EXAMPLE.—The limit of adhesion being $\frac{1}{6}$ the weight on the drivers, how steep a grade could be surmounted by a car with $\frac{1}{4}$ its weight on the drivers, starting from the level?

SOLUTION.—According to formula **6**,

$$G_r = \frac{\frac{2{,}000\ a}{y} - 25}{20} = \frac{\left(\frac{2{,}000}{4} \times \frac{1}{6}\right) - 25}{20} = 2.91 \text{ per cent. Ans.}$$

40. The foregoing data and formulas will enable approximate calculations to be made regarding the power required for a given number of cars. It is unsafe to give values of the power to be allowed per car, because there is such a wide variation in the size and weight of cars that such figures are not generally applicable. The safest method is to calculate the power required for any given case by taking into account the weight of the cars, speed, steepness of grades, etc., as indicated in the above formulas.

THE LINE.

41. The term **line,** when used in connection with a street railway, covers quite a large field of work; in the first place, the line may be an overhead-trolley system, a conduit system, a third-rail system, or a high-potential transmission line. Also, the name can include any of the several sectional surface systems, none of which, however, are in general enough use to warrant its consideration here. Whatever the system may be, its consideration calls for a study of the active trolley wire, its feeders, and their means of support.

OVERHEAD LINE CONSTRUCTION.

42. General Features.—When **overhead construction** is spoken of, it is generally understood to refer to the common overhead-trolley system that is used wherever it is permitted, because it is so much cheaper than any of the other

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systems. Overhead construction includes the setting of the poles, the stringing of the feed wires and the trolley wire, with its span wires, guard wires, anchor wires, insulating hangers, coupling devices, switches, etc. The feed wires, or feeders, i. e., the wires communicating directly between the generators at the station and the several points of distribution, are carried overhead or are laid underground if necessary. When the feeders are carried overhead, it is the rule to support them on cross-arms from the same poles that support the span wires and trolley. Sometimes, however, if the feeder followed the line of the track, it would be unnecessarily long. In such a case, its route would lay across country or across town, as the case might be.

43. In Fig. 16, *P* is the site of the power house; *k–a–C B–b–e* is the trolley wire, which of course has to follow the track. The trolley wire is divided into two sections, *a* and *b*, separated by the circuit-breaker *C B*; the term circuit-breaker used in connection with line work denotes a fitting for putting a break, or insulating joint, in the trolley line. Each section of the wire is fed by its own feeder. Feeder b_1 feeds into section *a* at *a* and follows the line of the track up to that point. Feeder b_2 feeds into section *b* at *b*, but instead of following the track and taking the long path around, as shown by the dotted line, it cuts across, as shown by the full line, thus effecting a great saving in length. It is, as a rule, cheaper in such cases to take the short cut, even if a pole line has to be erected just for the feeder, because great length in a feeder not only means a

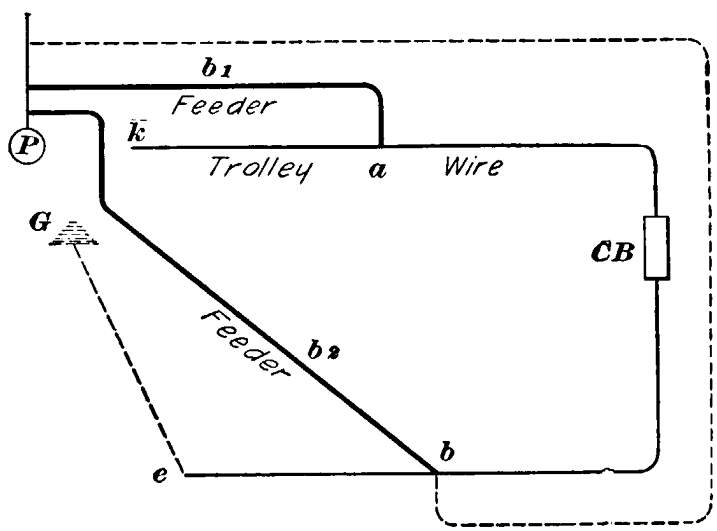

FIG. 16.

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great outlay in copper, but it also means that the additional resistance helps to defeat the purpose of the feeder—that of keeping the voltage up to a practicable value on the line.

44. Most overhead-trolley systems use a **rail return;** that is, the current leaves the power house by way of the feeders and perhaps the trolley wire, passes through the car motors and returns to the power house by way of the rails, the earth, and whatever water, gas, or other pipes may happen to parallel the track. The return circuit, then, is an item of just as much importance, as far as conductivity is concerned, as is the overhead work, and in some cases it is of more importance, because when the rail return is bad, so much current follows the path of neighboring pipes as to injure them and bring on lawsuits.

A glance at Fig. 16 will show that although feeder b_2 allows the current a short path from the power house to the point of distribution *b*, it does not provide a short path back to the power house. To reach the power house, the return current must follow the rail, and it would be very easy under such conditions for a greater drop to take place in the track return than in the overhead feeder. It is easily seen that, if a ground wire were run from some point on the rail in the neighborhood of *b*, or even from the end *e* to the ground bus-bar at the power station, it would greatly improve the conditions of the service.

