Electronics Radio Television Radar

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DIRECT-CURRENT CIRCUITS---OHM'S LAW

ASSIGNMENT 6

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In the preceding assignment which dealt with the fundamentals of electricity it was pointed out that there are three basic factors which are present in d-c circuits. These three factors are; (1) **Voltage**, (2) **Current**, and (3) **Resistance.** To have a thorough understanding of the operation of the circuits in electronics equipment you will have to understand just what voltage, current, and resistance are, and will have to understand the relationship which exists between these three. The relationship between voltage, current and resistance is commonly called **Ohm's Law.**

Before considering Ohm's Law, however, it will be well to further illustrate the basic factors of voltage, current and resistance so that you will have a clear understanding of what each of these factors actually means in a circuit. You should also know the units in which these factors are measured, the range of values of these units which will normally be encountered in electronics equipment, and the abbreviations and symbols used to represent them. These points were considered in the preceding assignment but will be taken up again at this time to provide greater clarity.

Voltage

Voltage is the term used to indicate the amount of **electromotive force** present. The **electro-** portion of this term means having to do with electricity. The **-motive force** portion of this term means; a force capable of producing motion. Thus the entire term means the force capable of producing a motion of the electricity in a circuit, or in other words, the force capable of causing the electrons to **move** within an electrical circuit. The electromotive force (abbreviated emf) is, therefore, the amount of electrical **pressure** in a circuit. In a water system, the pressure is measured in pounds per square inch; in an electrical system the pressure (emf) is measured in **volts.** The electrical pressure is generally referred to as the voltage in the circuit. There are three types of voltage; d-c voltage, pulsating d-c voltage and a-c voltage. In this assignment we will devote our attention to circuits employing d-c voltages. A d-c voltage is one which remains constant.

D-C voltages may be generated, or produced, in a number of different ways. Figures 1 and 2 illustrate a number of common voltage sources. Figure 1 illustrates several types of cells and batteries. (The term battery actually means a battery of cells, or in other words a group of cells.) Figure 1(A) shows a penlight cell, Figure 1(B) shows a flashlight cell and Figure 1(C) shows a size No. 6 dry cell. Each of these cells produces an emf of approximately 1.5 volts. In other words, the **voltage** of each of these cells is approximately 1.5 volts. Everyone is familiar with the use of the penlight cell and the flashlight cell. Size No. 6 dry cells are used in some doorbell circuits, in rural telephone circuits and in the old style battery operated radios.

The battery illustrated in Figure 1(D) is commonly referred to as a "B" battery. This battery produces an emf of approximately 45 volts. This type of battery was used very widely in the early types of battery radio receivers and smaller versions of this battery were used in portable battery type vacuum-tube radio receivers. The storage battery illustrated in Figure 1(E) produces an emf of approximately 6.3 volts. This type of battery, of course has been used very widely in automobiles. We will study about the different kinds of batteries in a future assignment.

Figure 2 illustrates two other sources of d-c voltage. These are the d-c generator shown in Figure 2(A) and the power supply shown in Figure 2(B). D-C generators may be constructed to produce output voltages ranging from a few volts to 1000 or more volts depending upon the application for which the generator is intended. A power supply arrangement somewhat as illustrated in Figure 2(B) is the most common d-c voltage source which will be encountered in electronics equipment. In practically all localities the voltage delivered by the power companies to the homes for lighting, heating, etc., is a-c voltage. However, the correct operation of the major portion of the circuit in electronics equipment requires d-c voltages. A power supply circuit is able to convert the a-c voltage into d-c voltage for use in this equipment. In industrial electronics equipment, the power supply is often built on a separate chassis in an arrangement similar to that of Figure 2(B). However, it is much more common in radio and television equipment to find the power supply built on the same chassis as the remaining portion of the equipment. The power supply shown in Figure 2(B) is one which you will construct in Laboratory Experiment No. 3.

The amount of voltage produced by the power supplies in electronics equipment is dependent largely upon the design of the unit. For example, the power supply in a small a-c, d-c portable radio receiver usually delivers an emf of approximately 90 volts. In the larger types of radio receivers the power supplies normally produce voltages ranging between 250 volts and 300 volts. Vacuum-tube TV receivers normally employ at least two power supplies, one of which produces a voltage of approximately 300 volts while the other power supply delivers a very high d-c voltage ranging from 9,000 volts in black-and-white receivers to 27,000 volts in color TV receivers. Transistorized equipment usually employs power supplies delivering from 4.5 volts to 30 volts.

It is inconvenient to spell out the entire word **volts**; consequently the abbreviation V is often used to indicate the word "volts." For example, a battery symbol in a schematic diagram may appear as shown in Figure 3. The 6.3 V alongside this battery symbol indicates that it produces an emf of 6.3 volts.

In addition to the battery voltages and power supply voltages in electronics equipment, other voltages are present. These voltages range from a value of several millionths of a volt to several volts. Thus it can be seen that a very wide range of voltages may be encountered in electronics equipment.

While the various voltage values encountered could be expressed as so many thousandths of a volt or so many millionths of a volt or so many thousands of volts it is more convenient to use prefixes with the term volt to indicate the size. The prefix used to indicate one thousandth of a volt is the prefix **milli**, the prefix used to indicate one millionth of a volt is **micro**, and the prefix used to indicate thousands of volts is **kilo**: (There are other prefixes that are sometimes encountered in electronics, but we will concern ourselves with these a little later in the program.)

Thus: 32 thousandths of a volt, or .032 volt, is normally expressed as 32 millivolts.

14/1,000,000 volt, or .000014 volt, is expressed as 14 microvolts.
8,000 volts is expressed as 8 kilovolts.

As pointed out the abbreviation V is often used to indicate the term volts. Likewise abbreviations are used for the prefixes milli, micro, and kilo. These are:

milli	m
micro	μ
kilo	k

Thus the figures stated above might be abbreviated as follows:

32 millivolts	abbreviated 32 mV
14 microvolts	abbreviated 14 μV
8 kilovolts	abbreviated 8 kV

Two other terms which are often used to indicate that an electromotive force is present in a circuit are: (1) difference in potential and (2) potential difference. Remember, however, that each of these terms is merely another way of saying electromotive force, and each is measured in volts. Thus, an emf of 18 volts, a voltage of 18 volts, a difference in potential of 18 volts, or a potential difference of 18 volts all mean the same thing.

Since the abbreviation V may be used in place of the longer term volts it would seem logical that in an electronics formula dealing with voltage, V would be employed. Unfortunately however, this practice is **not** followed. Instead, the symbol E is used to represent voltage in formulas. In this case, the E is an abbreviation of the term electromotive force. To illustrate this fact, let us suppose that you saw the electronics formula $E = I \times R$. In this case, the **E stands for the electromotive force in volts.**

Since the unit of electromotive force is the volt, the amount of electromotive force is measured with a voltmeter. The arrangement employed is illustrated in Figure 4. Figure 4(A) shows a pictorial diagram in which a voltmeter is connected to the dry cell to measure the amount of voltage produced. Figure 4(B) shows a schematic diagram of this same circuit. Notice that there are two leads on a voltmeter and to use a voltmeter to measure the voltage output of a dry cell, one of these leads is connected to the positive terminal of the cell and the other lead is connected to the negative terminal of the cell.

Voltmeters are manufactured in a wide variety of ranges so that a suitable meter can be used for measuring most any voltage value. For example, in measuring a cell as in Figure 4 which delivers approximately 1.5 volts a voltmeter having a full scale reading in excess of 1.5 volts would be employed. For example, a meter with a full scale reading of 2½ volts, 3 volts, 5 volts or possibly 10 volts would be employed. If a voltmeter is to be used to measure the output of the power supply which is illustrated in Figure 2(B) the full scale reading must be equal to or in excess of the voltage output of the supply. In this case a voltmeter with a full scale reading of 300, 400 or perhaps 500 volts would normally be employed. Voltmeters are also available for use in measuring values of voltage in the thousands of volts. These meters are commonly called kilovoltmeters. Voltmeters may also be obtained for measuring very small values of voltage. For example, a millivoltmeter would be employed if it were desired to measure voltages in the range of a few thousandths of a volt. Some typical voltmeters are shown in Figure 4(C).

To summarize this discussion on voltage it can be stated that the electromotive force in a circuit is measured in volts. It is this electromotive force or voltage which is the force in an electric circuit which can cause the various actions of the circuit to take place. It is the voltage which **causes** the current to flow in an electric circuit. Notice, however, that voltage and current are two entirely different things. The voltage is the **force** which causes current to flow in a circuit.

Current

When an emf is applied to a complete electrical circuit there is a motion of the electrical energy through the circuit. As explained in the previous assignment the condition which actually occurs is that the free electrons move through the circuit from the negative terminal of the voltage source toward the positive terminal. In other words, the electrons **flow** through the circuit. This motion of free electrons in an electrical circuit is called the **current.** The motion of the electrons in the circuit, or in other words, the current flowing through the circuit, cannot be seen. However, the effects of this current can be noted. It is the current flowing through the circuit which enables an electric motor to operate, which causes an electric stove to heat, which enables a loudspeaker to produce sound waves when it is connected to a radio receiver and which makes it possible for a television receiver to produce a picture of a scene taking place many miles away.

In a water system the flow of water, or in other words the current of water, is measured in gallons per minute. In an electrical circuit, current is measured in **amperes.**

The ampere is a rather large unit of current. To illustrate, when an electric iron is connected to an ordinary house wiring circuit only 6 to 10 amperes of current will flow through the iron, approximately one ampere of current will flow through a 100 watt light bulb when connected to the normal lighting circuit, and approximately 2/10 ampere flows through the bulb in a normal two-cell flashlight when the flashlight is turned on. The current which flows from the power supply to the various circuits in a radio receiver will range between .015 of an ampere and .075 of an ampere, and the current supplied by the power supply in a television receiver will range from approximately .075 of an ampere to .300 of an ampere. From this it can be seen that current in the order of amperes will seldom be encountered in electronics circuits. For this reason the prefixes **milli** and **micro** are used in conjunction with the term ampere quite often. As mentioned previously the prefix milli means "one thousandth part of," and micro means "one millionth part of." To illustrate the use of these terms let us suppose that one thousandth of an ampere (.001 ampere) of current flows from the power supply in an electronics unit through a particular vacuum tube circuit. In this case a technician would normally state that 1 milliampere of current is flowing in the circuit. Similarly if 15/1000 of an ampere of current flows through the circuit connected to an industrial electronics power supply a technician would normally state that 15 milliamperes of current flows in the circuit. Similarly, if 10/1,000,000 of an ampere of current flows through the base circuit of a particular transistor in a missile guidance system, a technician would state that 10 microamperes of current flows in the circuit.

Thus 5/1000 ampere or .005 ampere = 5 milliamperes (5 mA).
30/1000 ampere or .03 ampere = 30 milliamperes (30 mA).
20/1,000,000 ampere or .000020 ampere = 20 microamperes (20 μA).

It will be noted in the above, that to eliminate the necessity of writing out the word ampere in full, the abbreviation **A** is commonly used for the longer term ampere.

When current is to be used in an electronics formula the letter I is used to indicate it. Thus, in the formula $E = I \times R$, the **I stands for current in amperes.** The letter I is used for current since current is a measure of the **intensity** of the electron flow in a circuit.

The current which flows in a circuit can be measured by means of an ammeter or milliammeter. Figure 5 shows the manner in which this could be done. Notice that it is desired to determine how much current is **flowing in the circuit.** Thus the ammeter or milliammeter must be connected so that the current from the battery flows **through** the meter at the same time it is flowing through the remaining portion of the circuit. Notice in the circuit of Figure 5 that the current would flow from the negative terminal of the dry cell, through the resistor, through the meter and return to the positive terminal of the dry cell. Thus, the current which flows through the resistor will also flow through the meter, and the meter will indicate the amount of current flowing in the circuit.

