the current flows to *7* on motor *m'* and to *8* on motor *m*, thence through the field magnets to *6* and *5*, then to *k'* and *k*, respectively. The reversing switch at this part of the circuit is shown in its middle position; if the cord *n*, *n'* be drawn so that the insulating bars *l*, *l'* are carried to the right, the blades *e* and *f*, *e'* and *f'* will make contact with *h* and *k*, *h'* and *k'*, and the current will pass through *f* and *f'* to the brushes *b*, *b'* of the motors, and back to *h*, *h'* and the

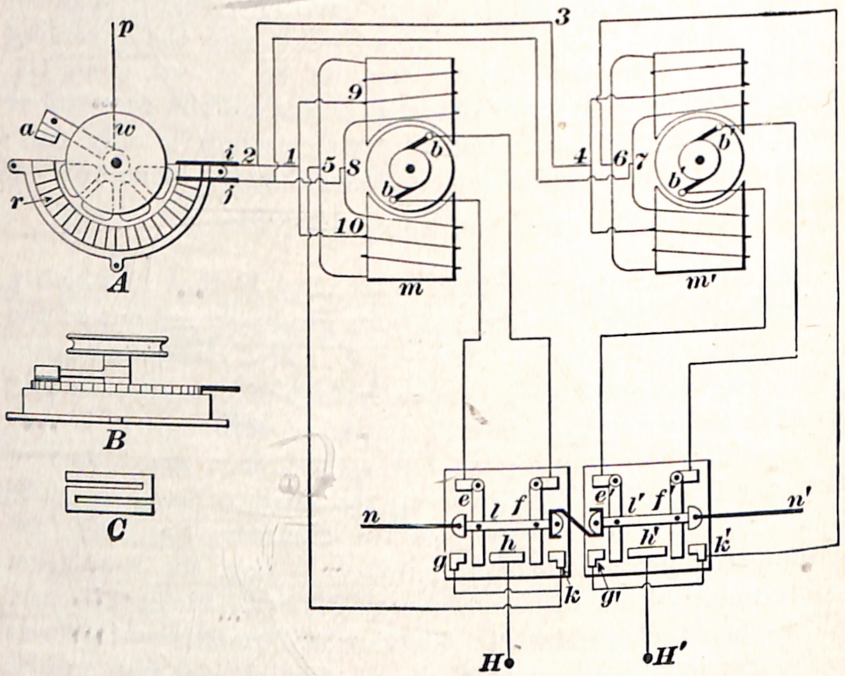

FIG. 1004.

ground *H*, *H'*. When the reversing switch is moved to the left, it will be seen that the armature connections are reversed, the current entering at *g*, *g'*; the fields are unchanged. The last point on the rheostat breaks the circuit at *j*, allowing the current to pass directly from *a* to *i*, dividing at *2* and going to *1*, *9*, and *10*, and to *5*, also to *3* and to *4*, through a portion of the fields to *6*. Cutting out some of the field-turns weakens the magnets, thereby increasing the speed of the armatures.

ELECTRIC HEATERS.

2551. The use of coal stoves in cars is attended with disadvantages in the way of useful space occupied, the constant attention required, and the coal dust and ashes scattered round. All these objections are overcome in the use of electric heaters; but there remains a serious drawback in the operating expense, which is at least three to four times that of coal stoves. Many railway managers nevertheless adopt the electric system on account of its popularity and the fact that no space is required for the installation which might be devoted to the accommodation of passengers. In Fig. 1005 is shown the plan of a car, with the wiring for the heaters *h*, which are placed under the seats near the wheel boxes *w*. Heat is generated by passing a current through a wire of high resistance embedded in enamel,

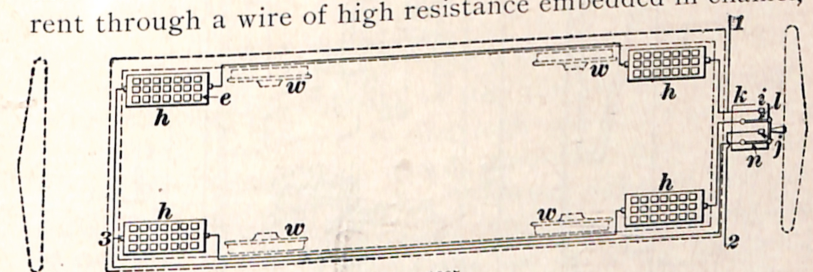

FIG. 1005.

or other substance of similar nature, which prevents oxidation of the wire by excluding all air from its surface. The outside of the metal case has projections *e* cast on it, in order to present a greater surface to the air. A switch is provided, by means of which the heaters are connected all in series, in series parallel, or cut out entirely. The series-parallel coupling is obtained by moving the switch handle upwards so that the lever *l* will make contact with *i*, and *n* with *j*. The circuit then becomes: From the trolley to *1* to *k*, dividing at this point and passing through the upper heaters (that is, on the right when viewed from the switch) to *3 n j 2* to ground; also from *k* through *i l*, the lower heaters to *3 n j 2* and ground. When the switch handle is thrown over so that the lever *l* makes contact with *j*, the heaters are connected in series. At the position shown they are cut out of circuit.

WIRING.

2552. The plan of wiring for a car using the series

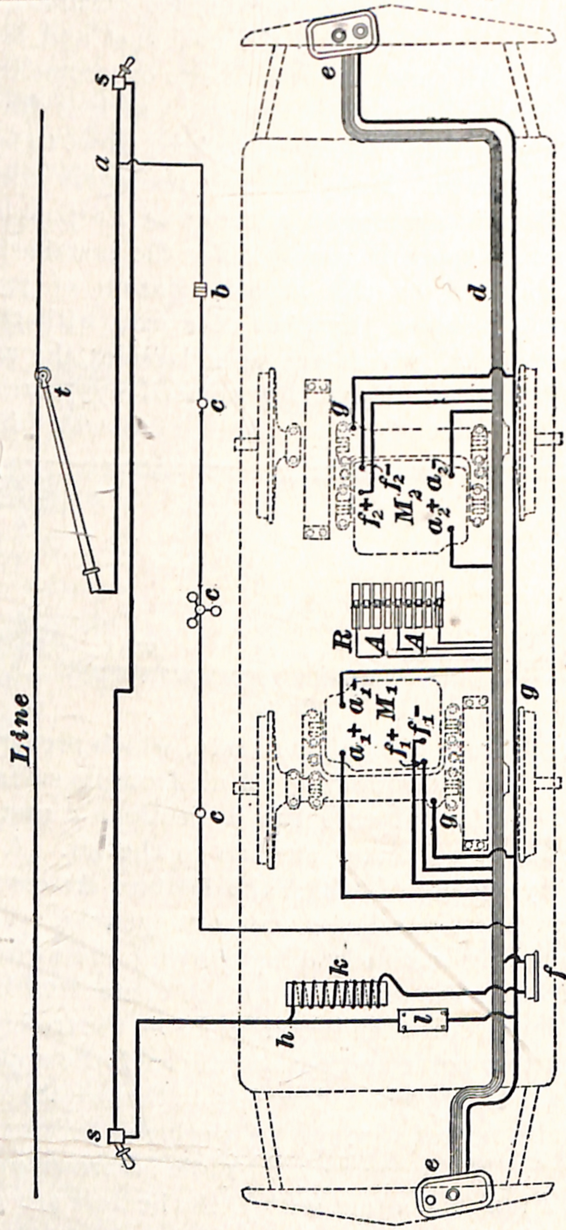

FIG. 1006.

parallel controller is given in Fig. 1006. The motors M_1, M_2 are shown in dotted outline, and the wires are put in

in heavy lines. There are two principal circuits branching at *a* (a point on the roof wiring) close to the base of the trolley *t* which takes current from the line. From *a* one circuit is through the fusible cut-out *b* and lamps *c* to the wire *g* which is connected to the ground; the other circuit is through the canopy switches *s*, *s* to *h*, where a shunt is carried to one side of the lightning arrester *l*, the other side being grounded. The main current passes through the choking coil *k* to the fuse box *f*, thence to the controllers *e* and motors, as already described in Arts. **2546** and **2547.** All these wires are bunched and wound over so as to make a single cable *d*, an arrangement reducing their liability to injury. The connections to the armatures are indicated at a_1+, a_1-, and a_2+, a_2-; the connections to the fields are shown at f_1+, f_1-, and f_2+, f_2-. The choking coil *k* consists simply of a few turns of wire wound over a wooden cylinder. This offers sufficient impediment to stop the passage of a lightning discharge, owing to the high self-induction of the oscillatory current, and it will, therefore, force its way across the air gap between the two plates of the arrester and so pass to ground. The rheostat *R* contains the starting resistance *A*, *A*, the use of which has been explained.

2553. In Fig. 1007 is given the wiring diagram for a car equipped with the rheostatic method of control. *A* is a plan of the roof wiring, *B* an end view of the same, and *C* the general wiring to the motors *a* and *a'*. From the base of the trolley pole *n*, the current for the motors passes through the canopy switches *c*, *c*, the fuse box *g*, and the lightning arrester *o*, to the rheostat *m*; then through *y* or *x* to the field terminals, reversing switch, armatures, and ground. The controllers are on the platforms at *k*, *k*; these are simply vertical shafts with handles, and carry at the lower end a wheel to which is made fast a rope which passes around the wheel of the rheostat. Short lengths of chain are introduced at the points most liable to wear. The reversing switch *e* is operated after the same manner

