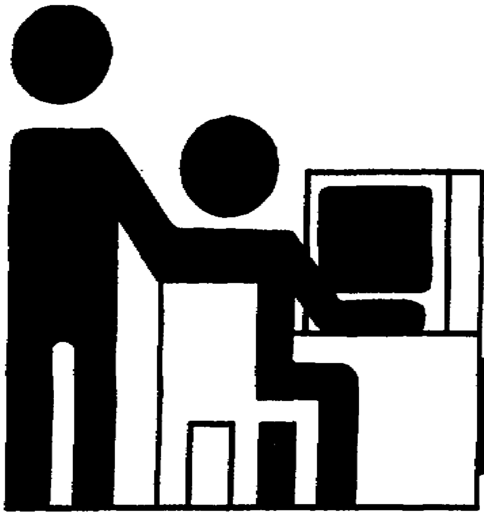
SUBCOURSE
OD1633

EDITION
8

BASIC ELECTRONICS

THE ARMY INSTITUTE FOR PROFESSIONAL DEVELOPMENT

ARMY CORRESPONDENCE COURSE PROGRAM



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US ARMY ARMAMENT REPAIR
TECHNICIAN WARRANT OFFICER
ADVANCED CORRESPONDENCE COURSE

MOS/SKILL LEVEL: 421A

BASIC ELECTRONICS

SUBCOURSE NO. OD1633

US Army Correspondence
Course Program

6 Credit Hours

GENERAL

The objective of this subcourse is to introduce the student to the principles of basic electronics. In task one of the subcourse text, the student will learn the elements of electricity, safety requirements, voltage, current, resistance functions, Ohm's law, and resistor color codes.

In task two, the student will employ the knowledge gained in task one to measure and compute voltage. In addition, we will cover the three types of circuits that will be encountered in the electronics field and how batteries are connected to each of these circuits.

Six credit hours are awarded for successful completion of this subcourse.

Lesson 1: BASIC ELECTRONICS

TASK 1: Describe the elements of electricity, safety requirements, voltage, current, resistance functions, Ohm's law, and resistor color codes.

TASK 2: Describe series, parallel, and series-parallel circuits, compute and measure voltage, and the current of batteries connected in series-parallel circuits.

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STUDENT NOTES

LESSON 1

BASIC ELECTRONICS

TASK 1. Describe the elements of electricity, safety requirements, voltage, current, resistance functions, Ohm's law, and resistor color codes.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within one hour

REFERENCES

No supplementary references are needed for this task.

1. Introduction

Electricity and electronics are a part of our everyday lives. When we get up in the morning the first thing we do is turn on the light; we have just used electricity. The television that we watch, the stereos and radios that we listen to, our heat, our air conditioning, frequently even our cooking all use electricity in one form or another.

Electricity also has many applications from a military standpoint. The sighting devices for artillery pieces often use electricity to enable the gun crew to aim the weapon at night, or in periods of limited visibility. The fire direction computers are used to semi-accurately aim weapons and weapons systems.

As an Armament Repair Technician you will manage activities and personnel engaged in intermediate direct support/intermediate general support (IDS/TGS) and depot maintenance of field artillery and related fire control devices. Since many of these devices work on electrical principles, you should possess a thorough knowledge of the principles of electricity and electronics. The purpose of this subcourse is to introduce the student to the principles of basic electronics. This task will discuss what electricity is, the safety requirements and first aid for working around electricity, voltage, current, resistance, Ohm's law, and the color codes for resistors.

In the succeeding task, we will cover the different types of circuits, the means of measuring and computing voltage, and current of batteries, especially those in a series-parallel circuit.

2. Electricity

a. *Composition of Matter.* Matter is defined as anything that occupies space and has weight; that is, the weight and dimensions of all matter can be measured. Examples of matter include air, water, automobiles, clothing, and even our own bodies. Therefore, we can say that matter may be found in any one of three states: solid, liquid, and gaseous.

All material substances, solids, liquids, and gases, are made up of tiny particles known as atoms. Atoms combine in small groups of two or more to form molecules. Atoms can be further subdivided into smaller particles, some of which have positive electrical charges and others which have negative electrical charges. The atoms of different material substances are discussed in the following paragraphs.

(1) There are over 100 different basic materials in the universe. These basic materials are called elements. Iron is one element, copper, aluminum, oxygen, hydrogen, and mercury are other elements. An element gets its name from the fact that it cannot be broken down easily into simpler (or more elemental) substances. In other words, these 100 basic elements are the building materials from which the universe is made. Close study of any one of these elements reveals that it is made up of those same basic particles, having a positive or a negative electrical charge.

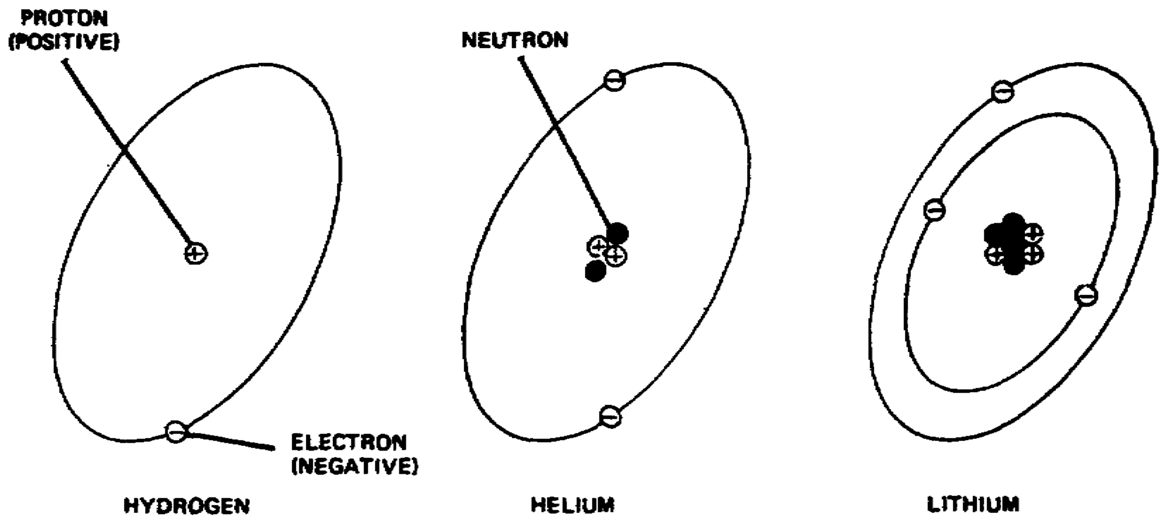
(2) The basic particles that make up all the elements, and thus the universe, are called protons, electrons, and neutrons. A proton is a basic

particle having a single positive charge; a group of protons produce a positive electrical charge. An electron is a basic particle having a single negative charge; therefore, a group of electrons produce a negative electrical charge. A neutron is a basic particle having no charge; a group of neutrons, therefore, would have no charge.

First, let us examine the arrangement of atoms in some elements, starting with the simplest of all, hydrogen. The atom of hydrogen consists of one proton, around which is circling one electron (figure 1 on the following page). There is an attraction between the two particles, because negative and positive electrical charges always attract each other. Opposing the attraction between the two particles, and thus preventing the electron from moving into the proton, is the centrifugal force on the electron, caused by its circular path around the proton. This is the same sort of balance achieved when a ball tied to a string is whirled in a circle in the air. The centrifugal force exerted tries to move the ball out of its circular path, and is balanced by the string (which can be defined as the attractive force). If the string should break, the centrifugal force would cause the ball to fly away. This is what happens at times with atoms. The attractive force between the electron and proton is sometimes not great enough to hold the electron in its circular path, and the electron gets away.

A slightly more complex atom, shown in figure 1, is the atom of helium. Notice that there are two protons in the center. Because there is an additional proton in the center, or nucleus, of the atom, an electron must be added so as to keep the atom in electrical balance. Notice also that there are additional particles in the nucleus; these are called neutrons. Neutrons overcome the tendency of the two protons to move apart from each other. Just as unlike electrical charges attract, so do like electrical charges repel. Electrons repel electrons. Protons repel protons, except when neutrons are present. Though neutrons have no electrical charge, they cancel out repelling forces between protons in an atomic nucleus and thus hold the nucleus together.

FIGURE 1. COMPOSITION OF MATTER.

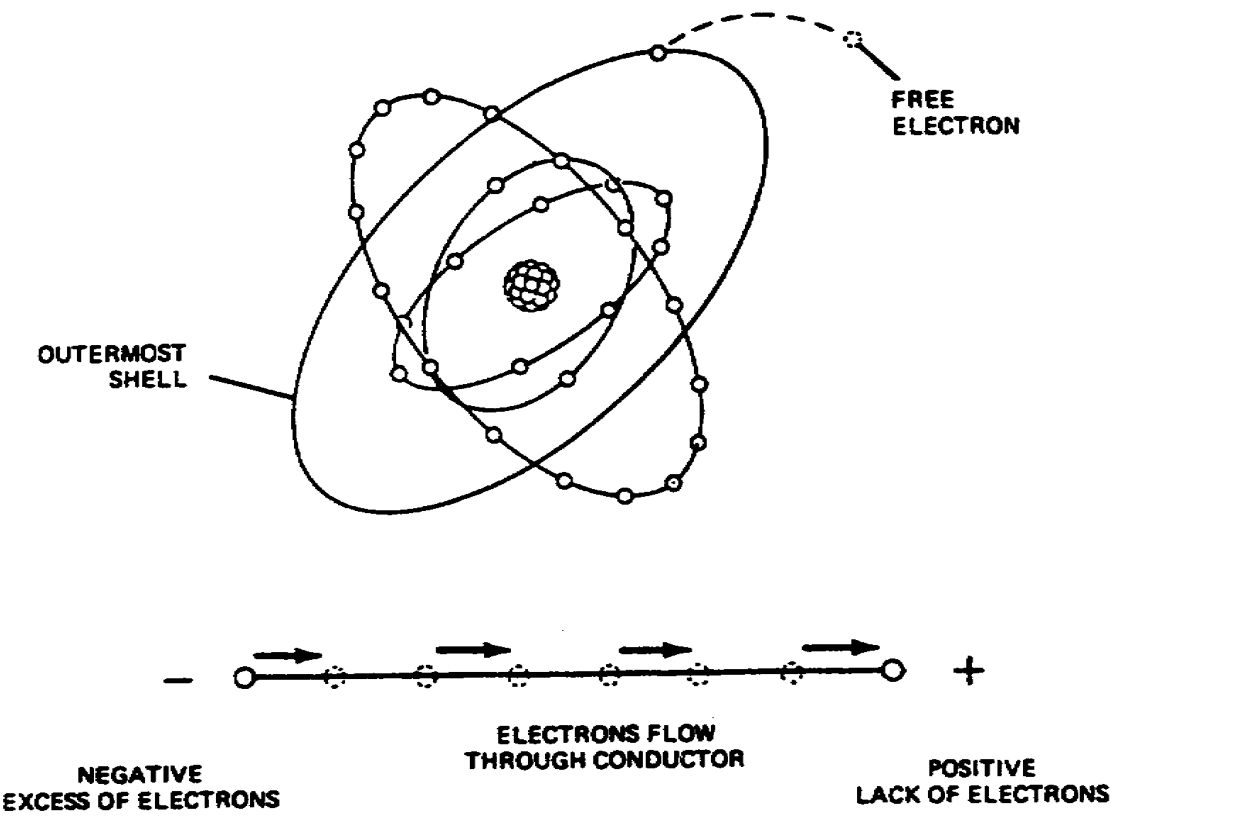


A still more complex atom, shown in figure 1, is the atom of lithium, a light, soft metal. Note that a third proton has been added to the nucleus and that a third electron is now circling around the nucleus. There are also two additional neutrons in the nucleus; these are needed to hold the three protons together.

The atoms of other elements can be analyzed in a similar manner. As the atomic scale increases in complexity, protons and neutrons are added one by one to the nucleus and electrons to the outer circles or shells, as they are termed by scientists. After lithium comes beryllium with four protons and five neutrons, boron with five protons and five neutrons, carbon with six and six, nitrogen with seven and seven, oxygen with eight and eight, and so on. In each of these, there are normally the same number of electrons circling the nucleus as there are protons in the nucleus.

b. *Composition of Electricity.* When there are more than two electrons in an atom, they will move about the nucleus in different size shells. The innermost shells of the atom contain electrons that are not easily freed and are referred to as bound electrons. The outermost shell will contain what are referred to as free electrons (see figure 2 on the following page). These free electrons differ

FIGURE 2. COMPOSITION OF ELECTRICITY.



from bound electrons in that they can be moved readily from their orbit.

If a point that has an excess of electrons (negative) is connected to a point that has a shortage of electrons (positive), a flow of electrons (electrical current) will flow through the connector (conductor) until an equal electric charge exists between the two points.

c. *Electron Theory of Electricity.* A charge of electricity is formed when numerous electrons break free of their atoms and gather in one area (see figure 2). When the electrons begin to move in one direction (as along a wire, for example), the effect is a flow of electricity, an electric current. Actually, electric generators and batteries could be called electron pumps, because they remove electrons from one part of an electric circuit. For example, a generator takes electrons away from the positive terminal and concentrates them at the negative terminal. Because the electrons repel each other (like electrical charges repel), the electrons push out through the circuit and flow to the positive terminal (unlike electrical charges attract). Thus, we can see that an electric current is, in fact, a flow of electrons from negative to positive.

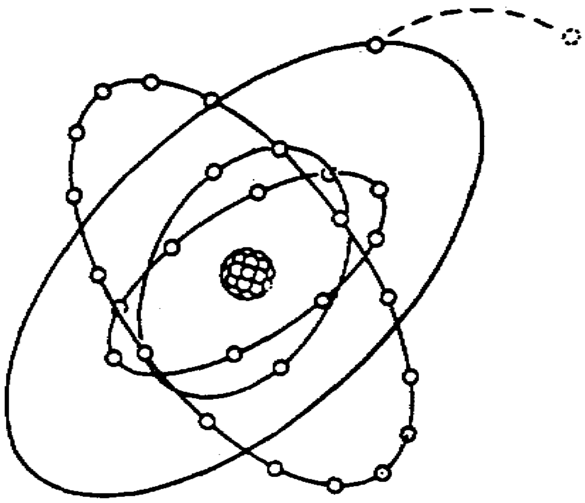
This is the reverse of the original idea of current flow. Before scientists understood what electric current was, they assumed that the current flowed from positive to negative. Their studies showed that this was wrong; they learned that current is the electron movement from negative (concentration of electrons) to positive (lack of electrons).

d. *Conductors and Insulators.* Any material that will allow electric current to flow through it is an electrical conductor. Any material that blocks electric current flow is an electrical insulator. Conductors are used in automotive equipment to carry electric current to the electrical system components. Insulators are necessary to keep the electric current from taking a shorter route instead of going to the intended component. The electrical properties of a substance depend mainly on the number of electrons in the outermost orbits of its atoms which cannot, at any time, contain more than eight electrons.

(1) *Conductors.* Whenever there are less than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be free. This will cause the substance to permit free motion of electrons, making it a conductor (see figure 3 on the following page).

Electrical energy is transferred through conductors by means of the movement of free electrons migrating from atom to atom within the conductor. Each electron moves a short distance to the neighboring atom, where it replaces one or more electrons by forcing them out or their orbits. The replaced electrons repeat this process in nearby atoms until the movement is transmitted throughout the entire length of the conductor, creating a current flow. Copper is an example of a good conductor because it has only one free electron. This electron is not held very strongly in its orbit and can get away from the nucleus very easily. Silver is an even better conductor of

FIGURE 3. CONDUCTORS.



A. COPPER - CONDUCTOR
(ONE FREE ELECTRON)

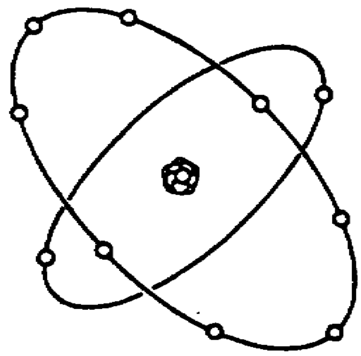
electricity but it is too expensive to be used in any great quantity. Because of this, copper is the conductor most widely used in various military applications.

(2) *Insulators.* Whenever there are more than four electrons in the outer orbits of the atoms of a substance, these electrons will tend to be bound, causing restriction of free movement, making the substance an insulator (figure 4 on the following page). Common insulating substances are rubber, plastic, Bakelite, varnish, and fiberboard.

3. Safety Requirements

Personnel should constantly be on the alert for any signs or indications which might indicate a malfunction of electric equipment. Besides the more obvious visual signals, the reaction of other senses, such as bearing, smell, and touch, can warn of possible electrical malfunctions. Examples of such signs are: fire, smoke, sparks, arcing, or an unusual sound from an electric motor. Frayed and damaged cords which feel warm to the touch; slight shocks felt when handling electrical equipment; unusually hot-running electric motors, and other electrical equipment which either fails to operate or operates irregularly; and electrical equipment which produces excessive vibrations are all indications of malfunctions. When any of the above signs are noted, they are to be reported **immediately** to a qualified technician. **DO NOT DELAY.** Do not operate faulty equipment. Above all, do not attempt to make any repairs yourself if you are not qualified to do so. Stand clear of any suspected hazard and instruct others to do likewise until the malfunctioning piece of equipment has been tested and/or the problem corrected.

FIGURE 4. INSULATORS.



B. NEON - INSULATOR
(OUTER SHELL FULL, NO FREE
ELECTRONS)

Warding signs have been placed for your protection. To disregard them is to invite personal injury as well as possible damage to equipment. Switches and receptacles with a temporary warning tag, that indicate work is being performed, are not to be touched.

When work must be performed in the immediate vicinity of electrical equipment, check with the technician responsible for the maintenance of the equipment so you can avoid any potential hazards.

Because of the danger of fire, damage to equipment, and injury to personnel, all repair and maintenance work on electrical equipment must be done only by authorized persons. Keep your hands off all equipment which you have not been specifically authorized to handle. Particularly, stay clear of electrical equipment opened for inspection, testing, and servicing.

Covers for all fuse boxes, junction boxes, switch boxes, and wiring accessories should be kept closed. Any cover which is not closed, or is missing, should be reported to the technician responsible for its maintenance. Failure to do so may result in injury to personnel and/or damage to equipment in the event accidental contact is made with exposed live circuits.

a. *Electrical Fires.* Carbon dioxide (CO_2) is the main firefighting agent used in electrical fires. However, potassium chloride or purple K (PKP) is also used to fight electrical fires, because it is a noncorrosive agent. In other words, CO_2 will corrode electrical circuits and PKP will not. Both substances are nonconductive and, therefore, are safe to use in terms of electrical safety. If, however, the horn of a CO_2 fire extinguisher is allowed to come in contact with an energized electrical circuit, an electrical shock may be transmitted to the person handling the fire extinguisher.

The very qualities which cause CO_2 and PKP to be valuable extinguishing agents also makes them dangerous to life. When they replace the oxygen in the air to the extent that combustion cannot be sustained, breathing also cannot be sustained. Exposure of a person to high concentrations of CO_2 or PKP will cause suffocation. For this reason, if you must fight an electrical fire in an enclosed space, wear an oxygen producing respirator and have assistants standing by to render assistance.

b. *First Aid for Electric Shock.* A fatal shock can occur from 0.1 amperes of current. However, voltages as low as 30 volts have been recorded as causing fatality. It is current which kills, not voltage.

A person who has stopped breathing is not necessarily dead, but is in immediate danger. Life is dependent upon oxygen, which is breathed into the lungs and then carried by the blood to every body cell. Since body cells cannot store oxygen, and since the blood can hold only a limited amount (and that only for a short time), death will surely result from continued lack of breathing.

However, the heart may continue to beat for some time after breathing has stopped, and the blood may still be circulated to body cells. Since the blood will, for a short time, contain a small supply of oxygen, the body cells will not die immediately. For a very few minutes, there is some chance that the person's life may be saved.

