power, the dielectric strength is of the greater importance, the electrical resistance having relatively little value. Steinmetz has remarked—I do not recall the exact wording—that it is a very nice thing indeed—on paper—to read that the insulation resistance of a transformer, for instance, is 25 or 30 megohms, or even higher; but when the insulation resistance has been determined in the usual way, by the application of 500 volts direct current though a voltmeter and suitable resistance in series with the insulation to be measured; it is not so nice in switching in your transformer upon the line for the first time to have an inductive or static charge break through 25 or more megohms, reducing the insulation resistance to practically nothing and burning out the transformer.

But on the other hand, the insulation resistance of a transformer may be suspiciously low—only a few hundred thousand ohms—and still it may run continuously for years under average conditions of load without breaking down, even getting better as the insulating material dries out by the heat developed in it when running.

What is needed then, is to insulate the electrical circuits of the transformer so that it will operate without breaking down under all reasonable conditions of service. The insulation resistance gives no definite information as to the reliablity of the insulation in a transformer. Air, which is about the poorest insulator in disruptive strength, has a very high ohmic resistance, while on the other hand, the insulating materials having the best disruptive strength such as mica, have a comparatively low ohmic resistance.

To see this more plainly, let us examine the behavior of different insulating materials.

### Behavior of Different Insulating Materials Under Test.

Take for instance two metallic plates and separate them by an air gap of say .004 inch. Now, measure the insulation resistance of the air at 100 volts difference of potential between the plates. It is higher than can be measured by means of the best instruments. Now raise the potential difference between the plates to 500 volts. A spark will pass across the gap and the insulation resistance which a moment before was infinite is now reduced to practically zero. Now insert in the air gap a piece of solid, dry insulating material, such as a piece of paper of the same thickness, and the insulation resistance will be measurable and very much smaller than the resistance of the air gap. Again, raise the potential to 500 or 1,000 volts and the piece of paper will withstand the pressure. If the paper is replaced by a sheet of mica of the same thickness its insulation resistance will be much smaller than that of the paper, to say nothing of the air. But the difference of potential at the terminals may now be raised to 10,000 volts or more and the mica sheet will not break down. "The electricity will rush out from the terminal plates upon the mica sheet in long, glowing streamers, beating against the mica with a hissing noise and forming a broad electrostatic aurora of violet light, and still the mica will not break down." This is the property desired. If this disruptive strength has anything in common with insulation resistance, its relation is not known. On the contrary, it seems that those insulating materials which have the highest resistance, like air, just happen to have the lowest disruptive strength, while those materials like mica which are relatively inferior in ohmic resistance, stand the electrical stress the best. Consequently the measured ohmic resistance of a transformer or other apparatus will not indicate its disruptive strength. As can readily be seen there may be two bare wires almost touching each other, but with a thin film of air between, giving a very high ohmic resistance which, upon applying normal voltage to the apparatus, will most likely break down instantly. On the other hand, the wires in a transformer may be insulated with material such as fibre or mica and if the insulation be a little damp—measuring perhaps only a few hundred thousand ohms resistance—and the transformer be put into service, its ohmic resistance will increase, likewise its dielectric strength will improve and the transformer will not break down.

A very high ohmic resistance is, therefore, not a measure of the reliability of the transformer against breakdowns.

The above considerations, then, in a measure indicate the proper method of determining the fitness of insulation to withstand the conditions under which it is forced to operate; that is, in testing samples we should actually subject them to an electrostatic stress until they break down and judge their quality by their dielectric strength, and not by their specific ohmic resistance. If the ohmic resistance is very low—comparatively speaking—the current which leakes through the insulation may be too small to do any harm. Ohmic resistance tests on transformers are of relative value only in so far as they give a clue as to whether there is somewhere a weak spot due to dirt and moisture, but this is not necessarily so.

They will not show how reliable it is. But if we apply a potential between the various parts of the circuit several times greater than that at which it normally operates without breaking it down, we have some assurance, then, other things being equal, that it will operate safely.

### Deductions from Characteristic Curve of Ohmic Resistance.

Fig. 1 is a characteristic curve of the ohmic resistance of a thin sheet of untreated fibrous insulating material taken from the stock and subjected to a drying process.

From the proceeding the following general points may be noted:

(1) The ohmic resistance and dielectric strength of moist insulation are higher when cold than when hot.

(2) In expelling the moisture from a transformer it is bound to accumulate more or less in certain parts owing to the complex structure of the transformer, thereby causing the ohmic resistance to vary considerably until such an amount is expelled that the remaining moisture passes out at a diminishing rate, when the ohmic resistance will begin to rise.

(3) In the case of a thin sheet of insulating material, where the moisture is free to get out at all points without accumulating perceptibly at any one place, the ohmic resistance will gradually decrease to a minimum and then increase gradually, forming practically a smooth curve as indicated in Fig. 1.

(4) The decrease in ohmic resistance with the rise of temperature is evidently due to the presence of moisture (provided no chemical changes take place); for after the moisture is expelled the resistance increases with increased temperature, within certain limits.

(5) Low ohmic resistance is not necessarily an indication of poor insulation, but probably an indication of the condition of the apparatus in regard to moisture.

(6) A high e.m.f. should not be applied to apparatus when the ohmic resistance of the insulation is low.

(7) Material which is badly deteriorated mechanically by heat may still have a high ohmic resistance but very poor insulating qualities.

Then,—as stated before—the ohmic resistance tests of insulation is of relative value only. The same readings may be obtained twice from the same apparatus under entirely different conditions of real dielectric or volt resisting value. There is no direct relation between the breaking down e.m.f. and the ohmic resistance. However, a low ohmic resistance usually means a low breakdown test, but a low breakdown test does not necessarily mean a low ohmic resistance. These two tests have been aptly compared to the chemical analysis and the tensile strength of iron. A poor chemical analysis does not indicate whether or not there are flaws in the metal.

The principle use, then, of ohmic resistance measurements of insulation lies in the comparison they afford of the damp-proof qualities of various dielectrics and in the measure of the degree of dryness attained in drying out a piece of electrical apparatus.

### Materials Used in Insulating.

Now we come to the comparatively short and simple description of what the materials actually used in construction consist of. We class all the materials usually used under the following head:

1. Friction tape.
2. Unbleached cotton tape.
3. Oiled cotton or silk.
4. Paper of various kinds.
5. Mica.
6. Micanite (of various forms).
7. Hard fibre and wood.

Of these most manufacturers at the present time use the cotton tape or oiled cotton to insulate the separate turns of the coil when winding the copper into the required formed coils.

Paper or micanite in the form of thin strips may be placed between each turn of these coils if made necessary by a high voltage between turns. When the coils are finished they are securely bound in place by three or four layers of friction tape.

Between the different layers of primary and secondary micanite or fibre barriers are placed to prevent arcing between high tension coils, and to prevent contact between high and low tension sides of the line. In small core type transformers this barrier usually takes the form of a micanite cylinder, which just fits the air gap between the primary and secondary coils. In the larger shell type construction, blocks and boards of fibre are used, these being placed between coils before clamping them in position.

### Oil and Air Insulation.

When we speak of oil and air insulation, we mean that in the one case oil is used for the insulating material and that in the other case the space occupied by the air takes the