Current measuring meters are manufactured in a wide variety of ranges so that a suitable meter can be used with most any circuit. For example, if it is desired to measure the exact amount of the current flowing in a circuit in which the current is in the order of several amperes, an ammeter which has a higher full scale reading than that which is flowing in the circuit would be employed. If, however, the circuit consists of a computer logic circuit in which a few milliamperes of current are flowing the current indicating meter employed will normally be a milliammeter. To illustrate; if approximately 3 milliamperes of current were flowing in the circuit, a milliammeter with a full scale reading of 5 milliamperes or perhaps 10 milliamperes would be used, and a partial deflection would be obtained on the meter. The calibrated scale on the meter would then be read to determine the exact amount of current flowing in the circuit.

To briefly summarize this portion of the discussion it can be said that current is the progressive flow of the free electrons around a circuit. Current will flow only when the electrons are being pushed, or forced, around the circuit by the electromotive force (voltage) which is applied to the circuit. Current is measured in amperes, milliamperes or microamperes.

Resistance

Resistance is a measure of the **opposition** the electrons encounter in flowing through a circuit. If a voltage is applied to the two ends of a piece of wire, current will flow through the wire. This current is made up of many free electrons bounding from one atom to another in a steady procession as explained previously. Instead of skipping neatly from one atom to the next, however, the electrons follow irregular paths as they "drift" along a piece of wire. If a piece of wire with a very small diameter is used the electrons encounter a "congested traffic condition" within the small wire. In other words, a considerable amount of opposition is offered to the flow of the free electrons. If a piece of special resistance material, carbon for example, is connected in the circuit, the opposition offered to the free electron flow (current) is high because most of the atoms in the carbon are holding their electrons tightly in their orbits and there are few free electrons present. In this case, we might consider our "congested traffic conditions" due to so many "parked" electrons.

Another analogy which illustrates the subject of resistance quite well is a bucket brigade fighting a fire. A person at the head of the line in the bucket brigade dips buckets of water out of a well and starts passing them along the line. The man at the other end of the line, of course, throws the water on the fire. If the line is working efficiently, the buckets of water are passed down the line rapidly and easily and the volume of water thrown on the fire is considerable. This might be compared in an electrical sense to a circuit with very low resistance since the current is passed through the circuit very efficiently.

To illustrate an analogy similar to a circuit containing resistance, let us assume that the fire had been set by a mob which, after the bucket brigade had been set up, did not wish the fire to be extinguished. In this case the rioters would interfere with the persons attempting to pass the buckets of water down the line, and the result would be that only a small amount of water would ever be applied to the fire. In other words, the passage of the water along the bucket brigade encounters a lot of opposition. This is equivalent in an electrical circuit to resistance which opposes the flow of electrons.

It should be borne in mind at all times when considering d-c circuits that resistance is the **opposition** offered to the flow of current. Notice that voltage causes current to flow, whereas resistance opposes the flow of current. It might seem that it would always be desirable to have a circuit with as low a value of resistance in it as possible. However, this is not the case. In the great majority of the circuits used in electronics equipment, resistors are inserted in the circuit for the particular purpose of opposing current flow. In other words when properly used, resistances are very necessary circuit components. Figure 6 illustrates some typical fixed resistors used in electronics equipment.

The unit of resistance is the ohm. Resistors normally encountered in electronics circuits range in value from a few ohms to several million ohms. To make it possible to handle the large values of resistance more easily the terms kilohm and megohm are employed. The term kilohm is seldom used to show a value of resistance although its abbreviation is often used. For example a schematic diagram might show a 10k resistor, this is of course ten kilohms, but would normally be read "ten thousand." Resistors in the megohm range are often encountered in electronics circuits. One megohm is equal to one million ohms and (capitol) M is its correct abbreviation, although the abbreviation Meg is often used. Generally, when speaking of these large value resistors, a technician will say "a 5-megohm resistor" or "a 10-megohm resistor," rather than a 5-million ohm or a 10-million ohm resistor.

The Greek letter omega (Ω) is very often used in place of the word ohms. To illustrate: 100Ω means 100 ohms; 5,000Ω means 5,000 ohms; 5kΩ means 5,000 ohms; 100kΩ means 100,000 ohms; and 3.3MΩ means 3.3 megohms, which is 3.3 million ohms, or 3,300,000 ohms.

In electronics formulas the letter R is used to indicate resistance. Thus, in the equation $E = I \times R$, the **R stands for resistance in ohms.**

To briefly summarize this portion of the discussion it can be said that resistance is the opposition offered to the flow of an electric current in a circuit. The unit of resistance is the ohm, and the values encountered in electronics equipment range from a few ohms to several million ohms. The

Greek letter omega (Ω) is often used as an abbreviation for the term ohm, the prefix k indicates 1000 and the term megohm (M) indicates one million ohms. The letter R stands for resistance in electronics formulas.

Ohm's Law

In his experiments dealing with simple electrical circuits, about 140 years ago, the German scientist, George Simon Ohm discovered that a definite relationship exists between the voltage applied to a circuit, and the resistance in the circuit. This relationship is now called Ohm's Law. Since the understanding of all d-c circuits requires the intelligent use of Ohm's Law, the remaining portion of this assignment will consist of an explanation of this law and its uses. You will use Ohm's Law from time to time as you progress in the training program and you will soon have a thorough understanding of it.

Before actually considering Ohm's Law let us consider a simple d-c circuit once more. As pointed out, the voltage applied to the circuit exerts a force on the electrons present in the circuit and will cause a movement of free electrons around the circuit if a complete circuit exists. In other words, the **voltage causes current to flow** in the circuit. However, the resistance present in the circuit **opposes** the flow of the current. Thus, the voltage attempts to cause the current to flow while the resistance attempts to keep it from flowing. It should be obvious that there is some relationship which exists between the amount of current which flows, the applied voltage, and the resistance present in the circuit. This simple relationship is Ohm's Law.

To illustrate the use of Ohm's Law a number of circuits will be shown in this assignment and problems associated with these circuits will be worked. It should be emphasized however, that the answers to the problems in this assignment are not important in themselves. The important thing in this assignment is that each and every answer must seem reasonable to you. The entire value of this assignment lies in the interest you take in finding out what happens and **why** it happens in an electrical circuit.

To illustrate Ohm's Law let us consider the simple circuits shown in Figure 7. George Ohm found that if he connected a simple circuit as shown in Figure 7(A), with a 1 volt battery and a 1 ohm resistor, 1 ampere of current would flow through the circuit. (Note that a calibrated scale is shown on the current meters in the various circuits of Figure 7 and the pointer on the meter indicates the current flowing in the circuit under the various conditions.) The schematic diagram of each of the various circuits is illustrated directly below the circuit. Notice in the circuit of Figure 7(A) that the 1 volt battery furnishes the electromotive force, or voltage, for the circuit. This emf exerts an electrical pressure on the electrons causing a current flow to occur. The path of this current flow is from the negative terminal of the battery, through the resistor, through the ammeter back to the positive terminal of the battery. Under the conditions illustrated in Figure 7(A) **1 ampere** of current flows.

Now examine the circuit of Figure 7(B). Notice that the only difference between this circuit and the circuit of Figure 7(A) is the fact that a ½ ohm resistor has been installed in place of the one ohm resistor of the previous circuit. Notice, however, that changing the resistor in the circuit has changed the current which flows in the circuit. With the ½ ohm resistor in the circuit more current (2 amperes) flows in the circuit. Notice that the current flowing in the circuit is increased when the resistor is made smaller. Doesn't this seem logical to you when it is recalled that the resistance is the opposition offered to the current flow? With less opposition one would expect more current to flow in the circuit and that is exactly what happens. If this particular point is not clear, you should stop at this point and review the previous material before proceeding.

Figure 7(C) shows the condition which occurs when a 2 ohm resistor is used in the circuit, and the voltage is being produced by the same 1 volt battery as was done previously. Under these conditions only ½ ampere of current flows as illustrated by the calibrated scale on the meter shown in this figure.

Examine the circuits of Figure 7(A), (B) and (C) very carefully and then see if you agree with the following summary of the action taking place. For a given voltage applied to the circuit, the larger the resistance present in the circuit the smaller will be the amount of current flowing and, conversely, the smaller the resistance present in the circuit, the larger will be the current which flows.

Figure 7(A), (B) and (C) illustrate the action which occurs in a simple circuit when the value of **resistance** in the circuit is changed. To determine the effect produced by changing the value of **voltage** applied to the circuit compare Figure 7(A) and (D). The circuit of Figure 7(A) consists of a 1 volt battery and a 1 ohm resistor. However, in Figure 7(D) a 2 volt battery has been installed in the circuit in place of the 1 volt battery of the previous circuit. Notice that under these conditions a current of 2 amperes flows as illustrated by the meter in Figure 7(D). Note particularly, in comparing Figure 7(A) and (D), that the same resistance is employed in each case, but that a larger voltage is applied to the circuit of Figure 7(D). Under these conditions notice also that more current flows. Let us briefly summarize this action. For a given resistance in a circuit, **more** current will flow if the voltage is increased. This also seems quite logical when we recall that voltage is the electrical force or pressure in the circuit. If the pressure is increased with a constant opposition, (resistance) the current flow should, logically, increase.

Ohm wrote these conclusions in a simple mathematical formula which is written below.

$$\text{Current} = \frac{\text{Applied voltage}}{\text{Resistance}}$$

Let us now write this formula using the symbols mentioned previously. The formula would then appear as follows:

$$I = \frac{E}{R} \quad \text{(Formula A)}$$

I stands for current in amperes
E stands for electromotive force in volts
R stands for resistance in ohms

This formula may be used in electronics circuits to determine the amount of current flowing in a circuit if the voltage and the resistance are known. By applying this formula the current which flows in a circuit can be determined without using a milliammeter or ammeter.

It is sometimes desirable to determine the amount of resistance present in a circuit if the voltage and the current are known. In this case the following formula, which we shall call Formula B, may be employed.

$$R = \frac{E}{I} \quad \text{(Formula B)}$$

The symbols of this formula have the same meaning as in (Formula A).

Under certain circumstances it is desirable to be able to determine the amount of voltage applied to a circuit if the current flowing in the circuit and the resistance of the circuit are known. In this case the following formula may be employed.

$$E = I \times R \quad \text{(Formula C)}.$$

It should be emphasized that these three formulas are not three separate formulas but are merely the same formula rearranged in three different manners so that the quantity which it is desired to determine is on the left side of the equation. Formula A may be used to find the amount of current flowing when the voltage and amount of resistance of the circuit are known and the value of current is unknown. Formula B may be used to find the amount of resistance in a circuit when the voltage and current are known, and Formula C may be used to find the applied voltage when the current and resistance are known.

Let us apply these formulas to some specific circuits to illustrate their use. For example let us apply Formula A to the circuits of Figure 7(A), (B) and (C) assuming in each that the amount of voltage produced by the battery is known and the size of the resistor is as shown, but that for some reason or other the ammeter in each circuit could not be read.

In Figure 7(A) we have 1 ohm of resistance and a 1 volt battery. Let us solve to find the amount of current which would be flowing in this circuit. Remember:

I stands for current in **amperes**

E stands for electromotive force in **volts**

R stands for resistance in **ohms**

To solve this problem, we first write down the correct formula, then we substitute the known quantities in the equation and solve for the unknown.

value of the battery voltage is assumed to be unknown. Formula C can be applied to determine the battery voltage.

$E = I \times R$ (I equals ½ ampere, R equals 2Ω)

$E = \frac{1}{2} \times 2$

$E = 1$ volt (Answer)

You are strongly advised to work several more problems for yourself using the circuits shown in Figure 7(A), (B), (C) and (D). For example, assume that the voltage is unknown in the circuit of Figure 7(D) and determine the value of this voltage by applying the appropriate Ohm's Law formula when the values of resistance and current are known. Check your answer against the value of voltage indicated in the circuit of Figure 7(D). By making similar assumptions work several problems concerning these four circuits until you are certain that you understand the use of the various Ohm's Law formulas. To provide you with added practice in the application of Ohm's Law, three circuits are shown in Figure 8. Apply the appropriate Ohm's Law formula to each one of these circuits to find the unknown quantity. Be sure and work these problems to the best of your ability before checking your answers with those given at the end of the assignment.