The process by which a person who has stopped breathing can be saved is called **ARTIFICIAL VENTILATION** (**RESPIRATION**). The purpose of artificial respiration is to force air out of the lungs and into the lungs, in rhythmic alternation, until natural breathing is re-established. Artificial respiration should be given only when natural breathing has stopped. It should **NOT** be given to any person who is breathing naturally. You should not assume that an individual who is unconscious due to electrical shock has stopped breathing. To tell if someone suffering from an electrical shock is breathing, place your bands on the person's sides, at the level of the lowest ribs. If the victim is breathing, you will usually be able to feel the movement. Remember: **DO NOT GIVE ARTIFICIAL RESPIRATION TO A PERSON WHO IS BREATHING NATURALLY.** Records show that seven out of ten victims of electric shock were revived when artificial respiration was started in **less than three minutes**. After three minutes, the chances of revival decrease rapidly.

Once it has been determined that breathing has stopped, the person nearest the victim should start the artificial respiration without delay and send others for assistance and medical aid. The only logical, permissible delay is that required to free the victim from contact with the electricity in the quickest, safest way. This step, while it must be done quickly, must be done with great care; otherwise, there may be two victims instead of one. In the case of portable electric tools, lights, appliances, equipment, or portable outlet extensions, this should be done by turning off the power supply. This can be accomplished in one of two ways; (1) by simply turning off the switch, (2) by removing the power cord from the receptacle. If the switch or receptacle cannot be quickly located, the suspected electrical device may be pulled free of the victim. Other persons arriving on the scene must be clearly warned not to touch the suspected equipment until it has been deenergized. Aid should be enlisted to unplug the device as soon as possible. The injured person should be pulled free of contact with stationary equipment (such as a bus bar) if the equipment cannot be quickly deenergized, or if considerations of military operation or unit survival prevent immediate shutdown of the circuits.

This can be done quickly and safely by carefully applying the following procedures:

First, protect yourself with dry insulating material. Then use a dry board, belt, clothing, or other available nonconductive material to free the victim from electrical contact. **DO NOT TOUCH THE VICTIM UNTIL THE SOURCE OF ELECTRICITY HAS BEEN REMOVED.**

Once the victim has been removed from the electrical source, it should be determined if the person is breathing. If the person is not breathing, a method of artificial respiration is used. Sometimes victims of electrical shock suffer cardiac arrest (heart stoppage) as well as loss of breathing. Artificial respiration alone is not enough in cases where the heart has stopped. A technique known as cardio-pulmonary resuscitation (CPR) has been developed to provide aid to a person who has stopped breathing and suffered a cardiac arrest. CPR is relatively easy to learn and is taught in courses available from the American Red Cross and most post installations, as well as from other civilian and military sources.

4. Voltage, Current, and Resistance

Every electrical circuit includes voltage, current, and resistance. Even a simple circuit consisting of a battery, wires, and a lamp has voltage, current, and resistance. The battery supplies the voltage which forces current through the wires and the lamp. The wires and lamp offer a certain amount of resistance to the current. The way in which current, voltage, and resistance affect each other is expressed in Ohm's law. Ohm's law uses "I" to represent current, "E" to represent voltage, and "R" to represent resistance.

In the paragraphs that follow, we will define the voltage, resistance, and current relationship stated by Ohm's law, and provide examples of applying Ohm's law to a basic electrical circuit.

a. *Amperage (Current) and Voltage.*

(1) *Amperes.* Current flow, or electron flow, is measured in amperes (I). While it is normally considered that one ampere is a rather small current of electricity (approximately what a 100-watt light bulb would draw), it actually involves a tremendous flow of electrons. More than six billion electrons a second are required to make up one ampere.

(2) *Voltage.* Electrons are caused to flow by a difference in electron balance in a circuit; that is, when there are more electrons in one part of a circuit than in another, the electrons will move to where they are lacking. This difference in electron concentration is called potential difference or voltage (E). The higher the voltage, the greater the electron imbalance becomes. The greater this electron imbalance, the harder the push on the electrons (more electrons repelling each other) and the greater the current of electrons in the circuit. When there are many electrons concentrated at the negative terminal of a generator (with a corresponding lack of electrons at the positive terminal), there is a strong repelling force on the electrons moving in the wire. This is exactly the same as saying that the higher the voltage, the more electric current will flow in a circuit; all other things, such as resistance, being equal.

b. *Resistance.* Even though a copper wire will conduct electricity with relative ease, it still offers resistance to electron flow. This resistance (R) is caused by the energy necessary to break the outer shell of electrons free, and the collisions between the atoms of the conductor and the free electrons. It takes force (or voltage) to overcome the resistance encountered by the flowing electrons. This resistance is expressed in units called Ohms. The resistance of a conductor varies with its length, cross-sectional area, composition, and temperature.

A long wire offers more resistance than a short wire of the same cross-sectional area. The electrons have farther to travel.

Some elements can lose electrons more readily than other elements. Copper loses electrons easily, so there are always many free electrons in a copper wire. Other elements, such as iron, do not lose their electrons quite as easily, so there are fewer free electrons in an iron wire (comparing it to a copper wire of the same size). Thus, with fewer free electrons, fewer electrons can push through an iron wire; that is, the iron wire has a higher resistance than the copper wire.

A small wire (in thickness or cross-sectional area) offers more resistance than a large wire. In the small wire, there are fewer free electrons (because fewer atoms), and thus fewer electrons can push through.

Most metals show an increased resistance with an increase in temperature, while most nonmetals show a decrease in resistance with an increase in temperature. For example, glass (a nonmetal) is an excellent insulator at room temperature but is a very poor insulator when heated to the point of becoming red.

In the next paragraphs, voltage, current, and resistance will be applied to Ohm's law.

5. Ohm's Law

a. *Defining Ohm's Law.* The general statements about voltage, current, and resistance can all be related in a statement known as Ohm's law, named for the scientist George Simon Ohm, who first stated that relationship. This law says that voltage is equal to amperage times Ohms. Or, it can be stated as the mathematical formula:

$$E = I \times R$$

where E is voltage in volts, I is current in amperes, and R is resistance in Ohms. For the purpose of solving problems, the Ohm's law formula can be expressed three ways:

- o To find voltage: $E = I \times R$
- o To find amperage: $I = \frac{E}{R}$

- To find resistance: $R = \dfrac{E}{I}$

This formula is a valuable one to remember because it makes understandable many of the things that happen in an electrical circuit. For instance, if the voltage remains constant, the current flow goes down if the resistance goes up. An example of this would be a lighting circuit that is going bad in a truck. Suppose the wiring circuit between the battery and the lights has deteriorated, due to connections becoming poor, strands in the wire breaking, switch contacts becoming dirty, or other similar problems. All of these conditions reduce the electron path or, in other words, increases resistance. And, with this increased resistance, less current will flow. The voltage of the battery stays the same (for example, 12 volts). If the resistance of the circuit when new (including light bulbs) was 6 Ohms, then 2 amperes will flow. To satisfy the equation, 12 (volts) must equal amperes times Ohms resistance (2 x 6). If the resistance goes up to 8 Ohms, only 1.5 amperes can flow. The increased resistance cuts down the current flow and, consequently, the amount of light.

b. *Applying Ohm's Law.* By using Ohm's law, you are able to find the resistance of a circuit, knowing only the voltage and the current in the circuit.

In any equation, if all the variables (parameters) are known except one, that unknown can be found. For example, using Ohm's law, if current (I) and voltage (E) are known, resistance (R) (the only parameter not known) can be determined as follows:

- Formula: $R = \dfrac{E}{I}$

Referring to figure 5 (on the following page), where E equals 10 volts and I equals I ampere, solve for R, using the above equation:

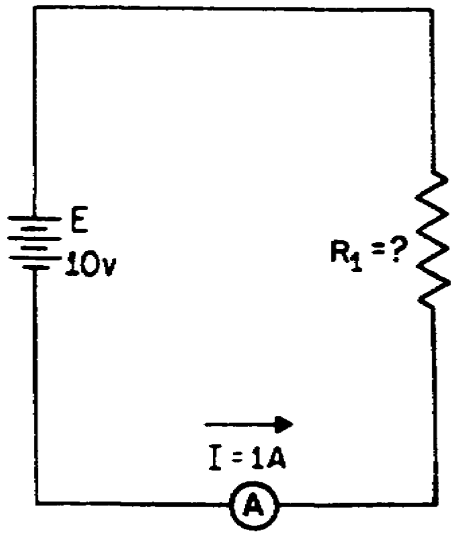
- Given: E = 10 volts

  I = 1 ampere

o Solution: $R = \dfrac{\text{10 volts}}{\text{1 ampere}}$

R = 10 Ohms

FIGURE 5. DETERMINING RESISTANCE IN A BASIC CIRCUIT.



Therefore, resistance equals 10 Ohms for the circuit shown in figure 5.

Using the equation below and the circuit shown in figure 6 on the following page, we will solve for the unknown E.

o Formula: E = I x R

o Given: I = 0.5 ampere

R = 45 Ohms

o Solution: E = 0.5 ampere x 45 Ohms

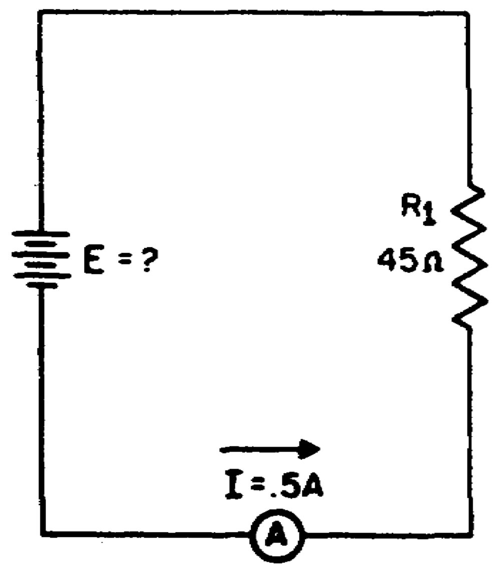
E = 22.5 volts

Therefore, voltage equals 22.5 volts for the circuit shown in figure 6.

The Ohm's law equation and its various forms may be obtained readily, with the aid of figure 7 on page

17. The circle containing E, I, and R is divided into two parts, with E above the line and I and R below the line. To determine an unknown quantity, first cover that quantity with a finger. The position of the uncovered letters in the circle will indicate the mathematical operation to be performed. For example, to find I, cover the I

FIGURE 6. DETERMINING VOLTAGE IN A BASIC CIRCUIT.



with a finger. The uncovered letters indicate that E is to be divided by R,

$$\text{or} \quad I = \frac{E}{R}$$

To find the formula for E, cover E with your finger. The result indicates that I is to be multiplied by R, or E = IR. To find the formula for R, cover R. The result indicates the R is to be divided by I,

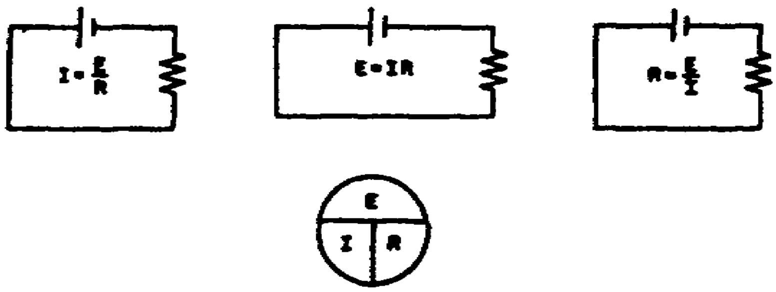
$$\text{or} \quad R = \frac{E}{I}$$

You are cautioned not to rely wholly on the use of this diagram when you transpose the Ohm's law formulas. The diagram should be used to supplement your knowledge of the algebraic method. Algebra is a basic tool in the solution of electrical problems.

6. Electrical Resistors

Resistance is a property of every electrical component. Sometimes its effects will be undesirable. However, resistance is used in many varied ways. Resistors are components manufactured to possess specific values of resistance. They are manufactured in many types and sizes. When drawn using its schematic representation, a resistor is shown as a series of jagged lines, as illustrated in figure 8 on the following page.

FIGURE 7. OHM'S LAW TN DIAGRAM FORM.



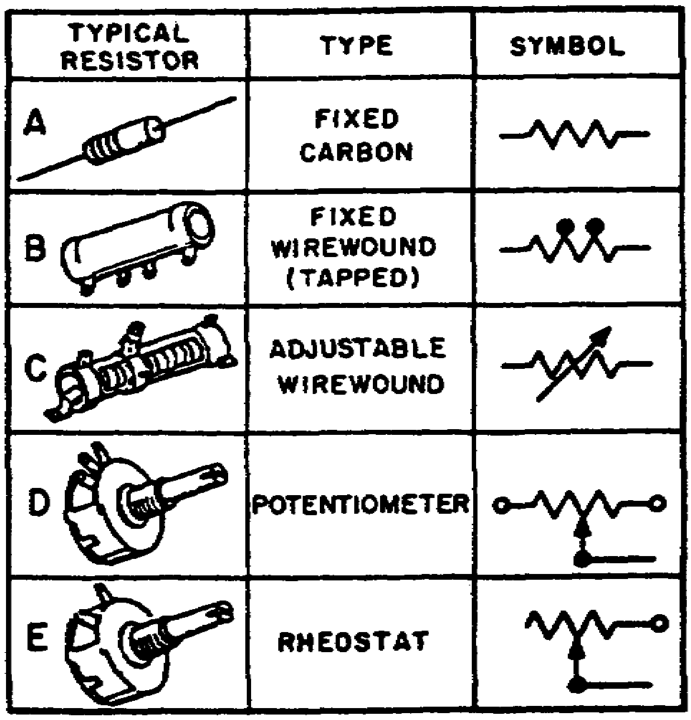
a. *Composition of Resistors.* One of the most common types of resistor is the molded composition, usually referred to as the carbon resistor. These resistors are manufactured in a variety of sizes and shapes.

The chemical composition of the resistor determines its resistance and is accurately controlled by the manufacturer in the development process. They are made in values that range from one Ohm to millions of Ohms. The physical size of the resistor is related to its wattage rating, which is the ability of the resistor to dissipate beat caused by the resistance.

Carbon resistors, have as their principal ingredient the element carbon. In the manufacture of carbon resistors, fillers, or binders are added to the carbon to obtain various resistor values. Examples of these fillers are clay, Bakelite, rubber and talc. These fillers are doping agents and cause the overall conduction characteristics to change.

Carbon resistors are the most common resistors found because they are easy to manufacture, inexpensive, and have a tolerance that is adequate for most electrical and electronic applications. Their prime disadvantage is that they have a tendency to change value as they age. One other disadvantage of carbon resistors is their limited power-handling capacity.

FIGURE 8. TYPES OF RESISTORS.



The disadvantage of carbon resistors can be overcome by the use of wirewound resistors. Wirewound resistors have very accurate values and possess a higher current-handling capability than carbon resistors. The material most frequently used to manufacture wirewound resistors is German silver which is composed of copper, nickel, and zinc. The qualities and quantities of these elements that are present in the wire determine the resistivity of the wire. The resistivity of the wire is the measure (or ability) of the wire to resist current. Usually the percentage of nickel in the wire determines the resistivity. One disadvantage of the wirewound resistor is that it takes a large amount of wire to manufacture a resistor of high ohmic value, thereby increasing the cost. A variation of the wirewound resistor provides an exposed surface to the resistance wire on one side. An adjustable tap is attached to this side. Such resistors, sometimes with two or more adjustable taps, are used as voltage dividers in power supplies and other applications where a specific voltage is desired to be "tapped" off.

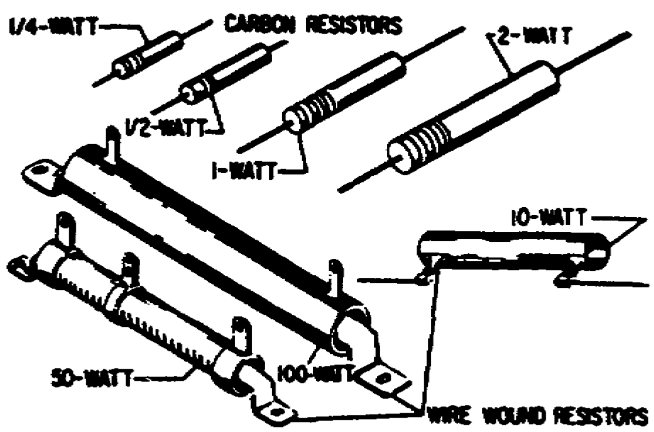
b. *Fixed and Variable Resistors.* There are two kinds of resistors, fixed and variable. The fixed resistor will have one value and will never change (other than through temperature, age, etc.). The resistors (shown in A and B, figure 8 on the previous page) are classed as fixed resistors. The tapped resistor illustrated in B has several fixed taps and makes more than one resistance value available. The sliding contact variable resistor shown in C has an adjustable collar that can be moved to tap off any resistance within the ohmic value range of the resistor.

There are two types of variable resistors, one called a potentiometer and the other a rheostat (see views D and E, figure 8). An example of a potentiometer is the volume control on your radio, and an example of the rheostat is the dimmer control for the dash lights in an automobile. There is a slight difference between them. Rheostats usually have two connections, one fixed and the other movable. Any variable resistor can properly be called a rheostat. The potentiometer always has three connections, two fixed and one movable. Generally, the rheostat has a limited range of values and a high current-handling capability. The potentiometer has a wide range of values, but it usually has a limited current-handling capability. Potentiometers are always connected as voltage dividers.

c. *Wattage Rating.* When a current is passed through a resistor, heat is developed within the resistor. The resistor must be capable of dissipating this heat into the surrounding air; otherwise, the temperature of the resistor rises causing a change in resistance, or possibly causing the resistor to burn out.

The ability of the resistor to dissipate heat depends upon the design of the resistor itself being dependent on the amount of surface area which is exposed to the air. A resistor designed to dissipate a large amount of heat must therefore have a large physical size. The heat dissipating capability of a resistor is measured in watts. A watt is the practical unit of electrical power. It is the amount of power used when one ampere of direct current (dc) flows through a resistance of one Ohm. Some of the more common wattage ratings of carbon resistors are: one-eighth watt, one-fourth watt, one-half watt, one watt, and two watts. In some of the newer state-of-the-art circuits of today, much smaller wattage resistors are used. The higher the wattage rating of the resistor, the larger is the physical size. Resistors that dissipate very large amounts of power (watts) are usually wirewound resistors. Wirewound resistors with wattage ratings up to 50 watts are not uncommon. Figure 9 shows some resistors which have different wattage ratings. Notice the relative sizes of the resistors.

FIGURE 9. RESISTORS OF DIFFERENT WATTAGE RATINGS.



d. *Standard Color Code System.* In the standard color code system, four bands are painted on the resistor, as shown in figure 10 on the next page.

The color of the first band indicates the value of the first significant digit. The color of the second band indicates the value of the second significant digit. The third color band represents a decimal multiplier by which the first two digits must be multiplied to obtain the resistance value of the resistor. The colors for the bands and their corresponding values are shown in table 1 on the following page.

FIGURE 10. RESISTOR COLOR CODES.

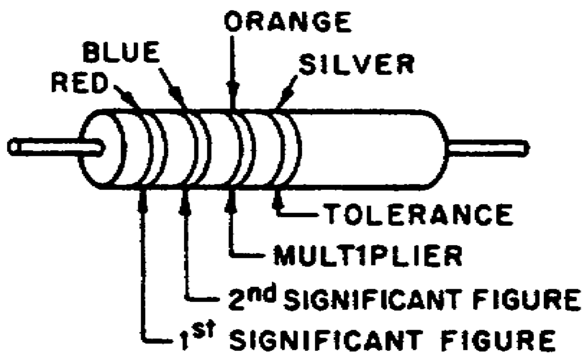


TABLE 1. STANDARD COLOR CODE FOR RESISTORS.

COLOR	SIGNIFICANT FIGURE	DECIMAL MULTIPLIER	RESISTANCE TOLERANCE	RELIABILITY LEVEL PER 1000 HRS.
BLACK	0	1	PERCENT ±	
BROWN	1	10	---	1%
RED	2	100	---	.1%
ORANGE	3	1,000	---	.01%
YELLOW	4	10,000	---	.001%
GREEN	5	100,000	---	
BLUE	6	1,000,000	---	
VIOLET	7	10,000,000	---	
GRAY	8	100,000,000	---	
WHITE	9	1,000,000,000	---	
GOLD	---	.1	5	
SILVER	---	.01	10	
NO COLOR	---		20	

Use the example colors shown in figure 10. Since red is the color of the first band, the first significant digit is 2. The second band is blue; therefore, the second significant digit is 6. The third band is orange, which indicates that the number formed as a result of reading the first two bands is multiplied by 1000. In this case 26 x 1000 = 26,000 Ohms. The last band on the resistor indicates the tolerance; that is, the manufacturer's allowable deviation from the numerical value given on the resistor. In this instance its color is silver, and the tolerance is 10 percent plus or minus the value of the resistor. The allowed limit of variation in ohmic value of this particular resistor is 23,400 to 28,600 Ohms.

