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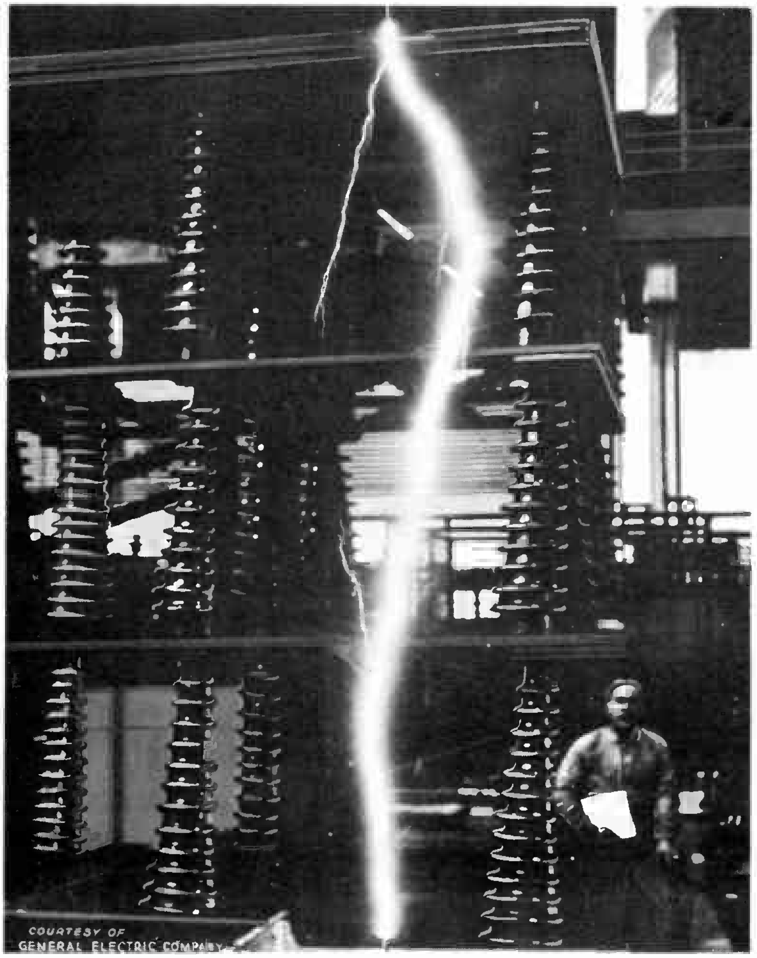
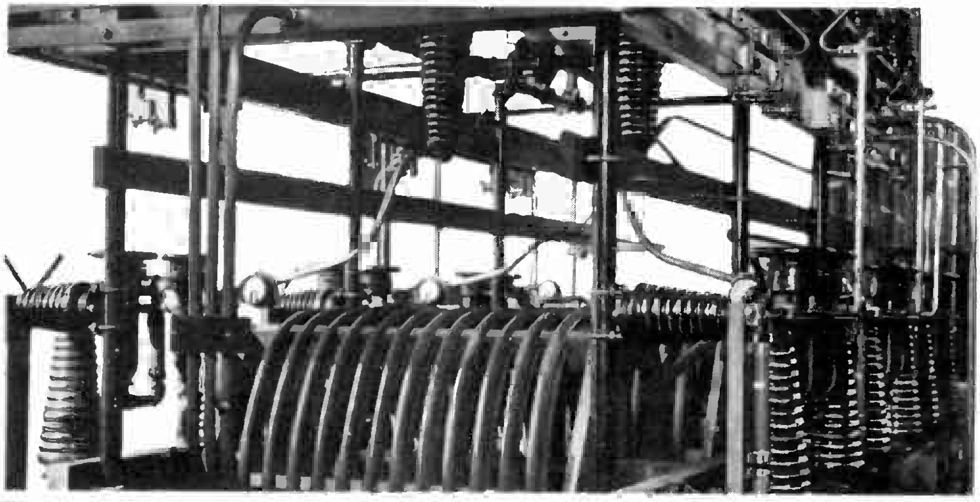


A 5,000,000-volt artificial lightning discharge breaks down the resistance of 15 feet of air.

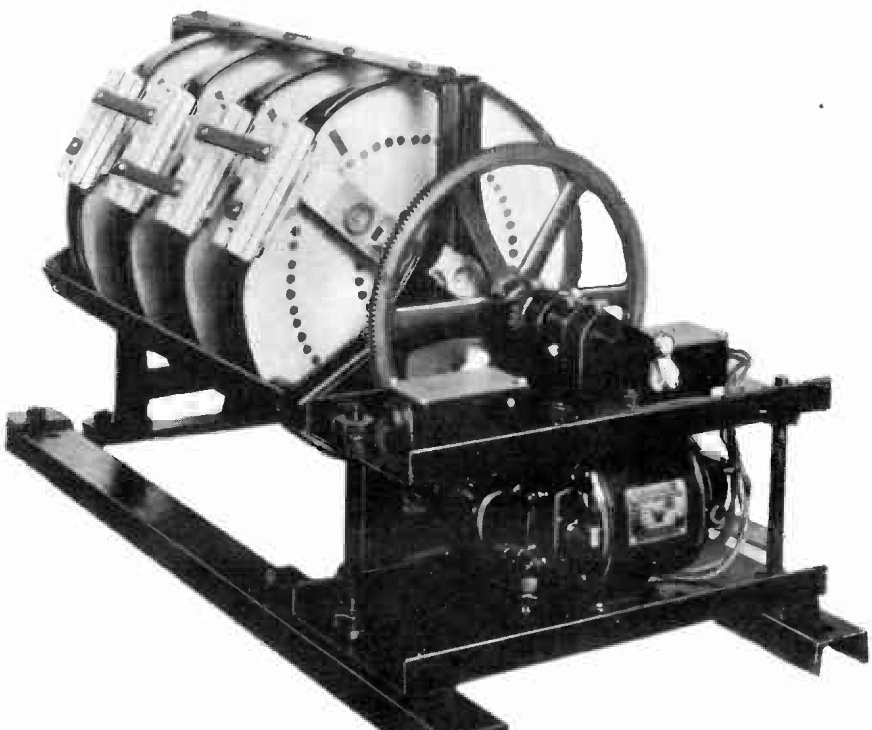
How Current Flow depends on Resistance and Conductance

VOL. 10, No. 6

Dewey Classification R100



Many long corrugated insulators are used to prevent electrical conduction between the parts and framework of this high voltage rectifier.



Resistance of these units is varied by means of an electric motor.

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RESISTANCE AND CONDUCTION

It is absolutely necessary in the study of any electrical subject to have a complete understanding of the three important quantities that govern the operation of every electrical circuit. These quantities are current, electromotive force and resistance. However, before one can really say he understands the relation between the amount of current flowing in a circuit, or part of a circuit, to the amount of electrical pressure that forces the current to flow he must also have a good working knowledge of the quantity "Resistance".

Hence, in this lesson we will deal chiefly with resistance and conduction, the latter being the inverse of resistance. The subjects pertain to explanations about different materials and their characteristics with regard to the ease or difficulty with which current will flow through them; also, how a change in temperature will change the resistance of a material; and the calculation of the resistance of wire, and so on. Our next lesson will explain in detail about the electrical circuit itself and how the three quantities mentioned above, current, electromotive force and resistance, are always associated together in a definite relationship which was discovered by George Simon Ohm, who gave to electrical science the famous and invaluable Ohm's Law.

It will be seen that resistance has to do with different kinds of materials that are used in the construction of an electrical circuit and the opposition that such materials offer to the progressive movement of its electrons, from atom to atom through the material, whenever pressure is suitably applied. It is to be remembered that the electron in motion is the electric current and that the value of the current is measured in the unit "ampere".

Also, the pressure or electromotive force that is responsible for causing the electron movement is measured in the unit "volt", and the resistance of the material which hinders the free movement of the electrons is measured in the unit "ohm". These units have already been defined in a previous lesson.

The word "resistance" should be familiar to everyone since it is frequently encountered in our every day life, and wherever the word is used it generally has one meaning which expresses an "opposition" of some sort.

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Many examples could be given showing how this applies but the following ones are sufficient. If you undertake to do any kind of work, and regardless of whether the task requires mental or physical effort, there are oppositions in one form or another that must be met and overcome before the work can be accomplished. Just what these oppositions are will depend, of course, upon the nature of the work. When you walk or run there are oppositions or resistances constantly present that retard your action. No doubt you have had the experience of rowing a boat through rough water, or against the tide, and found that a much greater effort was required to make the boat move forward than if the water were smooth and calm. Even in the latter case, that is, with the water smooth, the pull on the oars (which represents the energy expended in overcoming the opposition of the water which otherwise would prevent the forward movement of the boat) is often sufficient to tire out, in a short time, anyone but a strong person.

