Experiment # 3

Conductors: Conductance & Resistance

Principles

Conductors & Free Electrons

The binding energy of valence electrons of atoms of elements in our Periodic Table, varies considerably from element to element. For atoms of some elements it is found to have small or very small values. Electrons in such atoms are loosely bound to their nuclei and can easily be pulled out. Materials and substances made from such elements are called *conductors* or *conducting materials*. Metals are good examples. The binding energy of valence electrons here, is so small that the thermal energy, present in the conductor at room temperature, is sufficient to pull them our of their atoms. These electrons are called *free* electrons or *conduction* electrons. They are responsible for the conduction of electricity through the conducting material

When an electron is removed from the valence orbit of an atom, the atom is said to have been *ionized*. The process is called *ionization* and the remaining (or the left-over atom) is called a *positive* ion or a *singly ionized atom*. An ion or a singly ionized atom behaves like a free proton; its effectiveness as a free proton does not get reduced or affected in any way, by the presence of many other protons, neutrons, and electrons in the ion.

Conductors: Inside Story - Electrically Speaking

Free electrons in a conductor material keep roaming around randomly under the influence of the forces exerted on them by nearby nuclei and electrons. This is because they have as much probability of moving in one direction as in the opposite direction; and as such, they end up going no-where. The net displacement of an electron over a significant period of time, is found to be quite insignificant. Fig (1a) shows the random motion of an electron.

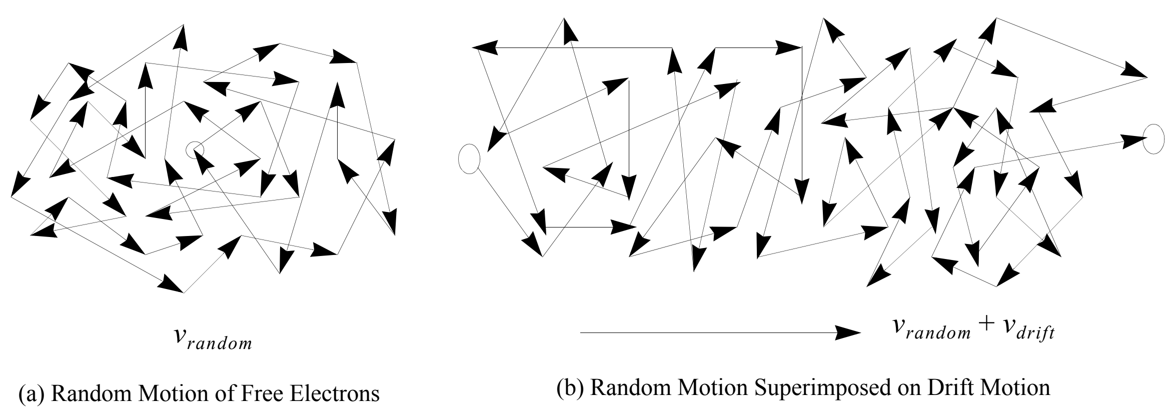

Fig (1) Random and Drift Motions of an Electron in a Conducting Material

It should be carefully noted that these free electrons do not produce an electric field within the conductor. Thus the many millions of free electrons do not produce an electric field, and the field everywhere inside the conductor, forever remains zero. Also, not to forget that overall, the number of positive and negative charges is equal

Placing the Conductor in an Electric Field

To study the interaction of electricity with conductor materials, we need to submerge the conductor materials in an electric field. For the study to be meaningful and quantitative, however, the field must be *uniform*. Uniform electric fields can *only* be produced in between a pair of parallel metallic plates, connected to a voltage source. It will be natural, therefore, to have the conductor material in the form of a rectangular or cylindrical block so that it would fit snugly in between the assigned pair of plates.

Consider a cylindrical block of a conductor material of cross-sectional area A and length l. We place the block in between a pair of parallel metallic plates, also of area A. When set in position, the two plates will be a distance l apart, which, of course, is the length of our conductor-block.