Should it be found desirable or should circumstances make it necessary to put the feeders underground, they should be handled with great care and should be substantially protected from any liability to abrasion, since faults are somewhat difficult to locate and expensive to remedy. The feeders, as a rule, are encased in a lead sheathing, which not only is a protection against abrasion and moisture, but leaves the feeder pliable and easy to handle. A break in the sheathing due to a bruise or a kink may not cause any trouble for months after the feeder has been in active service, but in course of time moisture will work through and establish conditions for setting up a leakage current, which

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will gradually convert the fault into a short circuit. Even in stringing feeders overhead on iron poles, a little carelessness on the part of the linemen will give rise to the same trouble. The ordinary practice in stringing such feeders is to set the reel upon which the feeder wire is wound near the first pole and on the off side; one end of the wire is then passed over the cross-arm of the pole and a horse or car is hitched to it to pull it to the next pole, over the cross-arm of which it is also raised and the operations continued until the wire is in place. If there happens to be a snag on the cross-arm or if the feeder gets caught, a hole is cut in its insulation. If, after the feeder is secured in place on its insulators, the injured part falls between poles, it can do no harm, unless a telephone or light wire happens to fall across it at some time; but if, as often happens, the abraded part falls over the cross-arm, then the first time a heavy wind lifts the feeder off the insulator and lets it down on the iron cross-arm, trouble begins.

FEEDERS.

45. The whole distributing system of an electric railway may be generally divided into two parts—the **feeders** and the **working conductor.** The latter usually takes the form of a trolley wire in overhead work, but it may be a third rail or the conductor rail in a conduit system. The feeders are usually in the form of heavy cables run out from the station to supply different sections of the working conductor. Feeders may be run overhead or underground. In small towns and cities or on cross-country roads, they are run on poles, because this is the cheapest construction. In large cities, however, they are run underground. City ordinances often prohibit running them overhead on account of their unsightliness and also on account of their being a nuisance and source of danger in case of fires. Underground construction is expensive, but it has its advantages. Electric-railway companies objected very strongly when

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they were first required to put their feeders underground, but many of them are now strongly in favor of it. Underground wires are not disabled by snow and sleet storms, and on the whole their service is more reliable than that of overhead wires.

Where feeders are run underground, they are usually in the form of lead-covered cables. These are pulled into ducts, and manholes are provided at intervals to allow access to the cables for making repairs and locating faults.

46. General Methods of Feeding.—The simplest method of line construction is to use a single wire, serving both the purpose of trolley wire and feeder; but with a heavy load, the drop of potential at the end of the line, except in special cases, would be too great if the trolley wire alone were used. It is more satisfactory to run a heavy cable alongside of the trolley wire and tap it into the wire

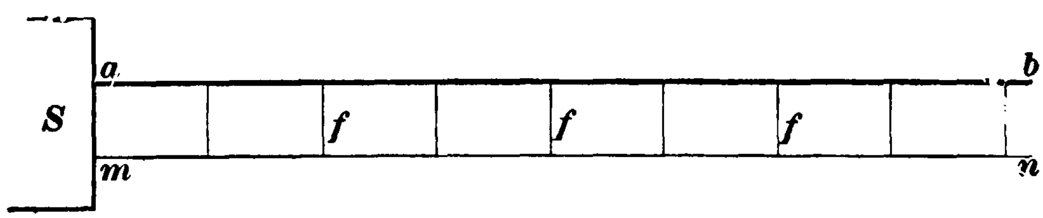

FIG. 17.

at intervals along the route: the two together will carry the load with much less loss in voltage than will the trolley wire alone. Such a plan is shown in Fig. 17, where *m n* is the trolley wire, *a b* the feeder, and *f*, *f* the several taps. The power station is supposed to be at one end of the line at *S*. It would be a much more economical arrangement were the power station in the center, as shown in Fig. 18, so that it might feed in both directions and thereby halve the distance from the power house to either end of the line.

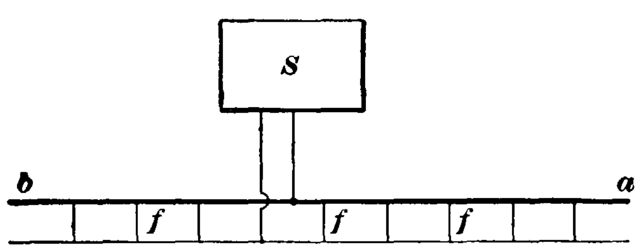

FIG. 18.

If the trolley wire is divided into a number of sections *c*, *d*, *e*, *f*, *g*, each connected at its center to the

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feeder *a b*, as shown in Fig. 19, the drop in potential at any point would be due only to the feeder and that portion of the trolley line between the point in question and the tap line. In case

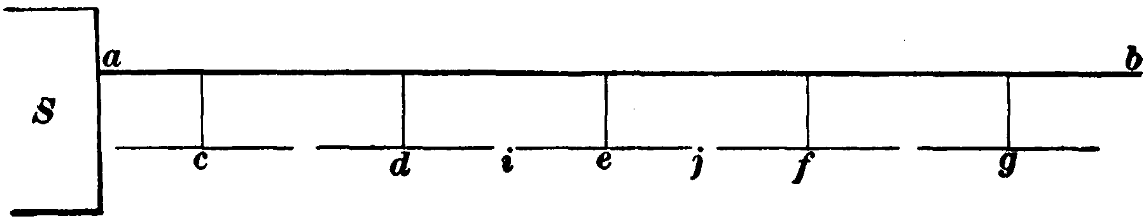

FIG. 19.