A good analogy is always at hand in the case of hydraulics, or water running through a pipe under a certain head pressure, to illustrate the relation existing between pressure, rate of flow, and opposition of resistance. It is easy to understand that water will flow fast or slow according to the pressure, but the oppositions in any particular system also have an important bearing on the rate of the flow as we will explain. Water running through a pipe, even under a strong head pressure, is retarded to some extent because as it rushes along it is constantly in contact with the inner walls of the pipe and this creates a certain amount of friction. If the pipe has a fairly large diameter, and its inner surfaces are clean and smooth the water will then flow with comparative ease, but if rust and silt are allowed to collect in the same pipe, either along its length, or at bends, elbows or joints, it will require more pressure to force the same quantity of water through than in the first case, or when the pipe was clean.

Thus we see that rust and silt form an obstruction, or resistance to the movement of water and this must be added to other oppositions in the pipe line. In general, the various oppositions in a water supply system would include the inner wall resistance as determined by the total length of the pipe and its inner surface condition, that is, whether smooth or rough, the pitch of the pipe at different locations, the area of cross section, and the size of the pipe at the end where the water flows out, the latter usually being regulated by a valve.

Now suppose that instead of thinking of the opposition or resistance presented to the flow of water by any piping system we thought of this system only in terms of the ease with which water was conducted through it. We could then compare two different systems and say that one conducted water more readily than the other. Here we have the use of the word "conducted" and it is evident that we have simply another way of looking at the same conditions. So, whether we say that the latter system has a higher resistance to water flow than the former we would in either case have conveyed the same idea. This illustrates the practical use of the terms "resistance" and "conduction".

ELECTRICAL RESISTANCE. Similar conditions of resistance and conduction are met with in the case of an electric current flowing

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ELECTRICAL RESISTANCE. Similar conditions of resistance and conduction are met with in the case of an electric current flowing through a circuit. First will be discussed the subject of resistance, and following that the subject of conduction.

Although the amount of current passing through a circuit depends primarily upon the amount of pressure that causes it to flow, yet the fact remains that the current strength is limited by the resistance of the circuit. Resistance is a property possessed by all substances that opposes the free movement of electricity through them. All materials have this property, but in some it is more pronounced than in others, and as a result substances are classified under two heads, namely: conductors and non-conductors or insulators.

After all, the resistivity of substances is only comparative and, therefore, it can be said that conductors are those materials which offer relatively low resistance to current flow and insulators are those which offer a very high resistance as compared to conductors. For all practical purposes an insulator is supposed to completely block the flow of current, and high grade insulators come very near doing this even when subjected to excessively high voltages.

Just how much a certain material will oppose current flow depends in general upon its natural properties, its physical dimensions, or size, and its temperature.

DEFINITION OF A STANDARD OHM. The unit in which resistance in measured is the OHM, as heretofore stated. Resistance is represented by the letter (R) and the electrical unit "ohm" is designated by the symbol (Ω) which is the Greek letter Omega.

The standard value of an ohm is defined as that resistance offered to an unvarying electric current by a column of pure mercury 106.3 centimeters long, of uniform cross-sectional area, and weighing 14.4521 grams at a temperature of melting ice, or 0 degrees Centigrade, which is the same as 32 degrees Fahrenheit.

Although the following does not strictly define an ohm, and only expresses the relationship of an ohm to voltage and current, yet it is often called a definition. "An ohm is said to be that resistance possessed by a circuit which allows one ampere of current to pass when an electromotive force of one volt is applied to the circuit".

RESISTANCE IN A D-C CIRCUIT. In a direct-current circuit resistance can be calculated very easily inasmuch as the only opposition presented to the current is by the materials which comprise the circuit and since all circuits are made up mainly of wire of some kind or other then the opposition is due principally to the wire. It is only at the closing or opening of a direct current circuit that oppositions other than the resistance of the wires are introduced which affect the flow of current. When the current reaches its steady value and flows without interruption in a d-c circuit, then only the resistance of the materials limits the current.

RESISTANCE IN AN A-C CIRCUIT. Current flow in an alternating current circuit is affected similarly by the materials and wires as in a d-c circuit, and also by another form of resistance due to the inductance of the circuit. This is explained as follows: In an a-c circuit the current is constantly changing in intensity and this current produces magnetic lines of force which likewise change in magnitude. Hence, in an a-c circuit an electromotive force is induced in the wires and coils which make up the circuit, this being accounted for by the action of the changing lines of force cutting the very wires in and around which they exist. In every case the induced e.m.f. opposes any change in current strength.

The induced e.m.f. may reach comparatively high values and seriously retard the current if coils are used which have too many turns of wire which would set up an excessively strong varying magnetic field around the coil for the particular circuit in question. Thus, we say that an a-c circuit contains inductance due to the wires used in the construction of apparatus and the wires used to supply power and connect the parts. We particularly think of inductance in the use of a coil because of the greater concentration of the lines of force in a given space when the conductors are wound in the form of a coil.

The e.m.f. induced in an a-c circuit (because of changing current and consequent action of the magnetic lines on the conductors and which tends at all times to oppose the changes in current as just explained) is a form of resistance called inductive reactance, which is measured in the same unit "ohm" as is the usual resistance presented by the wires or materials.

Now if an a-c circuit contains capacitance, such as could be easily provided by inserting a condenser in a circuit, there still will be another form of resistance present, because the a-c current will charge this condenser. Suppose the condenser used mica between its metal conducting plates. The mica will take on an electric charge but in so doing the current does not actually pass through this material as in the case of a copper wire. This is because the atoms of the mica (the mica is an insulating material) do not possess the necessary free electrons that can be forced to move progressively from atom to atom of the material, but rather what happens is the electrons in the mica atoms are merely pushed to one side, or shifted slightly from their usual positions in the atoms by the e.m.f. in the circuit. It requires an expenditure of force, or a certain amount of e.m.f. to cause this displacement of electrons in the atoms of the mica, and when in this stressed condition, the condenser is said to be charged. This form of resistance is called capacitive reactance, and it is also measured in the unit "ohm".

The student should know right from the start that current does not flow through insulating materials because such materials are lacking in free electrons which are the conductors of electricity, but an insulating material used in a condenser gives the effect of current passing through it since it can be charged and discharged by the action of its electrons being displaced in one case, and returning to their normal or unstressed positions in the other.

Thus, if an alternating current circuit contains coils and condensers, or as we would ordinarily say, inductance and capacitance,

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there will be three different forms of resistance present and acting at the same time. To sum up our statements, the three resistances are as follows:

(A) Resistance presented by the materials.
(B) Resistance due to inductive reactance.
(C) Resistance due to capacitive reactance.

Combining these resistances and knowing that they all affect the flow of current we have a term which expresses the sum total of the oppositions; this term is <u>impedance.</u> In our a-c circuits we will again come to this subject of impedance.

From these preliminary facts it is apparent that resistance is a factor to be considered in all alternating and direct current circuits. In a d-c circuit resistance is found in only one form, but in an a-c circuit it is present in more than one form as just outlined. The reason for again referring to this is because we often want to distinquish between resistance that materials of the circuit offer from other resistances due to the presence of inductance, or capacitance, or both. The resistance due to natural physical properties of materials or wires used is referred to as <u>ohmic resistance.</u>

It should now be clear that no electrical circuit could be designed without having some resistance. In some cases an excessive amount of resistance is undesirable and in other cases resistance is inserted purposely to limit the flow of current. Keep in mind that all substances have this property and that metals in general have by far less resistance than other substances. Therefore, it is obvious why metals serve best as carrying agents of electricity.

<u>ELECTRICAL CONDUCTANCE.</u> Conductance is just the inverse of resistance as we explained before, and its unit of measurement is the <u>MHO,</u> which is <u>OHM</u> spelled backwards. It expresses the ease with which current will flow in a conducting medium, that is, it indicates the ease with which electrons can be made to move in a progressive order between the atoms of a material when an electrical pressure is supplied.

> <u>EXAMPLES.</u> If a certain conductor, or circuit has a resistance of (R) ohms, its conductance will equal unity (1) divided by (R), that is, $1 \div R$. For example, if the resistance of three resistors were respectively 10 ohms, 400 ohms, and 5 ohms, the conductance for each would equal 1/10 mho, 1/400 mho, and 1/5 mho.
>
> The unit "mho" is not used to any great extent in our work and when used it is in the calculation of the resistance of a divided circuit. To find the resistance of a divided or parallel circuit in terms of conductance the following rule should be used. Add the conductances of the several branches in order to first obtain the total conductance of the combination, and this result when <u>inverted</u> will give the total resistance of the combination.