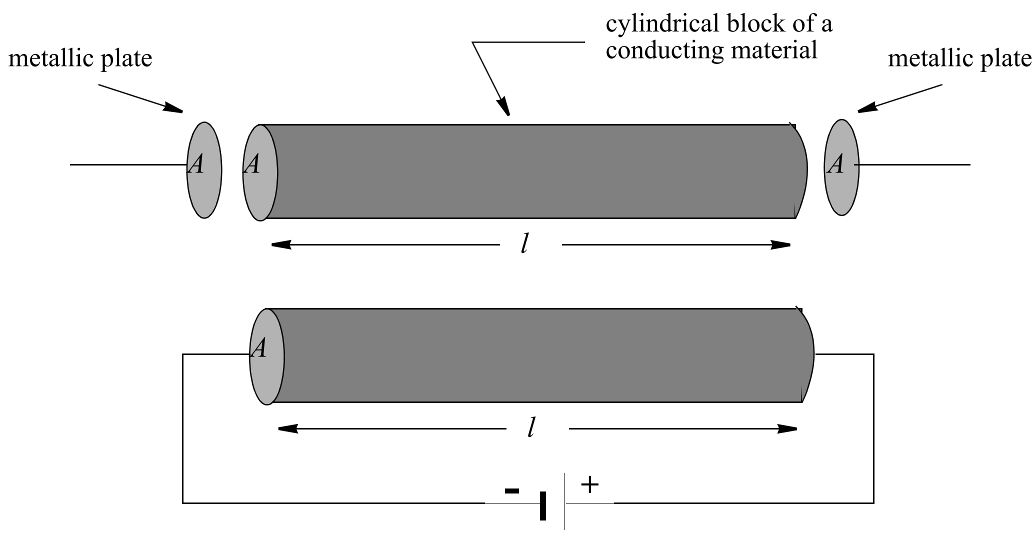

Fig (2) Placing the Conductor in an Electric Field

Coming to think of it, we really do not need the pair of metallic plates because the specimen is itself made of a conductor material. The two end-faces will serve as the pair of plates and all we need do, is to make sure that the two end-faces of the cylinder are parallel to one another. When these end-faces are connected to the battery, the battery sends charges and a potential difference is established across them. This potential difference, in turn, produces a uniform electric field E (given by the equation $V = El$), in which the block of the conductor material is being submerged.

The Interaction: (A) - How Does Electricity Affect the Conductor Material?

Electricity (the field) Imparts Drift Motion to Free Electrons

The uniform electric field exerts a force of constant magnitude on the free electrons of the conductor-block, and they begin moving opposite the field direction (i.e. towards the positive potential). This motion of free electrons is called *drift* motion, $\boldsymbol{v}_{drift}$. Drift motion $\boldsymbol{v}_{drift}$ gets superimposed on the random motion $\boldsymbol{v}_{random}$, that the free electrons already have. This is shown in Fig (1b). Electrons move slowly across the conductor-block and we say that electricity is being *conducted* through the conductor material. The total charge of the number of electrons, reaching the other end, per unit time, is defined as *electrical current.* We write I for it, and its unit is *coulombs per second* or C/s, also called an *ampere,* A. One *ampere* is one *coulomb per second.*

And that's the end of the interaction.

Magnitude of the Current I

The magnitude of current I that flows through the conductor-block, is a direct consequence of the drift motion of the free electrons in the conductor-block. Drift motion, in turn, is a direct consequence of the strength of the electric field E, established inside the conductor-block, The strength of the electric field, in turn, is a direct consequence of the potential difference V, established across the end-faces of the said block. The potential difference, in its turn, is a direct consequence of the charges Q, supplied by the battery. A battery is the sole provider of electrical charges.

The greater the magnitude of charge supplied by the battery, the greater will be the field and greater will (eventually) be the current I (and *vice versa*). We expect the capability of the battery to supply charges, to depend solely on the driving force (the emf) of the battery, expressed in terms of its voltage V_S (source voltage). The net outcome of this chain of *direct consequences* is that if V_S is large, the current I (conducted through the block) will be large and vice versa.

Using a source of variable voltage (denoted by V), and a current-monitoring device (an *ammeter*), we perform an experiment. We apply different voltages V to the conductor-block and monitor the corresponding currents I. Plotting voltages V on the x-axis and corresponding currents I on the y-axis, we find that our line of argument was indeed correct. The graph yields a straight line, telling us that the amount of current I passing through the conductor-block, is directly proportional to the voltage V, applied to its end-faces.

The slope of the straight line will be $\Delta I/\Delta V$ but as the line passes through the origin, we are permitted to write the slope simply as I/V. (Obviously when V is zero, I must be zero too.)

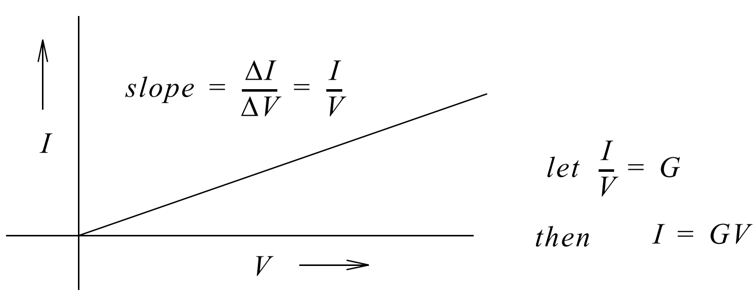

Fig (3) Dependence of I on Applied Voltage V

We define I/V as G and write:

$$G = \frac{I}{V} \qquad \text{..........(1)}$$

We interpret G as *conductance*, the ability of the driving force of electricity (in volts) to *conduct* an electric current through a given conductor-block. The unit of G is easily seen to be:

$$\frac{C/s}{J/C} = \frac{C^2}{Js}$$

The unit has been given the name *mho* for which we write: Ω^{-1} . A *mho* is a rather large unit and we often use smaller units such as *milli-mho* $m\Omega^{-1}$, or *micro-mho* $\mu\Omega^{-1}$ .These are respectively $m\Omega^{-1} = 1\times10^{-3}\,\Omega^{-1}$ and $\mu\Omega^{-1} = 1\times10^{-6}\,\Omega^{-1}$. Presently, we will recommend that you ignore the funny-ness of the name and the symbol of *conductance* G. It should evaporate soon

Rearranging, Eqn (1) we get an equation for the magnitude of current I, that flows through our conductor-block:

$$I = GV \qquad \text{..........(2)}$$

Eqn (2) is an important equation. We conclude:

The current passing through a conductor-block, is proportional to the driving force (emf in volts) of electricity. The constant of proportionality is defined as Conductance.

The magnitude of the drift motion of free electrons (or that of their drift velocity) is very small. It is estimated that the drift velocity of a typical free electron in copper (a good conductor) is just about few millimeters per hour! One would expect, therefore, that it should take free electrons, hours and hours to travel to the intended electrical device. How come a light bulb (for example) starts producing light, the moment it is switched on? The answer is that the electric and magnetic fields travel at the speed of light and activate the free electrons that are already present in the device (such as the light bulb).