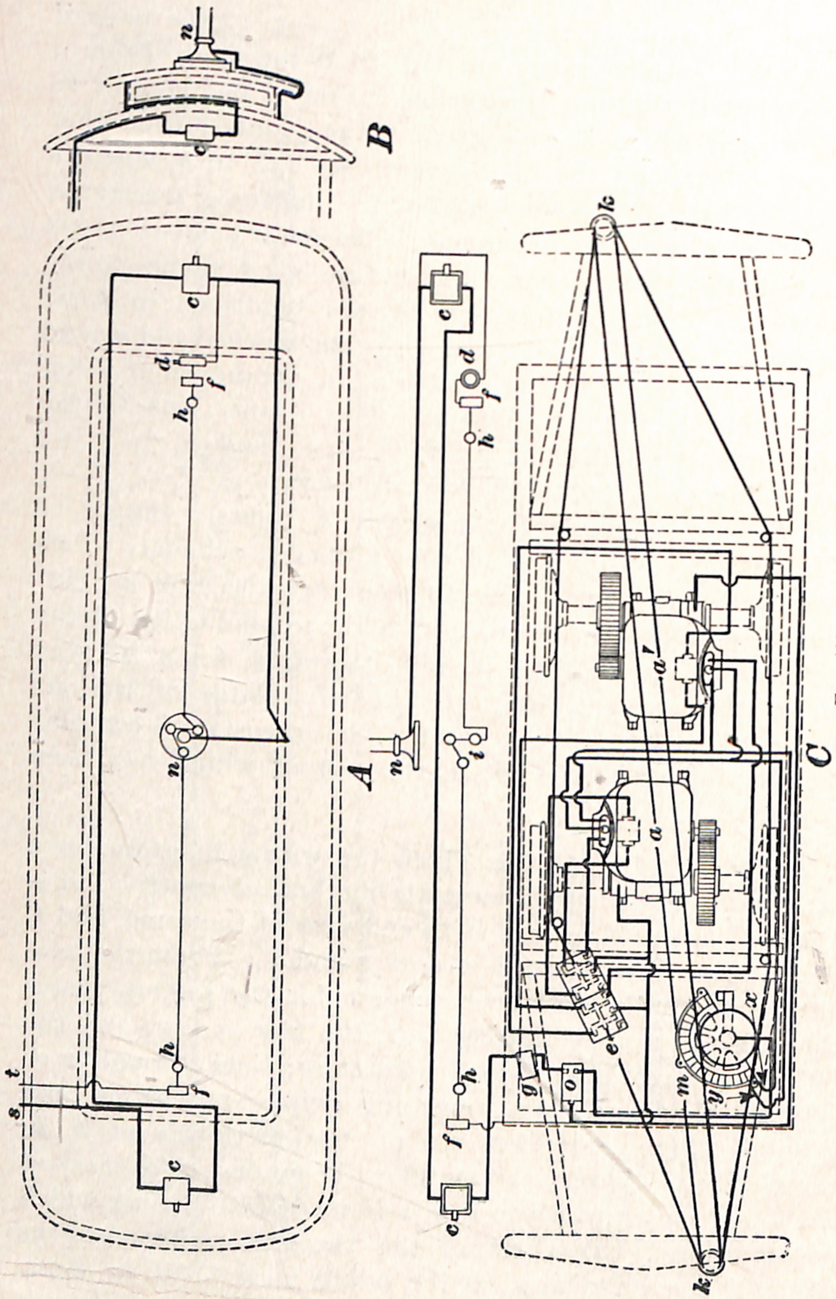

FIG. 1007.

by an independent lever, the ends of the cord being attached to the levers as shown. The lighting circuit branches from the roof wire, passes through the switch *d* and fuses *f*, *f* at each end of the car, the lamps being between. In the center is a cluster of lamps *i*, and at the ends *h* are additional ones, used as pilot lamps, with a colored glass outside. On the plan *A* of the roof wiring, the same reference letters apply; at the points *s*, *t* the wires are carried down the side of the car, their direction being easily seen from the other views.

SYSTEM OF POWER SUPPLY.

OVERHEAD LINE CONSTRUCTION.

2554. Overhead line construction includes the setting up of the trolley wire, with span wires, guard wires, the necessary coupling devices, switches, and insulators. The feeders, or wires communicating directly between the generators at the station and the various distributing points, may be carried overhead or laid underground, as most convenient. In the latter case they must be protected from abrasion, a lead sheath being frequently employed outside the insulation. Great care should be taken in handling, lest the covering be injured or broken, which would allow moisture to enter and gradually develop a fault.

There are three styles of support for trolley wires: They may be suspended directly from brackets on poles at the side of the road; or a double track may be provided with center poles carrying the wires on projecting arms on both sides; or the poles may be placed at the sides of the street, and the trolley wire supported by span wires stretched across. This last method is most common, because there is no obstruction in the roadway, as in the center-pole construction, and because the side of a road only can be used for the track in some localities, as on a country road.

2555. The poles may be of steel, iron, or wood. For cross-country roads, wooden poles are generally selected, and they are used frequently in city streets, although iron or steel poles are much more desirable. Fig. 1008 shows a sectional form of iron tubular pole adaptable to any type of construction, (*a*) being the side-pole, (*b*) the center-pole, and (*c*) the span-wire method. The poles are about 30 feet long,

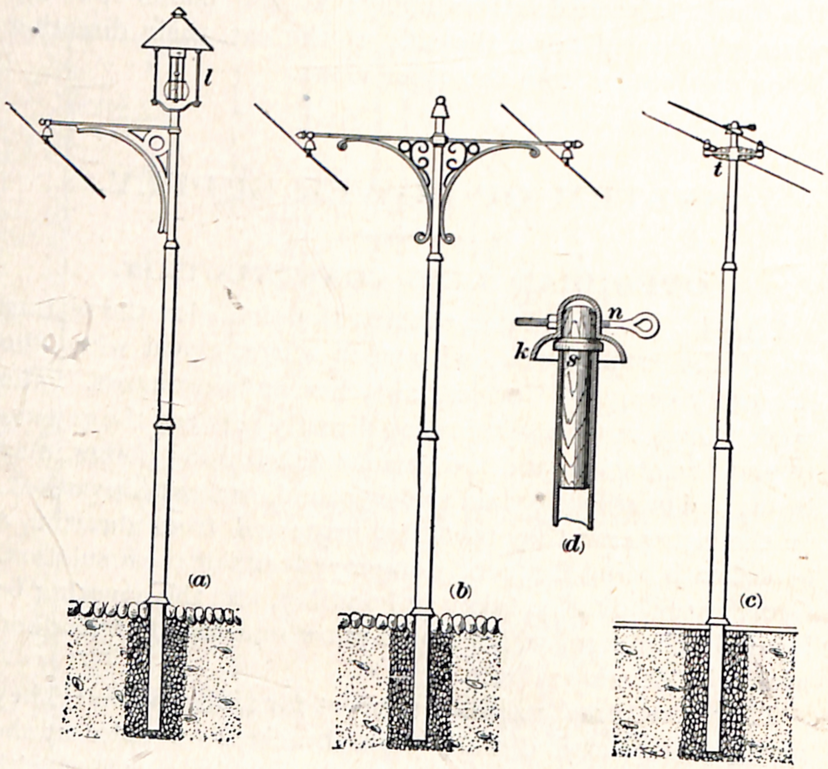

FIG. 1008.

the lower section being 6 or 8 inches diameter, and the others 1 inch smaller, successively, fitting inside each other with telescope joints at least 18 inches in length. The lower end of the pole is sunk into the ground to a depth of 6 or 7 feet, and filled around with cement. Allowance must be made, in setting, for the strain of the wires; and the top of the pole must slant away from the track about 5 inches, when span

wires are to be used. At (*d*) is an enlarged view of the top of pole (*c*), showing the insulated top *k*, supported on a wooden block *s* and carrying the tension bolt *n* to which the span wire is secured. The cross-arm *t* carries feeders to supply current at distant points; the pole may also be utilized to carry an arc lamp, as at *l*, in Fig. 1008 (*a*). Instead of a tension bolt, a ratchet may be placed on the top of the pole, as at *a*, Fig. 1009, provided with a counterbalanced pawl *b* engaging with the teeth. The base *c* has flaring sides to shed rain, and fits into the insulating wooden block *d*. In a slightly modified form the ratchet may be fastened to the side of the pole at any point, or bolted to a wooden pole.

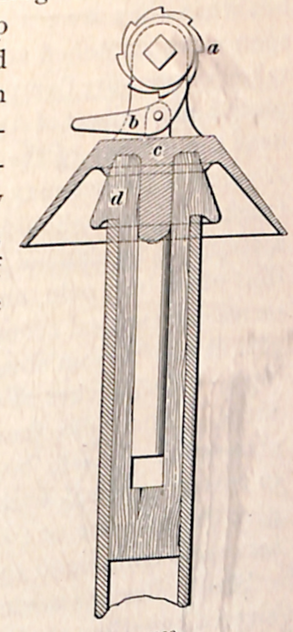

FIG. 1009.

2556. In both bracket and center-pole construction, it is now the practice to use a flexible support for the trolley wire hanger, which prevents the destructive hammer blow of the passing trolley wheel and reduces the sparking. Such an arrangement is shown in Fig. 1010, which represents the form used for the side-bracket construction. A

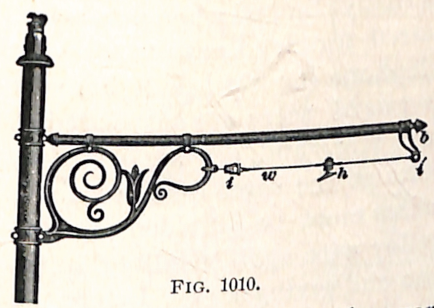

FIG. 1010.

span wire *w* holding the hanger *h* is stretched tightly between two insulators *i*, *i'*, the outer one being secured to a bracket *b* and the inner one held by a clamp on the frame-work. In the center-pole construction the brackets extend on both sides, and when the pole is of wood, a hole may be bored through it to receive the span wire.

2557. Wooden poles are generally set without concrete; but when they are placed at the side of the street to hold span wires stretched across, large stones should be used to take the pressure due to the pull of the wires, some being placed at the base of the pole away from the track, others near the surface of the ground at the side towards the track. A piece of timber may be substituted for the stones on the track side, and should be about 3 feet long and 4″ × 8″ in section. The slant of a wooden pole should be about double that of an iron pole, and when in position the ground must be solidly tamped around it to make a firm bed. The diameter at the bottom should be not less than 10 inches, tapering to 6 or 7 inches at the top, which may be cut to a conical shape. The pole from the ground up may be round or octagonal. It will be found to effect a considerable saving in cost of renewal, and also to prevent leakage of current, to give the pole one or two coats of paint, applying some preservative compound to that part which is to be underground.

Steel poles are made of sheet metal, of channel section, riveted together at short intervals throughout their length, and may have a flat piece through the middle, the section then being like a double **D**. Lattice work is also largely used, making a very neat and strong pole, which can be painted inside and out, and is easily climbed when necessary.

Guard wires may be required for city lines, to prevent contact between a falling telephone (or electric light) wire and the trolley wire. These guard wires are suspended 10 or 15 inches above the trolley wire, and are supported by span wires attached to the poles at the same distance above the trolley spans. Anchor wires must be provided at suitable intervals to secure the trolley wire against falling, in the event of the connection at one end giving way. Before this precaution was adopted, there were instances of a whole system being incapacitated through the breaking of a trolley wire.

2558. The general arrangement of wiring for a double track is shown in Fig. 1011. The poles *p* are placed not more

than 125 feet apart measured along the road, and between opposite poles are stretched the span wires *s*. At intervals

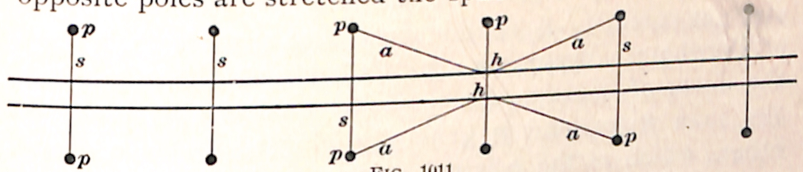

FIG. 1011.

of about 500 feet, and at the approach to all curves, anchor wires *a* are put up, being secured to the trolley wire by hangers *h*.