Other examples of the use of the term conductance are as follows:

> EXAMPLES. Inverted means that if the conductance of a combination were found to be 1/15, this fraction inverted would become 15/1, and 15 ÷ 1 equals 15, and the combination would have a resistance of 15 ohms; or, if we had 3/16 mhos as the conductance, this fraction inverted would be 16/3, and working this out, we would get 5.3 ohms as an answer. Additional explanations are given about parallel circuits in the lesson dealing with Ohm's law.

THE USE OF THE TERMS "RESISTANCE" AND "RESISTOR". Resistance is a property of all materials which opposes the free flow of an electric current, as we already know, but considering only the word itself, or "resistance", it is common knowledge that is is used loosely to indicate or identify any device made especially to be inserted in a circuit to limit the current flow. The proper term to apply to a piece of equipment intended for this purpose is "resistor". The term resistance, in its more correct use, is the inherent opposition offered by all substances to the flow of electrical current.

Three names in general use which designate resistance units are Resistor, Rheostat, and Potentiometer. You will become very familiar with these terms as you advance in your studies. Resistance devices are made up in innumerable sizes and shapes to meet any practical condition.

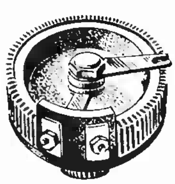

Figure 1

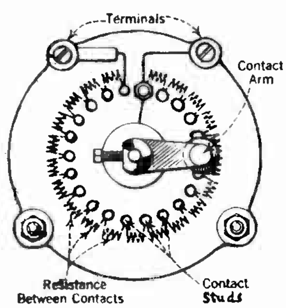

Figure 2

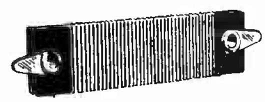

Figure 3

Figure 4

RHEOSTAT. When a resistance unit is constructed to permit the amount of resistance it contains to be altered, it is called a "rheostat". Two terminal connections are provided for such a unit; one of the connections goes to the movable contact arm which is firmly pressed against the wire by a spring, and the other to one end of the wire. By simply moving the arm across the wire it makes contact on different portions and, hence, more or less of the resistance wire will be included in the circuit in which the device is connected. This action is expressed by saying that resistance is cut in or cut out of the circuit. Thus, by the use of a rheostat current in a circuit can be controlled.

One form of rheostat is shown in Figure 1. Figure 2 illustrates a commercial type rheostat for regulating current in the field coils of a motor or generator. It is made with tap connections taken from different portions of the wire, and these taps terminate at brass

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studs or segments. In this type, when the contact arm or handle is moved over the studs, from one end to the other, sections of the wire are successively cut in or out, and the change in resistance causes the current supplied to the fields to be increased or decreased as the case may be. The resistance of the rheostat in Figure 2 is varied in sections, or, as we usually say, in steps, but the resistance of the rheostat in Figure 1 is continuously variable since the contact on the arm slides along the wire itself.

Resistor-Fixed Type. If there is no need for varying the current during the operation of a circuit, then resistors of the fixed type can be used to control the flow of current. The resistances of fixed resistors cannot be altered since no mechanical means are provided for doing so. An exception to this is in the case of fixed resistors wound with special wire which changes its resistance with changes in current strength, and these are used to provide automatic regulation for certain kinds of work. Figures 3 and 4 show fixed resistors.

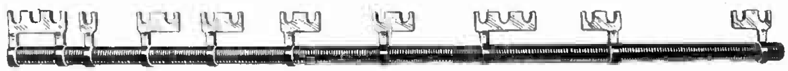

FIG. 5 — WIRE WOUND FIXED RESISTOR.

Potentiometer. The long narrow resistor in Figure 5 consists of many feet of resistance wire wound on a rod of insulating material with tapped connections taken from the wire at certain intervals. A unit of this kind is called a "potentiometer" and its function in

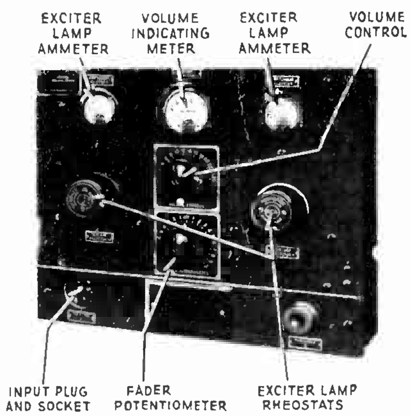

FIG. 6 — EACH CONTROL KNOB SHOWN IS USED TO VARY RESISTANCE.

a circuit is different from that of either a rheostat or fixed resistor. Although a potentiometer is physically a resistance device it is not used to limit current flow in a circuit but is used as a convenient method to supply voltages of different amounts to one or more circuits that may be suitably connected to the various terminals. Suppose for the sake of explanation that a battery having an e.m.f. of 30 volts was connected to the extreme ends of this potentiometer, then certain intermediate values of e.m.f. between 0 and 30 volts could be obtained at the taps. Since a potentiometer is primarily a voltage dividing device it is not referred to as a resistor. Potentiometers are built with resistances ranging all the way from a hundred ohms or less to several hundred thousand ohms.

PRACTICAL APPLICATIONS. A few examples of typical resistors built for various purposes are now given. Bear in mind that all of these resistors function in a similar way insofar as the electrical circuit is concerned.

Figure 6 is the front view of an input control panel made for use in certain types of sound picture equipment. In this view is seen the controls, while the resistors themselves are shown in the rear view in Figure 7. There are two rheostats of the continuously variable type used to control the amount of current passing through the exciter lamps. One of the two potentiometers is used to control the output current to the loudspeaker when changing from one projector to the other. It is so arranged that when the current from one amplifier to the loudspeaker is decreased, the current from the second amplifier is increased, which keeps the sound volume from

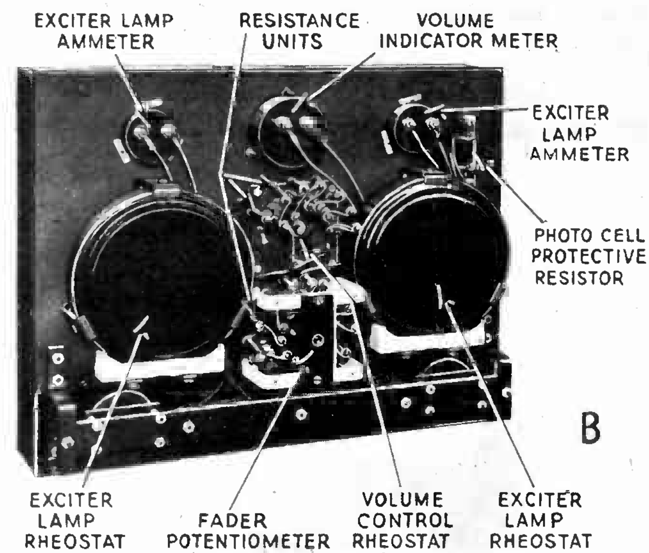

FIG. 7 — VARIOUS TYPES OF RESISTORS FORM PART OF THIS INPUT CONTROL PANEL.

the loudspeaker at the same level while the change is being made. This is called a "fader". The other potentiometer is used for the volume control. A fixed resistor is employed to control the current flowing in the photo-cell circuit.

The schematic diagram in Figure 8 illustrates the manner in which the rheostats are connected in the circuit. Figure 9 shows the volume control connections, while the fader connections are given in Figure 10.

The partially completed rheostat shown in Figure 11 is constructed along the lines of the rheostat in Figure 2. This particular type made by the Ward Leonard Co. is a Vitrohm dimmer plate before the application of the protective enamel coating to the resistance wire and the contacts.

The large motor-driven rheostat illustrated on one cover is used in theatres for dimming the stage lights. To provide the necessary changes in light a rheostat of this kind must be capable of handling hundreds of amperes and, therefore, it is very rugged in construction as the photograph indicates.

In Figure 12 are two illustrations showing a more recent application of resistors in the ignition systems of automobiles equipped with radio sets. Small resistors of the order of 25,000 ohms are used with each spark plug and the main high tension wire from the distributor head to suppress radio-frequency current which otherwise would seriously interfere with the clarity of the broadcast heard in the loudspeaker.

<u>MATERIALS USED FOR RESISTANCE PURPOSES—ALLOYS.</u> All electrical pieces of equipment built to give a predetermined amount of resistance are constructed, for practical and economical reasons, with the least amount of material and made into a unit of suitable physical proportions as governed by the use to which the part will be put.