of a fire at any place along the route or in case of a ground on a bridge or in a tunnel, the power could be shut off in that district without disturbing the other parts of the line, so that the whole road would not be shut down. In order to do this, each tap wire should be provided with a switch that is mounted on the pole at the point of connection to the feeder. Fig. 20 shows a line switch for this purpose. It is mounted on the pole and the lower terminal is connected to the trolley. When the switch is opened, the blade can be thrown all the way down and the door closed. All the exposed parts are then dead and the switch cannot be closed until the door is unlocked. The several sections of the trolley wire are well insulated from one another by line circuit-breakers, or section insulators, which will be described later.

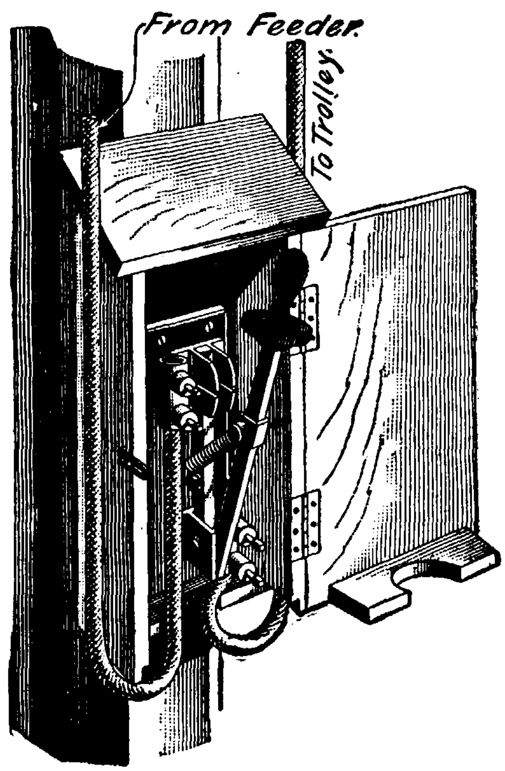

FIG. 20.

47. Fig. 21 is a plan of feeder wiring that approaches more nearly the trend of present practice than any of the other plans so far shown. It approaches the condition

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where the trolley wire is divided up into several sections, each of which is provided with its own feeder. But in the case shown in Fig. 21, each feeder supplies several sections of trolley wire by means of extension feeders or

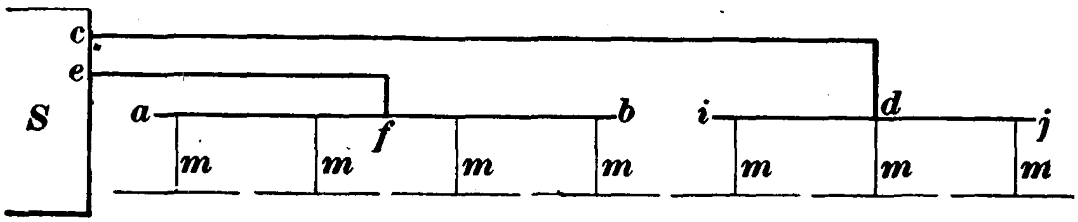

FIG. 21.

mains *a f*, *f b* on the end of the main feeder and an independent tap running to each section of trolley.

Fig. 22 shows the best plan for a feeder service. In this case, each trolley section has a feeder of its own. Of course, the feeder is tapped into its section in as many places as may be deemed advisable. Each feeder and its section of

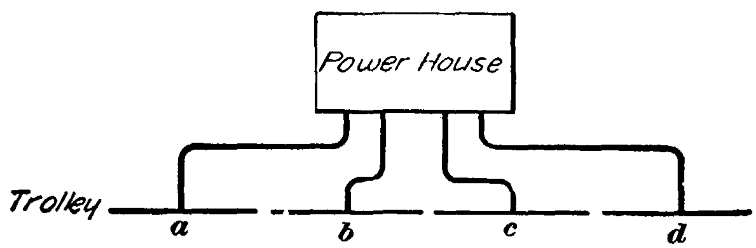

FIG. 22.

trolley wire may be looked on as a single unit, and the idea can be extended to any system, however large. Such a plan not only simplifies calculations, but limits the field for troubles as well. Any trolley section may be cut out by means of its feeder switch.

48. Overhead feeders are usually in the form of heavy stranded cables covered with weather-proof braided insulation. If a very large feeder is not required, solid wire may be used or two or more wires may be run in multiple to make up the requisite cross-section. The accompanying table

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gives the make-up of triple-braided weather-proof railway feeder cables as made by the American Electrical Works.