It is educative, at this point, to tell you that the random velocity of the same electron in the same conductor, is of the order of millions of meters per second.

The Interaction: (B) - How Does Conductor Material Affect Electricity (the Field)?

Conductor Material Determines the Magnitude of Conduction

If electricity affects conductor material, then it is imperative that the conductor material will also affect electricity. It is indeed so. We find that for a given source of electricity, it is the conductor material that determines the amount of charge that it will permit to pass across its territories, per unit time. Thus, it is the conductor material that determines the magnitude of current I. This we found by doing an intuitive experiment. We made a number of identical cylindrical blocks of different conductor materials and using the same battery, we measured the current in each case. We found them all to be *different* from one another. So, it is true: each conductor material conducts a current that is *totally* specific of its own nature.

The ability to control the current must come from some inherent electrical property that the materials and substances have. But the *only* electrical property that all materials and substances have is *permittivity.* So, the ability to control current must come from *permittivity.* We know permittivity. In fact, in the previous experiment (on insulator materials), we learned that the property *permittivity* was responsible for controlling the quantity of charge that would reside on the pair of parallel metallic plates. How will the same permittivity fit into the present case? Well, in case of insulator materials, the charges Q were at rest and hence they were in a state of static equilibrium. We can say that the permittivity ε of insulator materials was (and is) also of the static type. In case of conductor materials, however, charges Q are in motion, and as such, they are in a state of dynamic equilibrium. It is natural, therefore, to expect that the permittivity ε of conductor materials and substances, will also be of dynamic nature. As dynamic charges are *coulombs/sec*, dynamic permittivity must be *permittivity/sec* or *permittivity/unit time*.

Recall Eqn (1) of Experiment #2 (Insulators):

$$Q \propto \varepsilon$$

Divide both sides by time t (in seconds s)

$$Q/t \propto \varepsilon/t \qquad \text{..........(3)}$$

Now Q/t is current I. The right hand side ε/t, is our *dynamic* permittivity. Dynamic permittivity is peculiar to conducting materials only. Let's call it *conductivity* (our problem is quietly solved) and write σ for it. The unit of σ will be *permittivity per unit time,* or

$$\frac{C^2/(Nm^2)}{s} = \frac{C^2}{(Nm^2)s}$$

We now write Eqn (3) as:

$$I \propto \sigma \qquad \text{..........(4)}$$

To replace the sign of proportionality in Eqn (4), by sign of equality, we introduce a constant:

$$I = (constant)(\sigma) \qquad \text{..........(5)}$$

The unit of I (the left hand side), is *coulomb per second* (C/s) and that of σ is $C^2/(Nm^2s)$. To get C/s, on the right hand side also, the *constant* in Eqn (5) must have the unit $(Nm^2)/C$. Now Nm^2/C can be considered to be $(N/C)(m^2)$, which would conveniently make EA, both quite the components of our uniform electric field system. So we write:

$$I = (EA)(\sigma) = \sigma EA \qquad \text{..........(6)}$$

We conclude:

The current passing through a conductor material, depends on the nature of the conductor material (in terms of its conductivity) and will vary from one conductor material to another

Conductance and Conductivity

When electricity interacted with conductor materials, we got *conductance* and when conductor materials interacted with electricity, we got *conductivity.* How are the two related?

The end product in each case is conduction of electricity, in terms of current I. Consider Eqn (2), involving conductance and Eqn (6), involving conductivity. The left hand side in each case, is current I. Equating the two right hand sides, we get:

$$GV = \sigma EA$$

Writing $V = El$ (which is valid for all parallel plate arrangements), we get:

$$GEl = \sigma EA$$

Cancelling out E from the two sides and rearranging, we get:

$$G = \frac{\sigma A}{l} \qquad \text{..........(7)}$$

Eqn (7) spells out the relationship between *conductance* and *conductivity. Conductance* depends on the geometrical shapes and sizes of conductor materials. So it must be the property of objects (or devices) that we make from a conducting material. *Conductivity,* on the other hand, is independent of geometry, and as such, is the property of conducting *materials and substances* themselves and not of objects made thereof.

Eqn (7) allows us to calculate the conductance of an object, made from a given conductor material, by knowing its geometrical shape and size. We wouldn't need a variable voltage source and an ammeter, any more.

If an object is made from a conductor material in the form of a rectangular block (and not in the form of a cylindrical block), then it will have three different values of G, but only one of σ. The three values of G correspond to the three pairs of faces that the rectangular conductor-block has. These are (i) length x width, (ii) width x thickness, and (iii) thickness x length.