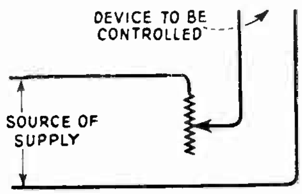

FIG. 8 — SCHEMATIC OF A RHEOSTAT CONNECTION.

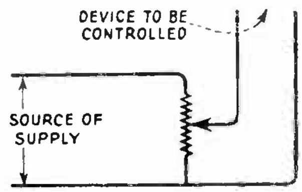

FIG. 9 — A CIRCUIT ARRANGEMENT FOR VOLUME CONTROL.

To grasp the importance of the idea of size in devices of this kind, just consider for a moment how much copper wire would be required to give a resistance of some comparatively low value, let us say 100 ohms. This can best be explained if we suppose that the resistor shown in Figure 3 has a resistance of 100 ohms. To construct a resistor of equivalent value, or 100 ohms, would take about 10,000 feet of copper wire, provided we used a No. 20 B. & S. gauge wire, and the copper would weigh approximately 30 lbs. A No. 20 wire has a diameter of 31.961 mils or .03196 inch. These figures are based on the data given in the "Wire Table" at the end of this lesson.

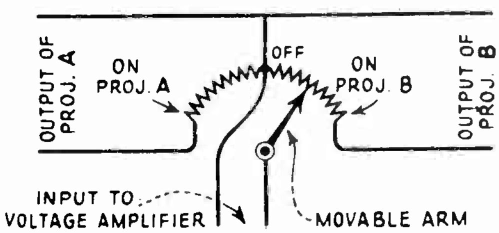

FIG. 10 — VARIABLE RESISTANCE IS USED IN A FADER UNIT.

It is easy to see that copper wire, because of its low resistivity, is not suited for use as a resistance material and, furthermore, the high cost of such a large bulk of copper would make its use prohibitive for this purpose. Copper is, however, the most widely used material for electrical conductors because of its low resistivity. Iron wire and aluminum wire are extensively used for conductors, the iron having a resistivity of about 7 times that of copper and the aluminum about 1.6 times. Galvanized iron wire is used on many telegraph lines.

Since pure metals such as copper, iron, aluminum and so on have comparatively low resistivity it is necessary to use materials which are alloys to obtain high resistances with reasonably small amounts of material. Alloys are combinations of different materials and are manufactured expressly to give high resistances. The resistance of an alloy can be made much higher than the resistance of the pure metals alone, that is, when not in the combination. Of course, the resistance of any alloy will depend upon the nature of the metals and the percentage of each used. Moreover, alloys are prepared with great care to obtain non-corrosive materials that will remain practically without change in resistance at different temperatures. Materials in this class should remain as nearly constant as possible under normal working conditions. There are some alloys used for the specific purpose of automatically limiting the current in a circuit; the resistance of such materials changes considerably for changes in temperature. This kind of alloy is used to make the photo-cell protective resistor shown in Figure 7.

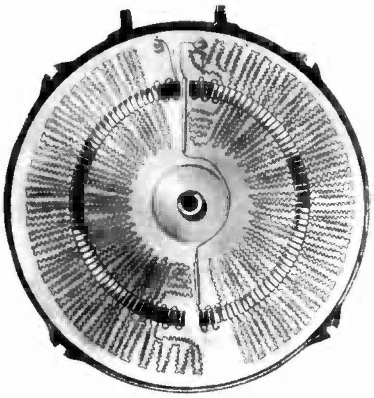

FIG. 11— RESISTANCE WIRE IN PLACE BEFORE PROTECTIVE ENAMEL IS APPLIED.

The resistivity of an alloy is greater than pure metals like copper, iron, aluminum, nickel, zinc, chronium and so on. This is explained y the following example. An alloy, such as manganin, consists of three metals, namely: copper, nickel, and iron-manganese and when combined in certain proportions the alloy can be made to have a resistance of three or four hundred ohms for each foot of wire when the wire is drawn to a diameter of .001 inch. Alloys of some of the materials mentioned above are made to give a resistance of more than 600 ohms per foot when in the form of a wire .001 inch in diameter. Notice that a foot of wire of .001 inch diameter is used as a unit for comparison of materials. This is known as a "milfoot". Monel metal is an alloy of approximately 71 per cent nickel, 27 per cent copper, and 2 per cent iron. Constantan, another alloy used in rheostats and measuring instruments, consists approximately of 60 per cent copper and 40 per cent nickel. In commercial practice we find rheostats and resistors constructed of rods, disks, strips of the resistance material, and resistance wire wound in coils, and so on. One type consists simply of a metallized deposit on a form of insulating material.

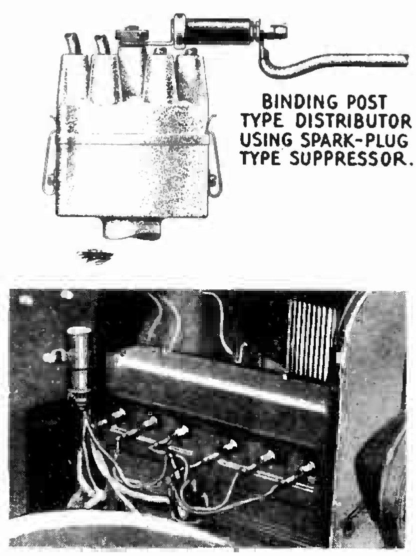

FIG. 12 — RESISTORS USED IN AUTOMOBILE IGNITION SYSTEM TO ELIMINATE INTERFERENCE.

The wires wound on the parts shown in Figures 1, 2, 3, 4, and 5 are alloys of different kinds. A resistor of one type may use iron wire and another may use carbon ground up and placed in tubes shaped in different forms, and so on. Since some heat is developed by these units the resistance wires on the parts in Figures 1 and 3 are wound on forms of a non-inflammable fibre material while porcelain is used to hold the wires in Figures 2 and 4.

Engineers who design electrical equipment for heating and other purposes take a great deal of care in selecting the proper material so

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that it will have the desired resistance and, not only that, the material must have sufficient cross-sectional area to be capable of radiating from its surface whatever heat is generated in the material by the current, at a rate that will never permit the temperature to rise high enough to damage the wire or insulation if this is used.

The dissipation of heat is measured in watts since the heat is due to the power supplied which in turn is represented by the voltage and current in the circuit. You will recall that a watt equals a volt multiplied by an ampere, the watt being the unit of electrical power. Every wire has its safe current-carrying capacity and if operated within the current limits specified excess temperature conditions will not exist.

RESISTANCE OF MATERIALS CHANGES WITH TEMPERATURE. In any of its forms a resistance material, or any conductor of electricity, dissipates a certain amount of heat proportionate to the current strength and resistance of the material. This relation of current (I) and resistance (R) is referred to as the "I R" loss, or heat loss. Changes in temperature of a material alter its resistance, but so long as the temperature remains constant the resistance will remain unchanged.

In general, the resistance of metals increases with a rise in temperature. Carbon is an example of a material that decreases in resistance with an increase in temperature. Other substances that exhibit this same peculiarity are porcelain, glass, and electrolytes. The latter name refers to solutions of water and various salts and acids. A solution of sulphuric acid and water such as is used in lead-acid type storage batteries is called an "electrolyte".

Another curious fact is that a certain substance will have the property of an insulator when cold, but that of a conductor when heated. This property exists to a very small degree in the carbon lamp filament which has a resistance when cold about twice that which it has when heated to incandescense.

Since in every wire or conductor the electrical energy consumed in setting up a flow of current (that is, in overcoming the resistance of the conducting materials) is turned into heat, then it can be said that some heat is produced in all kinds of electrical apparatus when current is flowing. The heat generated in overcoming electrical resistance is comparable to heat generated by mechanical friction in the moving parts of machinery.

Certain types of electrical equipment are made expressly for heating purposes such as electric soldering irons, toasters, percolators, electric heaters and so on. In all equipment of this kind the heat generated is put to a useful purpose. On the other hand, when heat is generated where it is not needed it is wasteful and represents a loss of energy. For instance, in an electric lamp which is used only to produce light the heat set up is a loss, and in an electric motor which is used to produce mechanical motion the heat developed by the parts is just so much energy wasted. The function of any resistor or rheostat which is used to regulate the flow of current is to absorb a certain amount of electrical energy applied to a circuit and this energy will be transformed into heat in this part, and this reduces the amount of energy available to other parts for performing useful work. In any resistance device used for limiting current the energy is wasted in heat instead of performing useful work.

Most of the electrical energy in a circuit may go into heat energy, or less of it may go into heat and more into other forms of energy. In an electric lamp, as just mentioned, heat and light energy are both present. In an active antenna system of a broadcast or commercial transmitter the electrical energy in the conductors is transformed into heat energy and, besides, energy is given off in the form of electromagnetic waves radiated into space. We can neither feel nor see the effects of radio waves in space but our senses permit us to detect the presence of heat and light energy.