2559. The method of setting up the trolley wire on curves is shown in Fig. 1012, where *A* represents the

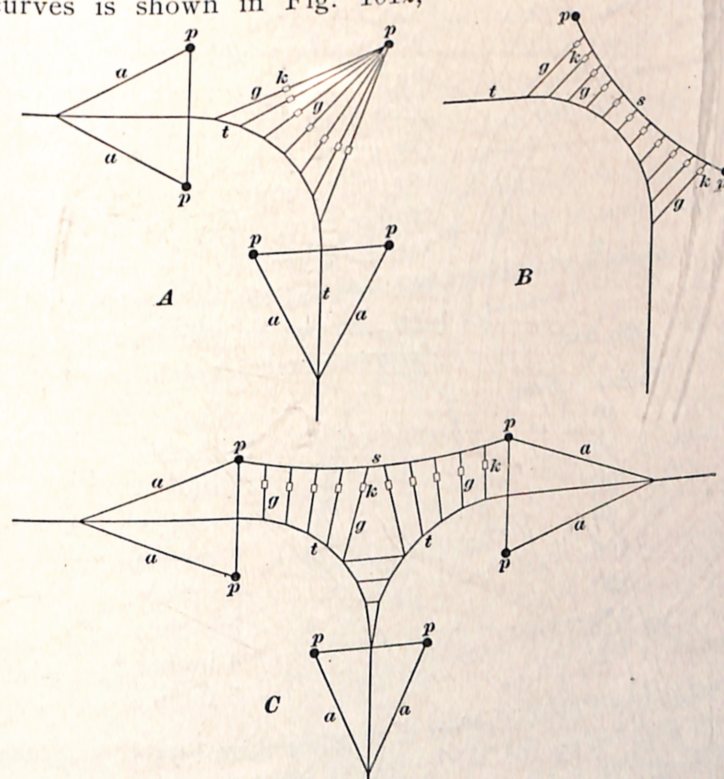

FIG. 1012.

arrangement of guy wires *g*, attached to the trolley wire *t*, when a single pole is used. Turnbuckles *k* are used to bring the wires to the proper tension, and anchor wires *a* to support the trolley wire at the beginning of the tangent or straight portion. A flexible method of suspension is given at *B*, where a heavy span wire *s* holds up the guy wires; this form of construction tends to equalize the strains on the span wires, and is generally adopted in place of the other, which is the original method. A double curve is shown at *C*, the different wires being designated by the same letters as in the preceding lay-outs, and the poles by *p*.

2560. In rounding a curve, the trolley wire does not follow the center line between the rails, but is carried over to the inside by an amount depending upon the radius of the curve. This variation is shown in Fig. 1013, where the curve *r* is the center line of the rails and *t* the line of the trolley wire. The amount of offset, measured at the middle of a 90° curve at the point indicated by the arrows in the figure, is as follows for curves of different radii:

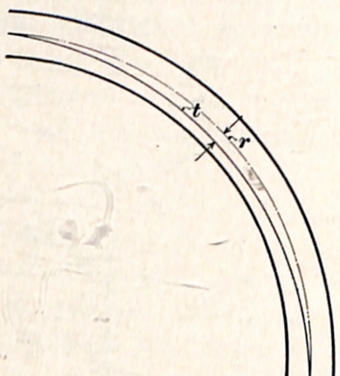

FIG. 1013.

Radius in Feet.	Offset.
40	16 inches.
50	13 inches.
60	12 inches.
80	8 inches.
100	6 inches.
120	5 inches.
150	4 inches.
200	3 inches.

The object of this offset is to allow the trolley wheel to lie more closely to the wire; this it would not do if the wire followed the track center line, since the wheel would then lie across the wire diagonally, causing a large amount of wear in passing round the curve. In some old lines this

effect is plainly visible, the wire showing splices at various points where breaks have occurred.

2561. Erection of Line.—The size of the trolley wire depends somewhat upon conditions of traffic, but it should never be less than No. 0 B. & S. hard-drawn copper. The guard wire, when used, may be of No. 8 B. & S. steel galvanized wire, and all span wires should not be less than

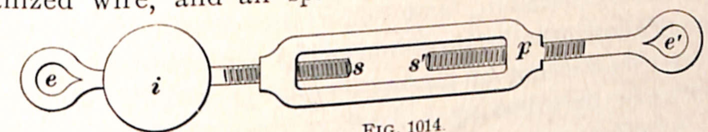

FIG. 1014.

No. 5 B. & S. steel wire, galvanized. The trolley wire should hang about 19 feet above the track when in position.

The first proceeding in putting up a line is to stretch the span wires across, and, as the insulation must be as perfect as possible, insulators are employed in two places, first, at or near the pole, and second, in the hanger. Those in the span wire are called strain insulators, an illustration of one form being given in Fig. 1014, where *i* is a globe of some suitable

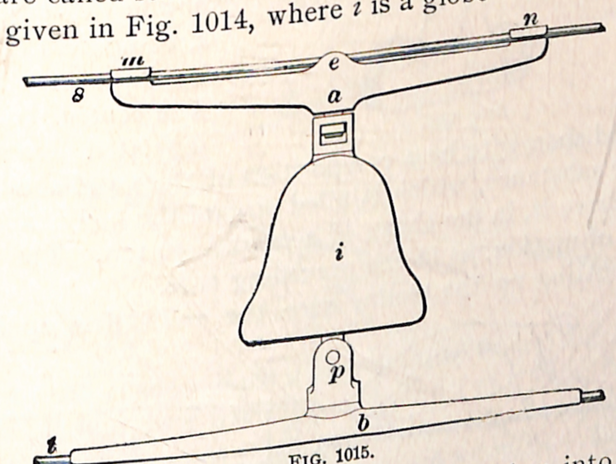

FIG. 1015.

insulating material, such as hard fiber or rubber, into which are secured the eye *e* and the bolt *s*; the turnbuckle *p*, which connects the bolts *s* and *s'*, is fitted with right and left-hand threads for regulating the tension, and the wires are fastened to the ends at *e*, *e'*. When a ratchet is used, the turnbuckle is unnecessary, and the insulator is simply in the form of a globe with two eye-bolts, or an insulating cylinder with the two bolts.

When the span wires are in position, the next operation is to set the hangers for the trolley wire. One form of hanger is shown in Fig. 1015, the span wires being passed under *m* and *n*, and over the center at *e*. A swivel joint at *a* permits of proper adjustment, and below the cup insulator *i* is a pivot *p*, allowing a longitudinal swing. A clamp *b* holds the trolley wire *t* either by having its edges pressed firmly over the wire or by soldering. Another form of hanger is illustrated in Fig. 1016, in which the trolley wire is held by a clamp *a* set up by means of screws. The span wire passes under the ears *b*, *b*, and lies in the groove *c*, being held in place by its own tension. The central bolt *d* is insulated from the ears and span wire by a composition of mica and shellac, or similar substance, which is filled around the body, and projects above it, in the shape of a mushroom top. The bolt *e* allows of motion, as in the preceding case.

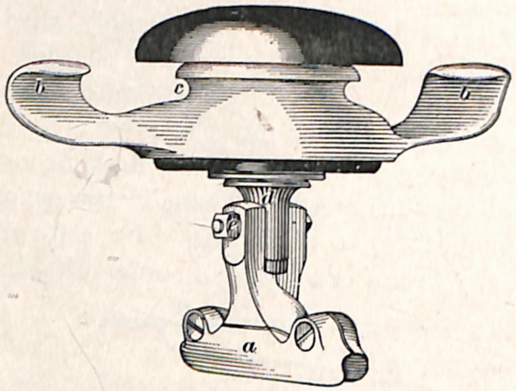

FIG. 1016.

In putting up the trolley wire, the end is first anchored,

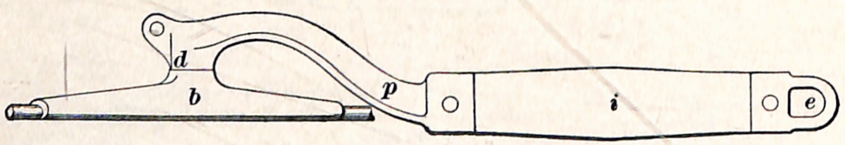

FIG. 1017.

and a length of, perhaps, 1,000 feet run off, supported by temporary wires from the clamps. This length is then drawn to the proper tension by means of a block and tackle, the hangers are permanently connected and the anchor wires put up. In rounding a curve the wire is first stretched

in temporary wire slings and anchored, after which the hangers, or pull-over clamps, are attached. For curves of small radius, a form such as is given in Fig. 1017 is used. The span wire is attached to the eye *e*, which is fastened by the insulating piece *i* to the arm *p* carrying the trolley-wire clamp *b* pivoted at *d*. For such operations a "tower wagon" is used, which consists of a platform supported on a wagon, at a convenient height for ready access to the wires. This platform is generally so arranged as to project beyond the wagon, so that the latter may stand clear of the tracks while repairs are in progress, and not interfere with regular traffic. When not in use, the platform may be lowered to the wagon.

2562. Branch Lines and Curves.—At the point where one line branches from another, overhead switches, or "frogs," are used to guide the trolley wheel from one

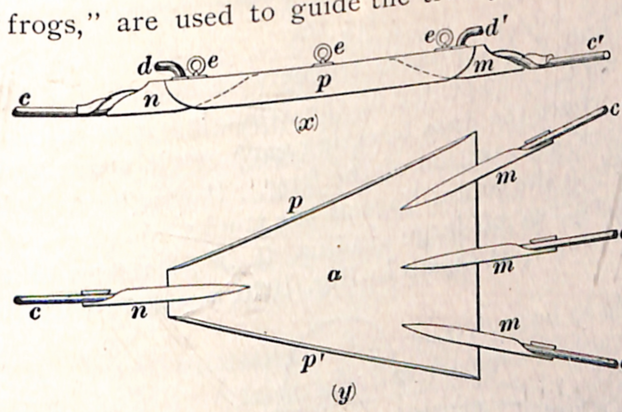

FIG. 1018.

wire to the other. Such a switch is shown in Fig. 1018 in which (*x*) is a view from the side, and (*y*) a view from the bottom; *a* is a plate with projecting edges *p*, *p'* at each side and spirally-grooved ears at *n* and *m*, *m*, *m*. The inner surface of the plate is at such a distance from the lower surface of the ears that the trolley wheel will run straight through, bearing on its flanges while under the plate, and passing from one wire to the other without any change in vertical position. The wires *c*, *c'* are secured by passing them over the ears, and bringing the ends through holes in the plate and bending them back, as at *d* or *d′*; the span wires are connected at the rings *e*. A switch for a single branch may be made by leaving out one of the ears *m*, and narrowing the plate accordingly.