Circuit Terminology

We will find as we progress in the subject of circuits that a number of different arrangements may be employed. There are three general circuit arrangements and these are called; **series circuits**, **parallel circuits**, and **series-parallel circuits.** However, before considering the various types of circuits, let us consider just what a circuit is, and what is meant by the terms closed circuit, open circuit, and short circuit.

By definition, a closed circuit or complete circuit is a complete path over which electrons can flow from the negative terminal of the voltage source through the parts and wires to the positive terminal of the same voltage source. Thus, any of the arrangements of Figures 7 or 8 would form a closed circuit or complete circuit. Note that for the circuit to be closed, or complete, **a path must be provided** for the electrons to flow from the negative terminal of the voltage source to the positive terminal of the same source.

An open circuit is a circuit which does **not** provide a continuous path for the electrons. Such a circuit is shown in Figure 9. Notice that the switch in this circuit is open. Under these conditions a complete path from the negative terminal of the voltage source is not provided through the parts and components to the positive terminal of the voltage source because the open switch will not pass electrons. Since a complete path is not provided in the circuit of Figure 9, **no current** will flow in the circuit. It is for this purpose that switches are connected in circuits. For example, in a normal house wiring circuit, switches are connected in series with the various lights. Thus in the day time the switch is turned off, or in other words, the switch is placed in an open position, and the electric light is not illuminated. However, when it is desired to have the light illuminated it is only necesssary to close the switch which completes the circuit, thereby enabling the electric current to flow through the filament of the light bulb and produce the desired illumination.

There is one point which should be made clear concerning an open circuit. If a switch is connected in the circuit and is in the open position, an open circuit will be formed. However, open circuits may be formed by other means, for anything which will cause the path of the electrons to be broken, will form an open circuit. For example, in the simple circuit of Figure 5, if one of the leads were to become disconnected from the terminal on the dry cell an open circuit would be formed. Similarly an open circuit might be formed in the circuit of Figure 5 by a defective ammeter, or perhaps by a lead breaking off the resistor. Thus, it should be borne in mind that an open circuit may result from a number of different causes.

The third circuit characteristic mentioned previously is the short circuit. By definition, a short circuit is a low resistance connection across a voltage source or between both sides of a circuit, usually accidental, which in most cases, results in excessive current flow that may cause damage. A short circuit is illustrated in Figure 10. Notice that in this case the lead coming from the positive terminal and the one from the negative terminal of the battery are accidentally touching. Thus a low resistance path is provided from the negative terminal of the battery around to the positive terminal and the current may follow this path instead of flowing through the resistor and meter as it should. The touching of the two wires is called a short circuit, or in some cases just a "short". Such a condition would in this case ruin the battery in very short order. In other circuits a short circuit may ruin other components such as meters, etc. Since short circuits are very undesirable, insulated wire is employed in most electrical circuits. For example, insulated wire is used in electronics units, insulated wire is used in house wiring circuits, in automobile ignition circuits, etc.

Now that the characteristics of circuits have been considered let us analyze the three fundamental types of circuits, the series circuit, the parallel circuit and series-parallel circuit.

Series Circuits

A series circuit is a circuit which is so arranged that all of the current which flows from the negative terminal of the voltage source passes through **each** component in the circuit and returns to the positive terminal of the voltage source. Two simple series circuits are illustrated in Figure 11. The path followed by the current in each case is illustrated by the dotted line. Notice in Figure 11(A) that the current leaves the negative terminal of the battery, flows through the resistor, through the meter, and finally returns to the positive terminal of the battery. The schematic diagram of the circuit is also shown. Thus, in the circuit of Figure 11(A) the resistor and meter are connected in series across the battery as **all** of the current flows through **each** of these components. Similarly in Figure 11(B) the current path indicates that the electrons flow through the meter and then through the resistor to return to the battery. Thus, the meter and the resistor are in series in this case. These circuits also illustrate the proper way to use a milliammeter to measure current in a circuit. The milliammeter is connected **in series** with the circuit.

Another factor which is illustrated by the circuits of Figure 11 is the fact that the milliammeter can be connected at any point in a series circuit. If the same size battery and resistor are employed in the circuits of Figure 11(A) and (B) the current flow as indicated by the meter in the two cases will be the same. The reason for this is that the current **is the same at all points in a series circuit.** The same amount of current that leaves the negative terminal of the battery re-enters the positive terminal of the battery. In the circuits of Figure 11 the same amount of current flows through the conductor connecting the negative terminal of the battery to the resistor as flows through the resistor. This current is also equal to the current flowing through the meter. By following this line of reasoning it should become clear to you that the meter can be connected either as shown in Figure 11(A) or (B) to indicate the amount of current flowing in the circuit.

To further illustrate the action of a series circuit consider the circuit illustrated in Figure 12(A). This circuit consists of a 1½ volt battery, a switch, a 500 ohm resistor and a milliammeter. In this circuit four meters are illustrated. The milliammeter is connected in series with the circuit to indicate the current which flows. In addition, a voltmeter is shown connected across the battery, another voltmeter is shown connected across the switch and a third voltmeter is connected across the resistor.

This circuit illustrates several points. One of the points illustrated is the proper way to connect meters. As may be noted the milliammeter is connected in series with the circuit as illustrated in Figure 11 and should require no further explanation. The manner in which the three voltmeters are connected illustrates the proper way to use such an instrument. One voltmeter is connected across the battery. That is, one lead of the voltmeter is connected to the positive terminal of the battery and the other lead of the voltmeter is connected to the negative terminal. When connected in this manner the voltmeter will indicate the emf of the battery in volts. The voltmeter to measure the voltage applied to the switch is connected **across the switch**, and the voltmeter to measure the voltage applied to the resistor is connnected across the resistor.

The following summarizes the proper manner in which meters should be connected: An ammeter or milliammeter should be connected **in series** with the circuit; Voltmeters should be connected **across** a component.

Let us look at the circuit of Figure 12(A) carefully, noting particularly the reading on the meters. The voltmeter connected across the battery reads the emf produced by this battery which is 1.5 volts. Notice also that although the milliammeter is connected properly, (in series with the circuit), there is no currrent flow indicated by the meter. The reason for this is the fact that the switch is open. As mentioned previously the open switch forms an open circuit and there is no complete path from the negative terminal of the battery around to the positive terminal. Since there is no complete path, current cannot flow.

Now notice the readings of the voltmeters at the various points in the circuit of Figure 12(A). The voltmeter connected across the battery indicates 1½ volts which is the emf produced by the battery. The voltmeter connected across the switch also indicates 1½ volts whereas the voltmeter across the resistor indicates zero. As mentioned the switch forms an open circuit and the entire voltage present in the circuit is applied across this switch attempting to force current through the switch. This accounts for the 1½ volt reading obtained on the voltmeter connected across the switch. However, since no current flows in the circuit there will be zero voltage across the resistor in the circuit.

Now examine Figure 12(B). It will be noted that this is the same as the circuit of Figure 12(A) except that the switch has been closed. When the switch is closed a complete circuit is formed, current flows in the circuit, and an entirely different condition exists from that of Figure 12(A). In the circuit of Figure 12(B) the milliammeter tells us that 3 milliamperes (.003 amperes) of current is flowing through the circuit. The voltmeter across the 500 ohm resistor now reads 1½ volts. This meter tells us that 1½ volts of electrical pressure are being used to force the 3 milliamperes of current through the 500 ohm resistor.

The voltmeter connected across the switch now reads zero. There is practically no resistance between the two terminals of the switch when the blade is closed. No voltage is needed to force the 3 milliamperes of current through the closed switch.

The voltmeter at the cell still reads 1½ volts, and the voltmeter connected across the resistor now reads 1½ volts also. The question naturally arises: Do we now have 3 volts in the circuit? The answer is a very definite: **No!** The voltage of the dry cell is the **source voltage** and the voltage appearing across the resistor is commonly called a **voltage drop.** Voltage drop is the term applied to the voltage which is applied across a particular component, such as a resistor, which causes current to flow through that particular component. In this particular case, the voltage drop across the 500 ohm resistor is equal to the voltage source as all of the voltage in the circuit appears across the 500 ohm resistor causing the current of 3 milliamperes to flow through this resistor. The subject of voltage drops will be taken up in greater detail presently.

In the circuit of Figure 12(B) the value of the resistance is known and the current and voltage present in the circuit are indicated by the meters in the circuit. In this circuit, as in many others however, we would not need the large number of meters indicated to determine voltage and current. We can use Ohm's Law.

The cell develops 1½ volts of electrical pressure. E therefore is 1½ volts. The total resistance in the circuit is 500 ohms; Therefore, R is 500 ohms.

To determine how much current would flow in the circuit of Figure 12(B) without the use of a milliammeter, we can use the formula that tells us:

$$I \text{ (current in amperes)} = \frac{E \text{ (Voltage in volts)}}{R \text{ (Resistance in ohms)}}$$

$$I = \frac{E}{R}$$

$$I = \frac{1.5}{500}$$

I = .003 ampere or 3 milliamperes (3mA).

Thus it can be seen that in the circuit of Figure 12(B) Ohm's Law can be used to determine the current which would flow if a 500 ohm resistor were connected across a 1½ volt battery.

To further demonstrate the use of Ohm's Law in series circuits consider the circuits of Figure 13. In Figure 13(A) is shown a circuit consisting of a 7½ volt battery, a milliammeter, a 5,000 ohm resistor and a switch. It will be noted that this is also a series circuit as only one path is provided for the current. The milliammeter in the circuit indicates that 1.5 milliamperes of current flows under these conditions. However, the amount of current flowing in this circuit could be determined without the use of a milliammeter merely by the proper application of Ohm's Law. The voltage is 7½ volts in the circuit and the resistance is 5,000 ohms. The current can be determined as follows:

$$I = \frac{E}{R}$$

$$I = \frac{7.5}{5000}$$

I = .0015 ampere or 1.5 mA.

In Figure 13(B) we have a circuit consisting of a 100 volt battery, a milliammeter, a 50,000 ohm resistor, and a switch. The milliammeter indicates that 2 milliamperes of current will flow in the circuit. Let us check this by the application of Ohm's Law.

$$I = \frac{E}{R}$$ (In this case E equals 100 volts and R equals 50,000 ohms.)

$$I = \frac{100}{50{,}000}$$

$$I = .002 \text{ ampere or } 2 \text{ mA.}$$

Notice that in our Ohm's Law problems we must always use the whole units; volts, ohms and amperes. If we care to we may change our answers to smaller units, as we did in this example, but in the solution of the problem we must use the fundamental units.

Figure 13(C) shows a circuit consisting of a 50 volt battery, an unknown value of resistance, and the milliammeter in the circuit indicates that 10 milliamperes of current is flowing. Let us apply Ohm's Law and find the unknown value of this resistance. The formula we will use in this case is: $R = \frac{E}{I}$ since we desire to determine the resistance in the circuit.

Note: **we must change the milliamperes to amperes before using the value of current in our formula.** If 1 milliampere of current equals .001 ampere, then 10 milliamperes equals 10 $\times$ .001 or .010 ampere.

$$R = \frac{50}{.010}$$

$$R = 5{,}000 \text{ ohms}$$

Notice that in this example Ohm's Law demonstrates the fact that if 10 milliamperes of current flows in a circuit connected to a 50 volt battery, the value of resistance present in the circuit must be 5,000 ohms.

To further illustrate the use of Ohm's Law consider the circuit of Figure 13(D) which consists of a battery, a 20,000 ohm resistor and a milliammeter which indicates a current of 2 milliamperes flowing in the circuit. Although the value of the battery voltage is unknown, Ohm's Law can be applied to determine the voltage. Since the voltage is the unknown in this case we will use the formula $E = I \times R$.