Special care is exercised in manufacturing electrical apparatus to keep the heat produced down to a safe value and in many installations provisions are made to carry off excessive heat in certain parts by various means, as for instance, by employing special insulating oil, fan blowers, cooling coils through which water circulates, and so on. These precautions are necessary to prevent an excessive rise in temperature of the parts that might be the possible cause of a breakdown of the equipment.

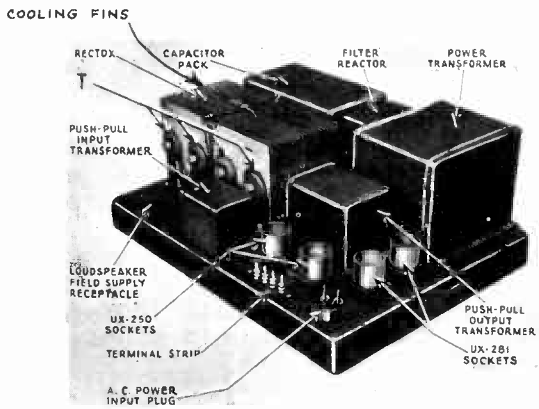

FIG. 13 — HEAT IS DISSIPATED BY MEANS OF THE COOLING FINS.

Figure 13 shows the units "T" of a dry metallic type rectifier used in sound picture installations to change alternating current into direct current. The passage of current through the unit causes considerable heat to be developed, and the "fins" shown in the photograph are used to quickly dissipate this heat by means of the large surface which they present to the surrounding air.

<u>Friction — Heat and the Electron.</u> In support of the fact that conductors do become warm when current flows and more heat is developed in some substances than in others, we have the electron theory which tells us that there is friction between electrons and the atoms among which they circulate in travelling through a material. It is thought that heat is produced in a wire or other conductor when current flows because of the countless numbers of collisions that occur between the electrons and atoms as the electrons are forcibly moved from atom to atom by the e.m.f., or pressure. Thus, an electron encounters friction and wherever there is friction present a certain

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amount of heat will be generated. Also, if a comparatively small current passes through a large sized wire then only a very small amount of heat will be produced, perhaps not sufficient to be noticeable. The same current in a much smaller wire might produce considerable heat. If the electrons had to travel through a long path rather than a short one it would increase the total friction and the total resistance, hence, more heat would be generated.

Keep in mind that there is friction encountered by each electron as it becomes attached to, and detached from, the large number of atoms which make up the conducting materials in circuits. The possible differences in the number and arrangement of the electrons gives us a plausible reason why the friction set up between the moving electrons and atoms is greater in some substances than in others. In this instance we are considering, of course, only the property of a substance and not its size, or cross-sectional area, as in the case of wires of different gauge.

Now consider the heat effects in two wires of equal length but one having double the cross-section area of the other and the same number of electrons moving in each wire. For the purpose of explanation assume that the electrons travel not only in the same direction but in sort of parallel rows. Electrons will be packed more closely together in the small wire than in the large one, consequently the total friction resulting in the large wire will be only half as great as in the small one.

EXAMPLES OF LOSS OF POWER DUE TO HEAT. Suppose a power transformer (which has no moving parts and is used merely to transform an a-c voltage of one value to an a-c voltage of either a higher or lower value) is supplied with 50 kilowatts of electrical power at its input side, and suppose that the transformer delivers from its output side only 48.8 kilowatts of electrical power. For this particular transformer operating under certain conditions the electrical power in kilowatts that is lost in producing heat which is not wanted, is 50 — 48.8 or 1.2 kilowatts.

Hence, we can conclude that in all electrical apparatus there is a certain amount of wastage due to heat which is unavoidable and this must be kept down to a minimum by careful design and proper operation of the equipment.

CONDUCTORS AND INSULATORS

If we consider from the viewpoint of the electron theory what happens in a material when it is subjected to an electric pressure it will make it fairly easy for most anyone to understand what causes the difference in electrical action between conductors and insulators. It will also help to further impress one with the convenience of this theory in accounting for the actions that go on unseen in electrical circuits. Once again, let us state that a movement or so-called drift of electrons from one place to another through any medium, whether it be a metal, a liquid, or air, in every case the electron flow constitutes an electric current.

According to the electron theory the atoms of one material naturally possess more or less free electrons than the atoms of some other material. Although the free electrons revolve rapidly about the positive nucleus of the atom they are not so firmly bound to it as are another group or inner circle of electrons which also whirl constantly about the same nucleus and remain associated with it. In each atom there are perhaps but one or two free electrons that can be forced out of their usual positions away from their parent atom by an e.m.f. After being detached from their parent atom these electrons will be moved to some other atom and in turn one or two electrons will be detached from that atom and will move to another atom, and so on. This movement or exchange of electrons from atom to atom occurs in the same direction as the pressure or e.m.f. which is forcing them to move.

Since the electron itself is electricity then the conduction of current through any substance is brought about by the movement of electrons. Thus, it is easy to figure out that if the atoms of a certain material have a sufficient number of free electrons available, then under a properly applied pressure there will be a flow of current. That is to say, electrons will move progressively from atom to atom through the material from one end to the other, or between the points where the pressure is applied. Hence, any material that is said to pass an electrical current is called a conductor. Also, that is why we call any metallic path, or other medium through which an electrical current can be made to flow, a conductive circuit.

Now, on the contrary, if the atoms of a certain substance have practically no free electrons for the conduction of electricity then it is reasonable to suppose that such a substance will offer a comparatively high opposition to the flow of current, or in other words its resistivity will be high. In certain materials there is no conduction for all practical considerations, and such materials are called non-conductors or insulators. Materials vary greatly in the amount of requisite electrons for conduction purposes. This is what classifies materials with regard to their resistivity. A chart is shown in the back of this lesson which gives the properties of materials used for conduction.

From the foregoing statements you can easily reason out that conductors form one group of substances offering relatively low resistance, whereas, insulators form another group that offer high resistance as compared with conductors.

When speaking in relative terms about the differences between materials and in a case where the resistance of a certain wire is low and its ability, therefore, to conduct electrons will be good, then in referring to this wire we would say, "it is a good conductor." Conversely, if the resistance of some other kind of wire is high its conductance will not be so good and for the latter wire we would say, "it is a poor conductor."

An examination of the chart giving the resistivity of different materials will show that silver is the best conductor while copper is almost as good. However, German silver has a much greater specific resistance than that of silver. The resistance of German silver, which is an alloy consisting of a mixture of copper, zinc and nickel, varies according to the method of manufacture and the materials used. Depending upon the percentage of nickel used in this alloy it can be made to have a resistance of from about 13 to 30 times, or more, the resistance of copper.

To give a reason for this difference in materials, and to review what we have already stated, we will compare silver and copper. It is assumed that when an e.m.f. is applied to silver and copper, the electrons are detached with less difficulty from the atoms to which they belong in the case of silver, and will move more freely from atom to atom than would those electrons that are detached and moved from atom to atom in the copper. Thus, if an e.m.f. of 1 volt is applied across two faces of a piece of silver having a mass an inch cube, the rate of flow of electrons will be greater from face to face in this metal than if the same voltage were applied to a piece of copper of similar size and tested under like conditions.

Furthermore, let us make it clear that there is no fixed line of distinction between conductors and insulators; it is simply a question of a material having the required electrons that can be forced to move from atom to atom by a pressure, or that something which we call electromotive force. Whether a material is called a conductor, a partial conductor, or an insulator is merely relative. Nothing but a perfect insulator could block completely a flow of current. Tests prove that an infinitesimal amount of current, so small as to be measureable only with the most sensitive laboratory meters, pass through even the highest grade insulators known. At the present time there is no substance known that has perfect insulating qualities any more than there is a perfect conductor, or one without resistance.

CONDUCTORS. Carbons, all the metals, solutions of salts and acids are conductors. A few substances are arranged below in the order of their conductivity. Silver heads the list since it is the best conductor.

Silver	Zinc	Lead	Acid solutions
Copper	Platinum	Mercury	Sea water
Aluminum	Iron	Carbon	Moist earth

INSULATORS. Some of the well-known insulators are given in the following list.

Dry air	Shellac	Wool and silk	Oils
Glass	Rubber	Dry paper	Slate
Mica	Paraffin Wax	Porcelain	

Water, dry woods and the human body are examples of partial conductors.