When measuring resistors you will find situations in which the quantities to be measured may be extremely large, and the resulting number using the basic unit, the Ohm, may prove too cumbersome. Therefore, a metric system prefix is usually attached to the basic unit of measurement to provide a more manageable unit. Two of the most commonly used prefixes are kilo and mega. Kilo is the prefix used to represent thousand and is abbreviated k. Mega is the prefix used to represent million and is abbreviated M.

Simplifying the Color Code. Resistors are the most common components used in electronics. The technician must identify, select, check, remove, and replace resistors. Resistors and resistor circuits are usually the easiest branch of electronics to understand.

The resistor color code sometimes presents problems to a technician. It really should not, because once the resistor color code is learned, he should remember it for the rest of his life.

Black, brown, red, orange, yellow, green, blue, violet, gray, and white is the order of colors the technician should know automatically. There is a memory aid that will help in remembering the code in its proper order. Each word starts with the first letter of the colors.

Bad Boys Run Over Yellow Gardenias Behind Victory Garden Walls.

or

Black	Bad
Brown	Boys
Red	Run
Orange	Over
Yellow	Yellow
Green	Gardenias
Blue	Behind
Violet	Victory
Gray	Garden
White	Walls

There are many similar memory aid sentences that are known to experienced technicians. An individual might find one of the other sentences easier to remember.

There is still a good chance that a mistake may be made on a resistor's color band. If a mistake is made on the first two significant colors, it usually is not too serious. If a mistake is made on the third band, this is more serious because the value is going to be at least 10 times too high or too low. Some important points to remember about the third band are:

When the third band is...

Black, the resistor must be a value which is less than 100 Ohms.

Red, the resistor must he in hundreds of Ohms.

Orange, the resistor must be in thousands of Ohms.

Yellow, the resistor must be in hundreds of thousands of Ohms.

Green, the resistor must be in megohms.

Blue, the resistor must be in tens of megohms or more.

Red, orange, and yellow are the most common colors for the third band. If this is kept in mind, the selection of resistors from a parts bin will be easier and a lot of trouble can be avoided.

The fourth band, which is the tolerance band, usually does not present too much of a problem. If there is no fourth band, it means that the resistor has a 20 percent tolerance, a silver fourth band has a 10 percent tolerance, and a gold fourth band has a 6 percent tolerance. In some cases, the third band will be silver or gold. It then becomes a multiplier, and you multiply the first two bands by 0.01 if it is silver, and 0.1 if it is gold. Resistors that conform to military specifications have an additional fifth band. The fifth band indicates the reliability level per 1000 hours as follows:

Fifth band color	Level
Brown	1.0%
Red	0.1%
Orange	0.01%
Yellow	0.001%

In applying the reliability level table for a resistor color coded brown, the chance of failure will not exceed 1 percent for every 1000 hours of operation of that resistor. In a piece of equipment containing 10,000 orange fifth band resistors, it means that no more than one resistor will fail during 1000 hours of operation. This is very good reliability.

Both wirewound and composition resistors will not use the resistor color code. These resistors will have the ohmic value and tolerance imprinted on the resistor itself.

7. Conclusion

In this task, we covered the elements of electricity, safety requirements to be used when working around electricity, voltage, current, resistance functions, Ohm's law, and resistor color codes.

In the next task, we will cover series, parallel, and series-parallel circuits. We will also measure and compute voltage and current of batteries connected in series--parallel circuits.

LESSON 1

BASIC ELECTRONICS

TASK 2. Describe series, parallel, and series-parallel circuits, compute and measure voltage, and the current of batteries connected in series-parallel circuits.

CONDITIONS

Within a self-study environment and given the subcourse text, without assistance.

STANDARDS

Within four hours

REFERENCES

No supplementary references are needed for this task.

1. Introduction

In the introduction to task one, we discussed how electricity and electronics affect our daily lives. Additionally, we discussed how electricity and electronics affect us from a military standpoint. As an Armament Repair Technician, you will be involved a great deal with electricity. Therefore, you should possess a very thorough knowledge of electricity and electronics. In task one, the elements of electricity were presented. Additionally, we covered safety requirements, voltage, current, resistance, Ohm's law and the color code system for resistors.

Task two will put some of this information to use by measuring and computing voltage. Also, we will cover the different types of circuits and the connection of batteries in each of these circuits.

2. Series Circuits and Computing and Measuring Voltage

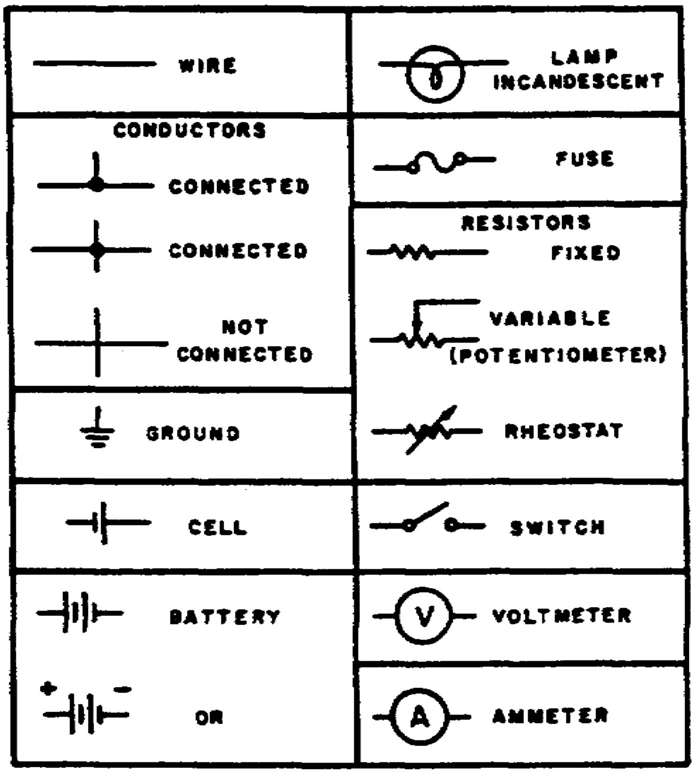
a. *The Basic Electric Circuit.* The flashlight is an example of a basic electric circuit. It contains a source of electrical energy (the dry cells in the flashlight), a load (the bulb) which changes the electrical energy into a more useful form of energy (light), and a switch to control the energy delivered to the load.

Before you study a schematic representation of the flashlight, it is necessary to define certain terms. The load is any device through which electrical current flows which changes electrical energy into a more useful form. Some common examples of loads are a lightbulb, which changes electrical energy to light energy; an electric motor, which changes electrical energy into mechanical energy; and the speaker of a radio, which changes electrical energy into sound. The source is the device which furnishes the electrical energy used by the load. It may consist of a simple dry cell (as in a flashlight), a storage battery (as in an automobile), or a power supply (such as a battery charger). The switch, which permits control of the electrical device, interrupts the current delivered to the load.

b. *Schematic Representation.* The technician's main aid in troubleshooting a circuit in a piece of equipment is the schematic diagram. The schematic diagram is a "picture" of the circuit that uses symbols to represent the various circuit components; physically large or complex circuits can be shown on a relatively small diagram. Before studying the basic schematic, look at figure 11 on the following page. This figure shows the symbols that are used in schematic diagrams. These, and others like them, are referred to and used throughout the study of electricity and electronics.

The schematic in figure 12 (on page 28) represents a flashlight. Part A of the figure shows the flashlight in the off or deenergized state. The switch (S1) is open. There is no complete path for current (I) through the circuit, and the bulb (DS1) does not light. In figure 12, part B, switch S1 is closed. Current flows in the direction of the arrows from the negative terminal of the battery (BAT), through the switch (SL), through the

FIGURE 11. SCHEMATIC SYMBOLS.



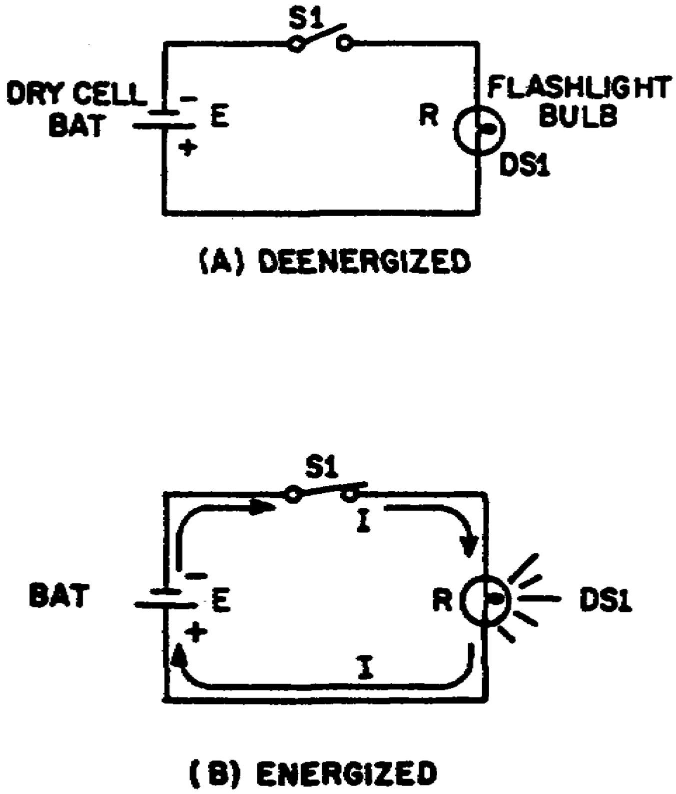
lamp (DS1), and back to the positive terminal of the battery. With the switch closed, the path for the current is complete. Current will continue to flow until the switch (S1) is moved to the open position, or until the battery is completely discharged.

c. *Graphical Analysis of the Basic Circuit.* One of the most valuable methods of analyzing a circuit is by constructing a graph. No other method provides a more convenient or rapid way to observe the characteristics of an electrical device.

The first step in constructing a graph is to obtain a table of data. The information in the table can be obtained by taking measurements on the circuit under examination, or can be obtained theoretically through a series of Ohm's law computations. The latter method is used here.

Since there are three variables (E, I, and R) to be analyzed, there are three distinct graphs that may be constructed.

FIGURE 12. BASIC FLASHLIGHT SCHEMATIC.



To construct any graph of electrical quantities, it is standard practice to vary one quantity in a specified way and note the changes which occur in a second quantity. The quantity which is intentionally varied is called the independent variable and is plotted on the horizontal axis. The horizontal axis is known as the X-axis. The second quantity, which varies as a result or the changes in the first quantity, is called the dependent variable and is plotted on the vertical or Y-axis. Any other quantities involved are held constant.

For example, in the circuit shown in Figure 13 (on the following page), if the resistance was held at 10 Ohms and the voltage was varied, the resulting changes in current could then be graphed. The resistance is the constant, the voltage is the independent variable, and the current is the dependent variable.

FIGURE 13. THREE VARIABLES IN A BASIC CIRCUIT.

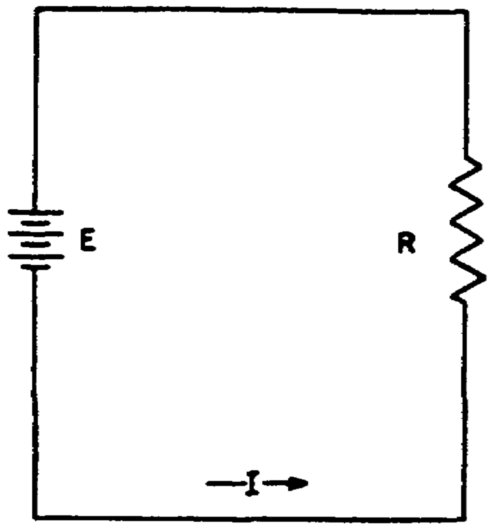
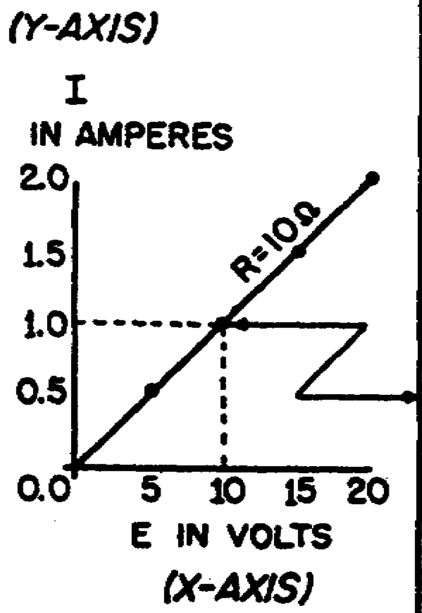


Figure 14 (on the following page) shows the graph and a table of values. This table shows R held constant at 10 Ohms as E is varied from 0 to 20 volts in 5 volt steps. Through the use of Ohm's law, you can calculate the value of current for each value of voltage shown in the table. When the table is complete, the information it contains can be used to construct the graph shown in figure 14. For example, when the voltage applied to the 10 Ohm resistor is 10 volts, the current is 1 ampere. These values of current and voltage determine a point on the graph. When all five points have been plotted, a smooth curve is drawn through the points.

Through the use of this curve, the value of current through the resistor can be quickly determined for any value of voltage between 0 and 20 volts.

Since the curve is a straight line, it shows that equal changes of voltage across the resistor produce equal changes in current through the resistor. This fact illustrates an important characteristic of the basic law--the current varies directly with the applied voltage when the resistance is held constant.

FIGURE 14. VOLT-AMPERE CHARACTERISTICS.



R=10Ω	
E	I
0	0.0
5	0.5
10	1.0
15	1.5
20	2.0

When the voltage across a load is held constant, the current depends solely upon the resistance of the load. For example, figure 15 (on the following page) shows a graph with the voltage held constant at 12 volts. The independent variable is the resistance, which is varied from 2 Ohms to 12 Ohms. The current is the dependent variable. Values for current can be calculated as:

Given: $E = 12$ volts

$R = 2$ Ohms to 12 Ohms

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

$$I = \frac{12 \text{ volts}}{12 \text{ Ohms}} = 1 \text{ ampere}$$

$$I = \frac{12 \text{ volts}}{10 \text{ Ohms}} = 1.2 \text{ amperes}$$

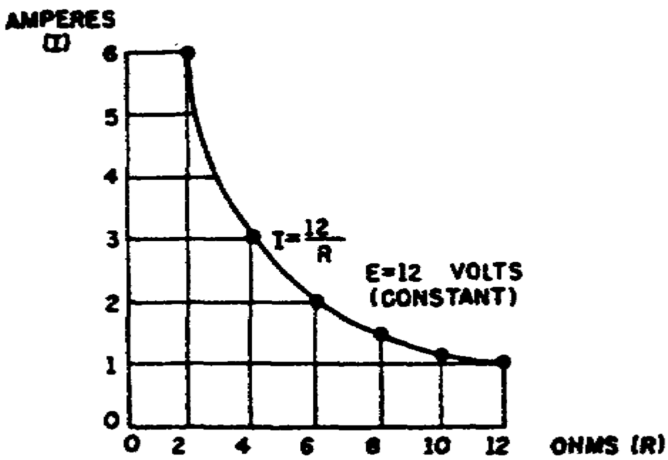
$$I = \frac{12 \text{ volts}}{8 \text{ Ohms}} = 1.5 \text{ amperes}$$

$$I = \frac{12 \text{ volts}}{6 \text{ Ohms}} = 2 \text{ amperes}$$

This process can be continued for any value of resistance. You can see that as the resistance is halved, the current is doubled; when the resistance is doubled, the current is halved.

This illustrates another important characteristic of Ohm's law--current varies inversely with resistance when the applied voltage is held constant.

FIGURE 15. RELATION BETWEEN CURRENT AND RESISTANCE.



d. *Power.* Power, whether electrical or mechanical, pertains to the rate at which work is being done. Work is done whenever a force causes motion. When a mechanical force is used to lift or move a weight, work is done. However, force exerted without causing motion, such as the force of a compressed spring acting between two fixed objects, does not constitute work.

Previously, it was shown that voltage is an electrical force, and that voltage forces current to flow in a closed circuit. However, when voltage exists but current does not flow because the circuit is open, no work is done. This is similar to the spring under tension that produced no motion. When voltage causes electrons to move, work is done. The instantaneous rate at which work is done is called the electric power rate, and is measured in watts.

A total amount of work may be done in different lengths of time. For example, a given number of electrons may be moved from one point to another in one second or in one hour, depending on the rate at which they are moved. In both cases, the total work done is the same. However, when the work is done in a short time, the wattage, or instantaneous power rate, is greater than when the same amount of work is done over a longer period of time.

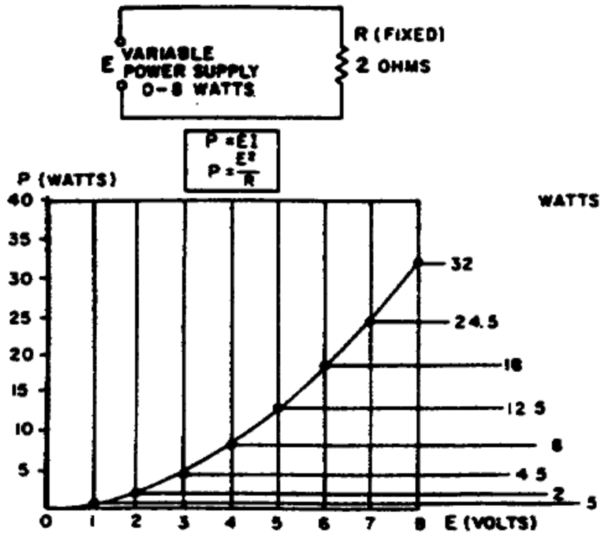
As stated, the basic unit of power is the watt. Power, in watts, is equal to the voltage across a circuit multiplied by current through the circuit. This represents the rate at which work is being done at any given instant. The symbol P indicates electrical power. Thus, the basic power formula is $P = E \times I$, where E is volts and I is current in the circuit. The amount of power changes when either voltage or current, or both voltage and current, are caused to change.

In practice, the only factors that can be changed are voltage and resistance. In explaining the different forms that formulas may take, current is sometimes presented as a quantity that is changed. Remember, if current is changed it is because either voltage or resistance has been changed.

Figure 16 (on the following page) shows a basic circuit using a source of power that can be varied from 0 to 8 volts, and a graph that indicates the relationship between voltage and power.

The resistance of this circuit is 2 Ohms; this value does not change. Voltage (E) is increased (by increasing the voltage source), in steps of 1 volt, from 0 volts to 8 volts. By applying Ohm's law, the current (I) is determined for each step of voltage. For instance, when E is 1 volt, the current is:

FIGURE 16. GRAPH OF POWER RELATED TO CHANGING VOLTAGE.



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

$$I = \frac{1 \text{ volt}}{2 \text{ Ohms}}$$

$$I = 0.5 \text{ ampere}$$

Power (P), in watts, is determined by applying the basic power formula:

$P = E \times I$

$P = 1 \text{ volt} \times 0.5 \text{ ampere}$

$P = 0.5 \text{ watt}$

When E is increased to 2 volts:

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

$$I = \frac{2 \text{ volts}}{2 \text{ Ohms}}$$

$$I = 1 \text{ ampere}$$

and

$$P = E \times I$$

$$P = 2 \text{ volts} \times 1 \text{ ampere}$$

$$P = 2 \text{ watts}$$

When E is increased to 3 volts:

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

$$I = \frac{3 \text{ volts}}{2 \text{ Ohms}}$$

$$I = 1.5 \text{ amperes}$$

and

$$P = E \times I$$

$$P = 3 \text{ volts} \times 1.5 \text{ amperes}$$

$$P = 4.5 \text{ watts}$$

You should notice that when the voltage was increased to 2 volts, the power increased from .5 watts to 2 watts or 4 times. When the voltage increased to 3 volts, the power increased to 4.5 watts or 9 times. This shows that if the resistance in a circuit is held constant, the power varies directly with the square of the voltage.

