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.20	1.25
	100	1000	10.9							
	250	2500	23.5	PS-35	$4\frac{3}{8}$	$9\frac{1}{4}$	Mog. screw	24	2.35	2.45
	400	4000	37.1	PS-40	5	10	Mog. screw	12	4.00	4.15
	600	6000	55.7	PS-40	5	10	Mog. screw	12	5.00	5.15
7.5	60	600	6.4	S-24½	$3\frac{1}{16}$	$7\frac{1}{4}$	Mog. screw	50	1.00	1.05
	80	800	8.0	S-24½	$3\frac{1}{16}$	$7\frac{3}{4}$	Mog. screw	50	1.20	1.25
	100	1000	9.6							
	250	2500	19.6	PS-35	$4\frac{3}{8}$	$9\frac{3}{4}$	Mog. screw	24	2.35	2.45
	400	4000	30.5	PS-40	5	10	Mog. screw	12	4.00	4.15
	600	6000	45.8	PS-40	5	10	Mog. screw	12	5.00	5.15
15.0	400	4000	15.3	PS-40	5	$12\frac{1}{2}$	Mog. screw	12	4.00	4.15
20.0	600	6000	15.5	PS-40	5	$12\frac{1}{2}$	Mog: screw	12	5.00	5.15
	1000	10000	25.9	PS-40	5	$12\frac{1}{2}$	Mog. screw	12	6.00	6.15

Orders for lamps of 250 c-p. and higher should specifically state if they are to be burned in other than pendent position. **The light center length of the 15 and 20 ampere MAZDA C lamps shown above is 9½ inches for burning in pendent position and 8¼ inches where ordered for burning tip up.**

* Medium Screw Skirted Base also supplied at same price, except the 400, 600 and 1000 c-p. lamps, which are supplied only with Mogul Screw Base as indicated.

MAZDA lamps for street series service selected for use on multiple compensators or for any other purpose where a single voltage or a range of voltages closer than stated are required will take a special price which may be obtained from the manufacturer upon application.

122. **When any lamp is hung so low that it lies within the range of vision** of a nearby observer the glare from the unit should be eliminated by the application of a proper reflector or shade.

123. **A reflector should always be used with any incandescent street-lighting lamp.** Where no reflector is used a large portion of the light generated is projected above the lamp into the air and is wholly ineffective in lighting the street.

124. **Where lamps are installed on streets bordered with trees** the lamps should always be hung a trifle lower than the lower branches of the trees. If they are not, heavy shadows will be cast by the branches and the effectiveness of the illumination will be greatly impaired.

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