EXAMPLES OF THE USE OF INSULATORS. All types of insulators are made for the purpose of preventing either short circuits or loss of electrical energy through leakage to the ground. The first requisite of an insulator is that it must block the passage of current at the e.m.f. it will be subjected to under working conditions and, besides, there should be a certain margin of safety for abnormal conditions. We find insulators made in various shapes and forms and of different materials. Just what particular type insulator is selected is determined by the amount of voltage in the circuit in which it will be used and whether it will be installed outdoors or indoors.

An insulator might be located at some point in a circuit where higher voltages are apt to be encountered than would be found in ordinary service. Because of the abnormal conditions possible in any circuit insulators for a particular use should be capable of preventing disruptive high voltages from breaking down the insulating qualities, of course, within certain limitations.

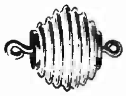

FIG. 14 - CORRUGATIONS INCREASE EFFECTIVE LENGTH OF INSULATOR.

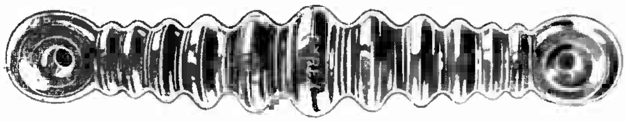

FIG. 15 — PYREX GLASS INSULATOR.

The insulators shown in Figures 14 and 15 are two popular types used in the erection of antennas, the latter type being Pyrex glass made by the Corning Glass Works. Insulators of this kind for receiving antennas are comparatively small, being only a couple of inches or more in length and an inch or so in diameter. The small insulators prove adequate because of the feeble signal currents that are carried by receiving antenna conductors. However, when intended for use in transmitting antennas they are made in large sizes of a foot or more in length and several inches in diameter. This is necessary because of the high voltages present in commercial radio transmitting antennas and because of the weight of the heavier wires which they must support.

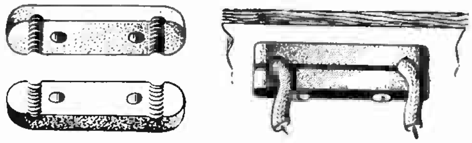

FIG. 16-PORCELAIN CLEATS USED TO SUPPORT WIRES.

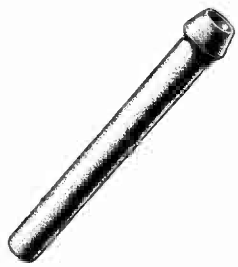

FIG. 17-TYPE OF PORCELAIN TUBE.

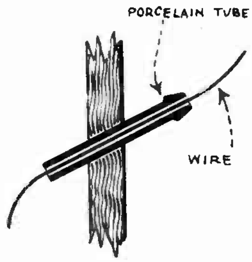

FIG. 17-A—TUBE SHOWN INSERTED IN WALL.

Observe that the corrugations on the surfaces of the insulators make their lengths along the outside much greater than the actual lengths of the insulators measured from end to end. The increased surface length gives an insulator better insulating qualities which is particularly advantageous when moisture or dampness collects on its surface. Since water is more or less a conductor of electricity a certain amount of "surface leakage" occurs in damp and stormy weather.

Figure 16 shows a pair of porcelain cleats and how they are used to hold two rubber covered wires in place, the cleats being screwed or nailed to a ceiling, wall or support of some kind. Another type of insulator is shown in Figure 17. This is a porcelain tube which allows a wire to be passed through it as illustrated in the sketch where the tube is shown installed in a wall or partition; 17-A.

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Figure 18 is a typical receiving antenna installation between an outbuilding and the house where the radio set is located. Notice that insulators of the types in Figures 14 and 15 are supporting the long horizontal antenna wire at its opposite ends and an insulator tube of the type in Figure 17 is used at the window casing where the lead-in wire enters the house.

Figure 19 is a Pyrex glass deck insulator, the metal rod to which the antenna conducting wire or lead-in is connected is carried through the cup shaped glass and the assembly is provided with a flange for mounting the insulator and making it watertight.

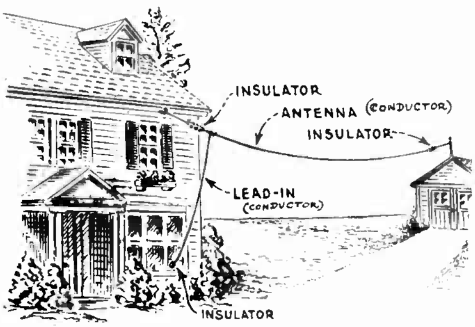

FIG. 18 — SHOWING USE OF CONDUCTORS AND INSULATORS IN A RECEIVING ANTENNA.

Insulators of the type in Figures 20 and 21 are employed in commercial radio transmitting equipment. These are made to be installed in decks, bulkheads, or at any place where the lead-in wire from the antenna is carried indoors. These types, in general, are called "deck insulators" and they are manufactured in various sizes to resist puncture or breakdown by e.m.f.'s which reach as high as 30,000 volts in some antenna systems. In radio transmitter antennas the working conditions are quite severe because of the high frequencies at which the electric stresses alternate. Also, at times there may be considerable heat developed by the high frequencies and this will have some effect on the insulating qualities of the insulator.

Moisture reduces the dielectric strength of any insulating material. Hence, when materials like porcelain are used they go through a special process of baking in hot furnaces that gives them a smooth glassy surface. If the glazed surface should become cracked or chipped the material will absorb moisture and its effectiveness as an insulator will be materially lowered and this will result in a reduction of the voltage at which a "flash-over" might occur. This simply means that the insulation will be weakened to the extent that it will allow current to pass through it at some particular voltage.

The insulator in Figure 20 consists of a heavy brass rod moulded into the insulating material with connection terminals at either end. The insulator is threaded at (A), and the upper half (B) carrying this threaded portion is inserted in a hold of proper size cut in the deck or bulkhead. The flange part (C) rests on rubber gaskets and when collar (D) is slipped over the lower part and drawn up tightly with a wrench a water-tight joint is provided. The type shown in Figure 21 serves the same purpose as the one in Figure 20.

MEASUREMENT AND CALCULATION OF RESISTANCE

Since the greater portion of radio and power circuits consists of wire to conduct the electrical current we will devote the balance of our lesson to the subject of wire.

WIRE GAUGE TABLES. There are several standard wire gauge tables, differing somewhat from one another, in general use for wire calculations. The B. & S. gauge originated by the Brown & Sharpe Manufacturing Co. is the one in most common use in this country and therefore it is often called the American gauge. The B.W.G. table (Birmingham Wire Gauge) is considered the standard in Great Britain. The table for the B. & S., or American gauge, will be found in the back of this lesson. There it will be seen that a few relations are given such as, diameter, area, weight, etc., for each size wire from No. 0000 (pronounced "four naughts") to No. 40, the latter being a very fine wire not much larger than a coarse human hair. Notice that the largest wire is given the smallest number and the numbers increase up to 40 as the wire sizes decrease.

MICROHM. In measuring resistances it is often convenient to use as a unit of value the one-millionth part of an ohm, which is called the microhm. If any value of resistance is stated in ohms the same value may be expressed in microhms by multiplying the given value in ohms by 1,000,000. For example: If a certain conductor has a resistance of 0.0058 ohms its equivalent value in microhms is 0.0058 x 1,000,000 or 5,800 microhms.

FIG. 19 — PYREX GLASS DECK INSULATOR.

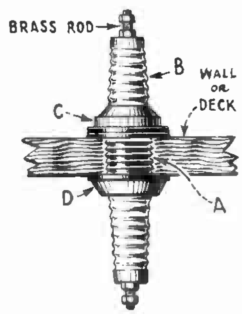

FIG. 20 — PORCELAIN TYPE DECK INSULATOR.

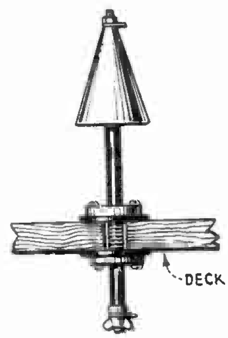

FIG. 21—A CANOPY PROTECTS INSULATOR FROM ELEMENTS.

MEGOHM. When very high resistances are measured the unit called a megohm is used. One megohm equals 1,000,000 ohms.

TEMPERATURE COEFFICIENT OF RESISTANCE. Refer to the table at the end of the lesson headed "Properties of Metals". In order to compare different metals in making up a table similar to this one a standard unit is necessary and for this the Bureau of Standards has adopted the resistivity of annealed copper standard which has a temperature coefficient of 0.00393 at 20° Centigrade. You will see this value in the second column opposite copper. Although "temperature coefficient of resistance" appears to be a big term yet it is easy to understand for it merely indicates a value which tells us how much the resistance of a material will increase for every degree rise in its temperature. The values of the temperature coefficients are based upon a change in resistance from 20° C. If the original temperature of the metal were something other than 20° C. when compiling a table then the temperature coefficient values would not be the same as those given in this table.