Another way of proving that power varies as the square of the voltage when resistance is held constant is:

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

By substitution in: $P = E \times I$

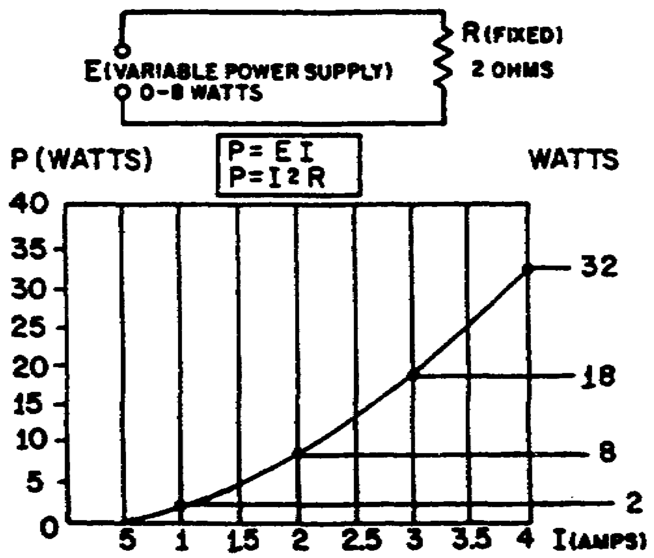
You get: $P = E \times \frac{E}{R}$

Or: $P = \frac{E \times E}{R}$

Therefore: $P = \frac{E^2}{R}$

Another important relationship may be seen by studying figure 17. Thus far, power has been calculated with voltage and current ($P_2 = E \times I$), and with voltage and resistance ($P = \frac{E^2}{R}$).

FIGURE 17. GRAPH OF POWER RELATED TO CHANGING CURRENT



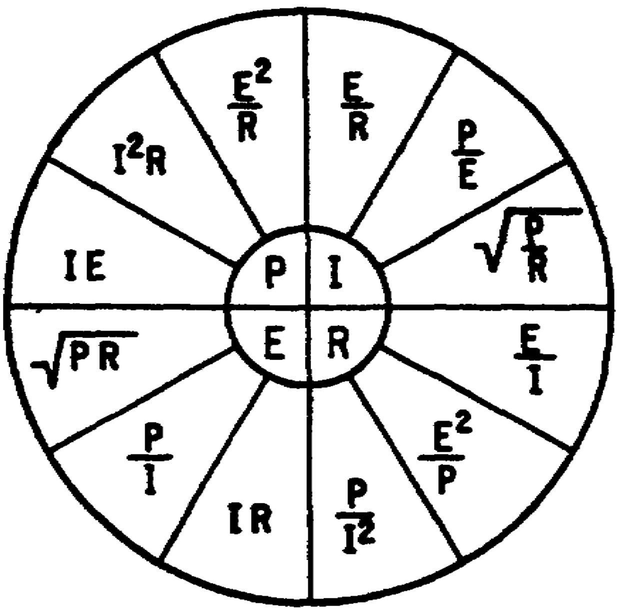
Referring to figure 16 on page 33, note that power also varies as the square of current, just as it does with voltage. Thus, another formula for power, with current and resistance as its factors is $P = I^2R$. This can be proved by:

Since:	$E = I \times R$
By substitution in:	$P = E \times I$
You get:	$P = I \times R \times I$
Or:	$P= I \times I \times R$
Therefore:	$p = I^2R$

Up to this point, four of the most important electrical quantities have been discussed. These are voltage (E), current (I), resistance (R), and power (P). You must understand the relationships which exist between quantities because they are used throughout your study of electricity. In the preceding paragraphs, P was expressed in terms of alternate pairs of the other three basic quantities E, I, and R. In practice, you should be able to express any one of these quantities in terms of any two of the others.

Figure 18 is a summary of 12 basic formulas you should know. The four quantities E, I, R, and P are at the center of the figure. Adjacent to each quantity are three segments. Note that in each segment, the basic quantity is expressed in terms of two other basic quantities, and no two segments are alike.

FIGURE 18. SUMMARY OF BASIC FORMULAS.



For example, the formula wheel in figure 18 could be used to find the formula to solve the following problem:

A circuit has a voltage source that delivers 6 volts and the circuit uses 3 watts of power. What is the resistance of the load?

Since R is the quantity you have been asked to find, look at the section of the wheel that has R in the center. The segment $\frac{E^2}{R}$ contains the quantities you have been given. The formula you would use is $R = \frac{E^2}{R}$. The problem can now be solved.

Given: $E = 6$ volts

$P = 3$ watts

Solution: $R = \frac{E^2}{P}$

$$= \frac{(6\text{ volts})^2}{3\text{ watts}}$$

$$R = \frac{36}{3} = 12\text{ Ohms}$$

3. Series Circuits

When two unequal charges are connected by conductor, a complete pathway for current exists. An electric circuit is a complete conducting pathway. It consists not only of the conductor, but also includes the path through the voltage source. Inside the voltage source current flows from the positive terminal, through the source, emerging at the negative terminal.

a. *Series Circuit Characteristics.* A series circuit is defined as a circuit that contains only one path for current flow. To compare the basic current that has been discussed and a more complex series circuit, figure 19 on the following page shows two circuits. The basic circuit has only one lamp and the series circuit has three lamps connected in series.

(1) *Resistance in a Series Circuit.* Referring to figure 19, the current in a series circuit must flow through each lamp to complete the electrical path in the circuit. Each additional lamp offers added resistance. In a series circuit, the total circuit resistance (R_T) is equal to the sum of the individual resistances.

As an equation: $R_T = R_1 + R_2 + R_3 + \ldots R_n$

FIGURE 19. COMPARISON OF BASIC AND SERIES CIRCUITS.

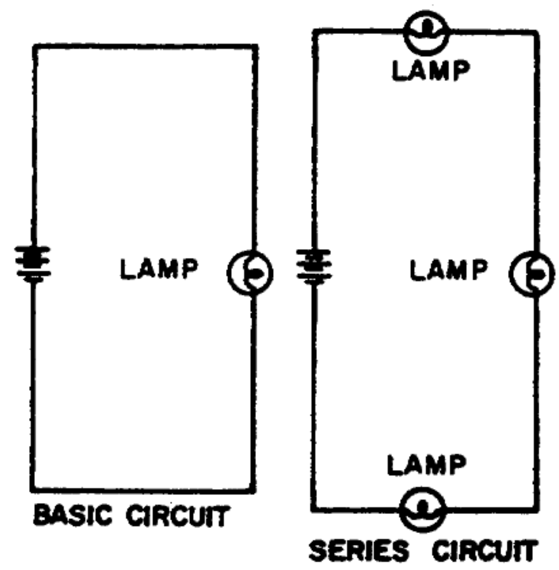
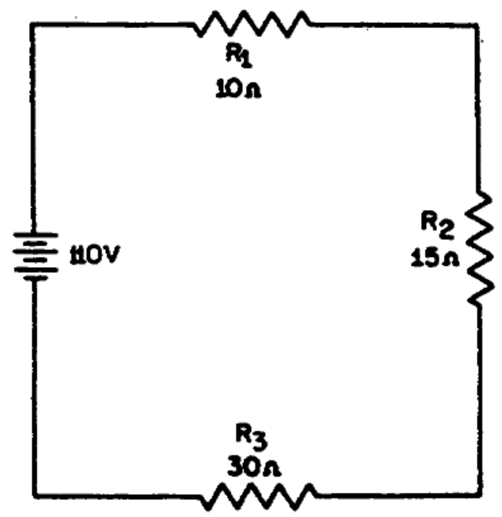


FIGURE 20. SOLVING FOR TOTAL RESISTANCE IN A SERIES CIRCUIT.



NOTE

The subscript n denotes any number of additional resistance that might be in the equation.

Example: In figure 20 a series circuit consisting of three resistors--one of 10 Ohms, one of 15 Ohms, and one of 30 Ohms--are shown. A voltage source provides 110 volts. What is the total resistance?

Given:

R_1 = 10 Ohms

R_2 = 15 Ohms

R_3 = 30 Ohms

Solution:

$R_T = R_1 + R_2 + R_3$

R_T = 10 Ohms + 15 Ohms + 30 Ohms

R_T = 55 Ohms

In some circuit applications, the total resistance is known and the value of one of the circuit resistors has to be determined. The equation $R_T = R_1 + R_2 + R_3$ can be transposed to solve for the value of the unknown resistance.

Example: In figure 21 (on the following page) the total resistance of a circuit containing three resistors is 40 Ohms. Two of the circuit resistors are 10 Ohms each. Calculate the value of the third resistor (R_3).

Given: R_T = 40 Ohms

R_1 = 10 Ohms

R_2 = 10 Ohms

Solution: $R_T - R_1 - R_2 = R_3$

Subtract $R_1 + R_2$ from both sides of the equation

$R_3 = R_T - R_1 - R_2$

R_3 = 40 Ohms - 10 Ohms - 10 Ohms

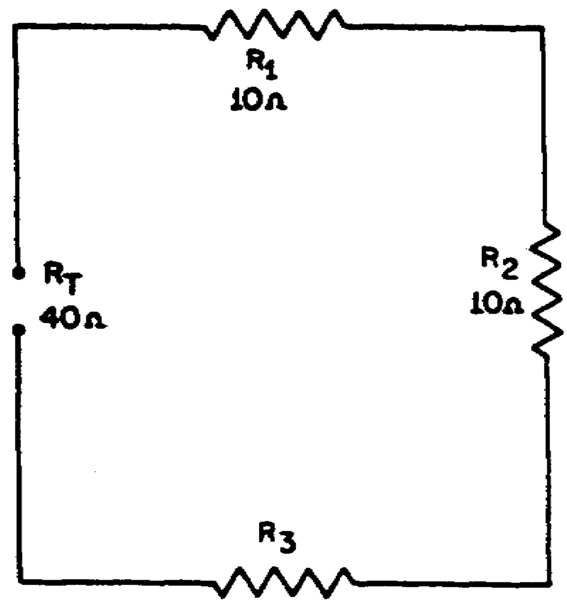
R_3 = 40 Ohms - 20 Ohms

R_3 = 20 Ohms

(2) *Current in a Series Circuit.* Since there is only one path for current in a series circuit, the same current must flow through each component of the circuit. To determine the current in a series circuit, only the current through one of the components need be known.

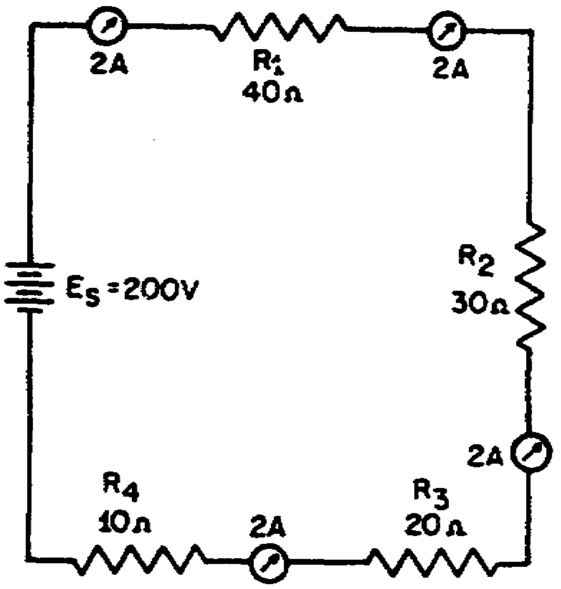
The fact that the same current flows through each component of a series circuit can be verified by inserting meters into the circuit at various points, as shown in figure 22 (on the following page). If this were done, each meter would be found to indicate the same value of current.

FIGURE 21. CALCULATING THE VALUE OF ONE RESISTOR IN A SERIES CIRCUIT.



(3) *Voltage in a Series Circuit.* The voltage dropped across the resistor in a circuit consisting of a single resistor and a voltage source is the total voltage across the circuit and is equal to the applied voltage. The total voltage across a series circuit that consists of more than one resistor is also equal to the applied voltage, but consists of the sum or the individual resistor voltage drops. In any series circuit, the sum of the resistor voltage drops must equal the source

FIGURE 22. CURRENT IN A SERIES CIRCUIT.



voltage. This statement can be proven by an examination of the circuit shown in figure 23 on the following page. In this circuit, a source potential (ET) of 20 volts is dropped across a series circuit consisting of two 5 Ohm resistors. The total resistance of the circuit (R_T) is equal to the sum of the two individual resistances, or 10 Ohms! Using Ohm's law, the circuit current may be calculated as follows:

Given: E_T = 20 volts

R_T = 10 Ohms

Solution:

$$I_T = \frac{E_T}{R_T}$$

$$I_T = \frac{20 \text{ volts}}{10 \text{ Ohms}}$$

$$I_T = 2 \text{ amperes}$$

Since the value of the resistors is known to be 5 Ohms each, and the current through the resistors is known to be 2 amperes, the voltage drops across the resistors can be calculated. The voltage (E_1) across R_1 is therefore:

Given: I_1 = 2 amperes

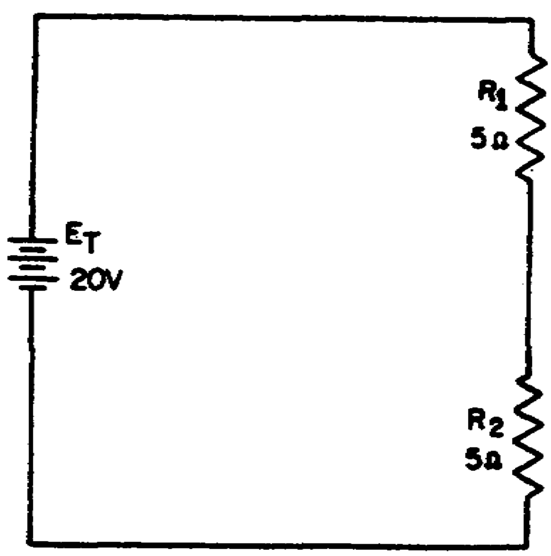
R_1 = 5 Ohms

Solution: $E_1 = I_1 \times R_1$

E_1 = 2 amperes x 5 Ohms

E_1 = 10 volts

FIGURE 23. CALCULATING INDIVIDUAL VOLTAGE DROPS IN A SERIES CIRCUIT.



By inspecting the circuit, you can see that R_2 is the same ohmic value as R_1 and carries the same current. The voltage drop across R_2 is therefore also equal to 10 volts. Adding these two 10 volt drops together gives a total drop of 20 volts, exactly equal to the applied voltage. For a series circuit then:

$$E_T = E_1 + E_2 + E_3 + \ldots E_n$$

Example: A series circuit consists of three resistors having values of 20 Ohms, 30 Ohms, and 50 Ohms, respectively. Find the applied voltage if the current through the 30 Ohm resistor is 2 amperes.

To solve the problem, a circuit diagram is first drawn and labeled (figure 24, on the following page).

Given: R_1 = 20 Ohms

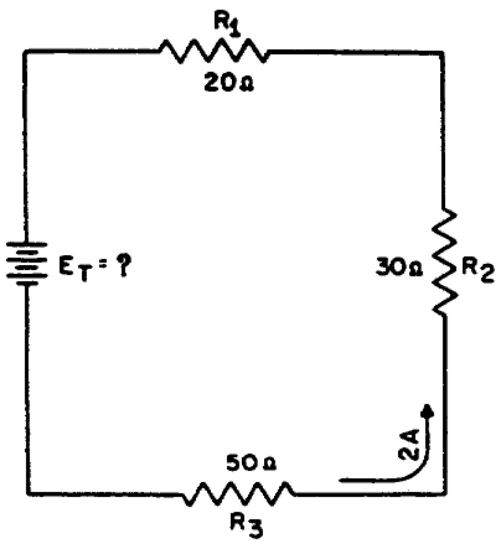
R_2 = 30 Ohms

R_3 = 50 Ohms

I = 2 amperes

Solution: $E_T = E_1 + E_2 + E_3$

FIGURE 24. SOLVING FOR APPLIED VOLTAGE IN A SERIES CIRCUIT.



$E_1 = R_1 \times I_1$ (I_1 = The current through resistor R_1)

$E_2 = R_2 \times I_2$

$E_3 = R_3 \times I_3$

Substituting:

$E_T = (R_1 \times I_1) + (R_2 \times I_2) + (R_3 \times I_3)$

E_T = (20 Ohms x 2 amps) + (30 Ohms x 2 amps) + (50 Ohms x 2 amps)

E_T = 40 volts + 60 volts + 100 volts

E_T = 200 volts

NOTE

> When you use Ohm's law, the quantities for the equation must be taken from the same part of the circuit. In the above example, the voltage across R_2 was computed using the current through R_2 and the resistance of R_2.

The value of the voltage dropped by a resistor is determined by the applied voltage and is in proportion to the circuit resistances. The voltage drops that occur in a series circuit are in direct proportion to the resistances. This is the result of having the same current flow through each resistor. The larger the ohmic value of the resistor, the larger the voltage drop across it.

(4) *Power in a Series Circuit.* Each of the resistors in a series circuit consumes power which is dissipated in the form of heat. Since this power must come from the source, the total power must be equal to the power consumed by the circuit resistances. In a series circuit, the total power is equal to the sum of the power dissipated by the individual resistors. Total power (P_T) is equal to:

$$P_T = P_1 + P_2 + P_3 + \ldots P_n$$

Example: A series circuit consists of three resistors having values of 5 Ohms, 10 Ohms, 15 Ohms. Find the total power when 120 volts is applied to the circuit (figure 25).

Given: R_1 = 5 Ohms

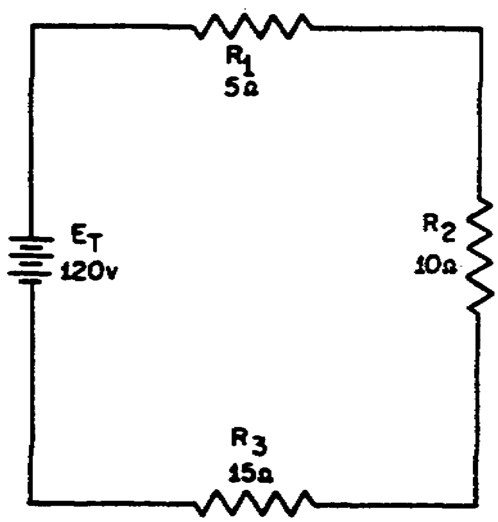
R_2 = 10 Ohms

R_3 = 15 Ohms

E = 120 volts

Solution: $R_T = R_1 + R_2 + R_3$

FIGURE 25. SOLVING FOR TOTAL POWER IN A SERIES CIRCUIT.



R_T = 5 Ohms 4 10 Ohms + 15 Ohms

R_T = 30 Ohms

By using the total resistance and the applied voltage, the circuit current is calculated.

$$I = \frac{E_T}{R_T}$$

$$I = \frac{120 \text{ volts}}{30 \text{ Ohms}}$$

$$I = 4 \text{ amps}$$

By means of the power formulas, the power can be calculated for each resistor:

For R_1:

$$P_1 = I^2 \text{ X } R_1$$

$$P_1 = (4 \text{ amps})^2 \text{ x } 5 \text{ Ohms}$$

$$P_1 = 80 \text{ watts}$$

For R_2:

$$P_2 = I^2 \times R_1$$

$$P = (4 \text{ amps})^2 \times 10 \text{ Ohms}$$

$$P_2 = 160 \text{ watts}$$

For R_3:

$$P_3 = I^2 \times R3$$

$$P = (4 \text{ amps})^2 \times 15 \text{ Ohms}$$

$$P_3 = 240 \text{ watts}$$

To obtain total power:

$$P_T = P_1 + P_2 + P_3$$

$$P_T = 80 \text{ watts} + 160 \text{ watts} + 240 \text{ watts}$$

$$P_T = 480 \text{ watts}$$

To check the answer, the total power delivered by the source can be calculated:

$$P_{source} = T_{source} \times E_{source}$$

$$P_{source} = 4 \text{ amps} \times 120 \text{ volts}$$

$$P_{source} = 480 \text{ watts}$$

The total power is equal to the sum of the power used by the individual resistors.

b. *Summary of Characteristics.* The important factors governing the operation of a series circuit are as listed below. These factors have been set up as a group of rules so that they may be easily studied. These rules must be completely understood before the study of more advanced circuit theory is undertaken.