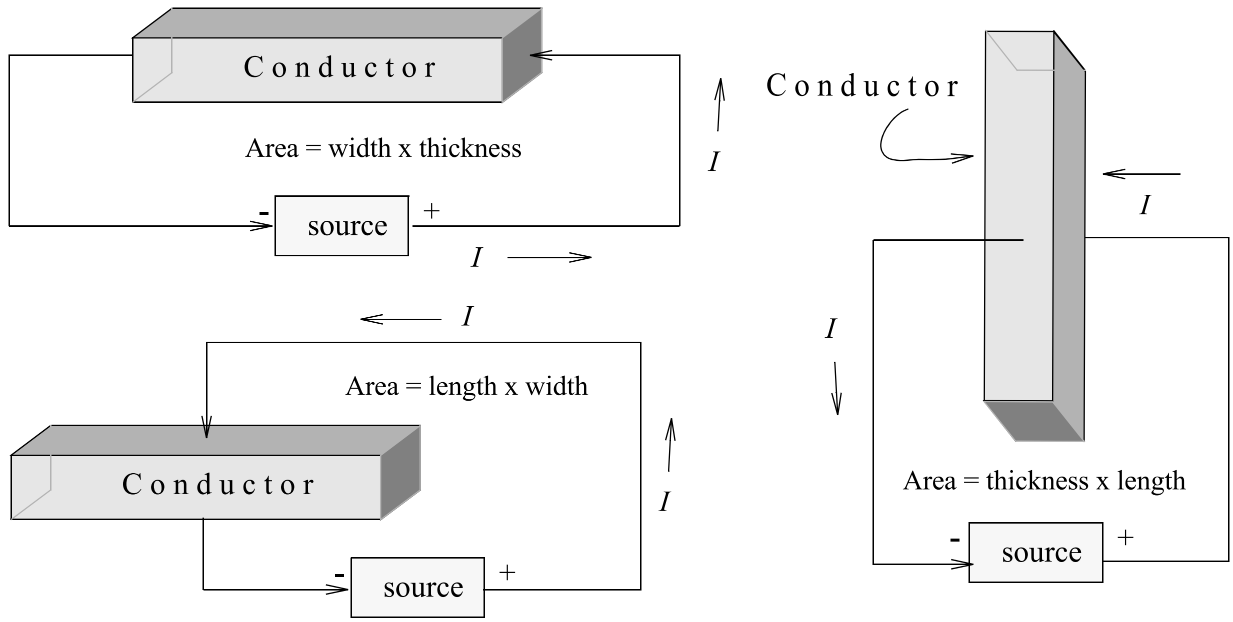

Fig (4) Dependence of Conductance on the Geometrical Shape & Size of the Conductor Block

Eqn (7) is an exact analog of Eqn (6) of Experiment # 2 (for Insulators):

$$C = \frac{\varepsilon A}{d}$$

where we had used the symbol d for the width of the insulator block (or the separation of the plates). In case of the cylindrical block of the conductor, it is customary to write l, for the length of the cylindrical block (or the separation of the plates). Essentially, the two are the same.

Conductance & Energy

Unlike capacitance, if we consider the area under the straight line in Fig (3), we do not get energy. Thus conductance does not lead to storing energy. The unit of the area, if calculated, will be found to be J/s, which is rate of doing work or power. A conductive device will dissipate power but we shall not talk about it here.

Random Motion: Resistance

So far, in describing the interaction (between electricity and conducting materials and substances), we concentrated solely on the *drift motion* that was imparted to the free electrons by the uniform electric field. And, in fact, that's all the interaction that there is. In doing so, we completely ignored the random motion of free electron which is inherent in all conductors and has a very large magnitude. We were fully justified as there is never any interaction between electricity and the random motion. Random motion remains fully and completely and totally opaque to the electric field (no matter how strong). So why bring it in, now?

Here is why:

It is observed that the miserably slow drift motion of free electrons in a given conductor, is a direct consequence of the random motion of those same electrons in that same conductor. It is found that, if the random motion in a conductor is large, the drift motion is small and if the random motion is small, the drift motion is large. It is a common knowledge that in *superconductors* where the random motion does not exist, electrons travel at the speed of light.

We find that random motion *impedes* drift motion. We also find that in doing so, random motion converts some electrical energy into thermal (heat) energy. So, it is an exact analog of *friction* that we studied in Mechanics. As we cannot call it friction (defined to be between two different solids), we choose a new name for it. This name is *resistance*. We write R for it.

This is quite like *smoothness* and *roughness* for a pair of solid surfaces. Smoothness is akin to conductance while roughness ia akin to resistance. For smoother surfaces, roughness goes down and vice versa.

Resistance of a conductor is defined to be a measure of the extent of the random motion of free electrons inside a given conductor-block. The extent of the random motion for a given conductor-block depends on the shape and size of the block. It will vary from one conductor-block to another.

Under the circumstances, one would expect resistance to be inversely related to conductance. This is indeed so! It is a well established fact that resistance is just the reciprocal of conductance. It would be correct to write:

$$R = 1/G \qquad \text{or} \qquad G = 1/R$$

The unit of R is the reciprocal of the unit of G. Thus it is $(JS)/C^2$. The unit is given the name *ohm* and the symbol is Ω. An *ohm* is a rather small unit and one may use larger versions of it, such as *kilo-ohm* or *mega-ohm*. These will respectively be: $k\Omega = 1\times10^3\,\Omega$, $M\Omega = 1\times10^6\ \Omega$.

Resistance

In Eqn (2) we may now replace G by $1/R$ and get:

$$I = (1/R)V$$

Rearranging, we get

$$V = RI \qquad \text{..........(8)}$$

Resistivity

Resistance of a block of conducting material, as stated above, depends on the geometrical shape and size of the block. Using the perfect reciprocity of R and G we proceed as follows:

$$G = \frac{\sigma A}{l} = \frac{1}{R} \qquad \text{or} \qquad R = \left(\frac{1}{\sigma}\right)\frac{l}{A}$$

Letting: $1/\sigma = \rho$, we get

$$R = \rho\frac{l}{A} \qquad \text{..........(9)}$$

where ρ is known as the *resistivity* of the conductor material and has units Ωm.