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SPECIFIC RESISTANCE. Let us first mention that the opposition to current flow by a substance is called its "resistivity" and the total opposition offered by an electrical circuit is called its "resistance" or "total resistance".

The resistivity of a unit length of material (as measured by the distance the current must travel in passing between opposite faces of the material) and a unit cross-sectional area at the predetermined temperature is known as its "specific resistance". The table shows that the resistivity values vary for different metals. Either a unit centimeter, or a unit inch, may be used as the basis for this measurement. If we have a block of copper 1 inch on all sides it is said to be an "inch cube" in dimensions, and if it is 1 centimeter on all sides it is a "centimeter cube".

CIRCULAR MIL. A circular mil is the area of a circle whose diameter is one mil, or one-thousandth of an inch. (Note: 1 mil = .001 inch and 1,000 mils = 1 inch. Hence, mils ÷ 1,000 = inches.)

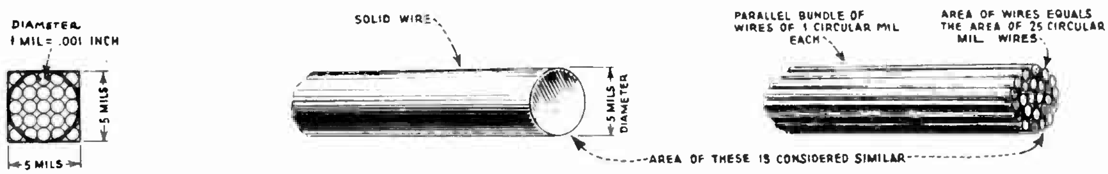

FIG. 22 — SHOWING RELATION BETWEEN AREA IN SQUARE MILS AND CIRCULAR MILS.

SQUARE MIL. A square mil is the area of a square whose sides are 1 mil. long. A circular mil is used in measuring cross-sectional area of a round wire instead of a square unit of area. In Figure 22 we have drawn a large circle inside of the square to show the relation between area which is represented by square mils or by circular mils.

Let us explain this relation in the following way: Suppose the diameter of each small circle is 1 mil, or 0.001 inch. It is seen that the length of each side of the square is 5 mils since there are 5 circles on each side. The area of the square, with sides measuring 5 mils, is 5 x 5, or 25 square mils. Now, the area of the large circle is equal to the diameter multiplied by itself, or d^2. Since there are 5 small circles, 1 mil each, in the diameter of the large circle then its diameter must be 5 mils, and the area of the large circle expressed in circular mils is therefore, 5 x 5, or 25 circular mils. Knowing that the area of the large circle equals the sum of the areas of the 25 small circles it can be said that the area of a wire in circular mils is equal to the diameter squared expressed in mils.

To cite examples: If a certain wire measures 3 mils in diameter it will have a cross-sectional area of 3 x 3, or 9 mils. A wire with a diameter of 162.02 mils has an area of 162.02 x 162.02, or 26,250 circular mils. Refer to Wire Table.

Keep in mind the following difference: The area of a circle in square mils is equal to the diameter squared multiplied by 0.7854 (or d^2 x 0.7854), whereas, the area in circular mils is equal only to the diameter squared (or d^2). Since we use 0.7854 (which is a value less than 1) in our calculation to find the area of a circle but not of a square, it follows that the area of any circle is 0.7854 of the area of a square.

From this it is evident that the square mil is slightly larger than the circular mil and, hence, there will always be a greater number of circular mils in any given area than there are square mils. Therefore, to convert a circular mil area into a square mil area we have merely to multiply the circular mil area by 0.7854 and the result will be in square mils.

(A) Area of a circle in circular mils $= d^2$

(B) " " " " " square mils $= d^2 \times 0.7854$

(C) Since 1 circular mil = 0.7854 square mils, then

(D) An area in square mils = circular mil area x 0.7854

In the expressions given in this work the letter "d" stands for diameter in mils.

<u>HOW 0.7854 IS DERIVED:</u> Area of a circle = radius$^2 \times \pi$, ($\pi = 3.1416$). If a circle has a diameter of 1 mil, its radius is .5 mil. Hence, the area of such a circle is equal to $r^2 \times 3.1416$ = .25 x 3.1416, or 1/4 x 3.1416 = 0.7854.

<u>MEANING OF THE LETTER (K) USED IN FORMULAS.</u> The letter (K) is used to represent the quality of a material as a conductor. A certain volume of the material must be considered, as for instance the volume of a <u>mil-foot</u>. A mil-foot is the <u>volume of a wire which is one foot long with a uniform sectional area equal to 1 circular mil.</u> For commercial copper the resistance of this particular volume, or 1 mil-ft., is 10.4 ohms at a temperature of 20° C. Hence, the (K) value for copper at this temperature is 10.4. There are different values for the constant (K) for various materials depending on their qualities as conductors, as just explained, and on the temperature selected as the basis for measurement. The (K) value for iron is 63.35 at a temperature of 68° F.

<u>HOW TO FIND THE RESISTANCE OF WIRE.</u> The resistance of a conductor varies with the kind of material used, directly as the length and inversely as the cross-sectional area. The letter (K) is the symbol that represents the kind of material and its resistivity, or specific resistance as mentioned before.

(1) <u>TO FIND THE RESISTANCE OF A WIRE:</u> Multiply the length in feet by the specific resistance (that is, the resistance per mil-foot) and divide this result by the cross-sectional area in

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circular mils. Writing this down in the form of an equation it would read:

$$R = \frac{K \times L}{d^2}, \text{ or } \frac{KL}{d^2}$$

(Note: When two quantities are written together, as KL for example, the multiplication of these quantities is understood, hence, K x L and KL are the same.)

In the above equation let
- R = resistance in ohms.
- L = length of wire in feet.
- d = diameter in circular mils. Therefore, d^2 = circular mil area.
- K = specific resistance of the material. Commercial copper at 20 C. has a specific resistance of 10.4 ohms.

PROBLEM. What is the resistance of 1,000 feet of copper wire having a cross-sectional area of 5,000 circular mils?

SOLUTION. Substituting all of the known values in the above formula, and solving, we have

$$R = \frac{10.4 \times 1{,}000}{5{,}000} = \frac{10{,}400}{5{,}000} = 2.08 \text{ ohms. Ans.}$$

(2) TO FIND THE LENGTH OF A WIRE WHEN THE RESISTANCE AND AREA IN CIRCULAR MILS ARE KNOWN: Apply the following formula:

$$L = \frac{R \times d^2}{K}$$

PROBLEM. If the size of a certain iron wire conductor is a No. 17 B. & S. gauge and its resistance is 15 ohms what is its length?

SOLUTION. Substitute the known values in the formula just given after first finding the value of d^2 from the wire table for a No. 17 wire. The value for d^2 is 2048, as given in the column marked, "Area—Cir. mils".

Let $K = 63.35$ for iron.
$d^2 = 2048$.

$$\text{Hence, } L = \frac{15 \times 2048}{63.35} = \frac{30{,}720}{63.35} = 484 \text{ ft. Ans.}$$

(3) TO FIND THE CIRCULAR MIL AREA OF A WIRE WHEN THE LENGTH AND RESISTANCE ARE KNOWN. Apply the following formula:

$$d^2 = \frac{L \times K}{R}$$

<u>PROBLEM.</u> Suppose the length of a coil of copper wire is 2,000 feet and its resistance is 20 ohms, find the circular mil area of the wire.

<u>SOLUTION.</u> Substitute the known values in the above formula and solve:

$$d^2 = \frac{2000 \times 10.4}{20} = \frac{20,800}{20} = 1,040 \text{ circular mils. Ans.}$$

(4) <u>TO FIND THE AREA OF SQUARE OR RECTANGULAR CONDUCTORS.</u> Some conductors are made square or rectangular in shape and these are measured in square mils. Suppose a certain conductor is rectangular then it will be a simple matter to find its area in square mils by multiplying its width by its thickness, or if the wire is square its area is found by squaring its sides. The dimensions, of course, must be expressed in mils.

<u>EXAMPLE.</u> If a conductor is square and 2 mils on each side its area will be 2 x 2, or 4 sq. mils. Or, if rectangular and 2 mils on one side and 4 on the other its area will be 2 x 4, or 8 square mils.

<u>HOW TO CONVERT SQUARE MILS TO CIRCULAR MILS AND VICE VERSA.</u>

(5) If it is desired to change,the area of a wire when given in square mils to an equivalent area in circular mils multiply the square mil area by 1.2732 as illustrated in problem worked out below.