(1) *Rules for Series DC Circuits.*

(a) The same current flows through each part of a series circuit.

(b) The total resistance of a series circuit is equal to the sum of the individual resistances.

(c) The total voltage across a series circuit is equal to the sum of the individual voltage drops.

(d) The voltage drop across a resistor in a series circuit is proportional to the ohmic value of the resistor.

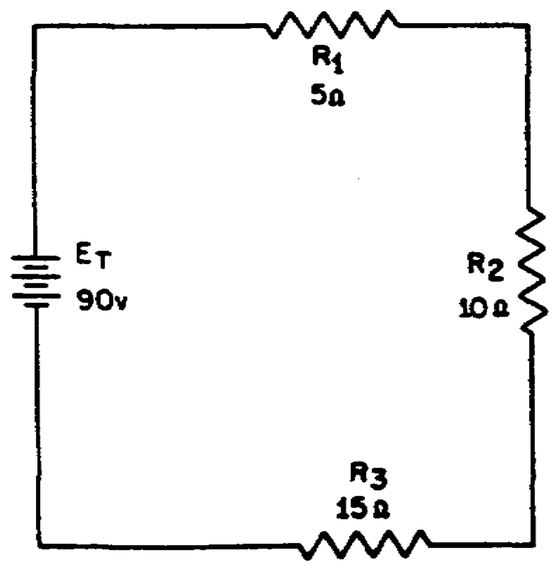
(e) The total power in a series circuit is equal to the sum of the individual powers used by each circuit component.

c. *Series Circuit Analysis.* To establish a procedure for solving series circuits, the following sample problems will be solved.

Example: Three resistors of 5 Ohms, 10 Ohms, and 15 Ohms are connected in series with a power source of 90 volts as shows in figure 26. Find the total resistance, circuit current, voltage drop of each resistor, power of each resistor, and the total power of the circuit.

In solving the circuit, the total resistance will be found first. Next, the circuit current will be calculated. Once the current is known, the voltage drops and power dissipations can be calculated.

FIGURE 26. SOLVING FOR VARIOUS VALUES IN A SERIES CIRCUIT.



Given: R_1 = 5 Ohms

R_2 = 10 Ohms

R_3 = 15 Ohms

E_T = 90 volts

Solution: $R_T = R_1 + R_2 + R_3$

R_T = 5 Ohms + 10 Ohms + 15 Ohms

R_T = 30 Ohms

$$I = \frac{E_T}{R_T}$$

$$I = \frac{90 \text{ volts}}{30 \text{ Ohms}}$$

I = 3 amps

$E_1 = IR_1$

E_1 = 3 amps x 5 Ohms

E_1 = 15 volts

$E_2 = IR_2$

E_2 = 3 amps x 10 Ohms

E_2 = 30 volts

$E_3 = IR_3$

E_3 = 3 amps x 15 Ohms

E_3 = 45 volts

$P_1 = I \times E_1$

P_1 = 3 amps x 15 volts

P_1 = 45 watts

$P_2 = I \times E_2$

P_2 = 3 amps x 30 volts
P_2 = 90 watts

$P_3 = I \times E_3$
P_3 = 3 amps x 45 volts
P_3 = 135 watts
$P_T = E_T \times I$
P_T = 90 volts x 3 amps
P_T = 270 watts
or
$P_T = P_1 + P_2 + P_3$
P_T = 45 watts + 90 watts + 135 watts
P_T = 270 watts

An important fact to keep in mind when applying Ohm's law to a series circuit is to consider whether the values used ate component values or total values. When the information available enables the use of Ohm's law to find total resistance, total voltage, and total current, total values must be inserted into the formula. To find total resistance:

$$R_T = \frac{E_T}{I_T}$$

To find total voltage:

$$E_T = I_T \times R_T$$

To find total current:

$$I_T = \frac{E_T}{R_T}$$

NOTE

I_T is equal to I in a series circuit. However, the distinction between I_T and I in the formula should be noted. The reason for this is that future circuits may have several currents, and it will be essential to differentiate between I_T and other currents.

To compute any quantity (E, I, R, or P) associated with a single given resistor, the values used in the formula must be obtained from that particular resistor. For example, to find the value of an unknown resistance, the voltage across and the current through that particular resistor must be used.

To find the value of a resistor:

$$R = \frac{E_R}{I_R}$$

To find the voltage drop across a resistor:

$$E_R = I_R \times R$$

d. *Kirchhoff's Voltage Law.* In 1847, G. R. Kirchhoff extended the use of Ohm's law by developing a simple concept concerning the voltages contained in a series circuit loop. Kirchhoff's law states: "The algebraic sum of the voltage drops in any closed path in a circuit and the electromotive forces in that path is equal to zero."

To state Kirchhoff's law another way, the voltage drops and voltage sources in a circuit are equal at any given moment in time. If the voltage sources are assumed to have one sign (positive or negative) at that instant and the voltage drops are assumed to have the opposite sign, the result of adding the voltage sources and voltage drops will be zero.

NOTE

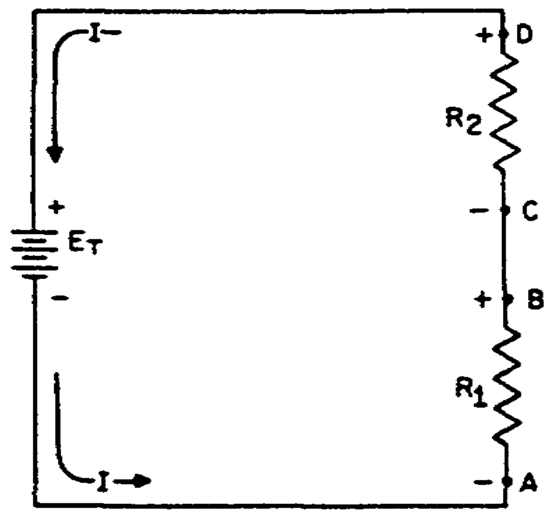
The terms electromotive force and EMF are used in explaining Kirchhoff's law when used in alternating current (ac) circuits. In applying Kirchhoff's law to direct current (dc) circuits, the terms electromotive force and EMF apply to voltage sources such as batteries or power supplies.

Through the use of Kirchhoff's law, circuit problems can be solved which would be difficult, and often impossible, with knowledge of Ohm's law alone. When Kirchhoff's law is properly applied, an equation can be set up for a closed loop and the unknown circuit values can be calculated.

e. *Polarity of Voltage.* To apply Kirchhoff's voltage law, the meaning of voltage polarity must be understood. In the circuit shown in figure 27, the current is shown flowing in a counterclockwise direction. Notice that the end of resistor R_1, into which the current flows, is marked negative (-). The end of R_1, at which the current leaves, is marked positive (+). These polarity markings are used to show, that the end of R_1, into which the current flows is at a higher negative potential than the end of the resistor at which the current leaves. Point A is more negative than point B.

Point C, which is at the same potential as point B, is labeled negative. This is to indicate that point C is more negative than point D. To say a point is positive (or negative) without stating what the polarity is based upon has no meaning. In working with Kirchhoff's law, positive and negative polarities are assigned in the direction of current flow.

FIGURE 29. VOLTAGE POLARITIES.



(1) *Applications of Kirchhoff's Voltage Law.* Kirchhoff's voltage law can be written as an equation, as shown below:

$$E_a + E_b + E_c + \ldots \quad E_n = 0$$

where E_a, E_b, etc., are the voltage drops around any closed circuit loop. To set up the equation for an actual circuit, the following procedures are used.

(a) Assume a direction of current through the circuit. (The correct direction is desirable but not necessary.)

(b) Using the assumed direction of current, assign polarities to all resistors through which the current flows.

(c) Place the correct polarities on any sources included in the circuit.

(d) Starting at any point in the circuit, trace around the circuit, writing down the amount and polarity of the voltage across each component in succession. The polarity used is the sign after the assumed current has passed through the component. Stop when the point at which the trace was started is reached.

(e) Place these voltages, with their polarities, into the equation and solve for the desired quantity.

Example: Three resistors are connected across a 50 volt source. What is the voltage across the third resistor if the voltage drops across the first two resistors are 25 volts and 15 volts?

Solution: First, a diagram (such as figure 28 on the following page) is drawn. Next, a direction of current is assumed (as shown). Using this current, the polarity markings are placed at each end of each resistor and also on the terminals of the source. Starting at point A, trace around the circuit in the direction of current flow, recording the voltage and polarity of each component. Starting at point A and using the components from the circuit:

$$(+E_X) + (+E_2) + (+E_1) + (-E_A) = 0$$

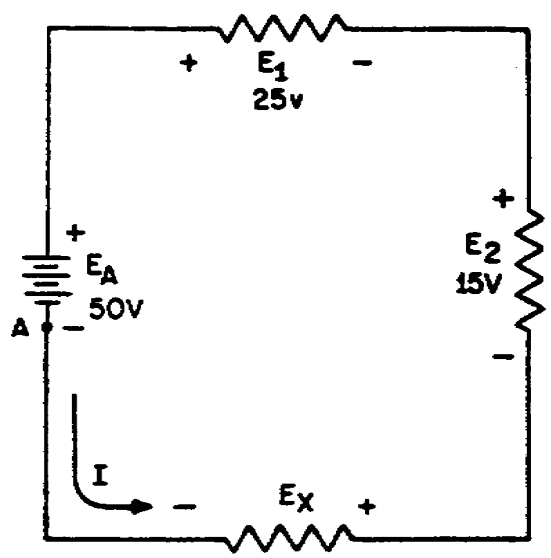
Substituting values from the circuit:

$$E_X + 15 \text{ volts} + 25 \text{ volts} - 50 \text{ volts} = 0$$

$$E_X - 10 \text{ volts} = 0$$

$$E_X = 10 \text{ volts}$$

FIGURE 28. DETERMINING UNKNOWN VOLTAGE IN A SERIES CIRCUIT.



The unknown voltage (E_X) is found to be 10 volts.

Using the same idea as above, you can solve a problem in the which the current is the unknown quantity.

Example: A circuit having a source voltage of 60 volts contains three resistors of 5 Ohms, 10 Ohms, and 15 Ohms. Find the circuit current.

Solution: Draw and label the circuit (figure 29 on the following page). Establish a direction of current flow and assign polarities. Next, starting at any point (point A will be used in this example) write out the loop equation.

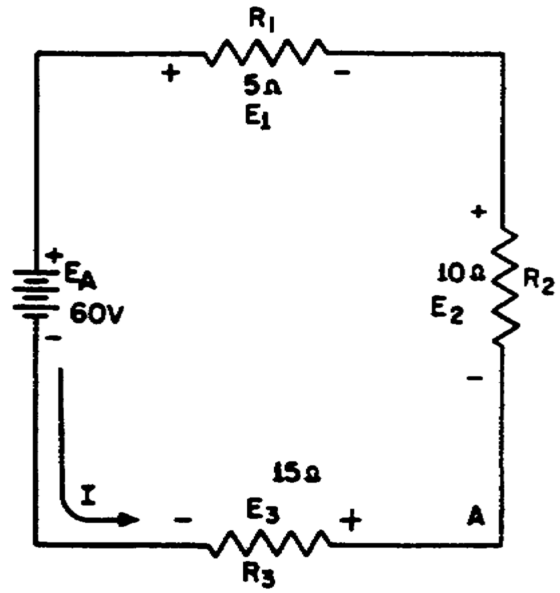
Basic equation:

$$E_2 + E_1 + E_A + E_3 = 0$$

Since E = IR, by substitution:

$$(I \times R_2) + (I \times R_1) + E_A + (I \times R_3) = 0$$

FIGURE 29. CORRECT DIRECTION OF ASSUMED CURRENT.



Substituting values:

$$(I \times 10 \text{ Ohms}) + (I \times 5 \text{ Ohms}) + (-60 \text{ volts}) + (I \times 15 \text{ Ohms}) = 0$$

Combining like terms:

$$(I \times 30 \text{ Ohms}) + (-60 \text{ volts}) = 0$$

$$I \times 30 \text{ Ohms} = 60 \text{ volts}$$

$$I = \frac{60 \text{ volts}}{30 \text{ Ohms}}$$

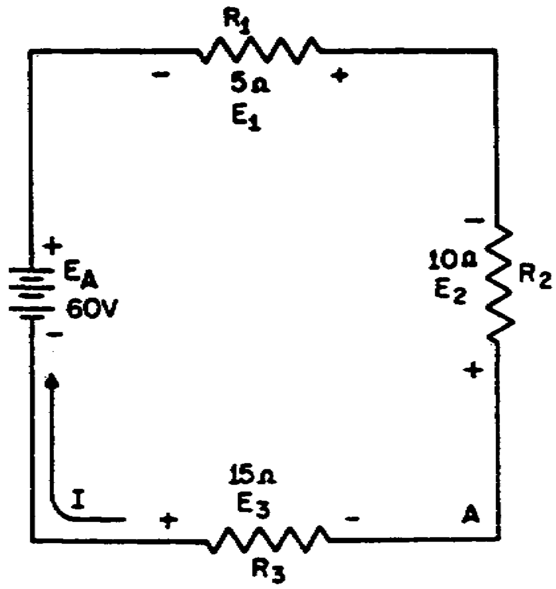
$$I = 2 \text{ amps}$$

Since the current obtained in the above calculations is a positive 2 amps, the assumed direction of the current was correct. To show what happens if the incorrect direction of current is assumed, the problem will be solved as before, but with the opposite direction of current. The circuit redrawn showing the new direction of current and the new polarities is in figure 30. Starting at point A, the loop equation is:

$$E_3 + E_A + E_1 + E_2 = 0$$

$$(I \times R_3) + E_A + (I \times R_1) + (I \times R_2) = 0$$

FIGURE 30. INCORRECT DIRECTION OF ASSUMED CURRENT.



Substituting values:

$$(I \times 15\text{ Ohms}) + 60\text{ volts} + (I \times 5\text{ Ohms}) + (I \times 10\text{ Ohms}) = 0$$

Combining like terms:

$$(I \times 30\text{ Ohms}) + 60\text{ volts} = 0$$

$$I \times 30 \text{ Ohms} = -60 \text{ volts}$$

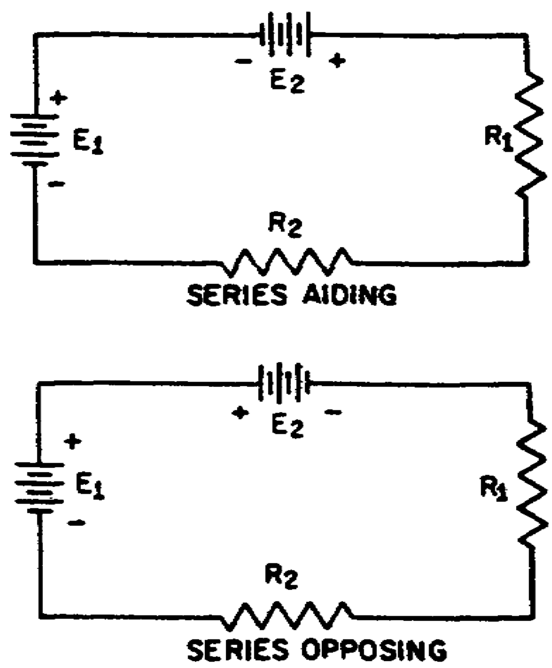
$$I = \frac{-60 \text{ volts}}{30 \text{ Ohms}}$$

$$I = -2 \text{ amps}$$

Notice that the amount of current is the same as before. The polarity, however, is negative. The negative polarity simply indicates the wrong direction of current was assumed. Should it be necessary to use this current in further calculations on the circuit using Kirchhoff's law, the negative polarity should be retained in the calculations.

(2) *Series Aiding and Opposing Sources.* In many practical applications, a circuit may contain more than one source of EMF. Sources of EMF that cause current to flow in the same direction are considered to be series aiding and the voltages are added. Sources of EMF that would tend to force current in opposite directions are said to be series opposing, and the effective source of voltage is the difference between the opposing

FIGURE 31. AIDING AND OPPOSING SOURCES.



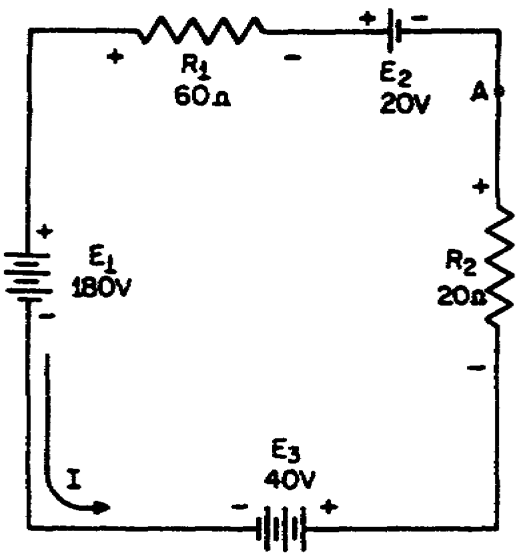
voltages. When two opposing sources are inserted into a circuit, current flow would be in a direction determined by the larger source.

Examples of series aiding and opposing sources are shown in figure 31 on the previous page.

A simple solution may be obtained for a multiple-source circuit through the use of Kirchhoff's voltage law. In applying this method, the same procedure is used for the multiple-source circuit as was used above for the single-source circuit. This is demonstrated by the following.

Example: Using Kirchhoff's voltage equation, find the amount of current in the circuit shown in figure 32.

FIGURE 32. SOLVING FOR CIRCUIT CURRENT USING KIRCHHOFF'S VOLTAGE CURRENT.



Solution: As before, a direction of current flow is assumed and polarity signs are placed on the drawing. The loop equation will be started at point A.

$E_2 + E_{R1} + E_1 + E_3 + E_{R2} = 0$

20 volts + (I x 60 Ohms) + (-180 volts) + 40 volts + (I x 20 Ohms) = 0

20 volts - 180 volts + 40 volts 4 (C x 60 Ohms) + (I x 20 Ohms) = 0

-120 volts + (I x 80 Ohms) = 0

I x 80 Ohms = 120 volts

$$I = \frac{120 \text{ volts}}{80 \text{ Ohms}}$$

I = 1.5 amps

4. Circuit Terms and Characteristics

Before you learn about the type of circuits other than the series circuit, you should become familiar with some of the terms and characteristics used in electrical circuits. These terms and characteristics will be used throughout your study of electricity and electronics.

a. *Reference Point.* A reference point is an arbitrarily chosen point to which all other points in the circuit are compared. In series circuits, any point can be chosen as a reference and the electrical potential at all other points can be determined in reference to that point. In figure 33, on the following page, point A should be considered the reference point. Each series resistor in the illustrated circuit is of equal value. The applied voltage is equally distributed across each resistor. The potential at point B is 25 volts more positive than at point A. Points C and D are 50 volts and 75 volts, more positive than point A respectively.

When point B is used as the reference, as in figure 34 on the following page, point D would be positive 50 volts in respect to the new reference point. The former reference point A, is 25 volts negative in respect to point B.

As in the previous circuit illustration, the reference point of a circuit is always considered to be at zero potential. Since the earth (ground) is said to be at a zero potential, the term ground is used to denote a common electrical point of zero potential. In figure 35, on page 60, point A is the zero reference, or ground, and the symbol for

FIGURE 33. REFERENCE POINTS IN A SERIES CIRCUIT.

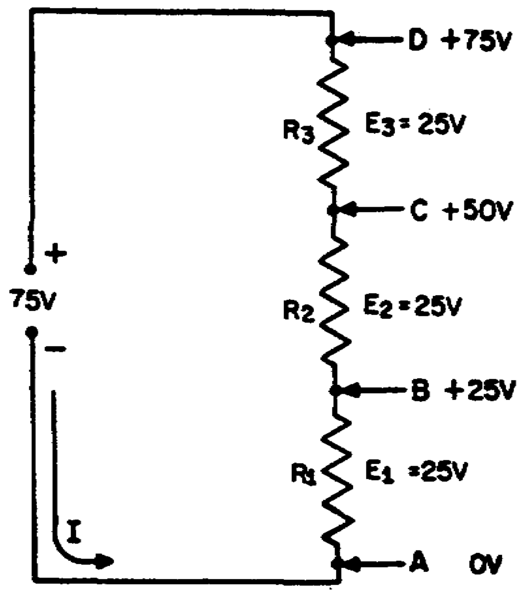


FIGURE 34. DETERMINING POTENTIALS WITH RESPECT TO A REFERENCE POINT.