The position for the frog may be found by the method shown in Fig. 1019, where *a b* is the main line, *c d* the

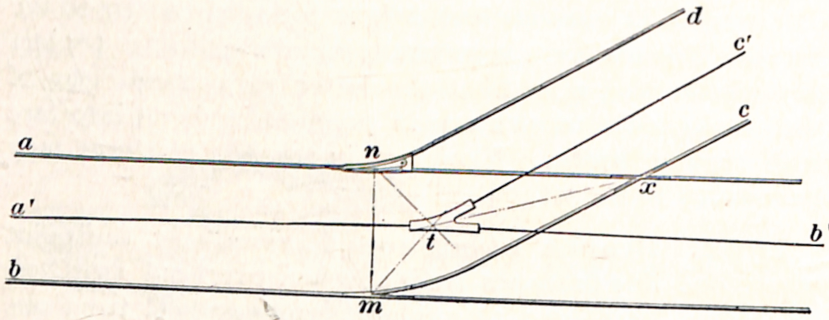

FIG. 1019.

branch line, *a′ b′* the main trolley wire and *t c′* the branch trolley wire. The center of the triangle *n x m* will be at a point *t* where the lines bisecting each angle meet, and this determines the position of the frog. It will be a little removed from the center lines of the tracks.

Upon curves of large radius, it is necessary to use a double clamp *c*, as shown in Fig. 1020, the span wires being

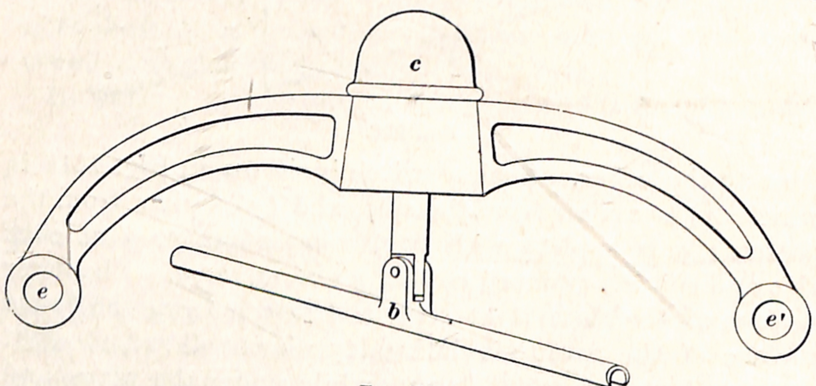

FIG. 1020.

secured at *e*, *e′* and the trolley wire at *b*. At the point of

intersection of two trolley lines, a cross-over is used similar in principle to the overhead switch, Fig. 1018.

2563. Section insulators are used at the junction of two divisions when they are supplied by separate feed wires direct from the station. One form is shown in Fig. 1021, in which the direct line of the trolley wire is unbroken, allowing the trolley wheel to run smoothly across the insulator. The span wire is in one piece between the poles, and is slipped under the hooks *a*, *a* and over the

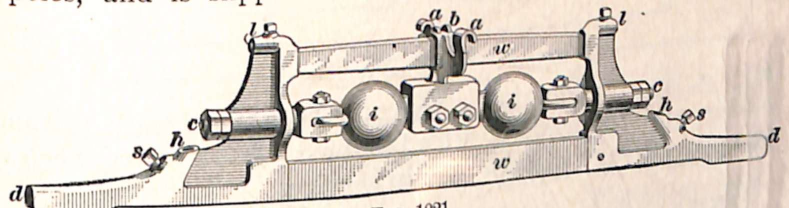

FIG. 1021.

notch at *b*. A double strain insulator *i i* and bolts *c*, *c* hold the parts together against the pull of the trolley wires from the two sections, which pass under the clamps *d*, *d* at each end, through the holes *h*, *h*, and are held by the set-screws *s*, *s*. The end castings are provided with lugs *l*, *l* and set-screws, by which connection may be made to the feeders. Distance pieces of wood, well filled to prevent absorption of moisture, are inserted at *w*, *w*.

2564. Wire Splicing.—The usual method of splicing overhead wires is the "telegraph," or Western Union, joint,

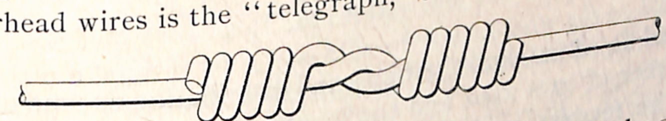

FIG. 1022.

Fig. 1022, in which the wires are wrapped one over the other and soldered. Rosin should be used as a flux instead of acid,

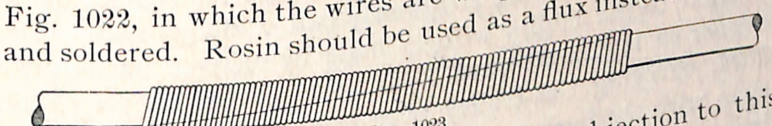

FIG. 1023.

as acid will in time corrode the wire. An objection to this joint for trolley wires is that it presents an obstruction to the trolley wheel, and other devices have been adopted, one of which is a scarf joint, at least six inches long, Fig. 1023, carefully cleaned and wrapped with tinned binding wire. The whole length of the joint is then filled in with solder, the ends of the trolley wire being held firmly throughout the process by means of a screw clamp. Another method of joining, which is more readily accomplished, is by the use of a brass tubular connector, as shown in Fig. 1024, the wires being introduced at each end and bent up through the open-

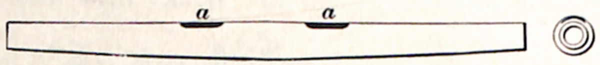

FIG. 1024.

ings *a*, *a*; the remaining space is then filled with melted solder, and the ends of wire trimmed off. This connector has proved very satisfactory in service.

2565. Feeders.—It is very important that the E. M. F. on an electric road should be maintained as nearly constant as possible throughout the whole system, and the trolley wire being usually far too small to accomplish this, extra cables are run to various points along the line. These are

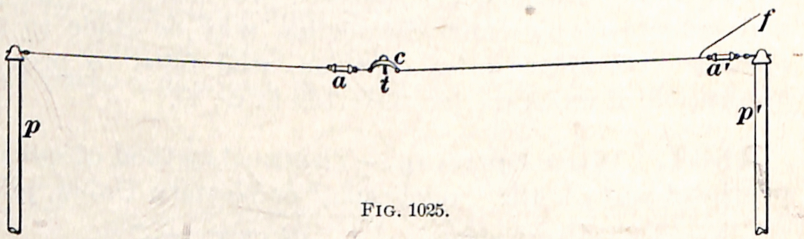

FIG. 1025.

called **feeders,** and their size and distribution depend on the number of cars used and the length of the road.

The feeders may be supported on the side poles, or on separate poles, but are frequently laid underground. Connection to the trolley wire is made by using a hard-drawn copper span wire attached to a non-insulating hanger *c*, Fig. 1025, carrying the trolley wire *t*; at the other end of the span wire the feeder *f* is joined on, and a strain insulator *a'* is introduced between it and the pole *p'*. On the other side

is a regular steel span wire between the pole *p* and the hanger, with an insulator at *a*.

The simplest method of line construction is to use a single wire, serving as working conductor and feeder; but, with a heavy load, the drop in potential at the end of the line would be considerable. It is evident that it would be more satisfactory to put up a cable alongside, tapping it at various points along the route, as this will carry the current with less loss than the trolley wire. Such an arrangement is shown in Fig. 1026, where *m n* is the trolley wire, *a b* the

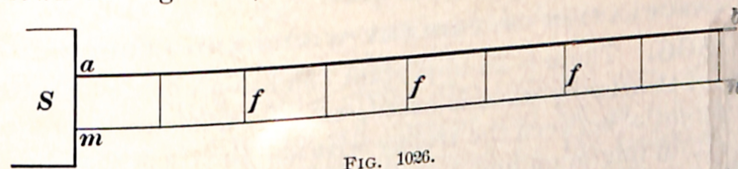

FIG. 1026.

feeder, and *f*, *f* the different connections. The power station is supposed to be at *S*, at one end of the line. If the trolley line were divided into a number of sections, *c*, *d*, *e*, *f*, *g*, each connected at its center to the feeder *a b*, as in Fig. 1027, the drop in potential at any point would be due only to the

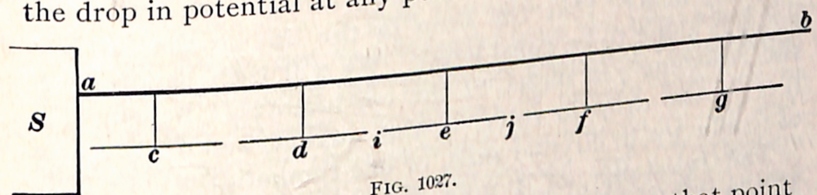

FIG. 1027.

feeder and that portion of the trolley line between that point and the connecting wire. In case of fire at any place along the route, the power can be shut off in that district without

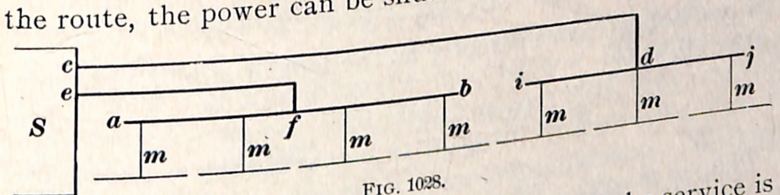

FIG. 1028.

disturbing the other parts of the line, so that the service is not entirely stopped. These switches are located on the poles at the point of connection to the feeder, and insulators are placed between sections, as at i, j.

The arrangement shown in Fig. 1028 constitutes the feeder and main system. This system, it will be seen, is an amplification of Fig. 1027. The feeders are $c\,d$ and $e\,f$, and are distinguished from the mains $a\,b$, $i\,j$ in that they are tapped for current at no points save at the ends, while connections m, m, etc., are made between the mains and trolley wires, wherever they may be required.

CALCULATION OF TROLLEY WIRES AND FEEDERS.

2566. There is an important condition upon which the size of the supply wires is based, namely, that the difference in potential between the trolley wire and the track shall have a certain minimum and a certain average value. To obtain this result, the drop in the line must not be allowed to exceed a certain amount, and will include the ground return as well as the overhead wiring.

For convenience, we will at first assume that there is no resistance in the return circuit through the rails and ground; hence, that the drop in the line to the furthest point is alone to be considered. We will then denote by R the resistance, in ohms, of the conductor; D, its length in feet; e, the drop in volts; C, the current, and d^2, the area of conductor in circular mils, or one-thousandths of an inch.

The resistance of 1 mile of copper wire at 75° F. is $\frac{56,970}{d^2}$ ohms; therefore, the resistance of a wire 1 foot long and 1 mil in diameter is $\frac{56,970}{5,280 \times d^2} = 10.79$ ohms, and, since the resistance varies directly as the length D and inversely as the area d^2,

$$R = \frac{10.79 \times D}{d^2}. \qquad \textbf{(362.)}$$

That is to say: *The resistance of a conductor is equal to 10.79 times the length in feet, divided by the area in circular mils.*

By Ohm's law, $R = \frac{e}{C}$, therefore $\frac{e}{C} = \frac{10.79 \times D}{d^2}$; whence,

$$d^2 = \frac{10.79\,C\,D}{e}. \qquad \textbf{(363.)}$$

The cross-sectional area of a wire in circular mils is equal to 10.79 times the product of the current flowing and the distance in feet, divided by the drop in volts.