Resistor: As a Device

The above described interaction of conducting materials with electricity, leads us to develop a device, mainly for impeding drift motion; which, in turn, causes electrical energy to be converted into heat energy. The device is called a *resistor*. A *resistor* utilizes the property *resistance* of conductor materials. It is essentially a conductor material, prepared in such a way that its resistance gets enhanced and its conductance gets suppressed. The electrical symbol of the device resistor is shown in Fig (5). As a device, resistors are used to control the flow of electricity and one would find resistors in almost all electrical devices ranging from light bulbs to televisions, stereo systems, ipods, computers and the like.

R

Fig (5) The Electrical Symbol of a Resistor

It should be clearly understood that a resistor slows down the pace of electrons; it does not absorb them. Electrons simply take longer to pass through the resistor. Hence the number of electrons passing through the resistor *per unit time* gets restricted.

Conductor: As a Device

Even though conductors are not considered to be a device, we do, at times, need them. Connecting wires, transmission lines must have minimal resistance. These are made by utilizing the property conductance of conductors. These are prepared in such a way that the conductance of the device gets enhanced and its resistance gets suppressed.

The Perfect Reciprocity of Conductance & Resistance

On the face of it, the perfect reciprocity of conductance and resistance appears to be amazing; given the fact that each has an independent origin. Statistical calculations on atomic level, do provide an explanation.

Why Resistance?

Even though the property *conductance* of a conductor is its natural and logical property from an academic point of view, the property *resistance* is more important from the practical point of view. This is why *conductance* remains in background. No independent unit has been assigned to it. The unit *mho* introduced earlier is a backward read-out of *ohm*. Similarly, the symbol Ω^{-1} is reciprocal of Ω. Sometime *Siemen* is used as the unit of conductance but the symbol remains unchanged. Early scientific studies of conductors also gave prominence to *resistance* of a conductor rather than to its *conductance*. In all academic studies, however, the property *conductance* gets preference.

Ohm's Law

George Simon Ohm (1787-1854) in early 19th century, studied the behavior of conductors in the presence of externally applied potential differences and established the following law, now known as *Ohm's Law*:

$$V = R\,I \qquad \text{..........(10)}$$

Eqn (10) is the same as Eqn (8) that we found earlier.

The law tells us that if we apply different potential differences (volts) to a conductor and monitor the corresponding currents (amperes) then the ratio of a voltage to its corresponding current will be found to be the same *always*! Let $V_1, V_2, \ldots\ldots V_n$ be the voltages applied to a conductor and let $I_1, I_2, \ldots\ldots I_n$ be the corresponding currents that pass through it, then we shall find:

$$\frac{V_1}{I_1} = \frac{V_2}{I_2} = \text{------} = \frac{V_n}{I_n} = \text{constant} \qquad \text{..........(11)}$$

The constant is identified as the resistance R of the conductor and Eqn (10) follows.

Ohm's law is a law of great importance in Electricity and Electromagnetism. It is an adequate parallel of Newton's second law in Mechanics. The development of the law in the early age of electricity, is a marvel of human intellect and ingenuity.

Resistors & DC Electricity

Fig (6) shows a resistor, connected to a source of DC electricity. Potential difference (or voltage) is applied to the resistor using connecting wires. The arrow across the battery shows that the voltage is variable. A voltmeter and an ammeter have been added for monitoring the voltages and currents in the circuit. In Fig (6) A and V are respectively an ammeter and a voltmeter.

As resistance owes its origin to the random motion of free electrons in the conductor and is totally indifferent to the applied potential differences, the magnitude of R stays constant for all voltages and Ohm's law is obeyed. For a given DC source of source voltage V_S, therefore, a constant current I_S will flow through R. We may write:

$$R = V_S / I_S \qquad \text{..........(12)}$$

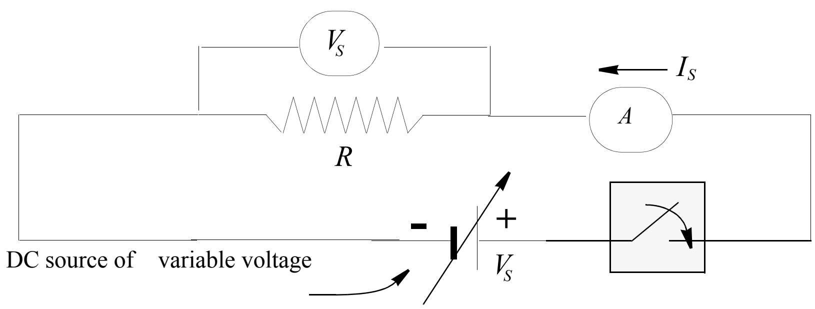

Fig (6) Resistor in a DC Circuit

Resistors & AC Electricity

Fig (7) shows a resistor, connected to a source of AC electricity. The circuit is essentially the same as that of Fig (6). Other than the obvious change of source, we have now used an AC voltmeter and an AC ammeter. These meters read *RMS* voltages and currents, as described in Experiment # 1 (The Basics of Electricity).