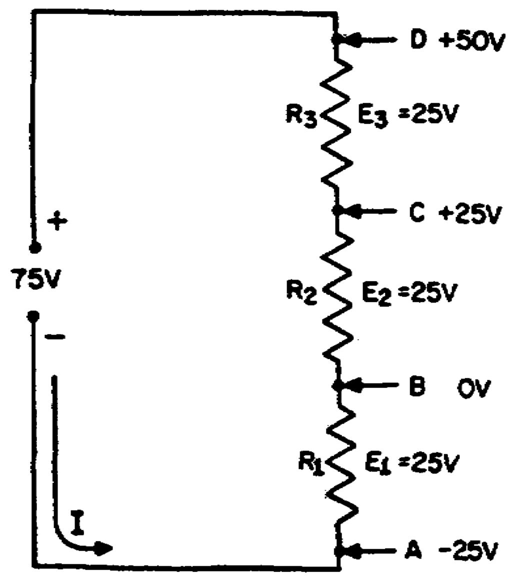
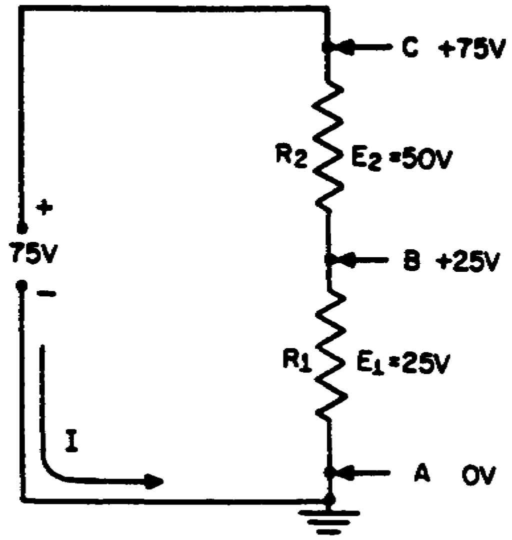


FIGURE 35. USE OF GROUND SYMBOLS.



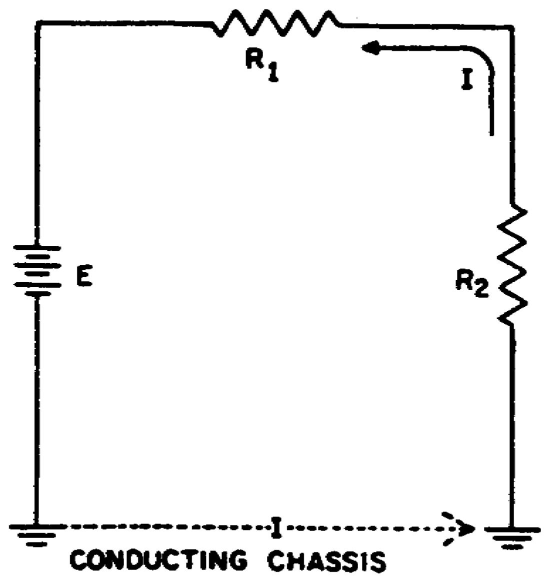
ground is shown connected to point A. Point C is 75 volts positive in respect to ground.

In most electrical equipment, the metal chassis is the common ground for the many electrical circuits. When each electrical circuit is completed, common points of a circuit at zero potential are connected directly to the metal chassis, thereby eliminating a large amount of connecting wire. The electrons pass through the metal chassis (a conductor) to reach other points of the circuit. An example of a chassis grounded circuit is illustrated in figure 36 on the following page.

Most voltage measurements used to check proper circuit operation in electrical equipment are taken in respect to ground. One meter lead is attached to a grounded point and the other meter lead is moved to various test points.

b. *Open Circuit.* A circuit is said to be open when a break exists in a complete conducting pathway. Although an open occurs when a switch is used to deenergize a circuit, an open may also develop accidentally. To restore a circuit to proper operation, the open must be located, its cause determined, and repairs made.

FIGURE 36. GROUND USED AS A CONDUCTOR.

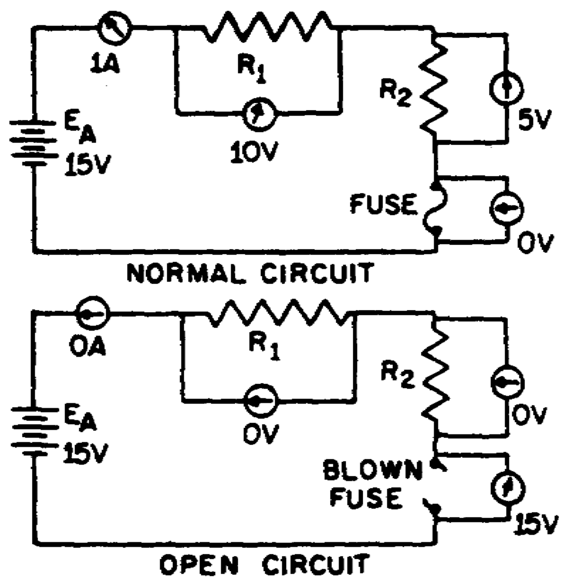


Sometimes an open can be located visually by a close inspection of the circuit components. Defective components, such as burned out resistors, can usually be discovered by this method. Others, such as a break in a wire covered by insulation or the melted element of an enclosed fuse, are not visible to the eye. Under such conditions, the understanding of the effect an open has on circuit conditions enables a technician to make use of test equipment to locate the open component.

In figure 37 (on the following page), the series circuit consists of two resistors and a fuse. Notice the effects on circuit conditions when the fuse opens.

Current ceases to flow; therefore, there is no longer a voltage drop across the resistors. Each end of the open conducting path becomes an extension of the battery terminals and the voltage felt across the open is equal to the applied voltage (EA). An open circuit has infinite resistance. Infinity represents a quantity so large it cannot be measured.

FIGURE 37. NORMAL AND OPEN CIRCUIT CONDITIONS. NORMAL CURRENT (A) EXCESSIVE CURRENT (B).



c. *Short Circuit.* A short circuit is an accidental path of low resistance which passes an abnormally high amount of current. A short circuit exists whenever the resistance of a circuit or the resistance of a part of a circuit drops in value to almost zero Ohms. A short often occurs as a result of improper wiring or broken insulation.

In figure 38 (on the following page), a short is caused by improper wiring. Note the effect on current flow. Since the resistor has in effect been replaced with a piece of wire, practically all the current flows through the short and very little current flows through the resistor R_1. Electrons flow through the short (a path of almost zero resistance) and the remainder of the circuit passes through the 10 Ohm resistor and the battery. The amount of current flow increases greatly because its resistive path has decreased from 10,010 Ohms to 10 Ohms. Due to excessive current flow, the 10 Ohm resistor becomes heated. As it attempts to dissipate this heat, the resistor will probably be destroyed. Figure 39 (on the following page) shows a pictorial wiring diagram, which indicates how broken insulation might cause a short circuit.

FIGURE 38. NORMAL AND SHORT CIRCUIT CONDITIONS.

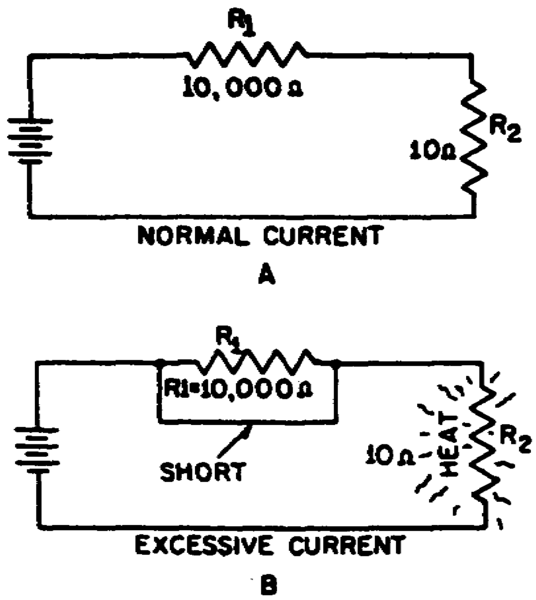
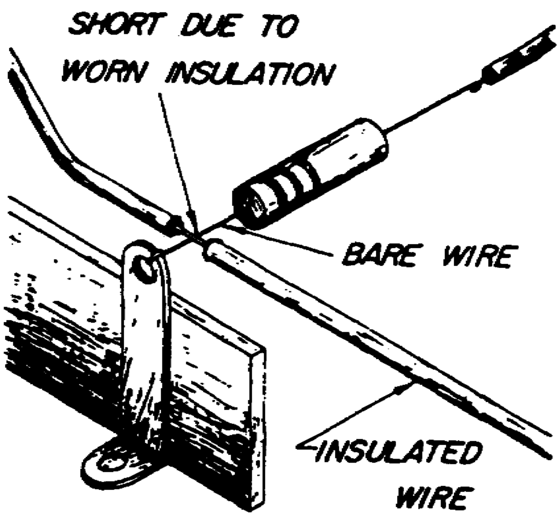


FIGURE 39. SHORT DUE TO BROKEN INSULATION.



d. *Source Resistance.* A meter connected across the terminals of a good 1.5 volt battery reads about 1.5 volts. When the same battery is inserted into a complete circuit, the meter reading decreases to something less than 1.5 volts. This difference in terminal voltage is caused by the internal resistance of the battery (the opposition to current offered by the electrolyte in the battery). All sources of electromotive force have some form of internal resistance which causes a drop in terminal voltage as current flows through the source.

This principle is illustrated in figure 40 (on the following page) where the internal resistance of a battery is shown as R_i. In the schematic, the internal resistance is indicated by an additional resistor in series with the battery. The battery, with its internal resistance, is enclosed within the dotted lines of the schematic diagram. With the switch open, the voltage across the battery terminals reads 15 volts. When the switch is closed, current flows causing voltage drops around the circuit. The circuit current of 2 amperes causes a voltage drop of 2 volts across R_i. The 1 Ohm internal battery resistance thereby drops the battery terminal voltage to 13 volts. Internal resistance cannot be measured directly with a meter; an attempt to do so would damage the meter.

The effect of the source resistance on the power output of a dc source may be shown by an analysis of the circuit in figure 41 on page 69. When the variable load resistor (R_L) is set at the zero Ohm position (equivalent to a short circuit) current (T) is calculated using the following formula:

$$I = \frac{E_s}{R_i} = \frac{100 \text{ volts}}{5 \text{ Ohms}} = 20 \text{ amperes}$$

This is the maximum current that may be drawn from the source. The terminal voltage across the short circuit is zero volts and all the voltage is across the resistance within the source.

If the load resistance (R_L) were increased (the internal resistance remaining the same), the current drawn from the source would decrease. At the same time, the terminal voltage applied across the load would increase and approach a maximum as the current approaches zero amps.

FIGURE 40. EFFECT OF INTERNAL RESISTANCE.

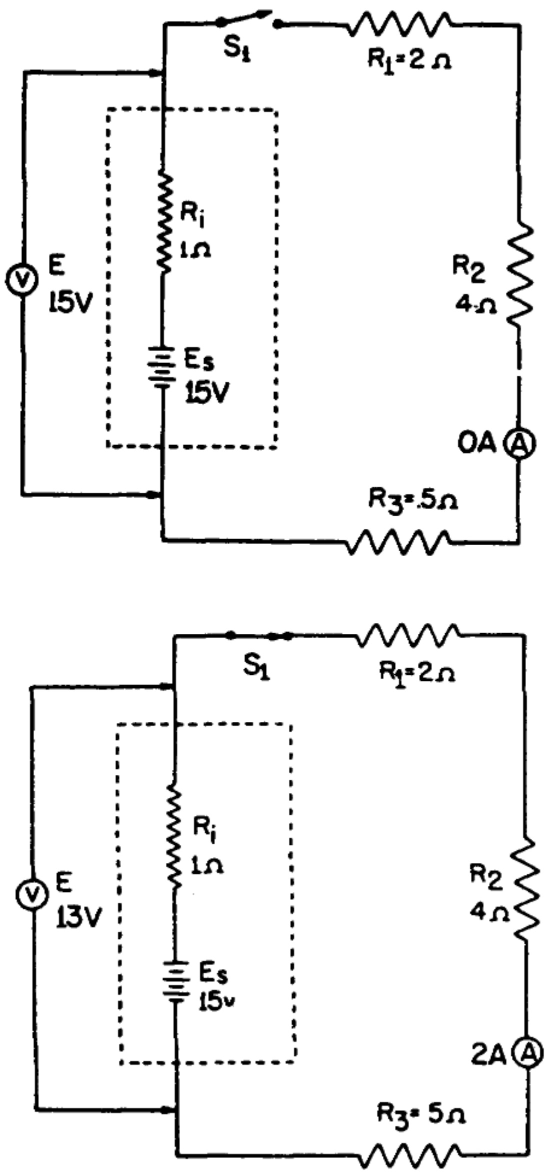
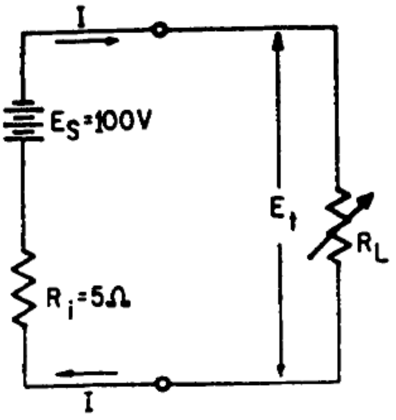


FIGURE 41. EFFECT OF SOURCE RESISTANCE ON POWER OUTPUT.

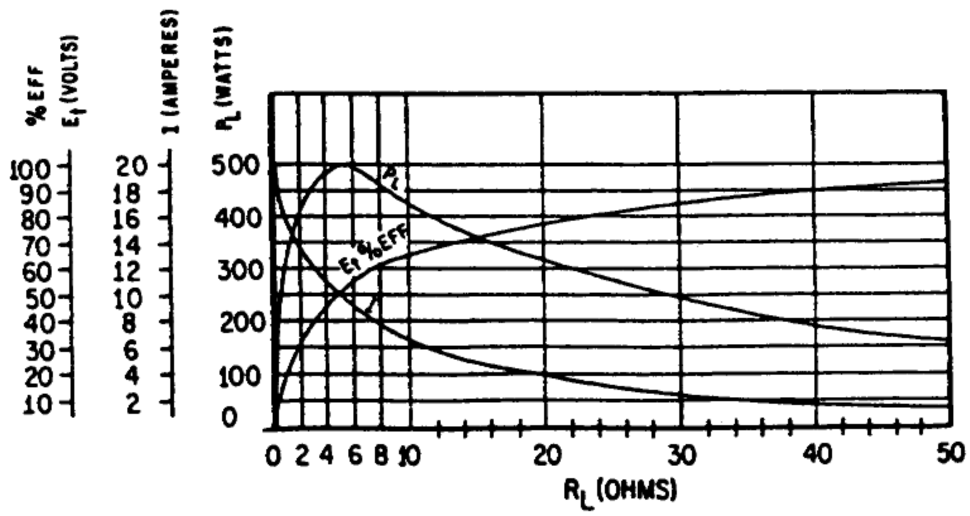


E_S= OPEN-CIRCUIT VOLTAGE OF SOURCE
R_i=INTERNAL RESISTANCE OF SOURCE
E_t=TERMINAL VOLTAGE
R_L=RESISTANCE OF LOAD
P_L=POWER USED IN LOAD
I =CURRENT FROM SOURCE
% EFF = PERCENTAGE OF EFFICIENCY

(A)
CIRCUIT AND SYMBOL DESIGNATIONS

R_L	E_t	I	P_L	% EFF.
0	0	20	0	0
1	16.7	16.7	278.9	16.7
2	28.6	14.3	409	28.6
3	37.5	12.5	468.8	37.5
4	44.4	11.1	492.8	44.4
5	50	10	500	50
6	54.5	9.1	496.0	54.5
7	58.3	8.3	483.9	58.3
8	61.6	7.7	474.3	61.6
9	64.3	7.1	456.5	64.3
10	66.7	6.7	446.9	66.7
20	80	4	320	80
30	85.7	2.9	248.5	85.7
40	88.9	2.2	195.6	88.9
50	90.9	1.9	172.7	90.9

(B)
CHART



(C)
GRAPH

e. *Power Transfer and Efficiency.* Maximum power is transferred from the source to the load when the resistance of the load is equal to the internal resistance of the source. This theory is illustrated in the table and the graph of figure 41 (on the previous page). When the load resistance is 5 Ohms, matching the source resistance, the maximum power of 500 watts is developed in the load.

The efficiency of power transfer (ratio of output power to input power) from the source to the load increases as the load resistance is increased. The efficiency approaches 100 percent as the load resistance approaches a relatively large value compared with that of the source, since less power is lost in the source. The efficiency of power transfer is only 50 percent at the maximum power transfer point (when the load resistance equals the internal resistance of the source). The efficiency of power transfer approaches zero efficiency when the load resistance is relatively small compared with the internal resistance of the source. This is also shown on the chart of figure 41 on the previous page.

The problem of a desire for both high efficiency and maximum power transfer is resolved by a compromise between maximum power transfer and high efficiency. Where the amounts of power involved are large and the efficiency is important, the load resistance is made large relative to the source resistance so that the losses are kept small. In this case, the efficiency is high. Where the problem of matching a source to a load is important, as in communications circuits, a strong signal may be more important than a high percentage of efficiency. In such cases, the efficiency of power transfer should be only about 50 percent; however, the power transfer would be the maximum which the source is capable of supplying.

You should now understand the basic concepts of series circuits. The principles which have been presented are of lasting importance. Once equipped with a firm understanding of series circuits, you hold the key to an understanding of the parallel circuits to be presented next.

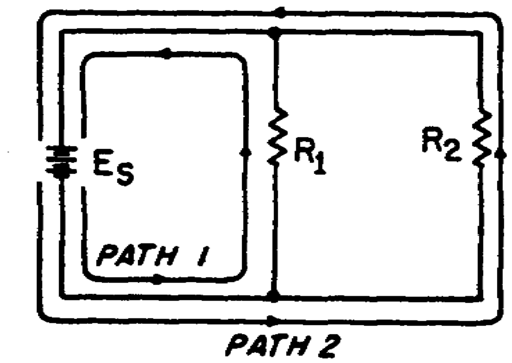
5. Parallel Circuits

The discussion of electrical circuits presented up to this point has been concerned with series circuits, in which there is only one path for the current to flow. There is another basic type of circuit known as the parallel circuit. Where the series circuit has only one path for current, the parallel circuit has more than one path for the current.

Ohm's law and Kirchhoff's law apply to all electrical circuits, but the characteristics of a parallel circuit are different to those of a series circuit.

a. *Parallel Circuit Characteristics.* A parallel circuit is defined as one having more than one current path connected to a common voltage source. Parallel circuits, therefore, must contain two or more resistances which are not connected in series. An example of basic parallel circuit is shown in figure 42.

FIGURE 42. EXAMPLE OF A BASIC PARALLEL CIRCUIT.



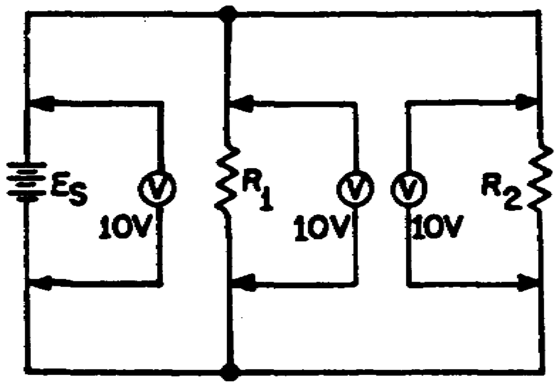
Start at the voltage source (E_S) and trace counterclockwise around the circuit. Two complete and separate paths can be identified in which current can flow. One path is traced from the source, through resistance R_1, and back to the source. The other path is from the source, through the resistance R_2, and back to the source.