Also,

$$e = \frac{10.79\,C\,D}{d^2}. \qquad \textbf{(364.)}$$

The drop in voltage along a conductor is equal to 10.79 times the product of the current and the length of conductor, divided by the area in circular mils.

Formula **363**, while giving the required area of conductor for any given length, current, and loss in volts, does not, as we have seen, make provision for the resistance of the return path through the rails and earth, which is a matter not easily determined in advance, unless the line is to be an extension of a system already in operation, and the characteristics of ground and track are similar. In such a case the resistance of the ground return as computed, multiplied by the total current to pass through, will give the drop in volts, which can then be subtracted from the total allowable drop, and the value of the remainder applied in the formula.

There are, broadly, two classes of supply wires to be considered, namely, those in which the load is at one end, and those having a uniformly distributed load. To the first class belong all feeders having no connections to the trolley wire or mains except at one point; in the second class are included single trolley lines without feeders, and mains connected to the line at many points throughout their length. For the first of these the formula given will hold good, but the second requires different calculation. The effect of a uniformly distributed load is that it requires only one-half the size of wire that would be necessary for an equal load at the end of the line, the same drop being allowed. We may say then that, for a uniformly distributed load,

$$d^2 = \frac{5.4\,C\,D}{e}. \qquad \textbf{(365.)}$$

The required area in circular mils of a conductor intended to carry a uniformly distributed load is equal to 5.4 times the product of current and length of line in feet, divided by the drop in volts.

By derivation from the above,

$$e = \frac{5.4\,C\,D}{d^2}. \qquad (366.)$$

The drop in volts in any given line having a distributed load is equal to 5.4 times the product of current and length of line in feet, divided by the area in circular mils.

2567. There are two questions affecting the size of wire for overhead power supply—one being a given drop of potential, and the other a given rise of temperature, and calculations made from the formulas given for overhead conductors should always be checked by rules based on practical experience, to ensure the ability of the wire to carry the current safely. Table 71 gives the current capacity for several different sizes of wire for a rise in temperature of 10°, 20°, 30°, and 40° C.

The table is applicable alike to uninsulated, bright wires, such as trolley wires, and to those with an insulating covering; for, in the latter case, the surface being black radiates heat more rapidly, and also presents a larger area to the cooling effect of the atmosphere. As a rough, general approximation, the following formula for determining the capacity of feeders will be found serviceable, but should not be used for final calculation:

Let C = current in amperes;
d = diameter of wire in mils.

$$C = \sqrt{\frac{d^3}{1{,}300}}. \qquad (367.)$$

The current which a given wire will carry safely, when exposed to the air, is equal to the square root of the quotient obtained by dividing the cube of the diameter of the wire by 1,300.

TABLE 71.

CURRENT CAPACITY OF OVERHEAD WIRES CORRESPONDING TO A TEMPERATURE RISE OF 10°, 20°, 30°, AND 40° C., RESPECTIVELY.

Diameter in Inches.	Area in Circular Mils.	Amperes.				Gauge Number.	Diameter in Mils, or 1/1000 Inch.	Area in Circular Mils.	Amperes.			
		10°	20°	30°	40°				10°	20°	30°	40°
1	1,000,000	410	570	700	800	0000	460.000	211,600	145	200	240	275
.95	902,500	380	530	650	750	000	409.640	167,805	125	170	210	235
.9	810,000	350	490	600	700	00	364.800	133,079	110	145	180	205
.85	722,500	320	455	560	645	0	324.950	105,592	95	125	150	180
.8	640,000	290	420	520	595	1	289.300	83,694	80	110	130	150
.75	562,500	265	385	470	545	2	257.630	66,373	70	95	115	130
.7	490,000	240	350	430	500	3	229.420	52,634	60	80	100	115
.65	422,500	220	310	390	450	4	204.310	41,742	55	70	85	100
.6	360,000	200	280	350	405	5	181.940	33,102	50	63	75	87
.55	302,500	180	250	310	360	6	162.020	26,250	40	52	64	75
.5	250,000	160	220	270	310	7	144.280	20,816	35	45	55	65

2568. In our calculations for size of conductor, we have considered an area sufficient to give a certain drop of potential at a temperature of 75° F. When the current is first turned on the line, this drop will result, but a heating effect may occur after a short time which will raise the resistance, and, consequently, reduce the current. Provided the rise of temperature is not much more than 30° C., it will be safe, but the E. M. F. of the generators must be increased to make up for the additional drop. It will be evident, then, that a correction in terminal drop is frequently necessary, and is obtained by using a new value for the specific resistance. Constants for the different temperatures may be found by the application of formula **309.**

At 75° F., the resistance of a wire one mil in diameter and one foot long is, as we have found, 10.79 ohms; then, taking the same temperature rises as those in Table 71, we have the following values:

Rise of 10° C. = 18° F., and resistance of 1 mil-foot—

$$r = 10.79 \times [1 + (.002155 \times 18)] = 11.21.$$

Rise of 20° C. = 36° F., $r = 10.79 \times [1 + (.002155 \times 36)] = 11.63.$

Rise of 30° C. = 54° F., $r = 10.79 \times [1 + (.002155 \times 54)] = 12.05.$

Rise of 40° C. = 72° F., $r = 10.79 \times [1 + (.002155 \times 72)] = 12.46.$

2569. The following examples will illustrate the method of determining the size of wire for any railway system by the formulas given:

EXAMPLE.—A road is proposed to be built, having a length of 1½ miles, single track. There are to be five cars, each taking an average (estimated) current of 15 amperes, and the allowable drop, exclusive of ground return, is to be 50 volts, or less. Will a single No. 0 trolley wire suffice?

SOLUTION.—By formula **365,**

$$d^2 = \frac{5.4 \times 75 \times 7,920}{50} = 64,152 \text{ circ. mils.}$$

$$d = \sqrt{64,152} = 253 \text{ mils} = .253 \text{ in.}$$

The diameter of No. 0 wire is .325; therefore, it will amply suffice, carrying the current with hardly any increase of temperature. Ans.

EXAMPLE.—(*a*) If, in the preceding example, the conductors were to be provided to allow of 50 volts drop with the load concentrated at the end of the line, what would be the required size? (*b*) What would be the drop if a No. 0 trolley wire alone were used?

SOLUTION.—(*a*) By formula **363,**

$$d^2 = \frac{10.79 \times 75 \times 7,920}{50} = 128,185 \text{ circ. mils.}$$

This area is greater than a No. 0 trolley wire, which is 105,592 circ. mils. Subtracting, 128,185 − 105,592 = 22,593 circ. mils.

$$\sqrt{22,593} = 150 \text{ mils} = .150 \text{ in.}$$

An additional feeder must, therefore, be added, to fulfil these conditions, its diameter being .150 in.; or, as an alternative, we might put up a No. 00 trolley wire, which measures .3648 in. in diameter, since $\sqrt{128,185} = 358$ mils = .358 in. Ans.

(*b*) From formula **364,** we obtain

$$e = \frac{10.79 \times 75 \times 7,920}{105,592} = \frac{6,409,260}{105,592} = 60.7 \text{ volts. Ans.}$$

EXAMPLE.—An electric railway is to be built having an arrangement as shown in Fig. 1029, with three feeders, 1,200, 2,100, and 3,300 feet in length, respectively. The mains are each 4,200 feet long, with the

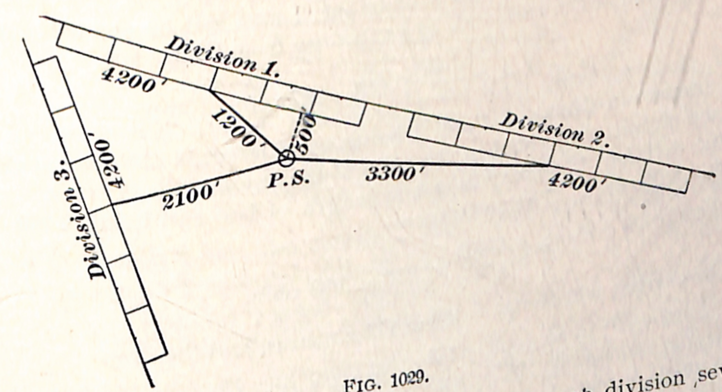

FIG. 1029.

feeder connection at the middle, and there are on each division seven sections of trolley wire 700 feet long, No. 0 B. & S. gauge. Double tracks are to be laid, having an estimated resistance of .025 ohm per mile, and 30 cars will be used, to take an average current of 14 amperes each. With a total drop on any division of about 50 volts, what sizes of feeders and mains will be required?

Solution.—A glance at the plan of the road shows that return feeders will be required, as the station is removed from the line of the railway, and that these will run from that portion of the track on each division nearest to the power house. For divisions *1* and *2*, a single return cable will suffice, but for division *3* another had better be provided, following the direction of the outgoing feeder.

We will first calculate the drop in pressure through that portion of the circuit containing the known resistance. Each division has an average of 10 cars, since there are 30 in all, and the current will be $14 \times 10 = 140$ amperes. When the proper distance between cars is maintained, there can never be two on one length of trolley wire between the sub-feeder from the main, at the center of the section, and the end of the section; therefore, the current is 14 amperes, and the length of wire, 350 feet; the size is No. 0; area, 105,592 circular mils, and the load being a moving one, we apply formula **366**, giving the drop

$$e = \frac{5.4 \times 14 \times 350}{105{,}592} = \frac{26{,}460}{105{,}592} = .25 \text{ volt.} \qquad (a)$$

The connection from the track to the power station *P. S.* is indicated by the dotted line. For the track resistance of division *1*, we will consider that portion lying to the left, its length being say 3,800 feet. The resistance at .025 ohm per mile is

$$R = \frac{3{,}800}{5{,}280} \times .025 = .018 \text{ ohm.}$$

The fall of potential with a distributed load will be one-half that with the load at the end, and, by derivation from Ohm's law,

$$e = \frac{C}{2} \times R = \frac{108}{2} \times .018 = .97 \text{ volt,} \qquad (b)$$

the current in divisions *1* and *2* being considered, in the case of the ground circuit, as divided in the ratio of the two lengths of track.