Size.	Style of Conductor.	Approximate Weight per Mile. Pounds.
1,000,000 C. M.	61 wires, .128 each.	19,000
950,000 C. M.	61 wires, .125 each.	18,250
900,000 C. M.	61 wires, .122 each.	17,280
850,000 C. M.	61 wires, .118 each.	16,320
800,000 C. M.	61 wires, .115 each.	15,360
750,000 C. M.	61 wires, .111 each.	14,400
700,000 C. M.	61 wires, .107 each.	13,450
650,000 C. M.	61 wires, .103 each.	12,480
600,000 C. M.	61 wires, .099 each.	11,600
550,000 C. M.	61 wires, .091 each.	10,560
500,000 C. M.	49 wires, .101 each.	9,800
450,000 C. M.	49 wires, .096 each.	8,600
400,000 C. M.	49 wires, .090 each.	7,500
350,000 C. M.	49 wires, .085 each.	6,500
300,000 C. M.	49 wires, .078 each.	5,500
250,000 C. M.	49 wires, .071 each.	4,860

TROLLEY WIRE.

49. In the early days of electric railways, the trolley wire was much smaller than that now used. No. 2, 3, or 4 B. & S. soft copper wire was used in many cases, but it was soon found that this wire was not strong enough mechanically. Hard-drawn copper wire is now used in most cases, and the size is generally from No. 0 to No. 000; in some cases, No. 0000 wire is used. Wire smaller than No. 0 should not be used. Hard-drawn copper wire has a little higher resistance than soft-annealed wire, but its tensile strength is very much greater; hence its use for trolley wire. Where a very strong wire is required, phosphor-bronze is sometimes used.

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50. Shape of Trolley Wire.—Trolley wire is nearly always round in cross-section. This answers for ordinary work in towns and cities where the speed is not high. Fig. 23 (*a*) shows the ordinary round wire held by a soldered ear. The ear is tapered down to an edge, so that it will allow the under-running trolley wheel to pass as smoothly as possible. Even if the fins on the ear are thin, there is always more or less of a jump when the wheel passes under the hanger, and this gives rise to trouble if the car runs at high speed. The sparking caused by the jump also eats the hanger away and causes breakage in course of time. The jump is even more pronounced if ears which clamp the wire, instead of being soldered, are used. Clamping ears project more than soldered ones, and hence there is more of a knock when the wheel passes under them.

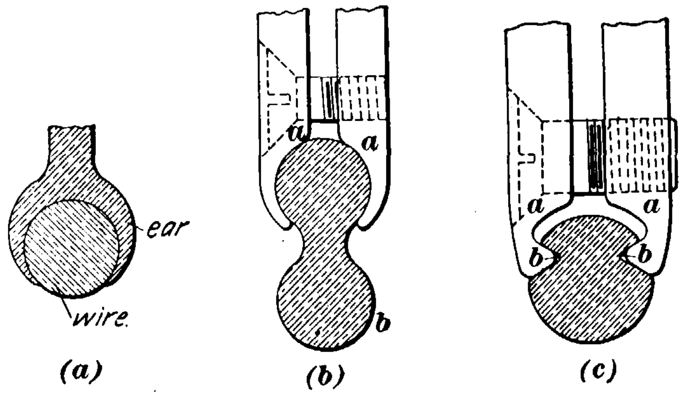

Fig. 23.

For cross-country or interurban roads, where high speed is attained, it is very desirable to have the trolley wire so suspended that it will offer a smooth running surface for the trolley. Fig. 23 (*b*) shows a wire designed to accomplish this. It is the shape of a figure 8 in cross-section and the upper part is gripped by the clamp ears *a*, *a*, the lower part *b* being free from obstruction. The objection to this style of wire is that if it becomes twisted between supports, so that it lies crosswise, the wheel does not run well.

Fig. 23 (*c*) shows another style of wire introduced by the General Electric Company. This wire is also supported by clamp ears *a*, *a*, and the surface presented to the trolley wheel is smooth. The wire is practically circular in cross-section, with the exception of the two grooves *b*, *b* in the side, so that if the wire twists between supports it does not interfere perceptibly with the smooth running of the wheel

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when high speeds are attained. Fig. 24 shows clearly the method of supporting this wire.

When soldered ears are used, the obstruction offered is so slight that a round wire answers in the great majority of

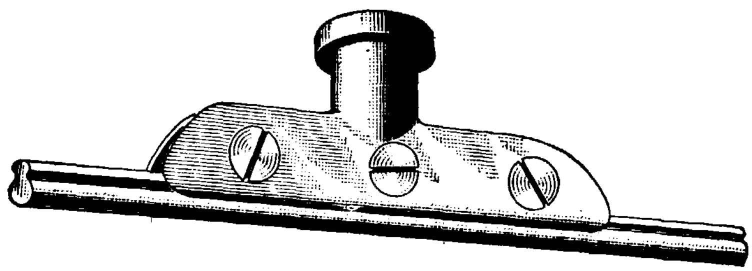

FIG. 24.

cases. When clamped ears, however, are desired, and when high speeds are developed, these special shaped trolley wires will be found advantageous.

METHODS OF ARRANGING TROLLEY WIRE.

51. 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 a projecting arm on either side; or the poles may be placed at the sides of the street and the trolley wire supported by span wires stretched across.