<u>PROBLEM.</u> A flat ribbon wire is 1/5" thick on one side and 1/2" wide on the other. Find its equivalent area in circular mils.

<u>SOLUTION.</u> Since the measurements are given in inches instead of mils you must first change 1/5" and 1/2" to mils. Thus, 1/5 x 1000 = 200 and 1/2 x 1000 = 500. The square mil area is next found by taking the product of these values, or 200 x 500 = 100,000 square mils. Now multiply the square mils just found by 1.2732 as follows:

$$100,000 \times 1.2732 = 127,320 \text{ circular mils. Ans.}$$

(6) If it is desired to convert the area of a wire expressed in circular mils to an equivalent area in square mils multiply the circular mil area by 0.7854 as shown in the following worked out problem.

<u>PROBLEM.</u> Find the square mil area of a wire having a diameter of 1/5 inch.

SOLUTION. First, change 1/5 inch to mils, or 1/5 x 1000 = 200 mils. The circular mil area is equal to the diameter in mils squared, or 200^2, or 200 x 200 = 40,000 C.M. (C.M. is the abbreviation for circular mils). Now multiply the circular mil area by 0.7854 as follows:

40,000 x 0.7854 = 31,416 square mils. Ans.

HOW TO FIND THE CIRCULAR MIL AREA WHEN DIAMETER IS GIVEN IN INCHES AND VICE VERSA.

(7) If the diameter of a round wire is expressed in inches its circular area can be found by squaring the diameter when expressed in mils. The following equation represents the relation.

Area in C.M. (circular mils) = d^2 (diameter in mils squared)

PROBLEM. What is the circular mil area of a wire having a diameter of 1/5 inch?

SOLUTION. The first thing to do is to change 1/5 inch to mils as follows: 1 inch = 1,000 mils, then 1/5 inch equals 1/5 x 1000, or 200 mils. Now find the area as follows:

$$C.M. = d^2 = d \times d = 200 \times 200 = 40{,}000 \text{ circular mils. Ans.}$$

(8) If the circular mil area of a wire is known and it is desired to find its diameter expressed in mils you have simply to extract the square root of the known area. Thus:

$$d = \sqrt{C.M.}$$

PROBLEM. What is the diameter in inches of a wire having an area of 4107 C.M. (circular mils)? (Area of a No. 14 gauge wire is 4106.8 as given in Wire Table).

SOLUTION. Work out the problem by finding square root of 4107, thus:

$$d = \sqrt{C.M.} = \sqrt{4107} = 64 \text{ mils, or } 0.064 \text{ inch, approximately. Ans.}$$

EXAMINATION QUESTIONS

1. What is the function of a resistor?

2. What is the difference between a fixed resistor and a rheostat?

3. What is the difference between an insulator and a conductor?

4. (a) What are the three forms of opposition or resistance in an a-c circuit?
   (b) Is there more than one form of resistance in a d-c circuit? Explain.

5. What does the coefficient of temperature mean?

6. (a) Is it possible for current to flow in a wire without producing some heat and why?
   (b) What is an alloy and why is it used in the manufacture of certain kinds of wire?
   (c) Name one alloy and give its composition.

7. How may the effective length of an insulator be increased?

8. If the resistance of a certain coil is known to be 0.06 ohms what is its resistance expressed in microhms?

9. Find the resistance of 1500 feet of copper wire having a cross-sectional area of 10,000 circular mils.

10. What is the square mil area of a wire 1/4 inch in diameter?

11. What causes substances to differ in their ability to conduct or insulate?

12. Give two reasons why resistors are connected in electrical circuits.

13. (a) How would you find the circular mil area of a square bus bar which measures $\frac{1}{4}$ inch on each side?
    (b) Show how you would change the circular mil area of 2,400 feet of #40 copper wire to square mils.

14. Give the weight, circular mil area and resistance of two miles of #6 copper wire.

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Resistance of International Standard Annealed Copper
American Wire Gauge (B. & S.)

B. & S. gauge, No.	Diameter in mils, d	Area in circular mils, d^2	Ohms per 1000 ft. at 20° C. or 68° F.	Pounds per 1000 ft.
0000	460.00	211,600	0.04901	640.5
000	409.64	167,810	0.06180	508.0
00	364.80	133,080	0.07793	402.8
0	324.95	105,530	0.09827	319.5
1	289.30	83,694	0.1239	253.3
2	257.63	66,373	0.1563	200.9
3	229.42	52,634	0.1970	159.3
4	204.31	41,742	0.2485	126.4
5	181.94	33,102	0.3133	100.2
6	162.02	26,250	0.3951	79.46
7	144.28	20,816	0.4982	63.02
8	128.49	16,509	0.6282	49.98
9	114.43	13,094	0.7921	39.63
10	101.89	10,381	0.9989	31.43
11	90.742	8,234.0	1.260	24.93
12	80.808	6,529.9	1.588	19.77
13	71.961	5,178.4	2.003	15.68
14	64.084	4,106.8	2.525	12.43
15	57.068	3,256.7	3.184	9.858
16	50.820	2,582.9	4.016	7.818
17	45.257	2,048.2	5.064	6.200
18	40.303	1,624.3	6.385	4.917
19	35.890	1,288.1	8.051	3.899
20	31.961	1,021.5	10.15	3.092
21	28.462	810.10	12.80	2.452
22	25.347	642.40	16.14	1.945
23	22.571	509.45	20.36	1.542
24	20.100	404.01	25.67	1.223
25	17.900	320.40	32.37	0.9699
26	15.940	254.10	40.81	0.7692
27	14.195	201.50	51.47	0.6100
28	12.641	159.79	64.90	0.4837
29	11.257	126.72	81.83	0.3836
30	10.025	100.50	103.2	0.3042
31	8.928	79.70	130.1	0.2413
32	7.950	63.21	164.1	0.1913
33	7.080	50.13	206.9	0.1517
34	6.305	39.75	260.9	0.1203
35	5.615	31.52	329.0	0.0954
36	5.000	25.00	414.8	0.0757
37	4.453	19.83	523.1	0.0600
38	3.965	15.72	659.6	0.0476
39	3.531	12.47	831.8	0.0377
40	3.145	9.89	1049	0.0299

PROPERTIES OF METALS

(Courtesy of the U.S. Bureau of Standards.)

Metal	Microhm-centimeters at 20° C	Temperature coefficient at 20° C	Specific gravity	Tensile strength, lbs./in.²	Melting point, °C
Advance. See Constantan.					
Aluminum	2.828	0.0039	2.70	30 000	659
Antimony	41.7	.0036	6.6	....	630
Bismuth	120	.004	9.8	....	271
Brass	7	.002	8.6	70 000	900
Cadmium	7.6	.0038	8.6	....	321
Calido. See Nichrome.					
Climax	87	.0007	8.1	150 000	1250
Constantan	49	.00001	8.9	120 000	1190
Copper, annealed	1.7241	.00393	8.89	30 000	1083
Copper, hard-drawn	1.771	.00382	8.89	60 000	....
Eureka. See Constantan.					
Excello	92	.00016	8.9	95 000	1500
German silver, 18 per cent	33	.0004	8.4	150 000	1100
German silver, 30 per cent. See Constantan.					
Gold	2.44	.00342	19.3	20 000	1063
Ia Ia. See Constantan.					
Ideal. See Constantan.					
Iron, 99.98 per cent pure	10	.0050	7.8	....	1530
Iron. See Steel.					
Lead	22	.0039	11.4	3 000	327
Magnesium	4.6	.004	1.74	33 000	651
Manganin	44	.00001	8.4	150 000	910
Mercury	95.783	.00089	13.546	0	−38.9
Molybdenum, drawn	5.7	.004	9.0	....	2500
Monel metal	42	.0020	8.9	160 000	1300
Nichrome	100	.0004	8.2	150 000	1500
Nickel	7.8	.006	8.9	120 000	1452
Palladium	11	.0033	12.2	39 000	1550
Phosphor bronze	7.8	.0018	8.9	25 000	750
Platinum	10	.003	21.4	50 000	1755
Silver	1.59	.0038	10.5	42 000	960
Steel, E. B. B	10.4	.005	7.7	53 000	1510
Steel, B. B	11.9	.004	7.7	58 000	1510
Steel, Siemens-Martin	18	.003	7.7	100 000	1510
Steel, manganese	70	.001	7.5	230 000	1260
Superior. See Climax.					
Tantalum	15.5	.0031	16.6	....	2850
Therlo	47	.00001	8.2	....	....
Tin	11.5	.0042	7.3	4000	232
Tungsten, drawn	5.6	.0045	19	500 000	3000
Zinc	5.8	.0037	7.1	10 000	419

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