$E = I \times R$ (2 milliamperes equals .002 amperes)
$E = .002 \times 20{,}000$
$E = 40$ volts

The Ohm's Law calculation just completed indicates that if 2 milliamperes of current flow through a circuit containing 20,000 ohms of resistance, the applied voltage must be 40 volts.

The circuits we have been discussing so far are **series circuits.** A series circuit is one in which there is only one path for the current to follow through the circuit. However, the circuits which we have been discussing have had only one resistor present although it is possible for a series circuit to contain several resistors. Figure 14 shows a circuit consisting of a 40 volt battery, a milliammeter and two 10,000 ohm resistors, all connected in series. The current path is indicated in this circuit and it can be seen that after leaving the negative terminal of the battery the electrons must flow through the milliammeter, then through the resistor labeled R_1, then through the resistor labeled R_2, then through the switch, finally returning to the positive terminal of the battery. Thus it can be seen that the resistors are in series since the current must flow through each of them. If each of these resistors offers 10,000 ohms of resistance, the current first encounters an opposition equal to 10,000 ohms and then encounters another opposition equal to 10,000 ohms. The total resistance is then 10,000 plus 10,000 or 20,000 ohms. The current flowing in the circuit is indicated to be 2 milliamperes by the milliammeter but could be determined if the milliammeter were not available. To do this we would apply Ohm's Law.

$$I = \frac{E}{R}$$

(Remember the total resistance in the circuit is 20,000 ohms.)

$$I = \frac{40}{20{,}000}$$

$I = .002$ ampere or 2 mA.

Now let us consider the voltage drops in this circuit. As the current follows the path indicated by the dotted line in Figure 14, it flows first from the negative terminal of the battery through the milliammeter, then through R_1, R_2, the switch, and finally returns to the positive pole of the battery. As the current flows through the various components in the circuit, voltage drops are produced across the components. However, since the resistance of the milliammeter and the closed switch are so small, they can be neglected for this discussion and we will consider the two voltage drops across R_1 and R_2. The polarity of the voltage present across each of these resistors is indicated in Figure 14. There is a very simple way in which the polarity of voltage drops in a series circuit can be determined. This can be done in tracing the current path from the negative terminal of the battery around through the circuit and back to the positive terminal of the battery. The polarity of the voltage drops across **each** resistor will be such that the end of the resistor that the current enters will be the **negative** end. Check the polarity of the voltage drops in Figure 14 to make sure that you understand this point.

Let us determine the value of the voltage drop across each resistor in the circuit of Figure 14. Our previous calculations have indicated that the current flowing in the circuit is 2 milliamperes, or .002 ampere. This current flows through R_1 which is a 10,000 ohm resistor. We may then apply Ohm's Law to determine the amount of voltage present across R_1.

$$E = I \times R$$
$$E = .002 \times 10,000$$
$$E = 20 \text{ volts}$$

This is the amount of voltage drop present across R_1. Since R_2 is also a 10,000 ohm resistor through which 2 milliamperes of current is flowing there will be a 20 volt drop across this resistor also. This circuit illustrates another important point concerning voltage drops. **In any series circuit the sum of the voltage drop is equal to the source voltage.** In this particular case the source voltage is 40 volts and the sum of the voltage drops is equal to the voltage drop across R_1 plus the voltage drop across R_2, or 20 plus 20 equals 40 volts.

Let us now connect several resistors in series in a similar circuit. Let us assume that we have the filaments of four tubes connected in series. (The filament of a tube is actually a special type of resistor.) Such a circuit is illustrated in Figure 15. Each filament has a resistance of 21 ohms. Checking the current path in the circuit of Figure 15 will indicate that after leaving the negative terminal of the battery and passing through the ammeter the current flows first through filament No. 1, then filament No. 2, then filament No. 3, and finally through filament No. 4 to the positive terminal of the battery. Thus if each of the filaments offers an opposition to the flow of current equal to 21 ohms, we have a total of 4 $\times$ 21 or 84 ohms of resistance in this circuit.

The ammeter in the circuit will read .3 ampere. This can be determined by the application of Ohm's Law.

$$I = \frac{E}{R}$$ (E is the total voltage of 25.2 V and R is the total resistance of 84 Ω.)

$$I = \frac{25.2}{84}$$

$$I = .3 \text{ ampere}$$

Since there are four resistors in the circuit of Figure 15 there will be four voltage drops. The polarity of each of these voltage drops is indicated in Figure 15 and you are advised to check the direction of the current flow and determine whether or not you agree with the polarity of each voltage drop indicated.

Let us now determine the amount of voltage across **each** filament. The current flowing through the circuit is .3 ampere and the resistance of each filament is 21 ohms. Thus Ohm's Law can be applied to determine the amount of voltage present across each resistor as follows:

$$E = I \times R$$
$$E = .3 \times 21$$
$$E = 6.3 \text{ Volts Per Filament}$$

Since the filaments have equal resistance there will be 6.3 volts across each filament. Thus, the voltmeters shown connected across each of the filaments in the circuit of Figure 15 would each read 6.3 volts.

In Figure 15 we have one voltmeter connected so as to indicate the voltage applied across two of the filaments—filament No. 3 and filament No. 4. This voltmeter would read 12.6 volts. We can check this reading by Ohm's Law. The total resistance of two of the 21 ohm filaments is $2 \times 21 =$ 42 ohms. The current flowing through the circuit is .3 ampere. Thus:

$$E = I \times R$$
$$E = .3 \times 42$$
$$E = 12.6 \text{ volts}$$

A point which has been mentioned previously which can be illustrated clearly by the circuit of Figure 15 is the fact that the current is the same at all points of a series circuit. This is true because the **same** current flows through each component in the circuit. Thus in the circuit of Figure 16, (You will recognize this circuit as being the same as Figure 15), the ammeter will indicate .3 ampere with the meter connected at the points indicated in any of the circuits shown in this Figure. Similarly the ammeter could be connected between the negative terminal of the battery and the "string" of filaments.

In Figure 15 the total resistance of the 4 filaments, or resistances, in series was the sum of these 4 resistances, or $21 + 21 + 21 + 21 = 84$ ohms. These four resistors could be replaced by one 84 ohm resistor which would cause the same amount of current to flow as the four series filaments cause. The value of resistance which could be used to replace several resistors, and still have the same current flow in the circuit, is called the equivalent resistance. In this example the equivalent resistance, of the four filaments in series, is 84 ohms. The equivalent resistance of series resistors is the sum of the various resistors. Stated mathematically this is:

$$R_t = R_1 + R_2 + R_3 + R_4 + \text{etc.}$$

In this formula R_t stands for the equivalent or total resistance.

Applying this formula to Figure 15 we would have:

$$R_t = R_1 + R_2 + R_3 + R_4$$
$$R_t = 21 + 21 + 21 + 21$$
$$R_t = 84 \text{ ohms.}$$

Figure 17 shows a circuit consisting of three resistors connected in series across a 30 volt battery. Let us determine the equivalent resistance, or in other words the total resistance, of these three resistors. This can be done by applying the formula used in the preceding example.

$$R_t = R_1 + R_2 + R_3$$
$$R_t = 5{,}000 + 10{,}000 + 15{,}000$$
$$R_t = 30{,}000\ \Omega$$

Thus the total opposition offered by the three resistors in the circuit of Figure 17 is 30,000 ohms. The amount of applied voltage is 30 volts as indicated in the schematic diagram. Thus Ohm's Law can be used to determine the amount of current which will flow in the circuit. We will use the formula:

$$I = \frac{E}{R}$$

$$I = \frac{30}{30{,}000}$$

$I = .001$ ampere or 1 mA.

Thus our computations have indicated that 1 milliampere of current flows from the negative terminal of the battery through the 5,000 ohm resistor, through the 10,000 ohm resistor, through the 15,000 ohm resistor, then through the milliammeter to the positive terminal of the battery. As mentioned previously, the current flowing through the series circuit will cause voltage drops to appear in the circuit and since we know the current which flows through each resistor and the ohmic value of the resistor, the value of each voltage drop can be computed. Before proceeding with the following calculations see if **you** can determine the amount of voltage drop across each resistor.

Ohm's Law states: $E = I \times R$. The voltage drop across a particular resistor is equal to the current through **that** resistor times the ohmic value of that resistor.

To find the voltage drop across R_1:

$$E = I \times R$$

(The current is 1 milliampere and the resistance of R_1 is 5,000 ohms.)

$$E = .001 \times 5000$$
$$E = 5 \text{ volts}$$

Note: This is the voltage drop across resistor R_1.

To find the voltage drop across R_2:

$$E = I \times R$$

(The current is still 1 milliampere and the resistance of R_2 is 10,000 ohms.)

$$E = .001 \times 10{,}000$$
$$E = 10 \text{ volts}$$

Note: This is the voltage drop across resistor R_2.

To find the voltage drop across R_3:

$E = I \times R$ (The current is still 1 milliampere and the resistance of R_3 is 15,000 ohms.)

$E = .001 \times 15{,}000$

$E = 15$ volts. Note: This is the voltage drop across resistor R_3.

The preceding calculations have indicated the amount of voltage drop present across each of the three resistors in the circuit of Figure 17. By tracing the current path as indicated in this figure the polarity of the voltage drops can also be determined. This is shown by the plus and minus signs associated with each resistor in the circuit. (Remember the end of a resistor which the current enters is the negative end of the voltage drop produced across that resistor.)

The total of the voltage drops in the circuit of Figure 17 can be found by adding the three individual voltage drops or, 5 volts + 10 volts + 15 volts = 30 volts. Thus it can be seen that the total of the voltage drops in the circuit equals the voltage source as mentioned previously.

Many of the circuits in electronics equipment consist of series circuits similar in nature to the one shown in Figure 17. Of course, the voltage may be supplied by a power supply instead of the battery indicated in this figure, but for practical purposes, the operation of the circuits is similar. For this reason, you should have a thorough understanding of series circuits. Although a basic understanding can be obtained by merely reading this assignment material, it is advisable for you to carry the process further by analyzing series circuits very carefully and working Ohm's Law problems. It is for this purpose that Figure 18(A) and (B) are shown. Notice that in each case a series circuit is illustrated and the things which should be found out about the circuit are indicated. Work the problems presented by each of these circuits very carefully applying the procedures which have been outlined previously. Then, after you have worked these problems to the best of your ability, refer to the solutions given at the end of this assignment to check your work. In this way you will be able to obtain a complete understanding of the operation of series circuits and Ohm's Law.

Parallel Circuits

Up to this point we have considered series circuits only. These are circuits in which there is only one path for the current. Another type of circuit is the **parallel** circuit. A parallel circuit is a circuit that provides two or more paths for the current.

Figure 19 illustrates a simple parallel circuit. Notice that two resistors are connected to the battery but these resistors are **not** in series since the same current which flows through one does **not** flow through the other. In the schematic diagram of this circuit, also illustrated in Figure 19, the two current paths provided by the parallel circuit are indicated. Notice that one path is provided for the current from the negative terminal of the battery through resistor R_1 back to the positive terminal of the battery. Likewise another path is provided from the negative terminal of the battery through resistor R_2 and back to the positive terminal. Thus this circuit provides two paths for the current. Such a circuit is called a parallel circuit.

Figure 20 illustrates another parallel circuit in which there are four parallel resistors. That is resistors R_1, R_2, R_3, and R_4 provide four paths for the current as illustrated in the schematic diagram of Figure 20. As would be expected from the fact that the current paths in the parallel circuit are entirely different from the current path in a series circuit, the operation of a parallel circuit is entirely different from the operation of a series circuit. The manner in which a parallel circuit operates will be considered in detail in a later assignment. This type of circuit is shown at the present time only to illustrate the various types of arrangements possible.