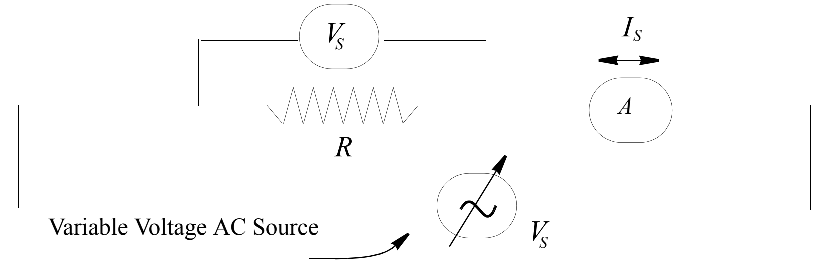

Fig (7) Resistor in an AC Circuit

As resistance owes its origin to the random motion of free electrons in the conductor and remains indifferent to the applied potential differences, it really does not care in what manner the voltage is applied. The arguments of the previous section follow and Ohm's law is obeyed. The value of R may be found using Eqn (12).

Objectives of the Experiment

(a) To determine the electrical resistance R of the given resistor, using Ohm's law and hence verify the law.
(b) To show that R does not depend on the type of electricity used.

Setting up

As per the *Objectives*, we shall use Ohm's Law:

$$V = RI \qquad \text{.......... Eqn (10)}$$

to determine the value of the given resistor R. In its present form, Eqn (10), is comparable to the equation of a straight line: $y = mx$ with the intercept b being zero. The comparison requires that we treat current I as the independent variable and apply different currents to the given resistor. To this end, we shall use a current divider network and apply different currents to the resistor. Corresponding values of voltage will be read on a voltmeter and a graph will be plotted(*).

The above is a direct verification. To get a greater degree of satisfaction, (sort of *money back* guarantee) one may, in addition, look for some sort of an indirect verification. To do so, we usually carry out some mathematical manipulations and develop a different form of the applicable equation or the law. In view of the simplicity of Ohm's law, no large scale modifications are possible. We may, however, try replacing *resistance* by *conductance*:

Rewrite Eqn (2) as:

$$I = VG \qquad \text{..........(13)}$$

We have caused V to be the slope of the straight line. So it must remain constant through the experiment. This constant voltage will be called V_o. A verification based on Eqn (13) is indeed possible. We shall select different values of R and for each, adjust the source current, using a rheostat, to keep the voltage constant at the preselected value: V_o. We shall convert R values to G values and plot a graph of I against G. The slope of the straight line should be V_o.

We shall use a DC voltage source to carry out the experiment. To establish that R does not depend on the type of electricity used, one would repeat one or both of the above, using an AC voltage source.

(*) It is customary to treat the voltage V as the independent parameter and apply different voltages to the given resistor using a voltage divider network. There is no need to violate the norms of Mathematics. We shall not use this approach.

Procedure

(a) Verification of Ohm's Law Using Resistances

(1) Let the value of the *given* resistor R be 1950 Ω (or as specified by the instructor). Set this value on a *resistance substitution box*, by activating the appropriate switches. Find the *exact* value of this resistance using an ohmmeter. To do this, use a digital multimeter as ohmmeter and set it at the appropriate resistance range (2 $k\Omega$ in this case). The necessary circuit diagram is given below, in Fig (8). This resistance box is shown as R in Fig (9).

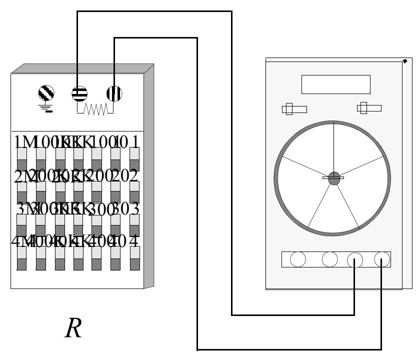

Fig (8) Using Ohmmeter to Determine the Exact Value of Resistor R

As can be seen, the two terminals of the resistance box are connected to the *red* and *black* terminals of the multimeter, in any order. Switch on the multimeter and read and record the resistance value that appears in the digital display. This value of R will be treated as its *expected* value.

(i) Ohm's Law & a Source of DC Electricity

(2) Set up the circuit as shown in Fig (9) using the DC power supply. You will need another resistance substitution box (named in the circuit diagram simply as *resistance box).* While setting up the circuit, assemble the *series* part of the circuit first. This means that do not pay any attention to the voltmeter (which is in parallel).

The *DC power supply*, comes with an *on/off* switch. Keep this switch in the *off* position.

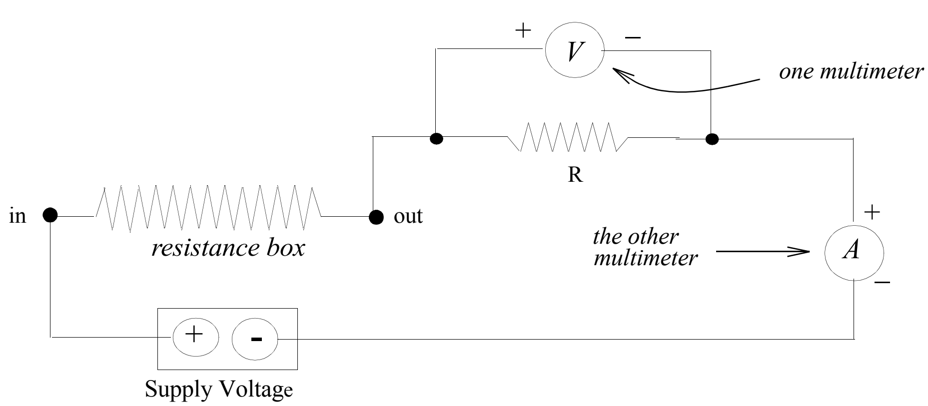

Fig (9) Circuit for Part (a-i) and (a-ii) of the Experiment

(3) Use one of the two multimeter as voltmeter and set to the 20 V DC range (or as directed by the instructor). Let the on/off switch of the multimeter be in the *off* position.