For division *2*, we may take the length of track as being $9{,}800 - 3{,}800 = 6{,}000$ feet. The resistance

$$R = \frac{6{,}000}{5{,}280} \times .025 = .028 \text{ ohm.}$$

The current will be $280 - 108 = 172$ amperes, and the drop

$$e = \frac{C}{2} \times R = \frac{172}{2} \times .028 = 2.41 \text{ volts.} \qquad (c)$$

In division *3*, the connection to the track is made at the middle of the line; there is then to be considered only half the load, in order to determine the fall of potential. There is a distributed load of $5 \times 14 = 70$ amperes over a distance of 2,450 feet, and the resistance

$$R = \frac{2{,}450}{5{,}280} \times .025 = .0116 \text{ ohm.}$$

The current is 70 amperes, and the drop

$$e = \frac{70}{2} \times .0116 = .41 \text{ volt.} \qquad (d)$$

Returning to division *1*, we have, so far, the drop of potential in the trolley wire and track. The calculations for the feeders and mains should be made with a view to an economical section of copper, provided an excessive fall in potential is not thereby occasioned. The main is in each division connected to the feeder at its center. A distributed load of 70 amperes is carried here, and allowing for a temperature rise of 15° C., the wire, as given in Table 71, is No. 3. The drop of potential

$$e = \frac{5.7 \times 70 \times 2{,}100}{52{,}634} = \frac{837{,}900}{52{,}634} = 15.9 \text{ volts.} \qquad (e)$$

The coefficient 5.7 is obtained by interpolation in Art. **2568**. The value is there given as 11.21 for a rise of 10° C., and 11.63 for a rise of 20° C. The mean between these is, for 15° rise, 11.42; for a distributed load one-half of this value is taken, or 5.7.

The current in the feeders will be 140 amperes, end load, and for an allowable rise of 15° C., the size will be No. 000. Then, for the outgoing feeder,

$$e = \frac{11.42 \times 140 \times 1{,}200}{167{,}805} = \frac{1{,}918{,}560}{167{,}805} = 11.43 \text{ volts.} \qquad (f)$$

For the return feeder, the proportional current may be taken as before, with reference to length of track, as being 108 amperes. For a temperature rise of 15°, use No. 0 wire; then,

$$e = \frac{11.42 \times 108 \times 500}{105{,}592} = \frac{616{,}680}{105{,}592} = 5.84 \text{ volts.} \qquad (g)$$

In the second division, the outgoing feeder is 3,300 feet long, and the current 140 amperes, the wire being No. 000, as before; then,

$$e = \frac{11.42 \times 140 \times 3{,}300}{167{,}805} = \frac{5{,}276{,}040}{167{,}805} = 31.4 \text{ volts.} \qquad (h)$$

In the return feeder, the current is $280 - 108 = 172$ amperes, and to carry this with a temperature rise of 15° we must use No. 0000, and

$$e = \frac{11.42 \times 172 \times 500}{211{,}600} = \frac{982{,}120}{211{,}600} = 4.64 \text{ volts.} \qquad (i)$$

If, now, we take for the main the same wire as in division *1*, the sum of the drops will be beyond the figure, being for the outgoing feeder, 31.4; for the main, 15.9; trolley wire, 0.25; track, 2.41, and return feeder, 4.64; total, 54.6 volts. We may take for the main the next size larger wire, No. 2, and the current being 70 amperes, the heating will only be to the extent of 10° C. rise. Then

$$e = \frac{5.6 \times 70 \times 2{,}100}{66{,}373} = 12.4 \text{ volts.} \qquad (k)$$

Substituting this value for that taken above, we have a total of 51.1 volts lost, which is sufficiently near the desired figure.

In division *3*, both feeders are of the same length, and carry the same current, 140 amperes. Allowing the same heating as in the other feeders, 15° C., we have No. 000 wire, and

$$e = \frac{11.42 \times 140 \times 2,100}{167,805} = \frac{3,357,480}{167,805} = 20 \text{ volts.} \qquad (l)$$

If the same main be used as in division *2*, the drop will be 12.4, and the total drop 53.06 volts. If necessary, this may be reduced by taking the next size larger wire, No. 1, and, with a temperature rise of, perhaps, 5°, the drop would be

$$e = \frac{5.5 \times 70 \times 2,100}{83,694} = \frac{808,500}{83,694} = 9.66 \text{ volts,} \qquad (m)$$

which will give a total drop of potential of 50.32 volts.

Instead of having wires of two different sizes for the return feeders of divisions *1* and *2*, we may use an equivalent of two No. 000. This is the size required for all the other feeders, so that uniformity is secured, and, as the two feeders in question run together, there will be no difference in the distribution of current. Each cable will carry half the total current of 280 amperes, and allowing for a rise in temperature of 15°, the drop

$$e = \frac{11.42 \times 140 \times 500}{167,805} = \frac{799,400}{167,805} = 4.76 \text{ volts,} \qquad (n)$$

which value may be substituted for the drop given in (g) and (i).

On adding together the different values found for the drop of potential in division *1*, the total will be found to be only 33.32. This is considerably below the limit of 50 volts, and we may, therefore, increase it. The return feeder, being used in conjunction with that of division *2*, must remain as already determined; so we have left the outgoing feeder and main. See (f) and (e).

For the former, we may use two wires in parallel, Nos. 3 and 4, the combined area being 94,376 circular mils, which will transmit the necessary current at a rise of temperature of 30°. The drop will then be

$$e = \frac{12.05 \times 140 \times 1,200}{94,376} = \frac{2,024,400}{94,376} = 21.45 \text{ volts.} \qquad (r)$$

With the same rise of temperature in the main, the drop would exceed the limit, but with a rise of 20°, No. 4 wire will carry the current, and

$$e = \frac{5.8 \times 70 \times 2,100}{41,742} = \frac{852,600}{41,742} = 20.42 \text{ volts.} \qquad (s)$$

We may now summarize as follows:

LOSS IN VOLTS.

Division	1.	2.	3.
Outgoing Feeder	21.45 (r)	31.4 (h)	20.00 (l)
Main	20.42 (s)	12.4 (k)	9.66 (m)
Trolley Wire	.25 (a)	.25 (a)	.25 (a)
Track	.97 (b)	2.41 (c)	.41 (d)
Return Feeder	4.76 (n)	4.76 (n)	20.00 (l)
Volts Lost, Total	47.85	51.22	50.32

SIZE OF WIRE.

Outgoing Feeder	One No. 3, One No. 4	000	000
Main	No. 4	2	1
Return Feeder	000	000	000

EXAMPLES FOR PRACTICE.

1. A road is proposed, similar to that shown in Fig. 1026, single track, 2¼ miles long, with one feeder in addition to the trolley wire which is No. 0 B. & S. gauge. There will be 6 cars, with an average current of 20 amperes each, and the total allowable drop is to average 65 volts. The track resistance is taken at .07 ohm per mile. What will be the size of feeder? Ans. No. 3 B. & S.

2. In the above example, if the trolley wire were divided into ten insulated sections, what size wire should be used for the feeder? (Note that length of feeder is one half-section less than trolley wire.) Ans. No. 000 B. & S.

3. In Fig. 1028 is shown a road having feeders and mains, with 4 sections in division *1*, and 3 sections in division *2*. If the total length of railroad is 3 miles, double track, the resistance being .035 ohm per mile, and 16 cars are run, taking an average current of 20 amperes each, what will be the size of feeders and mains, No. 00 trolley wire being used, and a drop of 75 volts being allowed on each division?

NOTE.—The current in each half of the main ab being taken off at two points only, provide one wire from f to a, and another from f to the first sub-feeder, one-third the distance from f to a. The track resistance on the first division is calculated in the usual way, the load being distributed, but for the second division the current may be taken as an end load at a distance Sd.

Ans. { Div. *1.* Feeder, 4,526 ft.; No. 0000.
Main, 3,394 } each side; No. 0.
Main, 1,131 } each side; No. 0.
Div. *2.* Feeder, 12,448 ft.; area, 356,608 circ. mils.
Main, 2,263 ft. each side; No. 0.

TRACK CONSTRUCTION.

FORMS OF RAIL.

2570. Substantial track construction is of supreme importance in electric railway work. The roadbed can not be too carefully built, and it is well to follow, in general, the best steam railroad practice when large lines are projected. The most satisfactory rail has been found to be the **T** rail,

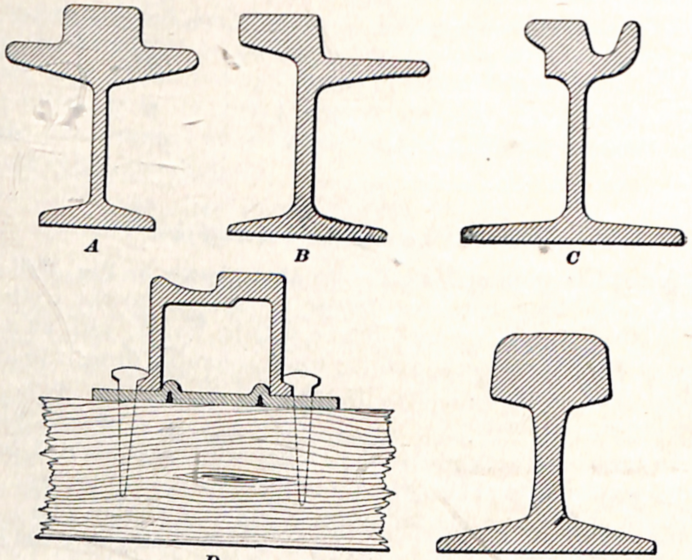

FIG. 1030.

such as is used on steam roads, but this can not be used in paved streets, and the girder rail takes its place. Of this there are many different designs. In Fig. 1030, *A* is a center-bearing, *B* a side-bearing, *C* a grooved, and *D* a box girder rail; a **T** rail is shown at *E*. The side-bearing girder rail is most employed for city lines; the grooved form is a type which presents least obstruction to the wheels of wagons

in crossing the tracks, but it is objectionable from the fact that the groove may become filled with dirt and cause the wheel to run on its flange. The box girder may be spiked down on the ties, as shown in the illustration, or held on a special support to raise it 3 or 4 inches. A light form of side-bearing girder rail is shown in Fig. 1031, with slightly curved channel plates *f*, *f'* to bind the rails together at the joints. They are laid upon longitudinal stringers *a*, in their turn supported on cross-ties, or sleepers, *b*, to which they are secured by the angle plates *m*, *m'* by spiking down. The foundation for the road is composed of a layer of large broken stones covered with gravel ballast at least a foot deep, upon which the ties are laid; additional gravel is filled in between and over the ties, and the paving stones are set on this.

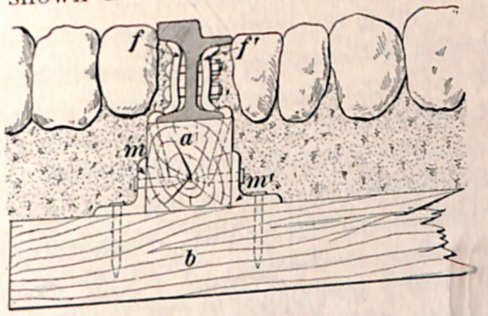

FIG. 1031.

Rails are made of deeper section now than formerly, being, for heavy cars, about 10 inches in height, so that there is room for the paving blocks without the use of extra supports. The base of the rail must be wide, so that it will not cut into the ties; the head should be so shaped that the wheel will be directly over the web, and the tram should not be too wide, unless made very strong, so that there may be no tilting of the rail when heavy wagons are run over it. The difference in height between tram and head is generally about $1\frac{1}{8}$ in., the head being 2 to $2\frac{1}{2}$ in. wide, the tram $2\frac{1}{2}$ to 3, and the base equal to these two.