The Series-Parallel Circuit

The third general type of circuit is the series-parallel circuit. As indicated by the name of this type of circuit, a series-parallel circuit consists of a combination of series and parallel circuits. Such a circuit is illustrated in Figure 21. Notice in this figure that the current leaving the negative terminal of the battery flows through resistor R_1 until it reaches the point at which resistors R_2 and R_3 are connected together. At this point two paths are provided for the current, part of the current flowing through R_2 and the remaining portion of the current flowing through resistor R_3. The two portions of the current then combine once more at the junction of resistors R_2 and R_3 and the total current returns to the battery. In this circuit, the combination formed by resistors R_2 and R_3 forms a parallel circuit as two paths are provided for the current. However, this parallel circuit is in series with the resistor R_1. After analyzing the circuit of Figure 21 it can be seen that a thorough understanding of a series-parallel circuit requires the understanding of the operation of a parallel circuit. Since parallel circuits will not be taken up at this time, the series-parallel circuit cannot be explained in detail. However, the series-parallel circuit shown in Figure 21 should illustrate to you a number of possible ways in which a circuit can be arranged.

Summary

This assignment has demonstrated the manner in which d-c circuits operate. The relationship between voltage, current and resistance is a definite factor and conforms to the operations known as Ohm's Law. When two of these factors are known, the third can be found by applying Ohm's Law. The three Ohm's Law formulas are:

For finding the current: $I = \frac{E}{R}$

For finding the resistance: $R = \frac{E}{I}$

For finding the voltage: $E = I \times R$

In these formulas I stands for current in **amperes**, E stands for voltage in **volts**, R stands for resistance in **ohms**.

There are three types of circuit arrangements which will be encountered. These are: series circuits, parallel circuits, and series-parallel circuits. The manner in which a circuit arrangement can be identified is by checking the current path. If the same current flows through each component in the circuit the arrangement is a series circuit. If two or more paths, or branches, are provided for the current, the circuit is a parallel circuit. If the current flows through one or more components and then branches before completing its path the circuit arrangement is a series-parallel circuit.

In a series circuit the term **equivalent resistance** is used to indicate a resistance which could be inserted in the circuit in place of the various series resistors and cause the same current flow in the circuit. The equivalent resistance of series resistors can be found by applying the formula:

$$R_t = R_1 + R_2 + R_3 + R_4 + \text{etc.}$$

In other words, the equivalent resistance of series resistors is equal to the sum of the individual resistors.

The importance of having a thorough understanding of the operation of d-c circuits and the application of Ohm's Law cannot be overemphasized. All electronics circuits contain sources of voltage, and resistances; therefore, current flows. In many actual electronics circuits, two of these electrical quantities will be known and it will be necessary to apply Ohm's Law to find the third. For this reason, you are advised to review this assignment several times as you progress in the training program. Also, when you encounter the application of Ohm's Law in the future assignments and any question arises in your mind, you should refer to this assignment to clarify the condition. It is also a very good plan to practice drawing the various types of circuits as you encounter them. For example, after you have completed your work on the portion of the assignment dealing with series circuits, draw several series circuits on a sheet of scratch paper and then compare your drawings with those of the series circuits in the assignment. In this manner you will become more familiar with the various types of circuits as you encounter them.

"HOW TO PRONOUNCE..."

(Note: the accent falls on the part shown in CAPITAL letters.)

polarity	(po-LAIR-i-tee)
pulsating	(PUL-sate-ing)

Answers to Exercise Problems

Problems Presented By Circuits Of Figure 8

Problem 8(A) I = 5 amperes. This answer is obtained as follows:

$$I = \frac{E}{R}$$

$$I = \frac{10}{2}$$

$$I = 5 \text{ amperes}$$

Problem 8(B) R = 20 ohms as found by the following calculations:

$$R = \frac{E}{I}$$

$$R = \frac{100}{5}$$

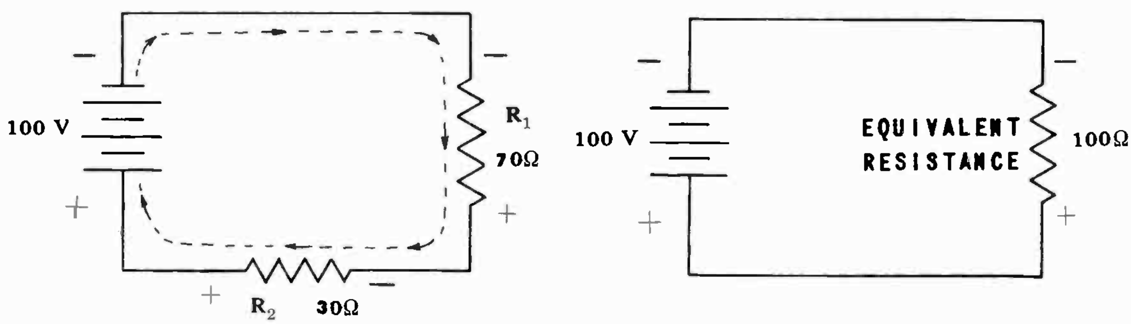
$$R = 20\ \Omega$$

Problem 8(C) E = 40 volts as found by the following calculations:

$$E = I \times R$$
$$E = 4 \times 10$$
$$E = 40 \text{ volts.}$$

Problems Presented By Circuits Of Figure 18

Problem 18(A)

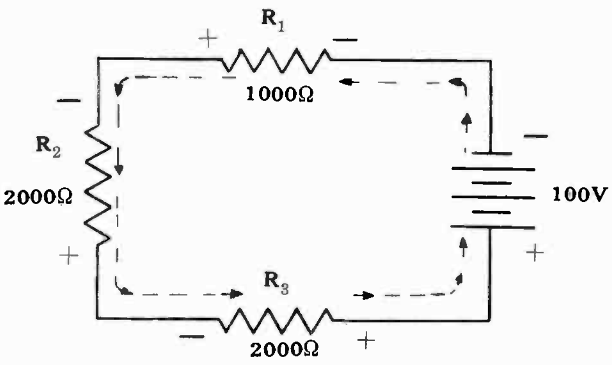


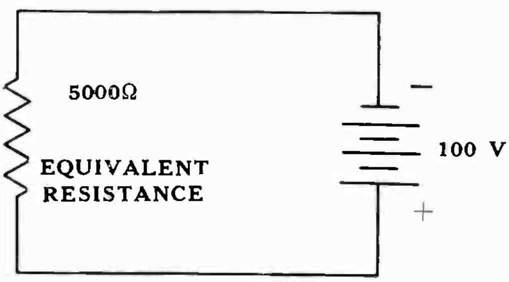
$$R \text{ Equiv.} = R_1 + R_2 = 70 + 30$$
$$R \text{ Equiv.} = 100\ \Omega$$

$$I = \frac{E}{R \text{ Equiv.}} = \frac{100}{100} = 1 \text{ ampere}$$

$$E_{R1} = I \times R_1 = 1 \times 70$$
$$E_{R1} = 70 \text{ volts}$$
$$E_{R2} = I \times R_2 = 1 \times 30$$
$$E_{R2} = 30 \text{ volts}$$

Problem 18(B)





R Equiv. $= R_1 + R_2 + R_3 = 1000 + 2000 + 2000$

R Equiv. $= 5000\ \Omega$

$$I = \frac{E}{R \text{ Equiv.}} = \frac{100}{5000}$$

$I = .02$ ampere

$ER_1 = I \times R_1 = .02 \times 1000$

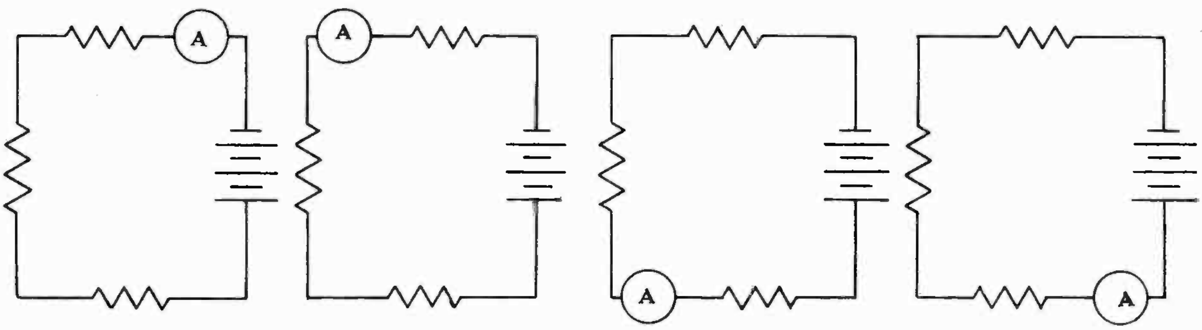
$ER_1 = 20$ volts

$ER_2 = I \times R_2 = .02 \times 2000$

$ER_2 = 40$ volts

$ER_3 = 40$ volts since R_3 is the same value as R_2.

Four Ways of Connecting Milliammeter In Circuit



Test Questions

Be sure to number your Answer Sheet Assignment 6.
Place your Name and Associate Number on **every** Answer Sheet.

Send in your answers for this assignment immediately after you finish them. This will give you the greatest possible benefit from our personal grading service.

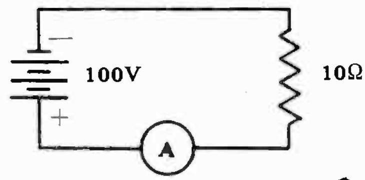
1. Is the current flowing in a circuit measured in: (a) amperes, (b) volts, or (c) ohms?

2. (a) What factor in an electrical circuit **causes** current to flow? VOLTAGE
   (b) In an electrical circuit what factor **opposes** the flow of the current? RESISTANCE

3. (a) What term is used to indicate one million ohms? MEG.
   (b) What term is used to represent one thousandth ampere? MILLI.

4. List the three forms of Ohm's Law.
   E=I×R I=E/R R=E/I

5. In the accompanying diagram how much current would be indicated by the ammeter? (Solve by Ohm's Law and **show your work.**)



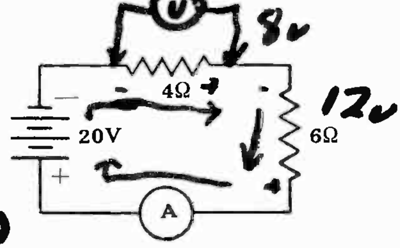
I=E/R 100/10 = 10 10 AMPS

6. Explain the difference between an open circuit, and a closed circuit or complete circuit. A COMPLETE CURRENT PATH

7. If an Ohm's Law problem gave a current value of 5 ma., to what should it be changed before working the problem? .005A

8. In a series circuit is the current the same in all parts of the circuit?
   YES

9. (a) In the accompanying circuit diagram what is the equivalent resistance of the two resistors in series? 10Ω
   (b) How much current would be indicated by the ammeter in this circuit? 2A



10. (a) On your Answer Sheet redraw the circuit of Question 9 indicating by means of a dotted line with arrow heads the direction of the current flow in the circuit. Also indicate by means of (+) and (—) signs the polarity of the voltage drop across each resistor. Also indicate the amount of voltage present across each resistor and show how a voltmeter would be connected to measure the voltage drop across the 4 ohm resistor.