52. Span-Wire Construction.—This is the most common method of suspension, and it is preferred for the following reasons: In the first place, it does not obstruct the center of the roadway as the center-pole construction does; in the second place, there are places where only one side of the road can be used, as on country roads, where passages for two teams must be left outside of the track. Again, where a single track is laid with the prospect in view of making it a double track if the traffic warrants doing so, the side-pole, span-wire construction leaves very little additional work to be done when the time comes for doubling the track. In such a case, it is often the practice to string two trolley wires

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alongside of each other about 8 inches apart. As long as the road is a single-track road, the cars use one wire going one way and the other wire coming back; this saves overhead special work at turnouts and saves copper in the feed wires. When the time comes for doubling the track, it is only necessary to slide one wire over into place and see to its insulation from the ground. In such straightaway construction, it may be that no feeders are used, in which case the road cannot be divided into sections, but the two wires must be continuous from the power house to the end of the line.

In Fig. 25, *a b* is one trolley wire and *c d* is the other; *T* is a turnout—a switch where cars can pass each other, and the other dotted line *e f* shows the position of the wire *a b* after it has been moved over to the second track. It is easy to see that the parallel construction does away with the necessity of any overhead special work at the turnouts. If all the turnouts are placed on the same side of the track, it leaves one wire straight.

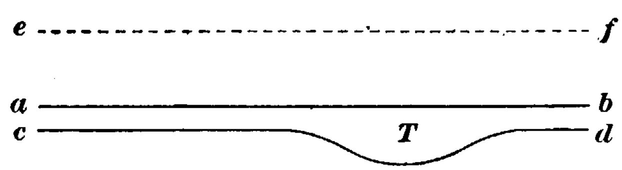

Fig. 25.

One rather unusual condition, under which the side-pole, span-wire method has a decided advantage, is where a projected road has trouble in obtaining right of way through the country. One owner may give the right of way in front of his property, but the owner across the road may refuse it, so that the track will have to be laid on one side of the neutral line. It may be necessary to do this several times in the course of a few miles, with the result that the line zigzags from one side of the road to the other. If the center-pole construction is used, the poles will have to zigzag with the track; but if side poles are employed, it will be necessary to make only the trolley wire itself conform to the serpentine track construction by sliding the wire one way or the other on the span wire. In course of time, if the track can be straightened, the only change necessary in the overhead construction is to move over the trolley wire.

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53. Fig. 26 shows the general arrangement of a span-wire suspension. In this case iron poles are shown, so that an insulating turnbuckle is used between the pole and the span wire. The trolley hanger is also insulated, so that there is high insulation between the trolley wire and the

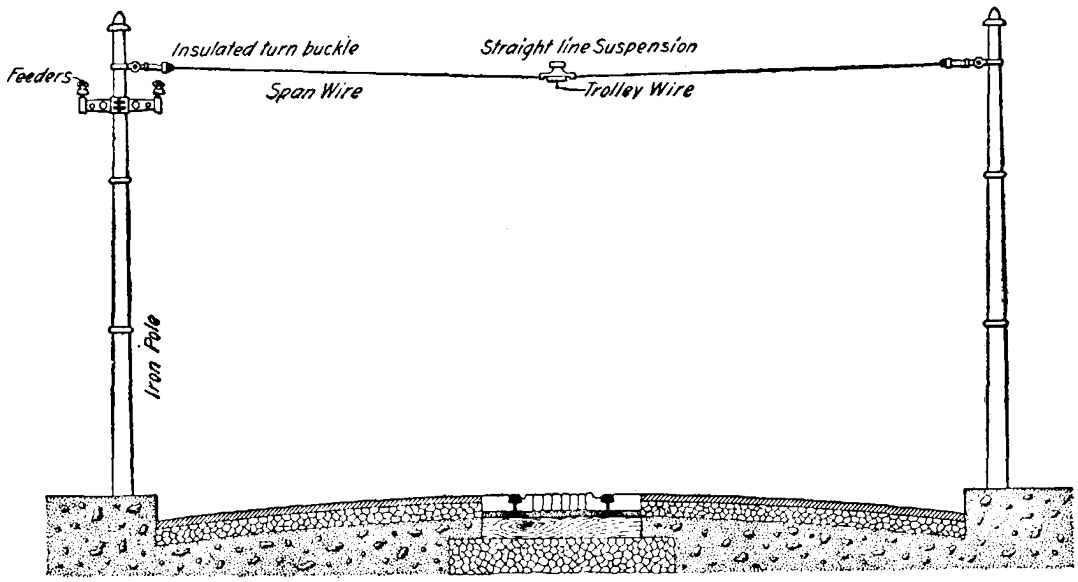

Fig. 26.

ground even though iron poles are used. The feeders are carried on cross-arms bolted to the poles. Where wooden poles are used, the insulated turnbuckles are often omitted. An eyebolt is simply passed through the pole and the span wire is stretched by screwing up a nut.

54. Center-Pole Construction.—Center-pole construction can be used to good advantage on very wide streets, where the poles will not be in the way. If ornamental center poles are used, the general appearance may be made very pleasing. Sometimes arc lamps are mounted on every other pole, thus adding to the general effect at night. Where ornamental construction is used, the unsightly feeders are generally run underground, but if this is impracticable or if it is undesirable to run the avenue feeders in a conduit, the same effect can be obtained by running the feeders overhead, but up a street that parallels the main avenue. In this case, the taps must run from the feeder in the side street to the trolley wire. This feed tap disappears

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into the ground just off the avenue and does not show again except where it is spliced to the trolley wire. From the side street to the pole it is carried in a tube; it then passes up through the center of the pole to the bracket and out to the wire.