(1) *Voltage in a Parallel Circuit.* You have seen that the source voltage in a series circuit divides proportionally across each resistor in the circuit. In a parallel circuit, the same voltage is present in every branch. A branch is a section of a circuit that has a complete path for current. In figure 42 on the previous page, this voltage is equal to the applied voltage (E_S). This can be expressed in equation form as:

$$E_S = E_{R1} = E_{R2}$$

Voltage measurements taken across the resistors of a parallel circuit, as illustrated by figure 43, verify this equation. Each meter indicates the same amount of voltage. Notice that the voltage across each resistor is the same as the applied voltage.

FIGURE 43. VOLTAGE COMPARISON IN A PARALLEL CIRCUIT.

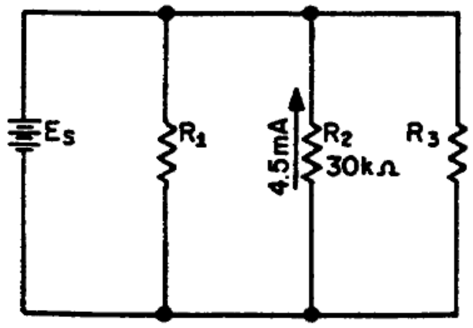


Example: Assume that the current through a resistor of a parallel circuit is known to he a 4.5 milliamperes (4.5 mA) and the value of the resistor 30,000 Ohms. Determine the source voltage. The circuit is shown in figure 44 on the following page.

Given: R_2 = 30,000 Ohms

I_{R2} = 4.5 milliAmps

FIGURE 44. EXAMPLE PROBLEM PARALLEL CIRCUIT.



Solution: $E = IR$

E_{R2} = .0045 amps x 30,000 Ohms

E_{R2} = 135 volts

Since the source voltage is equal to the voltage of a branch:

$E_S = E_{R2}$

E_S = 135 volts

To simplify the math operation, the values can be expressed in powers of ten as follows:

30,000 Ohms = 30 x 10^3 Ohms

4.5 mA = 4.5 x 10^{-3} amps

$E_{R2} = (4.5 \times 30 \times 10^{-3} \times 10^{3})$ volts
$(10^{-3} \times 10^{3} = 10^{-3+3} = 10^{0} = 1)$

E_{R2} = (4.5 x 30 x 1) volts

E_{R2} = 135 volts

E_S = R2

E_S = 135 volts

(2) *Current in a Parallel Circuit.* Ohm's law states that the current in a circuit is inversely proportional to the circuit resistance. This fact is true in both series and parallel circuits.

There is a single path for current in a series circuit. The amount of current is determined by the total resistance of the circuit and the applied voltage. In a parallel circuit, the source current divides among the available paths.

The behavior of current in parallel circuits will be shown by a series of illustrations using example circuits with different values of resistance for a given value of applied voltage.

View A of figure 45 (on the following page) shows a basic series circuit. Here, the total current must pass through the single resistor. The amount of current can be determined.

Given: E_S = 50 volts

R_1 = 10 Ohms

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

$$I_T = \frac{E_s}{R_1}$$

$$I_T = \frac{50 \text{ volts}}{10 \text{ Ohms}}$$

$$I_T = 5 \text{ amps}$$

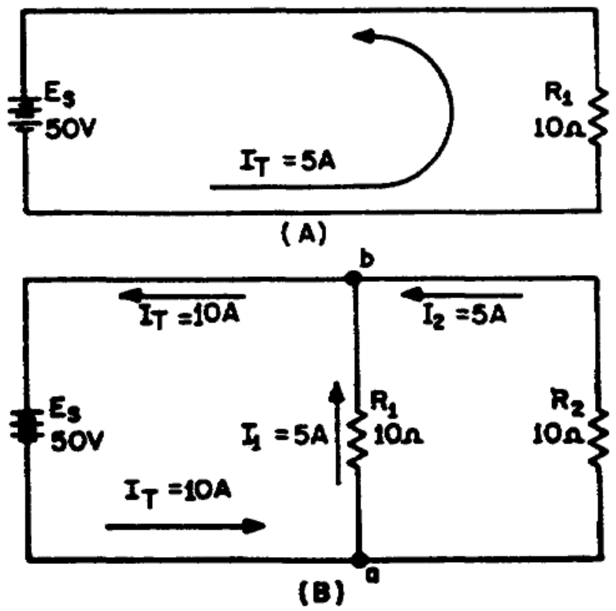
Part B shows the same resistor (R_1) with a second resistor (R_2) of equal value connected in parallel across the voltage source. When Ohm's law is applied, the current flow through each resistor is found to be the same as the current through the single resistor in part A.

Given: E_S = 50 volts

R_1 = 10 Ohms

R_2 = 10 Ohms

FIGURE 45. ANALYSIS OF CURRENT IN PARALLEL CIRCUIT.



Solution:

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

$$E_s = E_{R1} = E_{R2}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{I_{R2}}$$

$$I_{R2} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$$

$$I_{R2} = 5 \text{ amps}$$

It is apparent that if there are 5 amperes of current through each of the two resistors, there must be a total current of 10 amperes drawn from the source.

The total current of 10 amperes, as illustrated in figure 45, view B on the previous page, leaves the negative terminal of the battery and flows to point a. Since point a is a connecting point for the two resistors, it is palled a junction. At junction a, the total current divides into two currents of 5 amperes each. These two currents flow through their resistors and rejoin at junction b. The total current then flows from junction b back to the positive terminal of the source. The source supplies a total current of 10 amperes and each of the two equal resistors carries one-half of the total current.

Each individual current path in the circuit of figure 45 (view B) is referred to as a branch. Each branch carries a current that is a portion of the total current. Two or more branches form a network.

From the previous explanation, the characteristics of current in a parallel circuit can be expressed in terms of the following general equation:

$$I_T = I_1 + I_2 + I_3 + \dots I_n$$

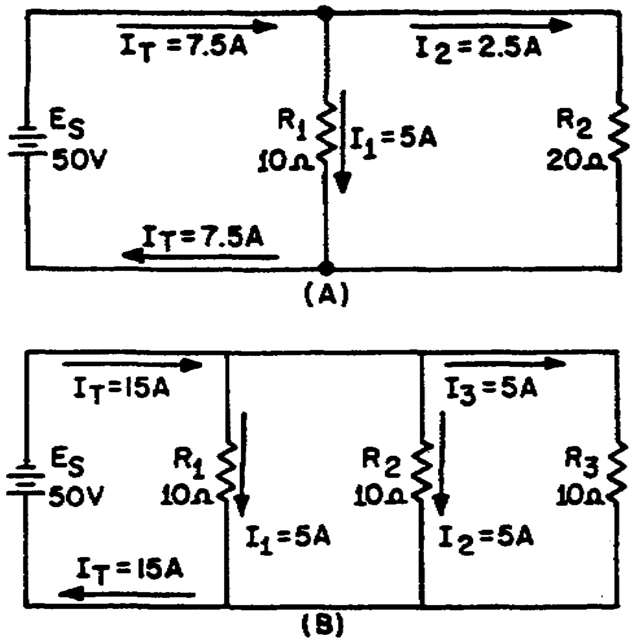
Compare view A of figure 46 (on the following page) with view B of the circuit in figure 45. Notice that doubling the value of the second branch resistor (R_2) has no effect on the current in the first branch (I_{R1}), but does reduce the second branch current (I_{R2}) to one-half its original value. The total circuit current drops to a value equal to the sum of the branch currents. These facts are verified by the following equations.

Given: E_S = 50 volts

R_1 = 10 Ohms

R_2 = 20 Ohms

FIGURE 46. CURRENT BEHAVIOR IN PARALLEL CIRCUITS.



Solution:

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

$$E_s = E_{R1} = E_{R2}$$

$$I_{R1} = \frac{E_{R1}}{R_1}$$

$$I_{R1} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$$

$$I_{R1} = 5 \text{ amps}$$

$$I_{R2} = \frac{E_{R2}}{R_2}$$

$$I_{R2} = \frac{50 \text{ volts}}{20 \text{ Ohms}}$$

I_{R2} = 2.5 amps

$I_T = I_{R1} + I_{R2}$

I_T = 5 amps + 2.5 amps

I_T = 7.5 amps

The amount of current flow in the branch circuits and the total current in the circuit shown in figure 46, view B, on the previous page are determined by the following equations.

Given: E_S = 50 volts

R_1 = 10 Ohms

R_2 = 10 Ohms

R_3 = 10 Ohms

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

$E_s = E_{R1} = E_{R2} = E_{R3}$

$I_{R1} = \frac{E_{R1}}{R_1}$

$I_{R1} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$

I_{R1} = 5 amps

$I_{R2} = \frac{E_{R2}}{R_2}$

$I_{R2} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$

I_{R2} = 5 amps

$I_{R3} = \frac{E_{R3}}{R_3}$

$$I_{R3} = \frac{50 \text{ volts}}{10 \text{ Ohms}}$$

$$I_{R3} = 5 \text{ amps}$$

$$I_T = I_{R1} + I_{R2} + I_{R3}$$

$$I_T = 5 \text{ amps} + 5 \text{ amps} + 5 \text{ amps}$$

$$I_T = 15 \text{ amps}$$

Notice that the sum of the ohmic values of the resistors in both circuits shown in figure 46 on page 77 is equal (30 Ohms), and that the applied voltage is the same value (50 volts). However, the total current in figure 44, view B, on page 73, (15 amps) is twice the amount in figure 44, view A (7.5 amps). It is apparent, therefore, that the manner in which resistors are connected in a circuit, as well as their actual ohmic values, affect the total current.

The division of current in a parallel network follows a definite pattern. This pattern is described by Kirchhoff's law which states:

"The algebraic sum of the currents entering and leaving any junction of conductors is equal to zero."

This law can be stated mathematically as:

$$I_a + I_b + \ldots \; I_n = 0$$

where I_a, I_b, etc., are the currents entering and leaving the junction. Currents entering the junction are considered to be positive and currents leaving the junction are considered to be negative. When solving a problem using Kirchhoff's law, the currents must be placed into the equation with the proper polarity signs attached.

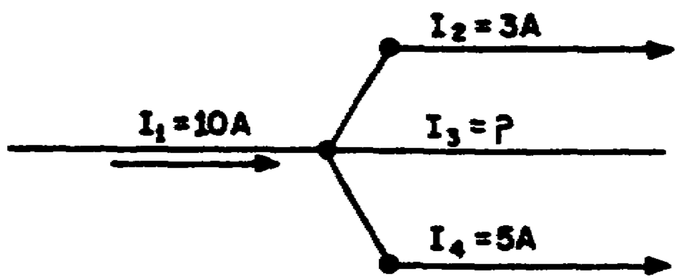
Example: Solve for the value of 13 in figure 47 on the following page.

Given: $I_1 = 10$ amps

$I_2 = 3$ amps

$I_4 = 5$ amps

FIGURE 47. CIRCUIT FOR EXAMPLE PROBLEM.



Solution: $I_a + I_b + \ldots\ I_n = 0$

The currents are placed into the equation with the proper signs.

$$I_1 + I_2 + I_3 + I_4 = 0$$

10 amps + (-3 amps) + I_3 + (-5 amps) = 0
I_3 + 2 amps = 0
I_3 = -2 amps

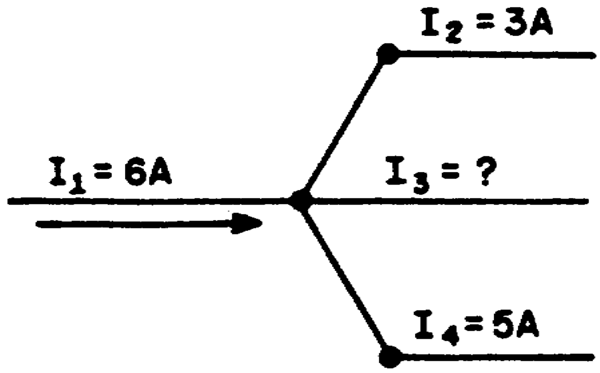
I_3 has a value of 2 amperes, and the negative sign shows it to be a current leaving the junction.

Now, use figure 48 on the following page and solve for the magnitude and direction of I_3.

Given: I_1 = 6 amps
I_2 = 3 amps
I_4 = 5 amps

Solution: $I_1 + I_2 + I_3 + I_4 = 0$
6 amps + (-3 amps) + I_3 + (-5 amps) = 0
I_3 + (-2 amps) = 0
I_3 = +2 amps

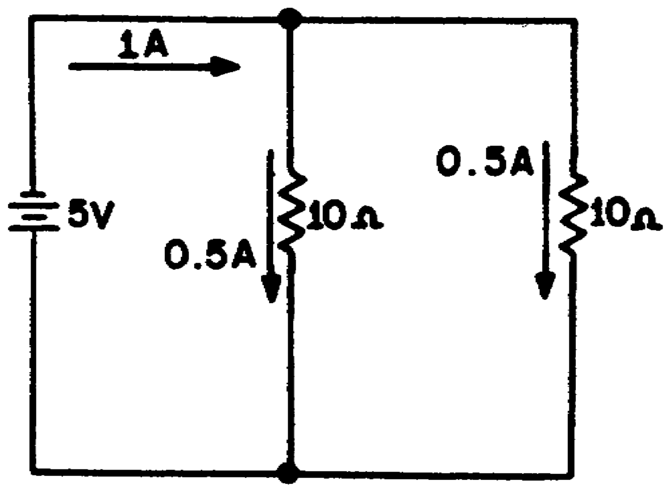
FIGURE 48. CIRCUIT FOR EXAMPLE PROBLEM.



I_3 is 2 amperes and its positive sign shows it to be a current entering the junction.

(3) *Resistance in a Parallel Circuit.* In the example diagram, figure 49, there are two resistors connected in parallel across a 5 volt battery. Each has a resistance value of 10 Ohms. A complete circuit consisting of two parallel paths is formed and current flows as shown.

FIGURE 49. TWO EQUAL RESISTORS CONNECTED IN PARALLEL.



Computing the individual currents shows that there is one-half of an ampere of current through each resistance. The total current flowing from the battery to the junction of the resistors, and returning from the resistors to the battery, is equal to 1 ampere.

The total resistance of the circuit can be calculated using the values of total voltage (E_T) and total current (I_T).

Given: E_T = 5 volts

I_T = 1 amp

Solution:

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

$$R_T = \frac{E_T}{I_T}$$

$$R_T = \frac{5 \text{ volts}}{1 \text{ amp}}$$

$$R_T = 5 \text{ Ohms}$$

This computation shows the total resistance to be 5 Ohms; one-half the value of either of the two resistors.

Since the total resistance of a parallel circuit is smaller than any of the individual resistors, total resistance of a parallel circuit is not the sum of the individual resistor values, as was the case in a series circuit. The total resistance of resistors in parallel is also referred to as equivalent resistance (R_{eq}). The terms total resistance and equivalent resistance are used interchangeably.

There are several methods used to determine the equivalent resistance of parallel circuits. The best method for a given circuit depends on the number and value of the resistors. For the circuit described above, where all resistors have the same value, the following simple equation is used:

$$R_{eq} = \frac{R}{N}$$

Where: R_{eq} = equivalent parallel resistance

R = ohmic value of one resistor

N = number of resistors

This equation is valid for any number of parallel resistors of equal value.

Example: Four 40 Ohm resistors are connected in parallel. What is their equivalent resistance?

Given: $R_1 = R_2 = R_3 = R_4$

R_1 = 40 Ohms

Solution:

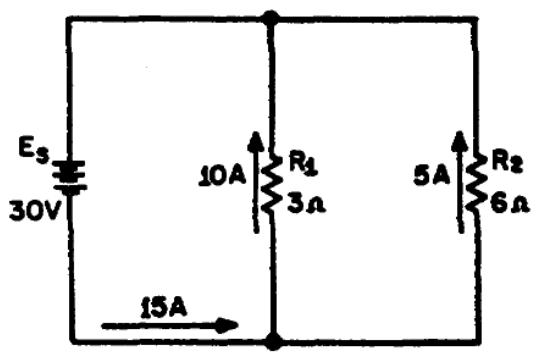
$$R_{eq} = \frac{R}{N}$$

$$R_{eq} = \frac{40 \text{ Ohms}}{4}$$

$$R_{eq} = 10 \text{ Ohms}$$

Figure 50 shows two resistors of unequal value in parallel. Since the total current is shown, the equivalent resistance can be calculated.

FIGURE 50. EXAMPLE OF CIRCUIT WITH UNEQUAL PARALLEL RESISTORS.



Given: $E_S = 30$ volts

$I_T = 15$ amps

Solution:

$$R_{eq} = \frac{E_s}{I_T}$$

$$R_{eq} = \frac{30 \text{ volts}}{15 \text{ amps}}$$

$$R_{eq} = 2 \text{ Ohms}$$

The equivalent resistance of the circuit shown in figure 50 on the previous page is smaller than either of the two resistors (R_1, R_2). A point to remember is that the equivalent resistance of a parallel circuit is always less than the resistance of any branch.

Equivalent resistance can be found if you know the individual resistance values and the source voltage. By calculating each branch current, adding the branch currents to calculate total current, and dividing the source voltage by the total current, the total can be found. This method, while effective, is somewhat lengthy. A quicker method of finding equivalent resistance is to use the general formula for resistors in parallel:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \ldots \frac{1}{R_n}$$

If you apply the general formula to the circuit shown in figure 50, you will get the same value for equivalent resistance (2 Ohms) as was obtained in the previous calculation that used source voltage and total current.

Given: $R_1 = 3$ Ohms

$R_2 = 6$ Ohms

Solution:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{R_{eq}} = \frac{1}{3 \text{ Ohms}} + \frac{1}{6 \text{ Ohms}}$$

Convert the fractions to a common denominator.

$$\frac{1}{R_{eq}} = \frac{2}{6 \text{ Ohms}} + \frac{1}{6 \text{ Ohms}}$$

$$\frac{1}{R_{eq}} = \frac{3}{6 \text{ Ohms}}$$

$$\frac{1}{R_{eq}} = \frac{1}{2 \text{ Ohms}}$$

Since both sides are reciprocals (each divided is into owe), disregard the reciprocal function.

$$R_{eq} = 2 \text{ Ohms}$$

The formula for equal resistors in parallel, $R_{eq} = \frac{R}{N}$, is a simplification of the general formula for resistors in parallel. There are other simplifications of the general formula for resistors in parallel which can be used to calculate the total or equivalent resistance in a parallel circuit.

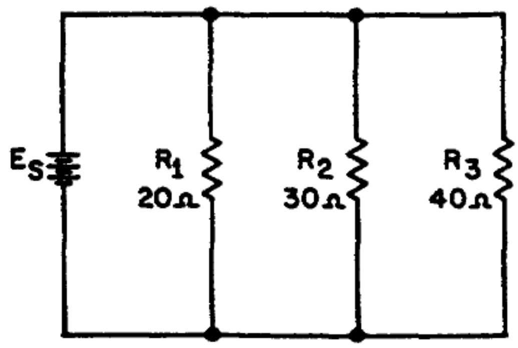
(a) *Reciprocal Method.* This method is based upon taking the reciprocal of each side of the equation. This presents the general formula for resistors in parallel as:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}}$$

This formula is used to solve for the equivalent resistance of a number of unequal parallel resistors. You must find the lowest common denominator in solving these problems.

Example: Three resistors are connected in parallel as shown in figure 51 (on the following page). The resistor values are: R_1 = 20 Ohms, R_2 = 30 Ohms, R_3 = 40 Ohms. Using the reciprocal method, what is the equivalent resistance?

FIGURE 51. EXAMPLE OF PARALLEL CIRCUIT WITH UNEQUAL BRANCH RESISTORS.



Given: R_1 = 20 Ohms

R_2 = 30 Ohms

R_3 = 40 Ohms

Solution:

$$R_{eq} = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

$$R_{eq} = \frac{1}{\frac{1}{20\text{ Ohms}} + \frac{1}{30\text{ Ohms}} + \frac{1}{40\text{ Ohms}}}$$

Now convert to the lowest common demoninator:

$$R_{eq} = \frac{1}{\frac{6}{120\text{ Ohms}} + \frac{4}{120\text{ Ohms}} + \frac{3}{120\text{ Ohms}}}$$

$$R_{eq} = \frac{1}{\frac{13}{120\text{ Ohms}}}$$

$$R_{eq} = \frac{120 \text{ Ohms}}{13}$$

$$R_{eq} = 9.23 \text{ Ohms}$$

(b) *Product Over the Sum Method.* A convenient method for finding the equivalent, or total, resistance of two parallel resistors is by using the following formula:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

This equation, called the product over the sum formula, is used so frequently it should be committed to memory.