VOLTAGE SOURCES

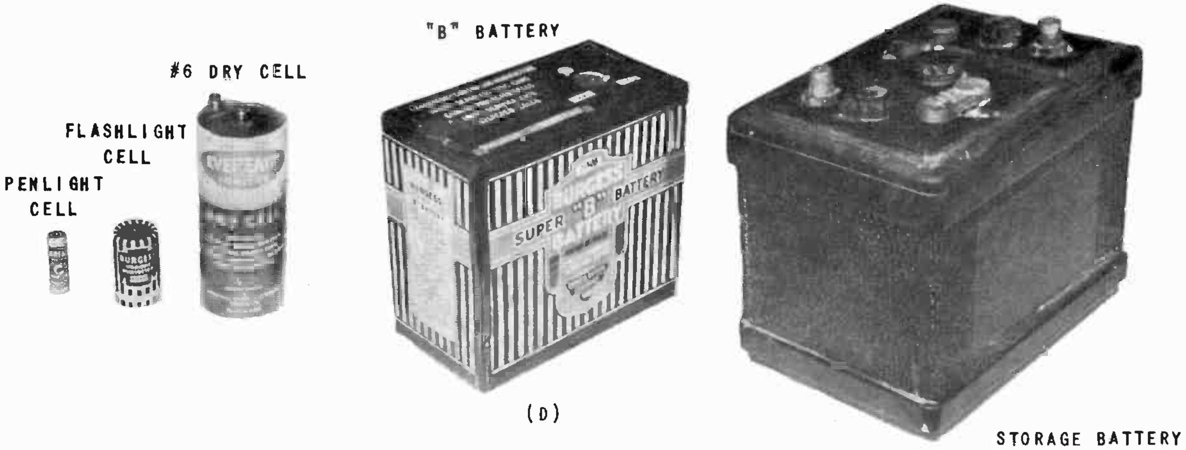


FIGURE I

VOLTAGE SOURCES

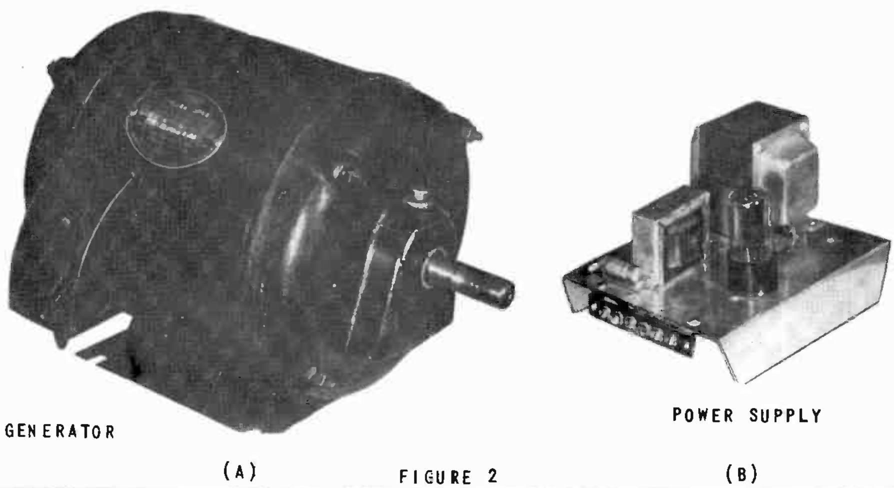


FIGURE 2

BATTERY SYMBOL

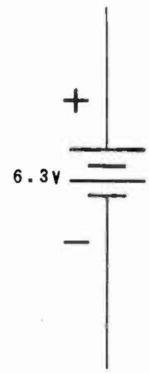


FIGURE 3

ILLUSTRATING TYPICAL VOLTMETERS AND METHOD OF MEASURING EMF OR VOLTAGE

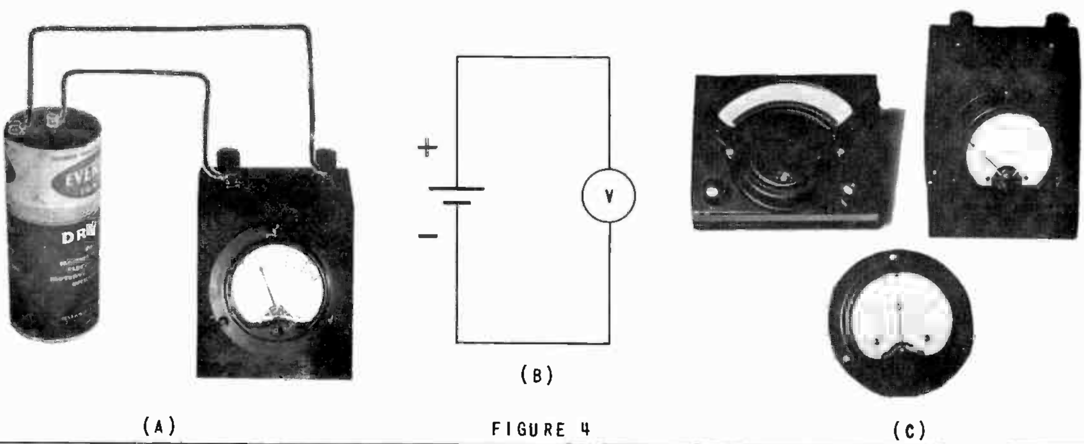


FIGURE 4

MEASURING CURRENT IN A CIRCUIT

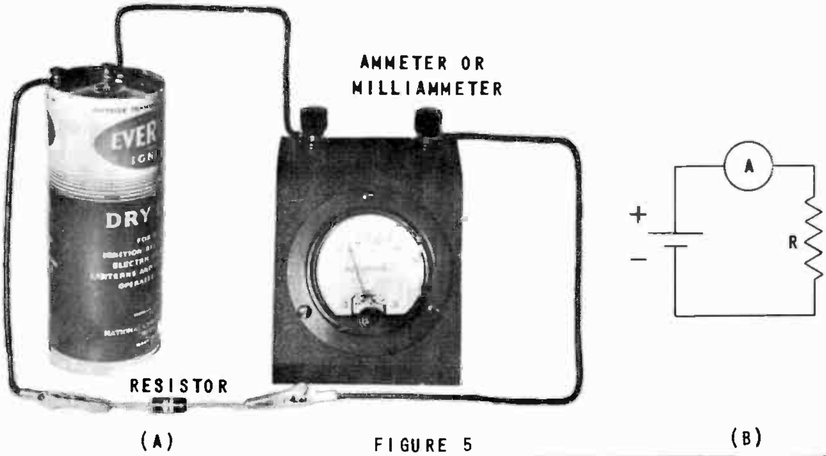
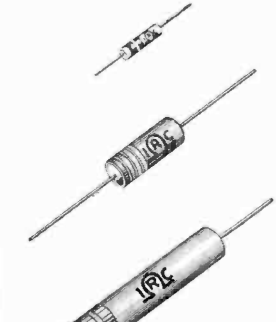


FIGURE 5

SOME TYPICAL FIXED RESISTORS



(Courtesy International Resistance Co.)

