THE ELECTRIC CIRCUIT.*

(Continued from April Number.)

Insulation.—Before proceeding to the practical details of the construction of the various apparatus in use, it will be advisable to devote a short space to the consideration of the most important of all points in connection with electrical engineering, viz., that of insulation. This is the rock that almost invariably wrecks the tyro in electrical matters, and more particularly even the man who, possessing but a slight knowledge of the science, fancies there is no mystery about it.

It will be remembered that it was stated at the beginning of the book that although bodies divided themselves roughly into three groups, which might be termed for convenience, conductors, semi-conductors, and insulators; yet the difference was only one of degree. All bodies conduct, all bodies offer some resistance; and whether a current passes or not, and what current passes, is decided by Ohm's law, no matter what the substance may be.

It has been already pointed out that a long length of fine wire offers a higher resistance than a river, for instance, though the wire is classed as good conductor, and water as a very bad one. It should also be noted that the conducting or insulating properties of *all* bodies vary with their physical condition. Thus dry cotton is a good insulator, wet cotton a very bad one. Dry glazed earthenware or glass are good insulators; the same with a film of moisture condensed on their surface are very bad insulators.

Further, the relative values of different substances as insulators vary with the E.M.F. opposed to them; and also, it must not be forgotten that the electrical resistance of the insulator *through* its substance follows the same law as to length and cross section as conductors, so that a substance which may insulate very well where only a small cross section is exposed to the E.M.F. present, may not do so if the section is large. As, for instance, in the case of two covered wires touching each other outside their covering; if they touch only at one point, the resistance of the insulating material—or the insulation resistance, as it is technically called—is high because the dimensions are small; but if the two wires are twisted, and lie together for some distance, the insulation resistance may be very much less.

A substance that will insulate perfectly in the presence of an E.M.F. of a few Volts, such as are used in telephone and electric bell work, may break down entirely under the strain, say, of 100 volts, the E.M.F. now used in most electric light work. And again, a substance that will answer for 100 volts, may break down under the strain of 2,000 volts, the E.M.F. which the Brush Cos. are using, and which apparently is to be used in town supply.

Again, in the choice of an insulator for any particular work, the electrolytic properties possessed by the current, and which have been already described, must not be overlooked, nor its ability to spark across short distances. A substance that may be a perfect insulator when new—if placed to separate two points or surfaces between which an E.M.F. exists—may gradually break down from the action of the current itself. Remembering, once more, that Ohm's law holds good here as elsewhere, whatever the fraction of an ampère of current may be which the law says shall pass; that current *will* pass, and will do work, and will probably alter the nature of the insulating substance, silently but surely, lowering the resistance of the insulator, till some mechanical action comes into play, such as the sharp edge of an iron plate, or a needle-point left in a casting, and either breaks the insulation down itself, or, by lessening the distance to the nearest point in the wire, provides the conditions necessary for a spark to pass, with practically the same result.

Again, the position of the points or surfaces that are to be insulated, with reference to the rest of the circuit, must be considered. Suppose a certain voltage, say 100 volts, to be present at the ends of the wires of the exciting shunt coils of a dynamo. Let the resistance of the coils be 50 ohms, the current passing in them will be 2 ampères. Now, it will be apparent that we have the full 100 volts present only between the outer ends of the coils. Between the middle and one end we have 50 volts only, because from Ohm's law $E = C R$, $C = 2$ as before, and $R = 25$ ohms. $\therefore E = 50$ volts. So, if the field magnets have four legs each with 12·5 ohms resistance, the E.M.F., or difference of potential existing between the ends of the coils on either leg, is 25 volts only; and this is no question of theory, it may be proved by an actual test with an instrument called a voltmeter, to be described later, or by any of the methods described in the text-books. It is obvious that we may carry this matter as far as we like. Say that there are 25 layers of wire on each leg. Assuming that the wire is uniformly wound, each layer will have a resistance of ·5 ohm, and as the same current passes, *viz.*, 2 ampères, the E.M.F. between any coil and the one above or below it will be 1 volt. Further, if the layer consist of 20 turns, the resistance of each turn will be = ·025 ohm, and the voltage between any two adjacent turns at any point $= {·}025 \times 2 = {·}05$, or $\frac{1}{20}$ volt.

Thus it will be seen that the E.M.F., or difference of potential, usually present between many points which are in close proximity in coils and other apparatus is very small indeed; and therefore as long as the voltage and insulation remain the same all goes well; but should the insulation of any part be lowered, as by wet, oil, etc., by adjacent coils coming into contact, or by the deterioration of the insulator, the normal strain is increased. Thus, suppose that a quarter of the resistance of the coils of the dynamo magnets before referred to be cut out, say by the ends of the coils of one leg having come into contact with each other, so that the current passes across this path instead of round the coils. Assuming that our E.M.F. remains the same, we have now only 37·5 ohms opposed to the 100 volts and $\frac{100}{37{·}5} = 2{·}66$ ampères passing, instead of 2 ampères. Our voltage will now be in each leg, $12{·}5 \times 2{·}66 = 33{·}75$ v., instead of 25 volts, and the rest in proportion.

An increase of this magnitude on the present construction of dynamos would probably not be serious, the only thing that would happen being increased heating of the coils that were not cut, and an alteration in the lines of force. But suppose the above figures were multiplied by 20, and the short circuiting of a coil gave rise to an increased voltage of 250 V., between the ends of the coil of one leg, then the matter might be very serious indeed.

The substances used for insulating are, silk and cotton, in places where they will not become wet, as in coils of bells, telegraph and telephone apparatus, dynamos, motors, etc., where also the space available for insulation is small, and the covering cannot easily be subject to mechanical injury. In some cases the cotton or silk is further protected by a coating of some insulating varnish, such as shellac or india-rubber; but it is necessary to avoid all possibility of chemical action between the varnish and the wire, or between the varnish and the covering.

For wires which are exposed to moisture, or that have to stand a certain amount of rough usage, india-rubber, gutta-percha and Callender's pitch compound are used, generally in combination with wrappings or plaits of cotton and tape.

For wires that run overhead, as telephone and telegraph wires, no covering is needed, the air being the very best insulator obtainable, *when it is dry*. For these wires the rests are formed of highly glazed porcelain, or vitreous earthenware, made into special forms, so that the path from the wire to the iron bolt carrying the insulator is as long as possible, and of as small a cross section as possible. Ohm's law comes in again here. With telephone and telegraph apparatus the wire is connected to ground at each end, and a branch circuit will be formed to ground from the wire by way of each insulator and its support, be it a pole or the roof of a house. It will be obvious that the resistance of a single such leakage path will be very high; and that, provided the E.M.F. be low, the leakage current must be very small indeed; and so, on short lines, it usually is. But it will also be apparent that, as the length of the line increases, the number of these leakage paths will increase also, and the leakage current may be a very serious matter.

It is this which makes the problem of telephoning over very long distances so difficult in our humid climate.

Where the E.M.F. is high, as with high tension electric light circuits, the leakage from even a comparatively small number of rests may be serious; but at present the loss by leakage on high-tension electric light circuits carried overhead is inappreciable, because the lengths of the lines are so small. It will be seen later on that the insulation resistance of these electric light

* Walker's "Electricity in Homes and Workshops."