CURVES.

2571. In the early days of electric railways, simple curves alone were used in rounding street corners; that is, they were laid out with a single radius; but more modern practice employs **transition curves.** These are formed by combining curves of different radii, so that the entrance of the car into the curve shall be gradual, and a sudden shock avoided. The theoretically correct method of laying out a curve would be to make a true spiral connection between the end of the straight track (called the tangent) and the center of the curve, but this would be practically impossible. Some engineers advocate a near approach to such practice, by starting with a radius of some 600 feet or more, and changing the radius every two feet, as measured along the track, when laying out the approach to a main curve of, perhaps, 35 feet radius. Such frequent change of radius

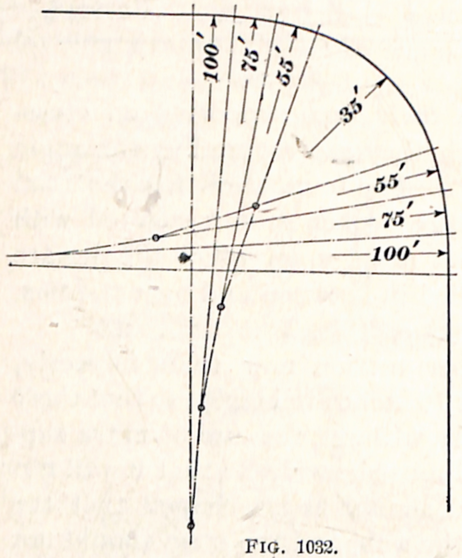

FIG. 1032.

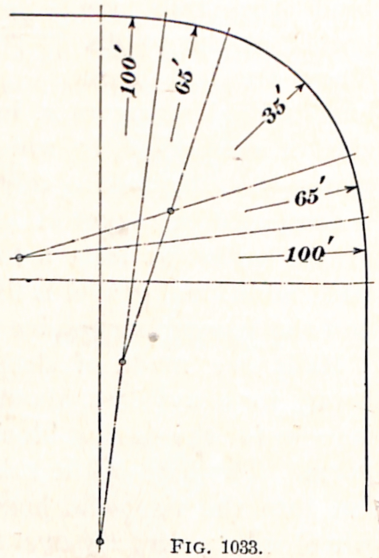

FIG. 1033.

would be very difficult for a trackman to accomplish, and would probably not be done; it is sufficient to change the radius at distances equal to the length of the wheel base, an initial radius of 100 feet being large enough for street railway work. It is not easy to construct switches for a greater radius, and since they are used on probably fifty per cent. of the curves, this must be taken into consideration. In Fig. 1032 are shown the transition curves for a main radius of 35 feet. Each chord, or length of curve having the same radius, is about equal to the wheel base of the cars, and there are three curves completing the transition, having radii,

respectively, of 100, 75, and 55 feet. Fig. 1033 shows a transition with only two curves. In both cases the initial curve has a radius of 100 feet, and the remaining curves should be divided equally between that radius and the radius of the main curve. Thus, for the curve forming the junction of the 100-ft. and 35-ft. curves, a radius of 65 feet, about midway between these numbers, is taken.

RAIL BONDS.

2572. The electrical connection between two abutting rails must be as nearly perfect as possible. Electric welding is probably one of the most satisfactory methods of making the connection, but where this is not possible, **rail bonds** are used. These may be of No. 4 B. & S. copper wire, provided with riveting terminals which are pressed into holes in the web, in the rails *n*, *m* as at *w*, *i*, Fig. 1034 (*y*), and

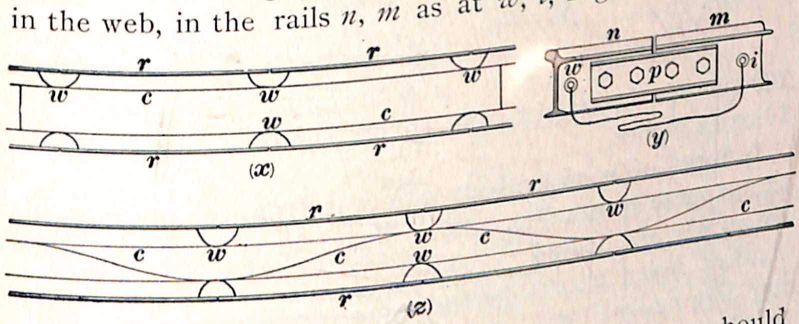

FIG. 1034.

headed over. To ensure a good connection, the holes should be reamed out just previous to inserting the plug, and, to allow for this, should be drilled a trifle smaller than the finished size. It will be found cheaper and more expeditious to drill the holes before the rails leave the mill. In addition to the bond wires, one or more continuous wires *c* must be run the whole length of the track, and connection made to each rail *r*. This is useful in supplementing the bonds, for, if they alone were to be depended upon, a broken wire would introduce a large resistance into the circuit. At (*x*) and (*z*) are shown different methods of making rail connections with the return wires.

Solid bonds of the type shown in Fig. 1035 are much used.

In applying this bond, the enlarged ends *a*, *a* are inserted into the holes in the rails, and taper plugs *b*, *b* are driven in,

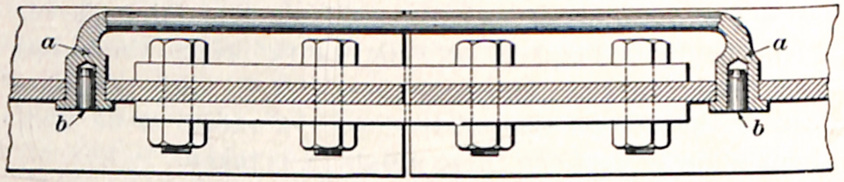

FIG. 1035.

which expand the copper heads so that they fit tightly in the hole in the rail, the edge being then hammered down.

A cast-welded joint is shown in Fig. 1036. The rails are held in a special clamp at the joint forming a mold, and into this is poured molten iron which, if the rail is first carefully cleaned, makes a joint mechanically strong and electrically of high conductivity. The cast iron (*i* in the figure) is approximately 100 pounds in weight, and covers the rails for a length of 10 or 12 inches.

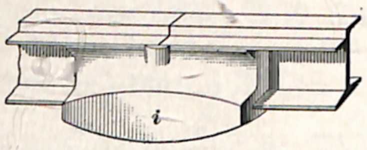

FIG. 1036.

A form of bond entirely different from the preceding is the **plastic bond,** Fig. 1037. Near the ends of two abutting rails are drilled shallow holes, entering diagonally downwards into the junction of the web and base. These are filled with a special mercury amalgam, and a **U**-shaped bridge *l* of amalgamated copper fits loosely into these holes, and is held in position by the fish-plate. This method of making contact between the rails is said to produce a more perfect joint than any other method, the conductivity being equal to that of the rail itself.

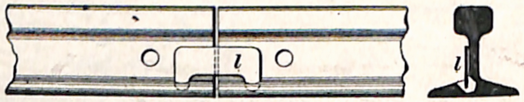

FIG. 1037.

In the matter of placing joints, whether opposite each other or broken, there is a wide difference of opinion among engineers, and much to be said on both sides. The practice almost universally followed in this country is to lay broken joints.

THE POWER STATION.

PLAN OF INSTALLATION.

2573. The **railway power station** is a building intended for the reception of all the apparatus necessary to the economical and reliable generation of power and its transformation into electric energy for transmission through outside circuits to the car motors. It is usual, when ground is not expensive, to build a one-story structure, providing room for offices, stores, machinery, and boilers; or a separate building may be erected for offices and stores. A fireproof construction is most desirable, and, in any event, there should be a fire wall with iron communicating doors between the boiler room and engine room. The complete separation of these departments will also prevent accumulation of dust on the engines and dynamos, due to the handling of coal and ashes. When the available ground space is limited, the usual arrangements provide for placing the engines and boilers on the ground floor and the dynamos on the next above, the power being transmitted by means of belts. One method employs individual driving from each engine to one or two dynamos located directly above, but a better one is to make use of countershafts on the engine or dynamo floor, or both; these countershafts are divided into sections and fitted with friction pulleys in such a way as to permit of any desired combination of engines and dynamos, an arrangement best calculated to ensure uninterrupted

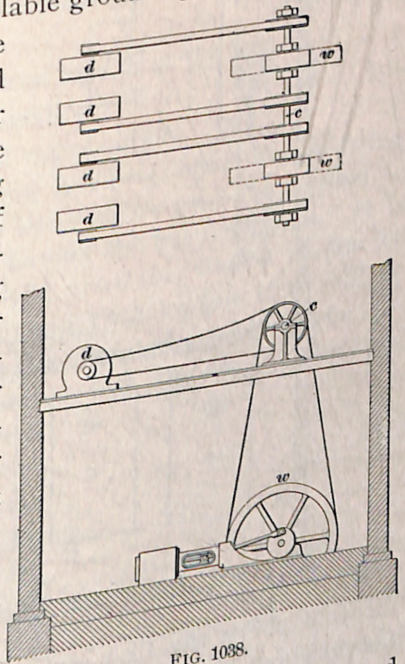

FIG. 1038.

service. A simple example of such an installation is shown in Fig. 1038, the lower view being an elevation; the engines are on the lower floor, the countershaft *c* on the upper floor

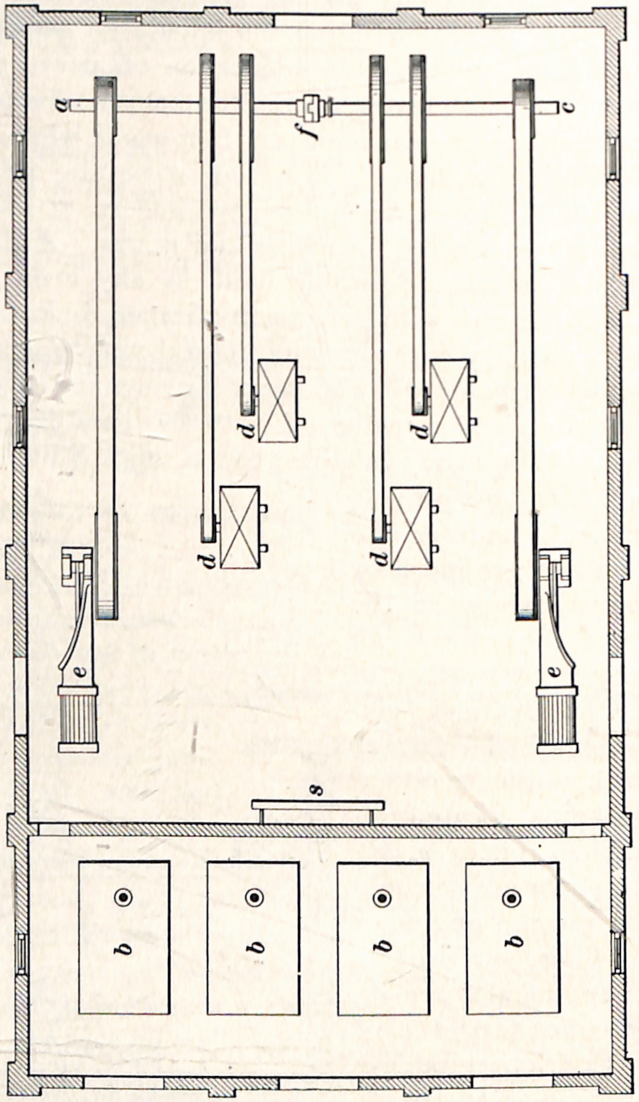

FIG. 1039.

directly above the fly-wheels and connected by belting to the dynamos *d*. Two engines are indicated, their fly-wheels *w*, *w* being dotted in the plan. This system allows of

considerable extension, and may, of course, be laid out on one floor. A further economy of space may be attained by installing a second row of dynamos between the first row and the countershaft, and providing another set of pulleys.