FIGURE 6

OHM'S LAW DEMONSTRATION

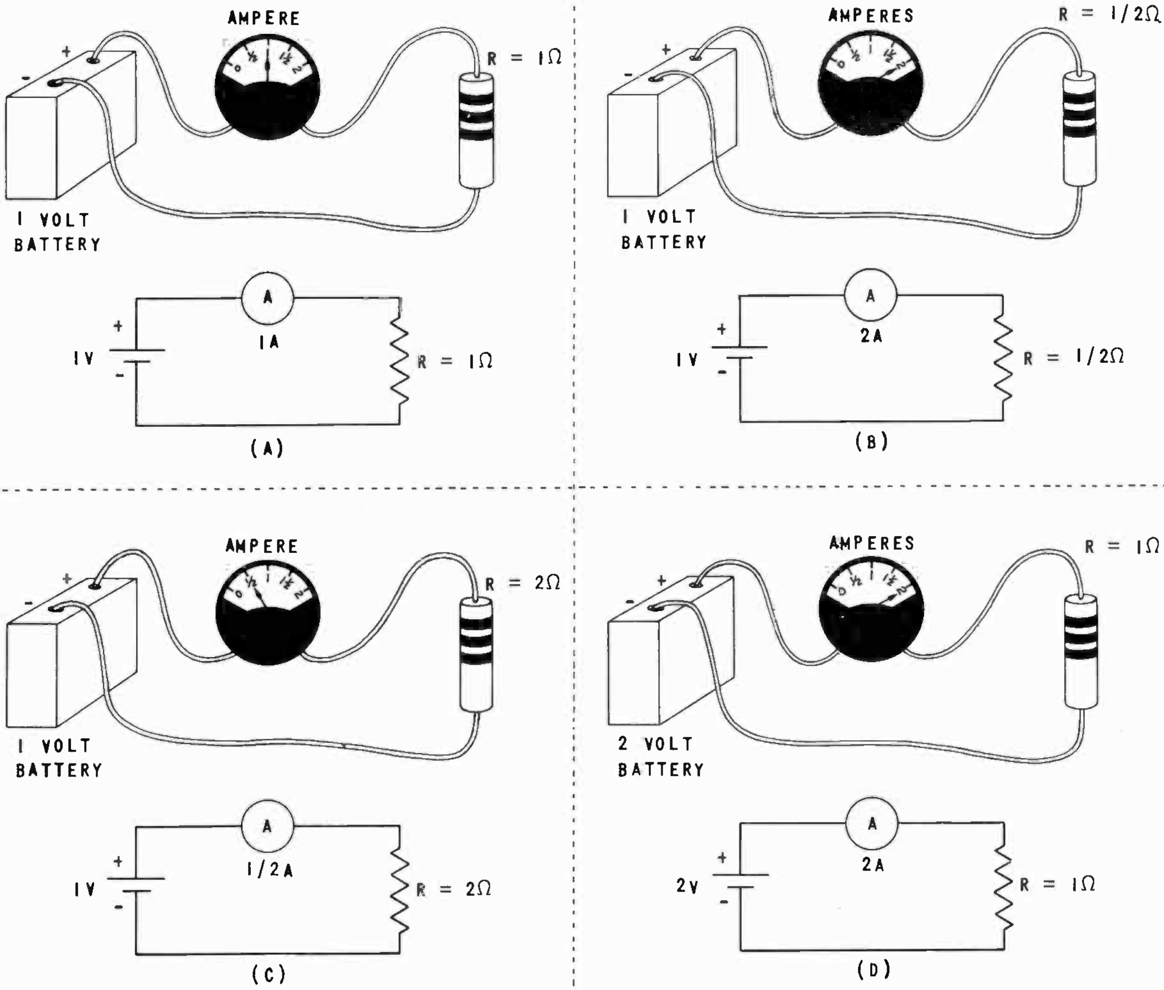


FIGURE 7

CIRCUITS FOR OHM'S LAW PROBLEMS

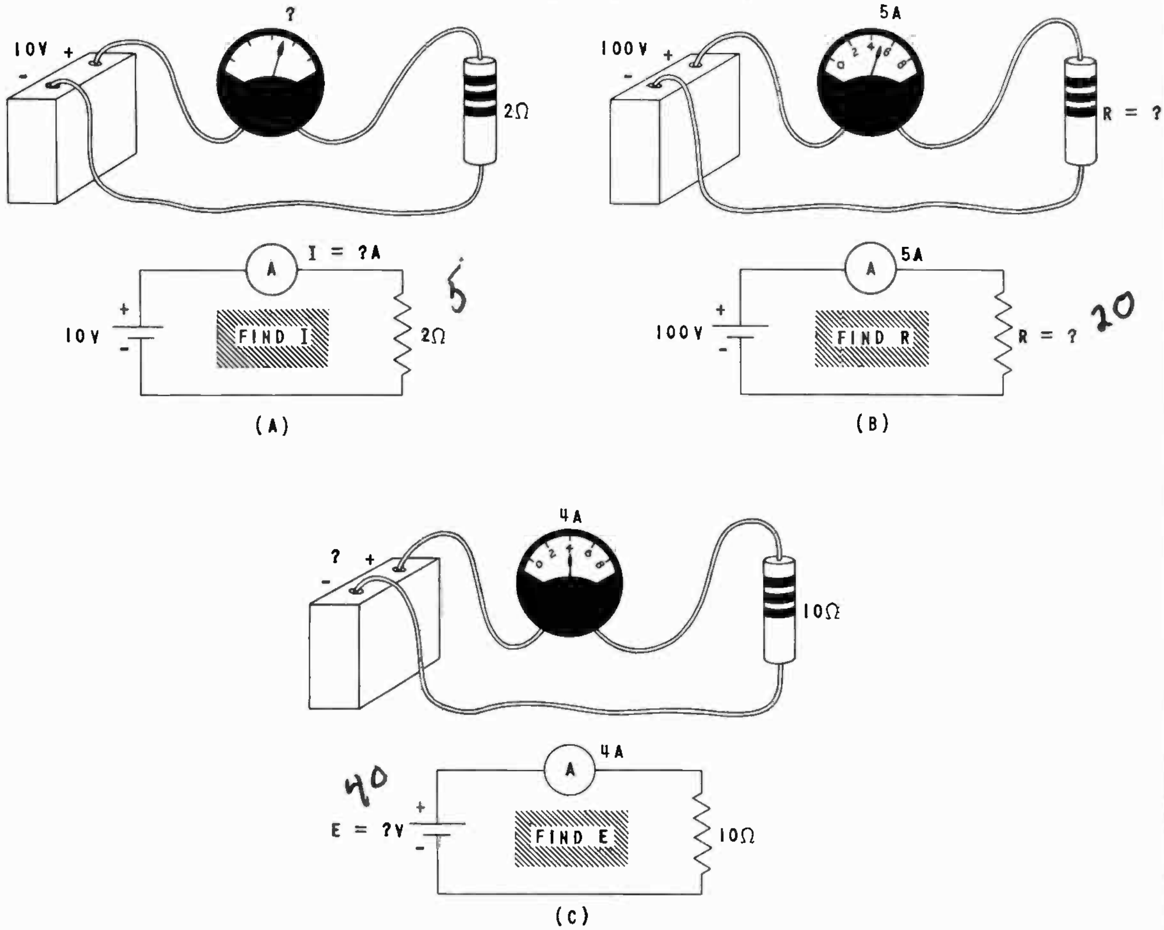


FIGURE 8

OPEN CIRCUIT

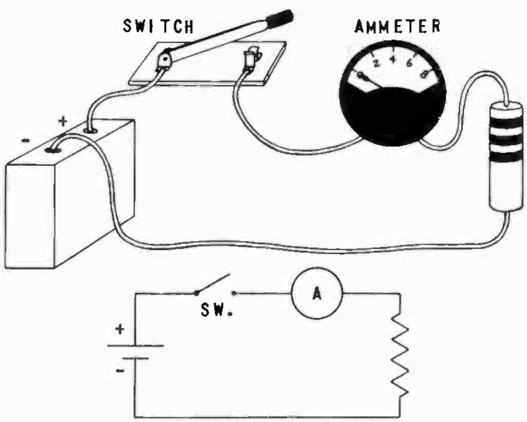


FIGURE 9

SHORT CIRCUIT

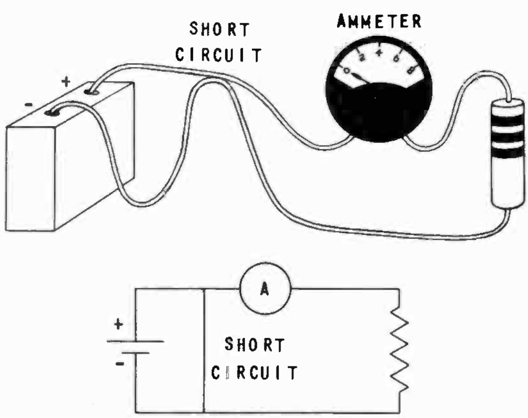
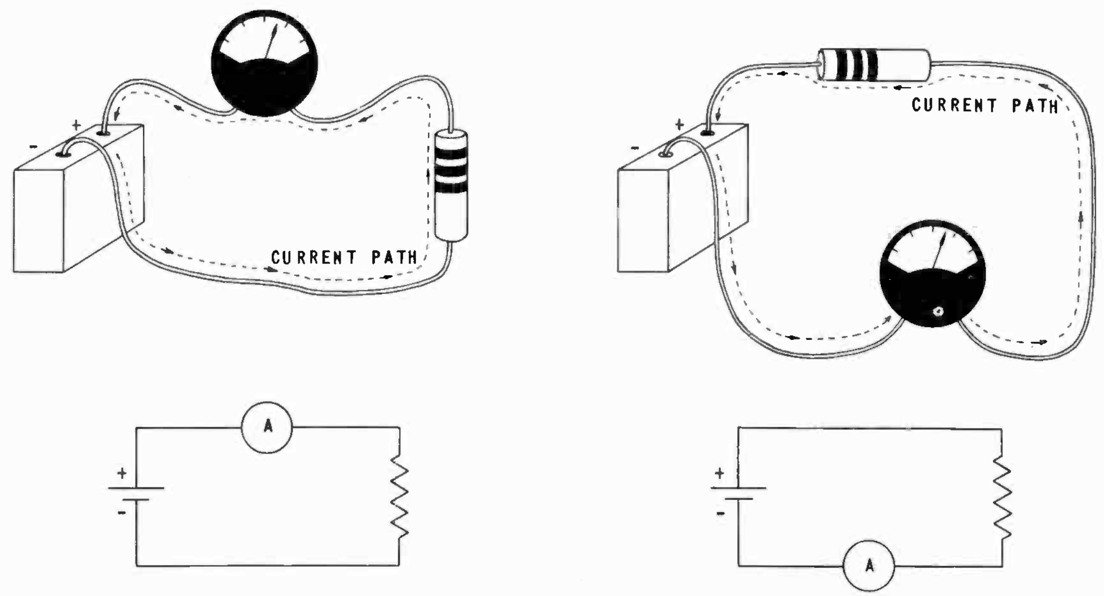


FIGURE 10

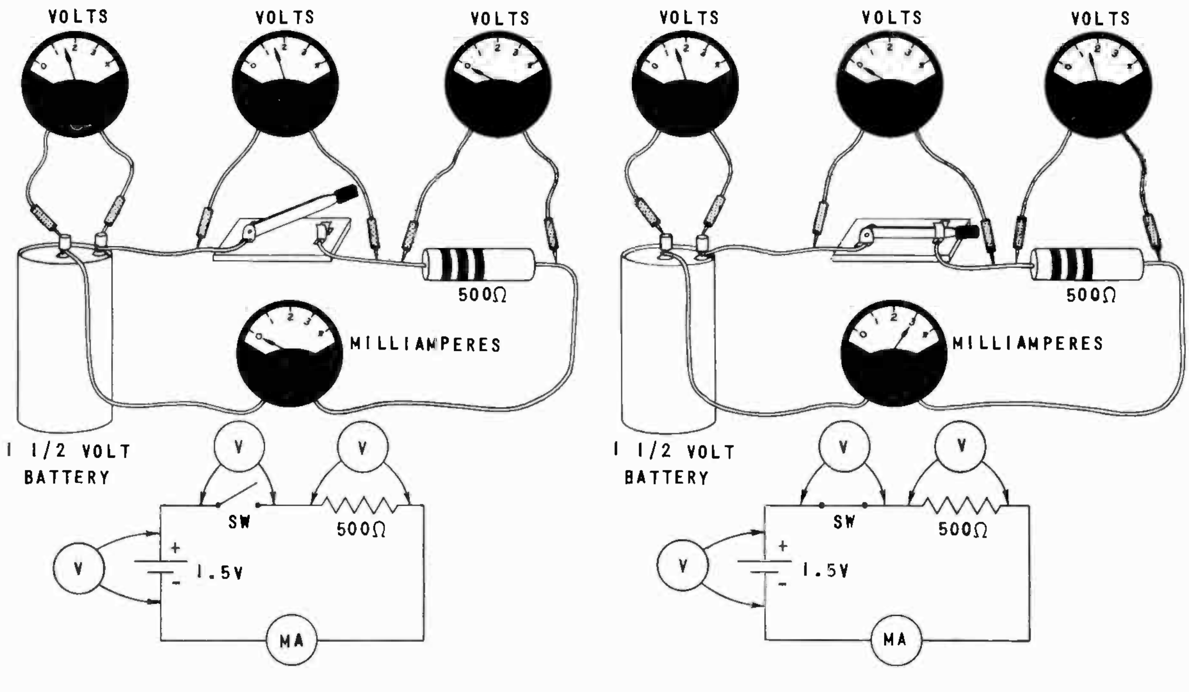
SIMPLE SERIES CIRCUITS ILLUSTRATING CURRENT PATHS



(A) (B)

FIGURE 11

DEMONSTRATING ACTION OF A SWITCH AND PROPER METHOD OF CONNECTING METERS IN A CIRCUIT



(A) (B)