55. Side-Bracket Construction.—When this construction is used, the track is generally on one side of the street. It is used most extensively for cross-country lines where

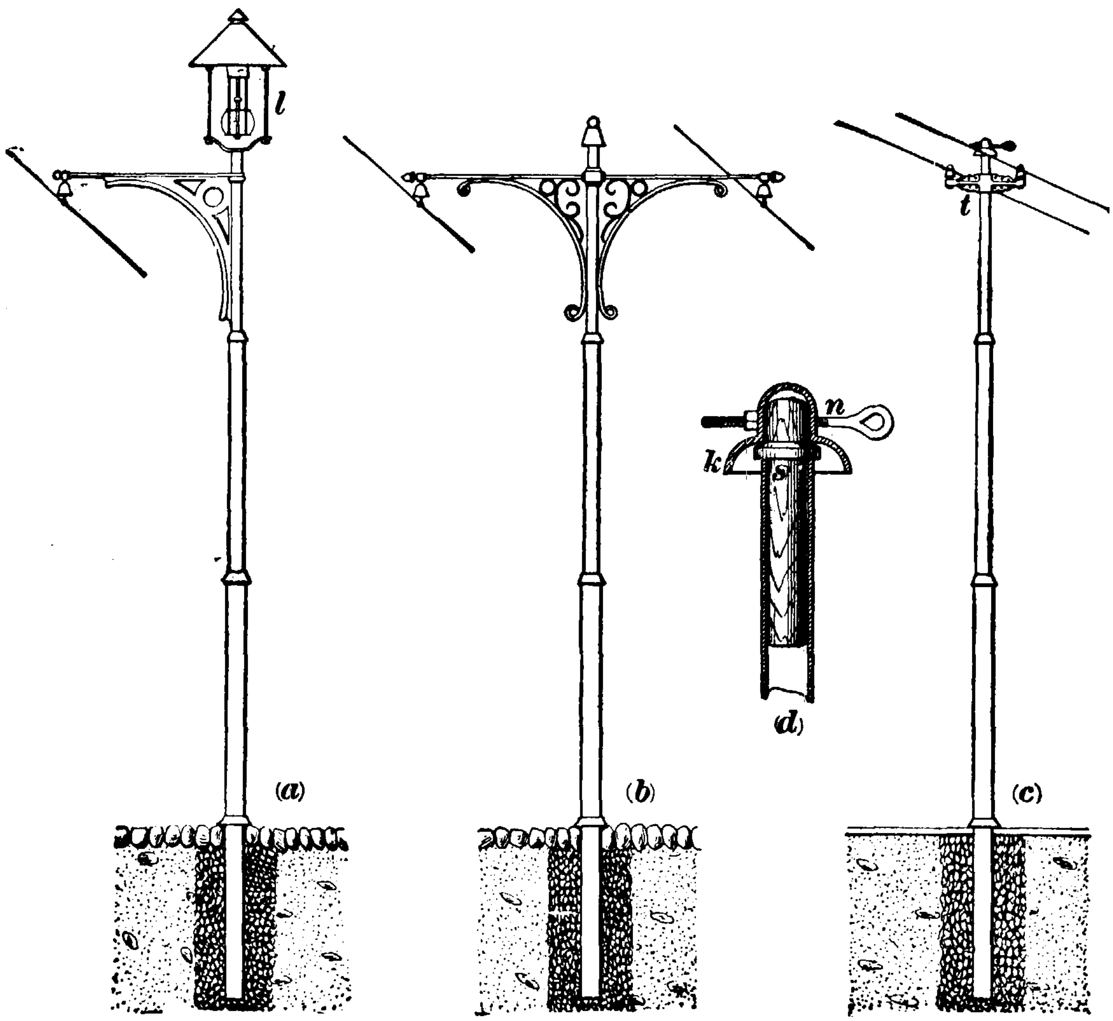

FIG. 27.

a single track runs along one side of the road. For this class of work, cheap gas-pipe brackets are generally used, and since the construction calls for only one pole, whereas a span wire requires two, it is inexpensive.

56. Steel and Wood Poles.—At the present time, the poles used are either steel or wood. For cross-country or

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suburban roads, wooden poles are as a rule selected, because appearances are not so much a matter of consequence, and they are even used in city streets where no very strong objection is made to them. Steel poles are, however, much the better for city streets. There are a great many tubular steel poles of the telescope type in use in cities; in fact, many cities will not allow the use of wooden poles on the ground that they are unsightly. Seamless steel-tube poles are also coming much into favor, as they are strong and last a long time. Such poles are invariably set in concrete.