2574. A plan showing the general arrangement of machinery and boilers for a small station is given in Fig. 1039. The engines *e* are placed near the walls, allowing the whole center of the room for the dynamos *d*. At one end is the countershaft *a c*, which may be divided and fitted with a coupling at *f* for disconnecting one-half of the generating plant when the load is light. The switchboard *s* should be near the dynamos, but not so close as to be liable to injury from a broken belt. Beyond the fire wall are the boilers *b*, arranged so that the distance from them to the engine shall be as small as possible, to avoid condensation of steam in the pipes.

2575. The choice of location of the power house is a most important matter. The principal considerations affecting this question are:

1st. Probable distribution of load over the system.

2d. Cost of ground for building site.

3d. Coaling facilities and water supply.

Concerning the first point, it is best, other things being equal, to have the station situated as near as possible to that portion of the system having the heaviest load. It is not necessary, or always right, that the station should be located alongside one of the main tracks, but it should be placed in what we may call the center of gravity of the system, when the largest feeders will also be the shortest. Suppose a road is projected in a town, and it is expected that the traffic on the different streets will have the relative values of *1*, *3*, *5*, *9*, and *11*; also, that a map would indicate the distributing centers to be spaced about as shown in Fig. 1040. The center of gravity may be determined

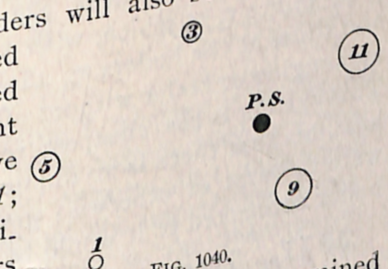

FIG. 1040.

graphically, and will, in this case, be at the point marked *P. S.*, which determines the location of the power station. There are still the other governing factors to be considered, namely, the cost of land, and the matter of coal and water supply. If real estate in that particular neighborhood were cheap, it might be well to build there, but such an advantage may be more than offset by inconvenience and expense in coal transportation. On this account a water front is a desirable location; for coal may then be unloaded from barges, and brought on cars over a special track direct to the boiler room; and water for the boilers and for condensing purposes may be obtained at a cost not exceeding that of the necessary pumping outfit.

STEAM PIPING.

2576. The **steam piping** for the station should receive the most careful thought, as it is of the greatest importance, and upon its correct design will depend the prime requisite of successful operation, which is that, under no circumstances, should there be failure of the current supply to the line. The engines must be kept turning all the time, except during those few hours when, in the case of some roads, the cars are not required to run. The simplest means of connection is to supply steam to each engine from an independent boiler; but the objection to this is that in the event of trouble with any boiler, necessitating repairs, its engine would also be put out of service. To overcome this difficulty, the boilers might all be connected together by a steam main, as at *m*, Fig. 1041; this is provided with gate valves *v*, *v*, which, with the valves v_1 at the engines and those at the boilers v_2, afford a means of disconnecting any engine or boiler without affecting the rest of the plant. This system is the cheapest reliable one, but it is not the best, because there is no duplication of the pipes, and if one were to burst or otherwise get out of order, the engine or boiler connected to it would be put out of service.

2577. There are two principal methods of installing a duplicate system, and they differ at first sight only in point

of size of pipes. A diagram of the arrangement is shown in Fig. 1042. Two mains *m*, m_1 run the whole length of the boiler room, being connected on one side with leaders to the boilers *a*, *b*, *c*, and on the other to leaders passing through the fire wall *w* to the engines. These connecting pipes, it will be seen, are all in pairs, and start from the two mains; each one is provided with a gate valve *v* at the end, and

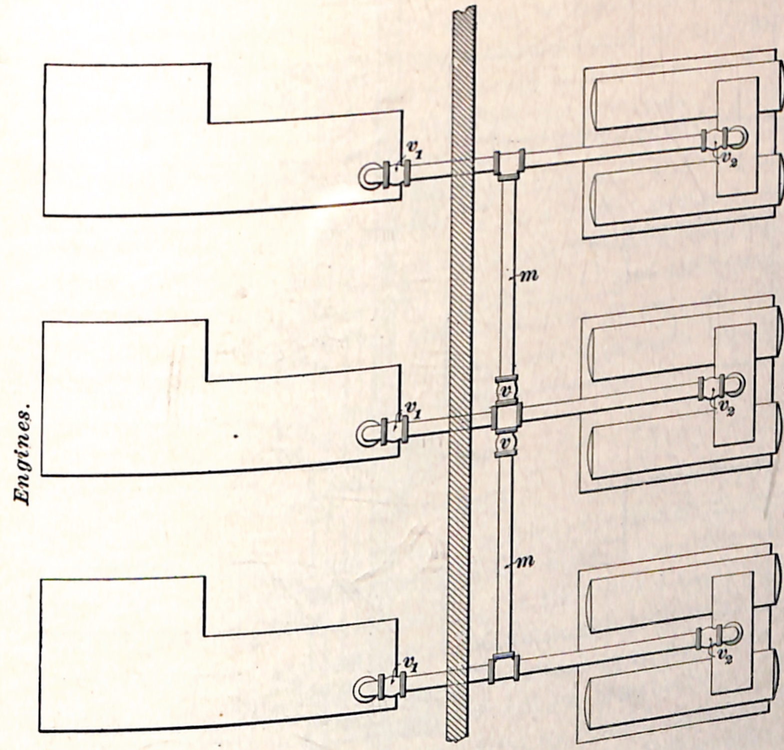

FIG. 1041.

every pair terminates in a cast-iron **Y**, whether at the drum of the boiler or at the engine. This system, therefore, provides a double path for the steam between any engine and any boiler, and renders almost wholly improbable a suspension of operation due to accident to the steam power generating plant. The difference alluded to between the two methods of duplicating is that in one pipes are provided of such size that one set alone will carry the steam for the engines, and the duplicate piping is held as a reserve, while in the other the pipes are of smaller size and are in use all the time, their combined area of cross-section being necessary for delivering the steam at the determined pressure. The first system is employed quite frequently, but has, nevertheless, many disadvantages. It is impossible to keep

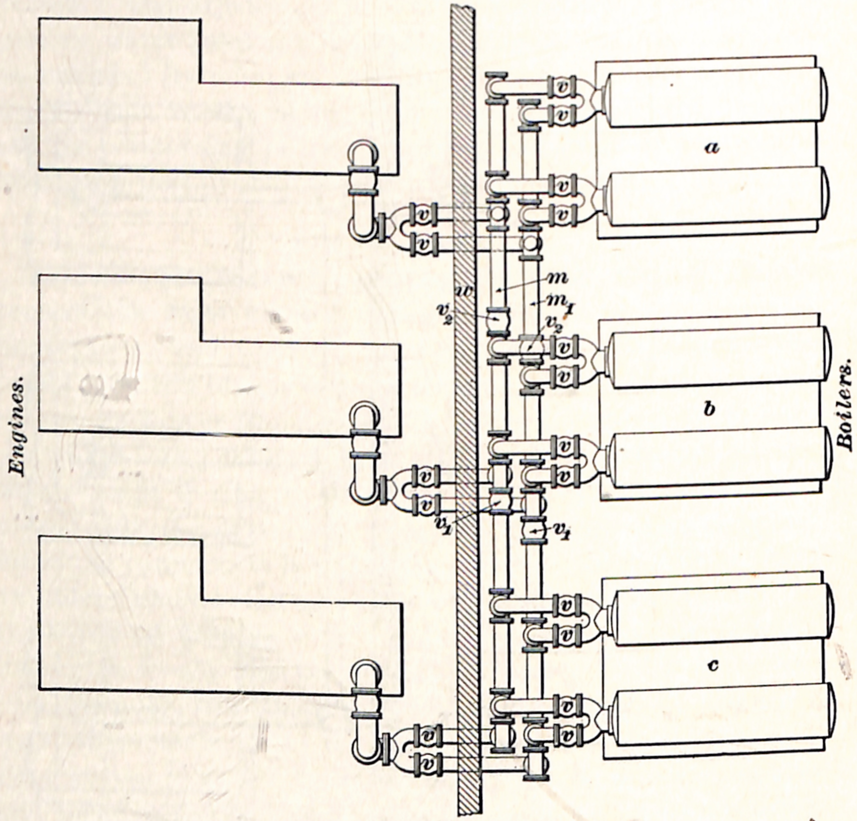

FIG. 1042.

the valves connecting with the reserve piping closed so tightly that no steam will leak past, and there is always a pressure indicated on the gauge. The exposure of all this surface to condensation, even though protected by non-conducting covering, entails a continual waste of energy, and the drips always have to be left open to prevent the pipes filling up with water. Then, the first cost of such a

system is considerably higher than if the smaller pipes were used, and repairs are more expensive. It may also happen that an engineer will habitually use one set of pipes alone for a long period, and when an accident compels him to close this set, he finds that the valves of the auxiliary piping have become seated through rust or deposits from the water and are immovable, and a shut-down is the result. With the second system, which presents another advantage in that the exposed surface of pipes is less, both sides are in service continually, and, if an accident should occur to one branch, the remaining one will furnish steam until a repair is accomplished. There would be, through the one pipe, a greater drop in pressure, but this could easily be remedied by closing the valves v_1, v_1 or v_2, v_2 communicating with the rest of the system, and running one boiler at a higher pressure for a time. Other methods of piping are sometimes resorted to, but these two, as illustrated in Figs. 1041 and 1042, will be found to generally satisfy the conditions of simple connections on the one hand, or the more expensive but more reliable construction on the other.

BOILERS.

2578. The boilers in most general use are those carrying the water in tubes, and called water-tube boilers, the reason for the preference being that they steam rapidly, and will, therefore, respond quickly to extra demands made upon them. Many stations are, nevertheless, equipped with return-tubular boilers, which give entire satisfaction. For steady work this type is preferred by many station managers, *as the steam pressure* in a water-tube boiler will fall as easily as it rises, if the boiler is not properly fired; on the score of safety, the latter are, however, probably superior. When space is very limited, vertical boilers are sometimes put in.

Mechanical stokers are much used when it is desired to burn fine coal, and in such cases generally prove economical; also, economizers may be placed in the chimney, close to the