FIGURE 12

DEMONSTRATING THE USE OF OHM'S LAW IN SERIES CIRCUITS

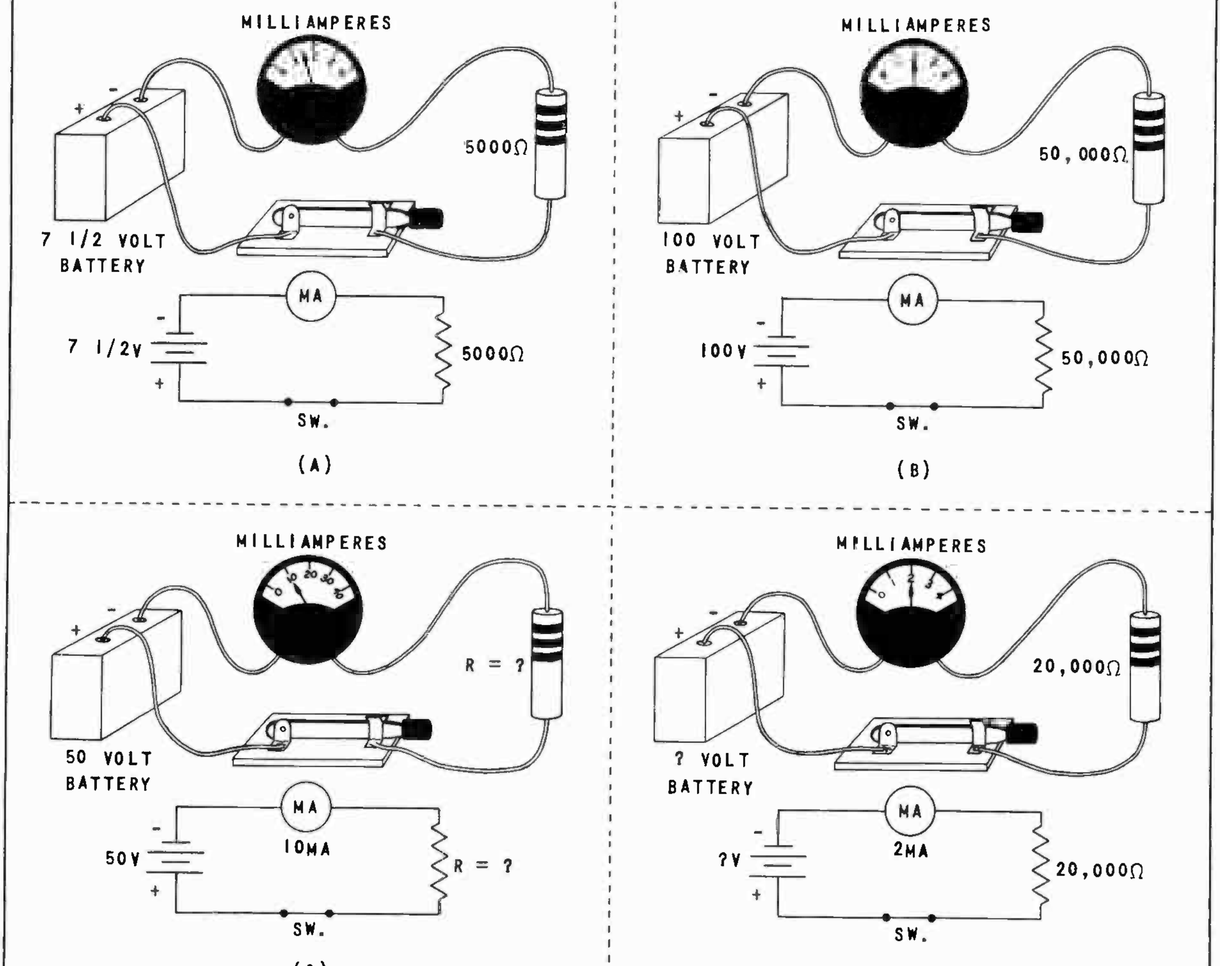


FIGURE 13

SERIES CIRCUIT CONTAINING TWO RESISTORS

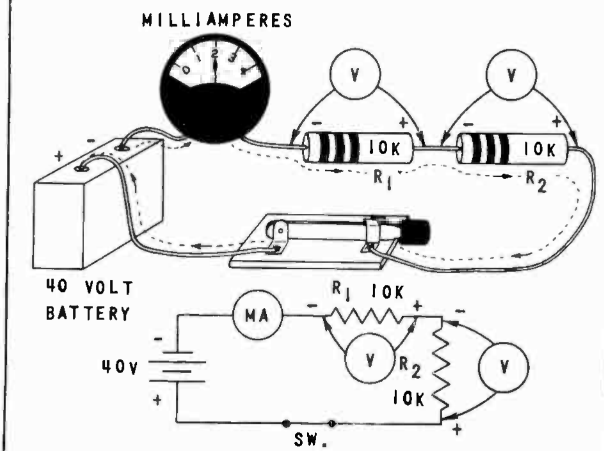


FIGURE 14

SERIES CIRCUIT CONTAINING SEVERAL RESISTANCES

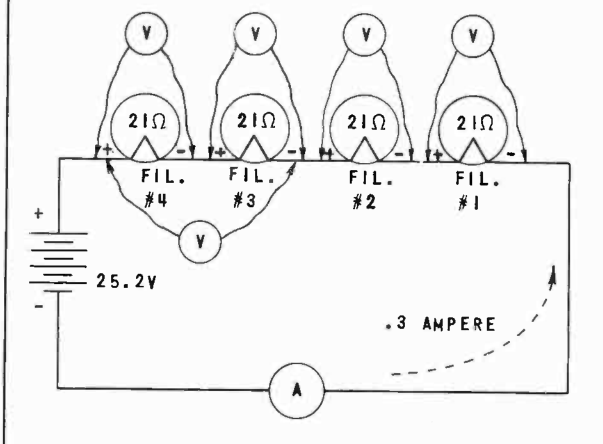


FIGURE 15

DEMONSTRATING THAT THE CURRENT IS THE SAME AT ANY POINT IN A SERIES CIRCUIT

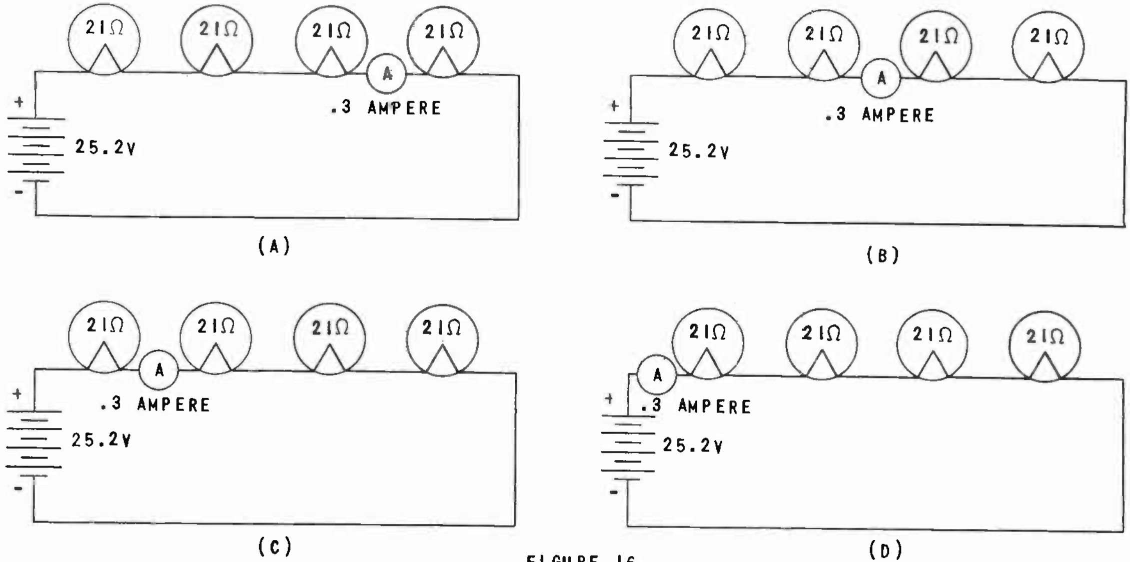


FIGURE 16

SERIES CIRCUIT

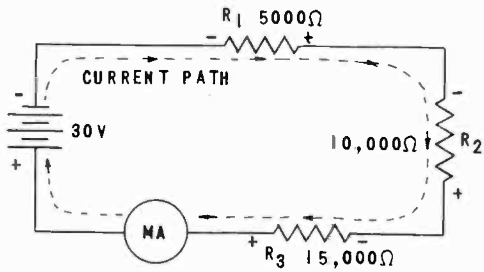


FIGURE 17

PARALLEL CIRCUIT

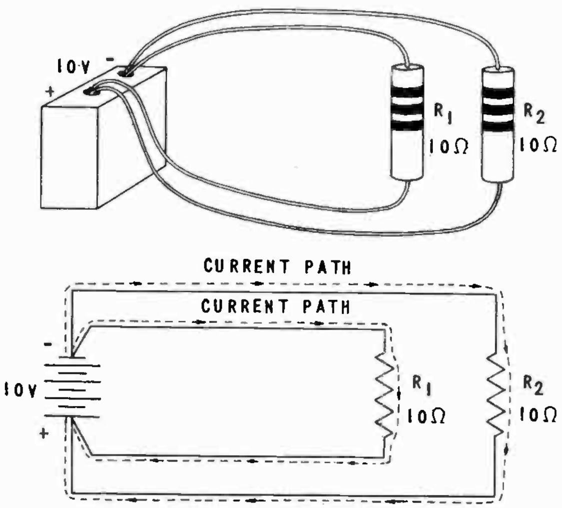
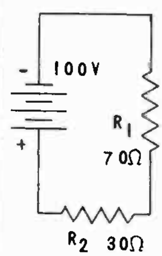


FIGURE 19

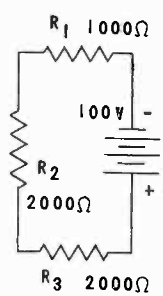
SERIES CIRCUIT PROBLEMS



FIND:
EQUIVALENT RESISTANCE OF R_1 AND R_2.
CURRENT WHICH WOULD FLOW IN CIRCUIT.
VOLTAGE DROP ACROSS R_1.
VOLTAGE DROP ACROSS R_2.

SHOW:
CURRENT PATH BY MEANS OF DOTTED LINE.
POLARITY OF EACH VOLTAGE DROP.

(A)



FIND:
EQUIVALENT RESISTANCE OF R_1, R_2 AND R_3.
CURRENT WHICH WOULD FLOW IN CIRCUIT.
VOLTAGE DROP ACROSS R_1.
VOLTAGE DROP ACROSS R_2.
VOLTAGE DROP ACROSS R_3.

SHOW:
CURRENT PATH BY MEANS OF DOTTED LINE.
POLARITY OF EACH VOLTAGE DROP.
FOUR WAYS IN WHICH A MILLIAMMETER COULD BE CONNECTED IN CIRCUIT.

(B)

FIGURE 18

PARALLEL CIRCUIT

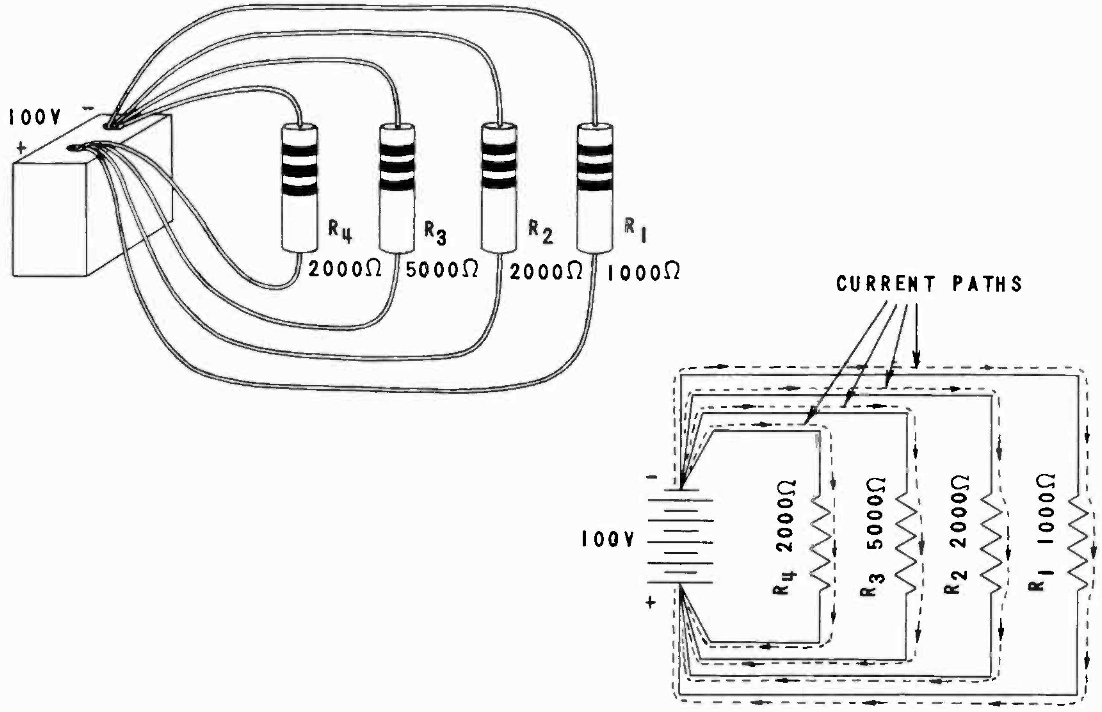


FIGURE 20

SERIES-PARALLEL CIRCUIT

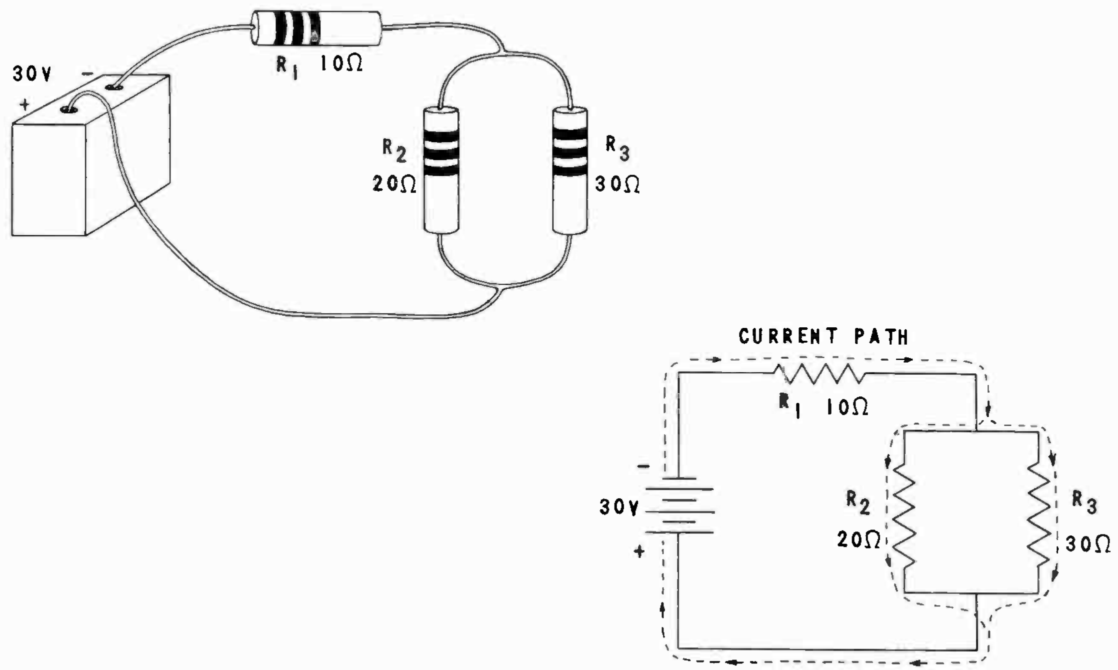


FIGURE 21