57. Tubular Steel Poles.—Fig. 27 shows a tubular pole adapted to the various types of construction; (*a*) is the side bracket, (*b*) the center pole, and (*c*) the plain pole for span-wire construction. The poles are about 30 feet long, the lower section being 6 or 8 inches in diameter and the others 1 inch smaller successively, fitting inside of each other with telescope joints that ought to be at least 18 inches long. Fig. 27 (*d*) is an enlarged view of the top of the pole shown in (*c*) without a bracket. It shows the insulated top *k* supported on a wooden block *s* and carrying the tension bolt *n*, to which the span wire is secured through the medium of an insulator. The cross-arm *t* carries feeders to supply current at distant points. The pole may also be utilized to carry an arc lamp shown at *l* in (*a*). Instead of a tension bolt, there may be placed on the top of the pole, as shown at *a*, Fig. 28, a ratchet provided with a counter-balanced 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

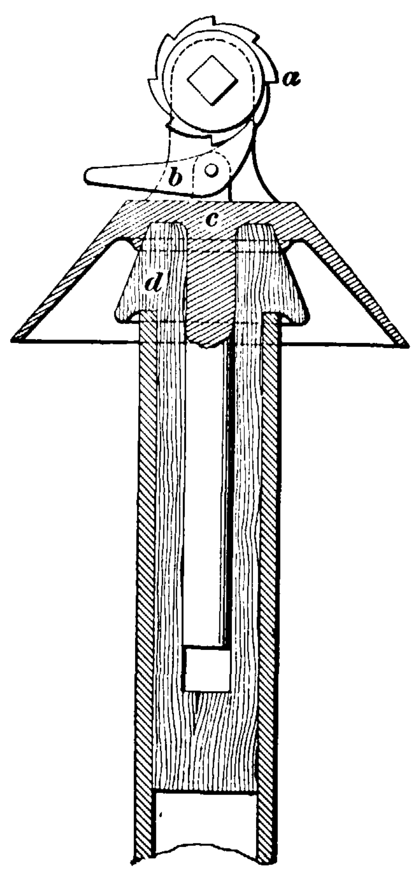

FIG. 28.

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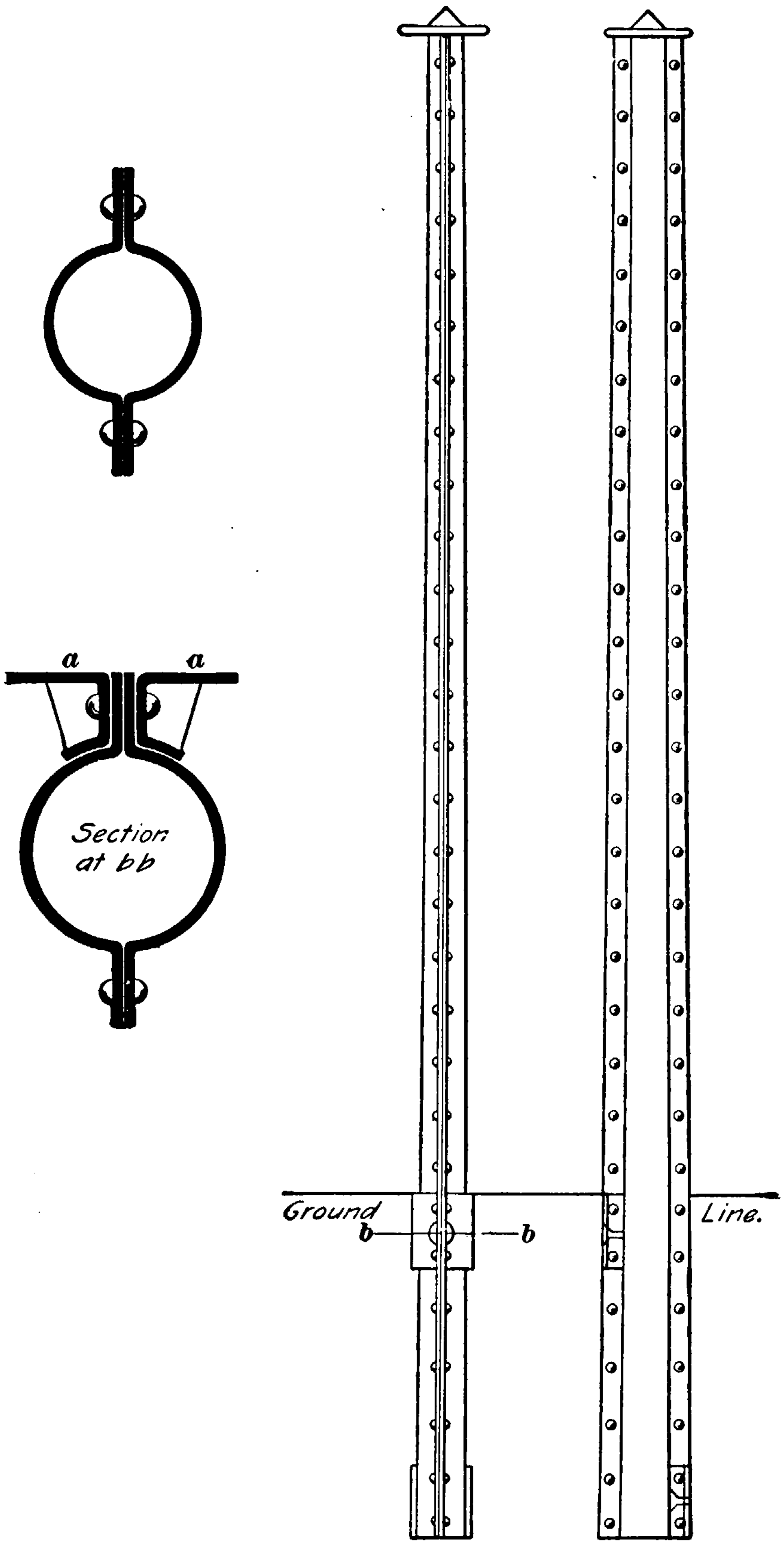

FIG. 29.