(4) Use the other multimeter as ammeter and set to 20 mA DC range (or as directed by the instructor). Let the on/off switch of the multimeter be in the *off* position.

(5) The resistance box shown in the circuit of Fig (9) is our current-controlling mechanism. The current in the circuit will depend on the amount of resistance, activated in this box. For the selection of current for the first trial, activate 200 Ω on this resistance box.

(6) When the circuit has been checked by the instructor, switch on (i) the power supply (ii) the voltmeter, and (iii) the ammeter; in that order.

(7) Read and record the values of current (that we selected) and the voltage (that developed across R as a result of this selection), as displayed by the meters. This is your first trial.

(8) Select the following values on the resistance box: 400 Ω, 600 Ω,.........until 3200 Ω.

(9) For each resistance selected in step (8) above, read and record values of current and voltage as displayed by the respective meters.

(10) Switch off the circuit in reverse order. (see step 6)

(ii) Ohm's Law & a Source of AC Electricity

(11) We shall use the circuit of Fig (9) for this part of the experiment also, but use a Digital *function generator*, in place of the DC power supply. Function generators produce AC voltages at selectable frequencies. When you will switch on the digital function generator, it will show an Ac voltage supply at 1000 Hz. This is the universally acknowledged *test* frequency. We shall leave it as it is. Using the amplitude control knob of the function generator, set its output voltage to approximately 5 volts. You will need an additional multimeter (set to 20 V AC), or may be asked to temporarily disconnect the existing voltmeter from your circuit, to carry out this setting.

(12) Without disturbing the circuit, switch the voltmeter to 20 volt, AC range (in case you didn't have to disconnect it) and the ammeter to 20 mA, AC range.

(13) Repeat steps (5) through (10), as above.

(14) Disconnect the circuit completely, and get ready to start the next part of the experiment.

(b) Verification of Ohm's Law Using Conductances

(1) The resistance box that was set to $R = 1950\ \Omega$ and was used as the *constant of the equation* in part (a) of the experiment, will not be needed any more. You may put it aside. However, we do need one resistance box to be used as our *independent variable*. We shall just call it *resistance box*.

(2) Set up the circuit as shown in Fig (10) using the DC power supply. While setting up the circuit, assemble the *series* part of the circuit first. This means that do not pay any attention to the voltmeter (which is in parallel).

(3) Set the sliding contact of the rheostat for near-maximum resistance (or as suggested by the instructor).

(4) Set the voltmeter to 200 V, DC (to reduce the number of decimal places in the display from 3 decimal places to 2), and the ammeter to 20 mA, DC.

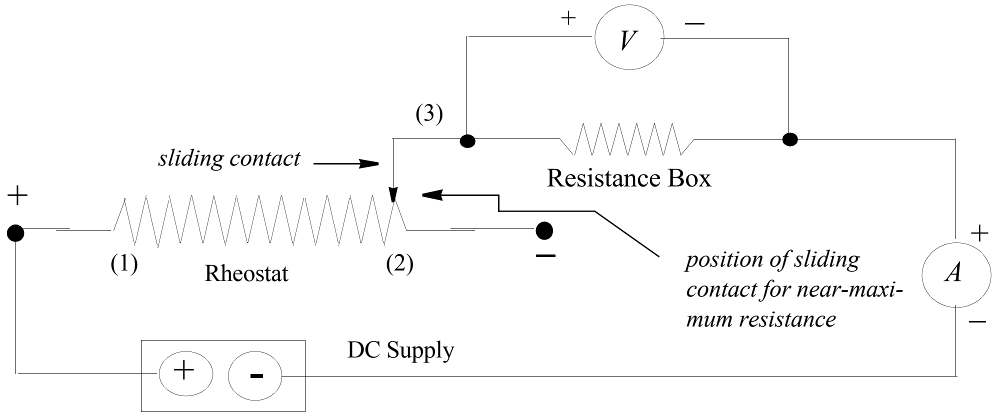

Fig (10) A circuit for the Study of the: Dependence of I *on* G

(4) We shall select a value of V_o for this part of the experiment. This value will have to be kept constant, precisely to two decimal places, for each of the16 trials. We shall select 16 different values of resistance R (the independent variable) on the *resistance box,* and, for each, we shall adjust the position of the sliding contact of the rheostat such that the voltage is restored to its preselected value V_o . The corresponding values of the current (the dependent variable) will then be read on the ammeter and recorded. These resistances will later be converted to conductances.

(5) For the first trial, set the resistance in the resistance box to 2500 Ω (or as specified by the instructor). This is R_1 . The rheostat at this time, stays in the position set in step (3).

(6) Switch on (i) the power supply (ii) the voltmeter, and (iii) the ammeter; in that order. Read and record the voltmeter reading. This is your V_o . Record this value in the Data Sheet in the appropriate place. Also, at this time, read the value of current (in mA), as displayed by the ammeter and call it I_1 . Record the pair of values: R_1 and I_1 in the Data Table as your first trial.

The voltage V_o that we read and recorded, is the voltage that will have to be kept constant throughout the experiment and it is also the *expected* value of the slope of the I *vs* G graph.