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at any point or bolted to a wooden pole. In addition to these arrangements, a clamp may be used on the pole in connection with a turnbuckle, as shown in Fig. 26.

58. Structural-Steel Poles.—Steel poles are sometimes made in other than telescope tubular form. Fig. 29 shows a pole made of pressed steel halves riveted together. Pieces *a*, *a* are riveted on at the bottom and at the ground level, so that the pole will have a flat surface of considerable area to enable it to better withstand the strain due to the span wire.

Latticework poles are also largely used; they are neat and strong and can be painted inside and out. They are also easy to climb.

59. In both bracket and center-pole construction, it is now the practice to use a flexible support for the trolley-wire hanger, to prevent the destructive blow of the passing trolley wheel and reduce the sparking. Such an arrangement is shown in Fig. 30, which represents a form used for the side-bracket construction. A span wire *w* holding the hanger *h* is stretched tightly between two insulators *i*, *i'*; the outer one is secured to a bracket *b* and the inner one is held by a clamp on the framework. In the center-pole method of 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. Of course, in the ordinary side-pole, span-wire method of construction, no such device is needed to cushion the blow of a passing trolley, as this trouble is looked after by the natural flexibility of the suspension.

FIG. 30.

60. Wooden Poles.—For ordinary use, the diameter of the base of a wooden pole should not be less than 10 inches,

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tapering to 6 or 7 inches at the top, which should be cut to a conical shape so as to shed water. The pole from the ground up may be round or octagonal. Octagonal poles look better, but poles naturally round last longer. It will be found to prolong the life of a wooden pole and also lessen the liability to current leakage if the part above the ground is covered with two coats of paint. The part that is to be under the ground should receive a preservative of some sort, such as tar.

61. Setting Iron Poles.—The lower end of the pole is sunk in the ground 6 or 7 feet and filled around with cement and broken stone. The amount of concrete to be used at the base of each pole cannot be laid down as a general rule, because it varies according to the soil encountered. In some places it is necessary to blast the holes for the poles in the solid rock ; in such a case only enough concrete need be used to give the pole a firm set. In other localities there may be no rock and yet the subsoil may have plenty of body, in which case the hole may be made about the diameter of an oil barrel and the space surrounding the pole filled in with concrete. The concrete is used to increase the surface on which the lateral pressure at the base of the pole acts. It must be borne in mind that the span wires are strung under considerable tension and that they tend to pull together the tops of the tube poles to which they are connected, and the poles will yield unless they are firmly fixed in the ground. The concrete sticks to the pole base as if it were a part of it, and in this way increases the diameter of the base and enables the pole to resist any effort to pull it over. Some soils are so very giving in nature that it is necessary to dig a hole several feet in diameter around the pole ; the pole is then set in concrete and the rest of the hole is tamped full of stones, broken brick, etc.

62. Guy Wires and Slanting of Poles.—Sometimes even the above treatment does not secure a setting that

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can be relied on, so it is supplemented by a guy wire that puts a strain on the pole opposite to that exerted by the span wire. These guy wires are most often called for on corner poles that support feed wires turning at that point. To offset the tendency of the span wires to pull the tops of the poles together, the poles are all canted outwards, about 6 inches out of plumb. In some cases even more slant than this is needed. Too much stress cannot be laid on the importance of setting the poles properly and doing the work so that they will stay so ; for when a pole gives to the tension of the span wire, it makes a zigzag in the trolley wire, which is rigidly attached to the span wire through the medium of its insulator. As soon as the wire gets out of line the never-ending trouble of the car trolley pole jumping the wire begins. When the pole flies off at one span wire, it generally manages to strike the next one or two, and the trouble goes from bad to worse.

63. Setting Wooden Poles.—Wooden poles are not, as a rule, set with concrete, although there is no good reason why they should not be. When the side-pole, span-wire construction is used, the wooden poles should have their earth bearing increased by the proper disposal of several large stones. A couple of stones should be jammed into the hole alongside of the pole on the side away from the track and a couple more near the mouth of the hole on the side next the track. This will do a geat deal towards preventing the span wire from pulling the tops of the poles together. A piece of timber may be substituted for the stones on the track side, and in such a case should be about 3 feet long and 8 inches in cross-section. The outward slant of a wooden pole should be about twice that of a steel pole in the same soil, and when in position, the pole should be solidly tamped around to make a firm bed. The tamping should be done while the pole is free; if done while there is tension on the span wire, the effect will be just the opposite to that desired.

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The selection of wooden poles for an extensive system should be left to a man thoroughly familiar with the work. The buying of metal poles is not such a risky undertaking, because they can be bought under guarantee to fill certain specifications, but almost any one not long identified with the business is liable to make mistakes in selecting wooden poles.

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