(7) For the second and subsequent trials, reduce the value or R in the *resistance box*, in steps of 100 Ω, to get values for $R_2, R_3, ...R_{16}$. Every time R is reduced, V_o is likely to change slightly. To restore it to its preselected value, adjust the position of the sliding contact of the rheostat by sliding it backward. When the voltmeter shows the preselected value of V_o (precisely to two decimal places), read the ammeter and record the current value as $I_2, I_3, ...I_{16}$.

(8) When all 16 trials are completed, switch off the circuit in reverse order.

(9) The experiment ends. Disconnect the circuit and place all components and meters in an orderly manner.

Calculations & Graphs

(i) Part (a) (i & ii): Plot voltages V (in volts) on the y-axis and the currents I (in mA) on the x-axis, using the Cricket graph program (on a computer). For each graph, read the slope as printed out by the computer. *Multiply the slope by 1000.* It should now match the actual value of R, as determined using an ohmmeter, in step (1) of part (a). Compare and find percent errors.

(ii) Part (b): Calculate G as $1/R$ for all 16 trials, using the computer. You should have three significant decimal places here. Plot currents I (in mA) on the y-axis and the values of G on the x-axis. Read the slope of the straight line as printed out by the computer. *Divide the slope by 1000.* It should now match the voltage V_o, as determined in step (6) of part (b). Compare and find percent error.

(iii) Complete the report with *Results*,.

Conclusions and Discussions

Write your conclusions from the experiment and discuss them.

What Did You Learn in this Experiment?.

A hearty and thoughtful account of what you learned in this experiment. You may mention (among other things) the sensitivity of meters and stability of power supply. How patient you had to be to set the voltage precisely to two decimal places?

After Effects (The Hangover)

Conductance is the natural property of conductors and a good conductor will have a decent conductance (naturally). On the other hand, if a conductor has a bad conductance, it will have good resistance. In fact the smaller the conductance of a conductor, the larger will its resistance be. We can safely say that the badder the conductor, the gooder a resistor it is.

Alas! Our immense hunger for the resistance of conductors, has made us look only for the badness of conductors.

So, like it or not, we the physicists, are obsessed with how bad a conductor is.

A physicist attends an orchestral performance and is later introduced to the majestically dressed, trim and proper, conductor of the orchestra.

The physicist greets the conductor enthusiastically, shakes hands cordially and says, “It’s a pleasure meeting you, Mr. conductor. Tell me how bad you are!”

Data & Data Tables

Name.................................... **Date**..............................

Instructor.............................. **Lab Section**...................

Partner.......................... **Table #**..........................

(a) Verification of Ohm's law using Resistances

(i) Ohm's Law & the DC Power Supply

(i) Value of resistance, set on the resistance box: R_{box} = (Ω)

(ii) Value of R, as checked by the ohmmeter: R_{meter} = (Ω)

(iii) Ammeter set to: mA, DC

(iv) Voltmeter set to: V, DC

Table 1: Voltage - Current Relationship of a Resistance

Serial #	Resistance values set on the resistance box that replaces rheostat	Voltages V (V)	Currents I (mA)
1	200 Ω		
2	400 Ω		
3	600 Ω		
4	800 Ω		
5	1000 Ω		
6	1200 Ω		
7	1400 Ω		
8	1600 Ω		
9	1800 Ω		
10	2000 Ω		
11	2200 Ω		
12	2400 Ω		
13	2600 Ω		
14	2800 Ω		
15	3000 Ω		
16	3200 Ω		

(ii) Ohm's Law & the AC Power Supply

(i) Ammeter set to: mA, AC

(ii) Voltmeter set to: V, AC

(iii) Function generator set to V at Hz

Table 2: Voltage - Current Relationship of a Resistance

Serial #	Resistance values set on the resistance box that replaces rheostat	Voltages V (V)	Currents I (mA)
1	200 Ω		
2	400 Ω		
3	600 Ω		
4	800 Ω		
5	1000 Ω		
6	1200 Ω		
7	1400 Ω		
8	1600 Ω		
9	1800 Ω		
10	2000 Ω		
11	2200 Ω		
12	2400 Ω		
13	2600 Ω		
14	2800 Ω		
15	3000 Ω		
16	3200 Ω		

(b) Verification of Ohm's Law using Conductances

(i) Initial value of resistance, set on the *resistance box*: $R_1 = 2500\ \Omega$

(ii) Voltage, as read on the voltmeter: $V_o =$ V

Table 3: Data For Using Conductances

Serial Number of Trials	Resistor Values R (Ω)	Current Values I (mA)
1	2500 Ω	
2	2400 Ω	
3	2300 Ω	
4	2200 Ω	
5	2100 Ω	
6	2000 Ω	
7	1900 Ω	
8	1800 Ω	
9	1700 Ω	
10	1600 Ω	
11	1500 Ω	
12.	1400 Ω	
13	1300 Ω	
14	1200 Ω	
15	1100 Ω	
16	1000 Ω	

Additional Data or Information (if any):

Additional Table in Case the Instructor Specifies a Different Value of R

(i) Initial value of resistance, set on the *resistance box*; R_1 = Ω

(ii) Voltage, as read on the voltmeter: V_o = V

Table 4: Data For Using Conductances

Serial Number of Trials	Resistor Values R (Ω)	Current Values I (mA)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12.		
13		
14		
15		
16		