Example: What is the equivalent resistance of a 20 Ohm and a 30 Ohm resistor connected in parallel, as in figure 52 on the following page.

Given: R_1 = 20 Ohms

R_2 = 30 Ohms

Solution:

$$R_{eq} = \frac{R_1 \times R_2}{R_1 + R_2}$$

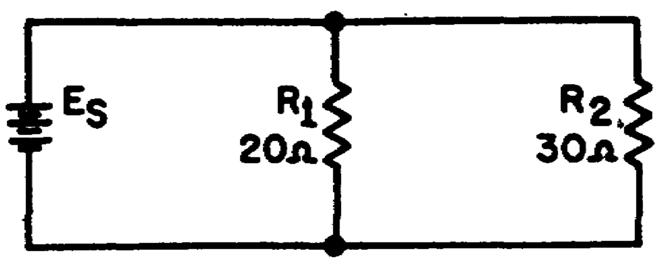
$$R_{eq} = \frac{20 \text{ Ohms} \times 30 \text{ Ohms}}{20 \text{ Ohms} + 30 \text{ Ohms}}$$

$$R_{eq} = \frac{600 \text{ Ohms}}{50 \text{ Ohms}}$$

$$R_{eq} = 12 \text{ Ohms}$$

(4) *Power in a Parallel Circuit.* Power computations in a parallel circuit are essentially the same as those used for the series circuit. Since power dissipation in resistors consists of heat loss, power dissipations are additive, regardless of how the resistors are connected in the circuit. The total power is equal to the sum

FIGURE 52. PARALLEL CIRCUIT WITH TWO UNEQUAL RESISTORS.

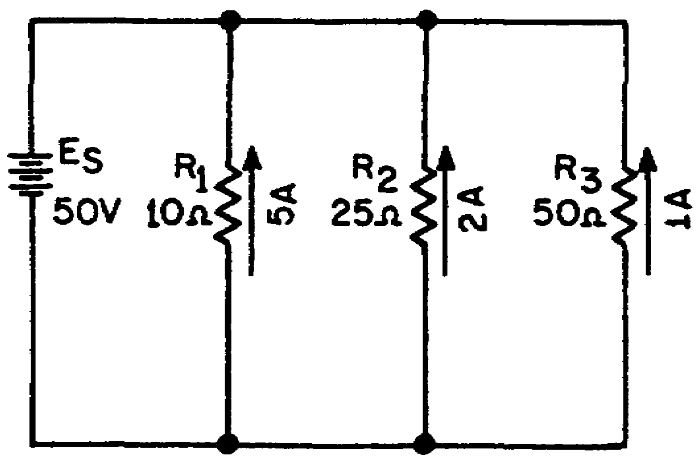


of the power dissipated by the individual resistors. Like the series circuit, the total power consumed by the parallel circuit is:

$P_T = P_1 + P_2 + \ldots P_n$

Example: Find the total power consumed by the circuit in figure 53.

FIGURE 53. EXAMPLE PARALLEL CIRCUIT.



Given: $R_1 = 10$ Ohms
$I_{R1} = 5$ amps
$R_2 = 25$ Ohms
$I_{R2} = 2$ amps
$R_3 = 50$ Ohms
$I_{R3} = 1$ amp

Solution: $P = I^2 R$
$P_{R1} = (I_{R1})^2 \times R_1$
$P_{R1} = (5 \text{ amps})^2 \times 10 \text{ Ohms}$
$P_{R1} = 250$ watts
$P_{R2} = (I_{R2})^2 \times R_2$
$P_{R2} = (2 \text{ amps})^2 \times 25 \text{ Ohms}$
$P_{R2} = 100$ watts
$P_{R3} = (I_{R3})^2 \times R_3$
$P_{R3} = (1 \text{ amp})^2 \times 50 \text{ Ohms}$
$P_{R3} = 50$ watts
$P_T = P_{R1} + P_{R2} + P_{R3}$
$P_T = 250 \text{ watts} + 100 \text{ watts} + 50 \text{ watts}$
$P_T = 400$ watts

Since the total current and the source voltage are known, the total power can also be computed by:

Given: $E_S = 50$ volts

$I_T = 8$ amps

Solution: $P_T = E_S \times I_T$

$P_T = 50 \text{ volts} \times 8 \text{ amps}$

$P_T = 400$ watts

(5) *Equivalent Circuits.* In the study of electricity, it is often necessary to reduce a complex circuit into a simpler form. Any complex circuit consisting of resistances can be redrawn (reduced) to a basic equivalent circuit containing the voltage source and a single resistor representing total resistance. This process is called reduction to an equivalent circuit.

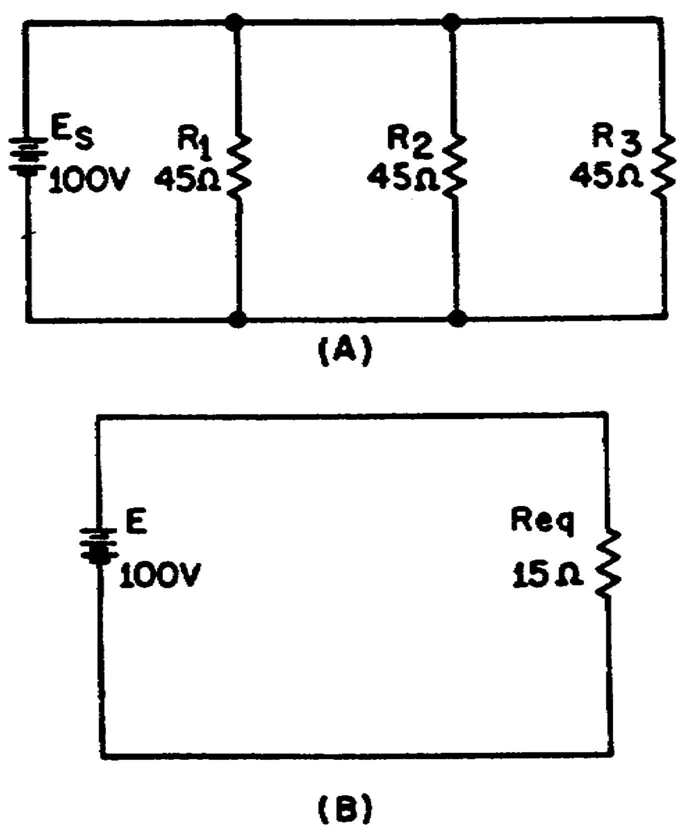
Figure 54 shows a parallel circuit with three resistors of equal value and the redrawn equivalent circuit. The parallel circuit shown in part A shows the original circuit. To create the equivalent circuit, you must first calculate the equivalent resistance.

Given: R_1 = 45 Ohms

R_2 = 45 Ohms

R_3 = 45 Ohms

FIGURE 54. PARALLEL CIRCUIT WITH EQUIVALENT CIRCUIT.



Solution:

$$R_{eq} = \frac{R}{N}.$$

$$R_{eq} = \frac{45 \text{ Ohms}}{3}$$

$$R_{eq} = 15 \text{ Ohms}$$

Once the equivalent resistance is known, a new circuit is drawn consisting of a single resistor (to represent the equivalent resistance) and the voltage source, as shown in view B.

b. *Rules for Parallel Circuits.*

Rule 1: The same voltage exists across each branch of a parallel circuit and is equal to the source voltage.

Rule 2: The current through a branch of a parallel network is inversely proportional to the amount of resistance of the branch.

Rule 3: The total current of a parallel circuit is equal to the sum of the individual branch currents of the circuit.

Rule 4: The total resistance of a parallel circuit is found by the general formula:

$$R_{eq} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots \frac{1}{R_n}$$

or one of the formulas derived from this general formula.

c. *Solving Parallel Circuit Problems.* Problems involving the determination of resistance, voltage, current, and power in a parallel circuit are solved as simply as in a series circuit. The procedure is the same: (1) draw the circuit diagram, (2) state the values given and the values to be found, (3) select the equations to be used in solving for the unknown quantities, based upon the known quantities, and (4) substitute the known values in the equation you have selected and solve for the unknown value.

6. Series-Parallel Circuits

In the previous discussions, series and parallel circuits have been considered separately. The technician will encounter circuits consisting of both series and parallel elements. A circuit of this type is referred to as a combination circuit. Solving for the quantities and elements in a combination circuit is simply a matter of applying the laws and rules discussed up to this point.

a. *Solving Combination-Circuit Problems.* The basic technique used for solving combination-circuit problems is the use of equivalent circuits. To simplify a complex circuit to a simple circuit containing only one load, equivalent circuits are substituted (on paper) for the complex circuit they represent.

The procedures for working these type of problems were covered in paragraph 5a(5), on page 87, and will not be repeated here.

b. *Redrawing Circuits for Clarity.* You will notice that the schematic diagrams that you have been working with have shown parallel circuits drawn as neat square figures, with each branch easily identified.

In actual practice, the wired circuits and more complex schematics are rarely laid out in this simple form. For this reason, it is important to recognize that circuits can be drawn in a variety of ways, and to learn some of the techniques for redrawing them into their simplified form. When a circuit is redrawn for clarity or to its simplified form, the following steps are used:

Step 1: Trace the current paths in the circuit.

Step 2: Label the junctions in the circuit.

Step 3: Recognize points which are the same potential.

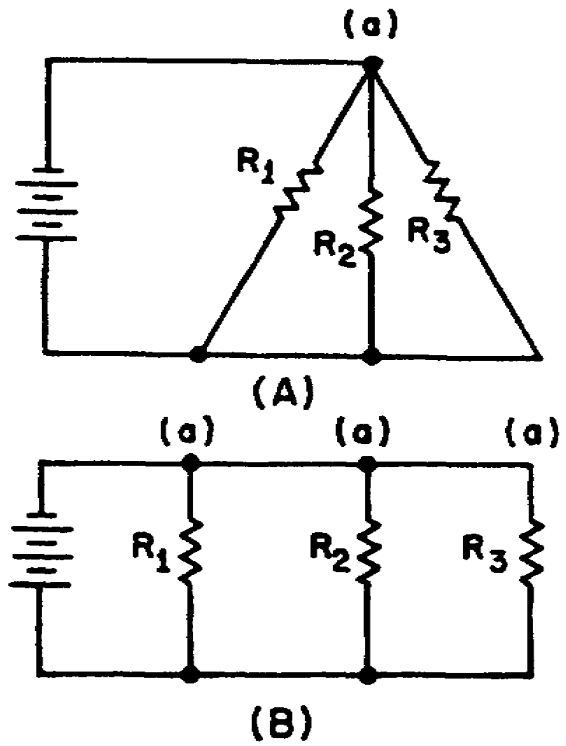
Step 4: Visualize a rearrangement, "stretching” or "shrinking" of connecting wires.

Step 5: Redraw the circuit into simpler form (through stages if necessary).

To redraw any circuit, start at the source, and trace the path of current flow through the circuit. At the junctions (points where the current divides), parallel branches begin. These junctions are key points of reference in any circuit and should be labeled as you find them. The wires in circuit schematics are assumed to have no resistance, and there is no voltage drop along any wire. This means that any unbroken wire is at the same voltage all along its length, until it is interrupted by a resistor, battery, or some other circuit component. In redrawing a circuit, a wire can be "stretched" or "shrunk" as much as you like without changing any electrical characteristics of the circuit.

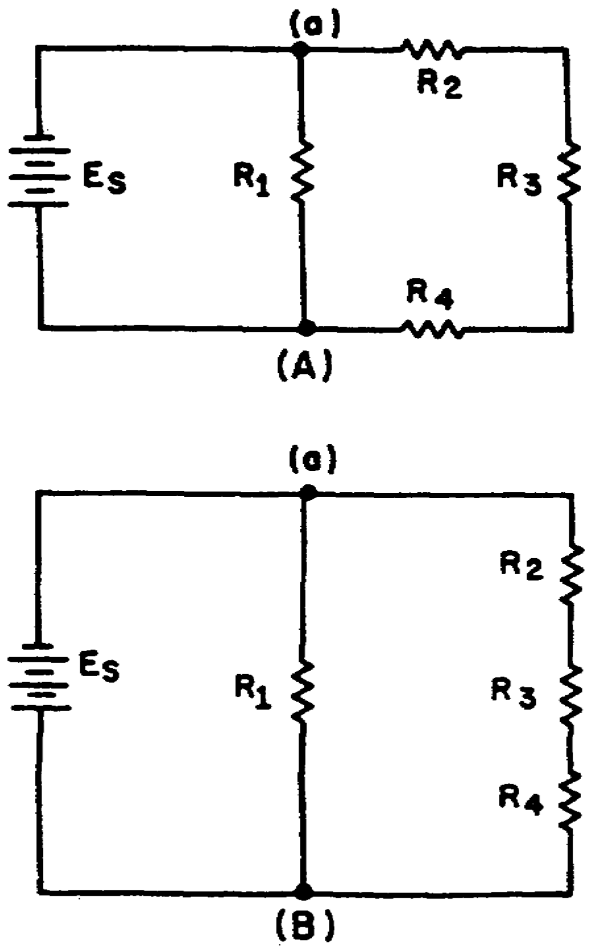
Figure 55, view A, is a schematic of a circuit that is not drawn in the box-like fashion that was used in previous illustrations. To redraw this circuit, start at the voltage source and trace the path for current to the junction marked (a). At the junction, the current divides into three paths. If you were to stretch the wire to show the three current paths, the circuit would appear as shown in view B.

FIGURE 55. REDRAWING A SIMPLE PARALLEL CIRCUIT.



While these circuits may appear to be different, the two drawings actually represent the same circuit. The drawing in figure 55, view B, on the previous page is the familiar box-like structure and may be easier to work with. Figure 56, view A, is a schematic of a circuit shown in a box-like structure, but way be misleading. This circuit in reality is a series-parallel circuit that may be redrawn as shown in figure 56, view B. The drawing in view B of the figure is a simpler representation of the original circuit and could be reduced to just two resistors in parallel.

FIGURE 56. REDRAWING A SIMPLE SERIES-PARALLEL CIRCUIT.



c. *Redrawing a Complex Circuit.* Figure 57, view A, on the following page, shows a complex circuit that may be redrawn for clarification in the following steps.

NOTE

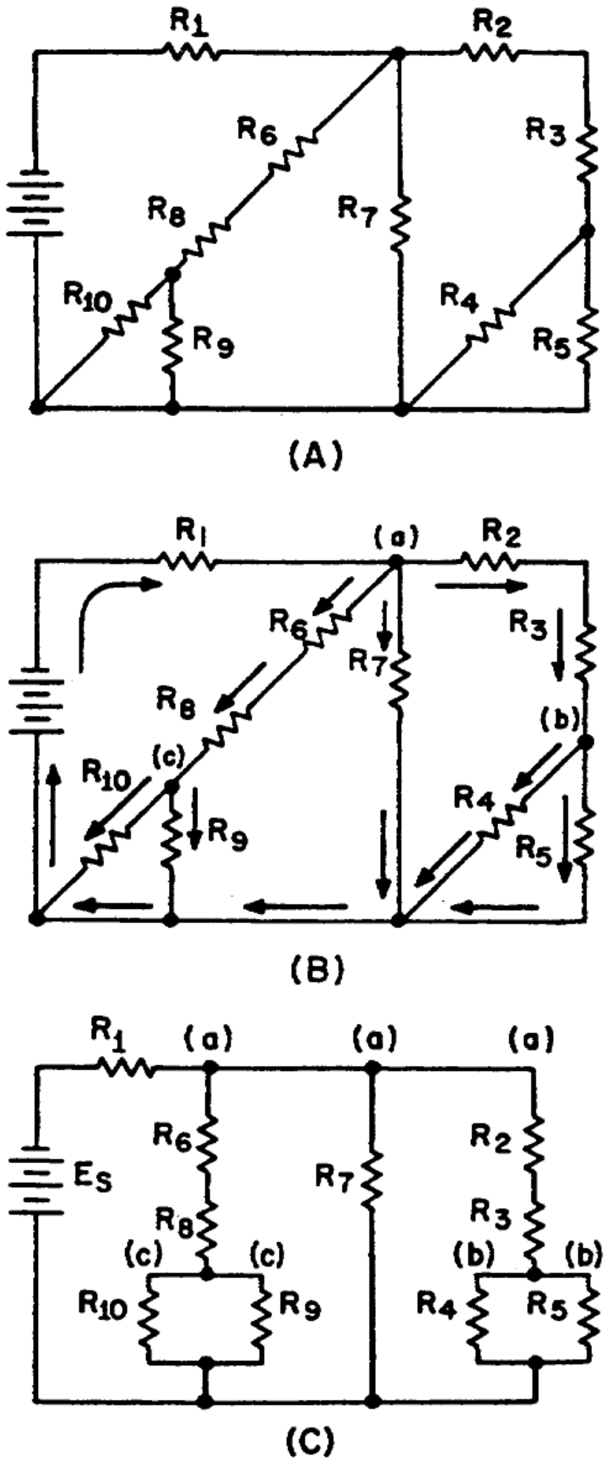
As you redraw the circuit, draw it in simple box-like form. Each time you reach a junction, a new branch is created by stretching or shrinking wires.

Step 1: Start at the negative terminal of the voltage source. Current flows through R_1, to a junction and divides into three paths; label this junction (a). Follow one of the paths of current through R_2 and R_3 to a junction where the current divides into two more paths. This junction is labeled (b).

The current through one branch of this junction goes through R_5 and back to the source--the most direct path. Now that you have completed a path for current to the source, return to the last junction, (b). Follow the current through the other branch from this junction. Current flows from junction (b) through R_4 to the source. All the paths from junction (b) has been traced. Only one path from junction (a) has been completed. You must now return to junction (a) to complete the other two paths. From junction (a) the current flows through R_7 hack to the source. There are no additional branches on this path. Return to junction (a) to trace the third path from this junction. Current flows through R_6 and R_8 and comes to a junction. Label this junction (c). From junction (c) one path for current is through R_9 to the source. The other path for current from junction (c) is through R_{10} to the source. All the junctions in this circuit have now been labeled. The circuit and junction can be redrawn as shown in figure 57 (view C). It is much easier to recognize the series and parallel paths in the redrawn circuit.

d. *Effects of Open and Short Circuits.* Earlier in this topic, the terms open and short circuits were discussed. The following discussion deals with the effects on a circuit when an open or a short occurs.

FIGURE 57. REDRAWING A COMPLEX CIRCUIT.



The major difference between an open in a parallel circuit and an open in a series circuit is that in the parallel circuit the open would not necessarily disable the circuit. If the open condition occurs in a series portion of the circuit, there will be no current because theme is no complete path for current flow. If, on the other hand, the open occurs in a parallel path, some current will flow in the circuit. The parallel branch where the open occurs will be effectively disabled, total resistance of the circuit will increase, and total current will decrease.

To clarify these points, figure 58 on the following page illustrates a series-parallel circuit. First, the effect of an open in a series portion of this circuit will be examined. View A shows the normal circuit R_T = 40 Ohms and I_T = 3 amps. In view B, an open is shown in the series portion of the circuit. There is no complete path for current, and the resistance of the circuit is considered to be infinite.

In view C, an open is shown in the parallel branch of R_3. There is no path for current through R_3. In the circuit, current flows through R_1 and R_2 only. Since there is only one path for current flow, R_1 and R_2 are effectively in series.

Under these conditions, R_T = 120 Ohms and I_T = 1 amp. As you can see, when an open occurs in a parallel branch, total circuit resistance increases and total circuit current decreases.

A short circuit in a parallel network has an effect similar to short in a series circuit. In general, the short will cause an increase in current and the possibility of component damage, regardless of the type of circuit involved. To illustrate this point, figure 59 on page 96 shows a series-parallel network in which shorts are developed. In view A, the normal circuit is shown (R_T = 40 Ohms and I_T = 3 amps).

In view B, R_1 has shorted. R_1 now has zero Ohms of resistance. The total of the resistance in the circuit is now equal to the resistance of the parallel network of R_2 and R_3, or 20 Ohms. Circuit current has increased to 6 amps. All of this current goes through the parallel network (R_2, R_3), and this increase in current would most likely damage the components.

FIGURE 58. SERIES-PARALLEL CIRCUIT WITH OPENS.

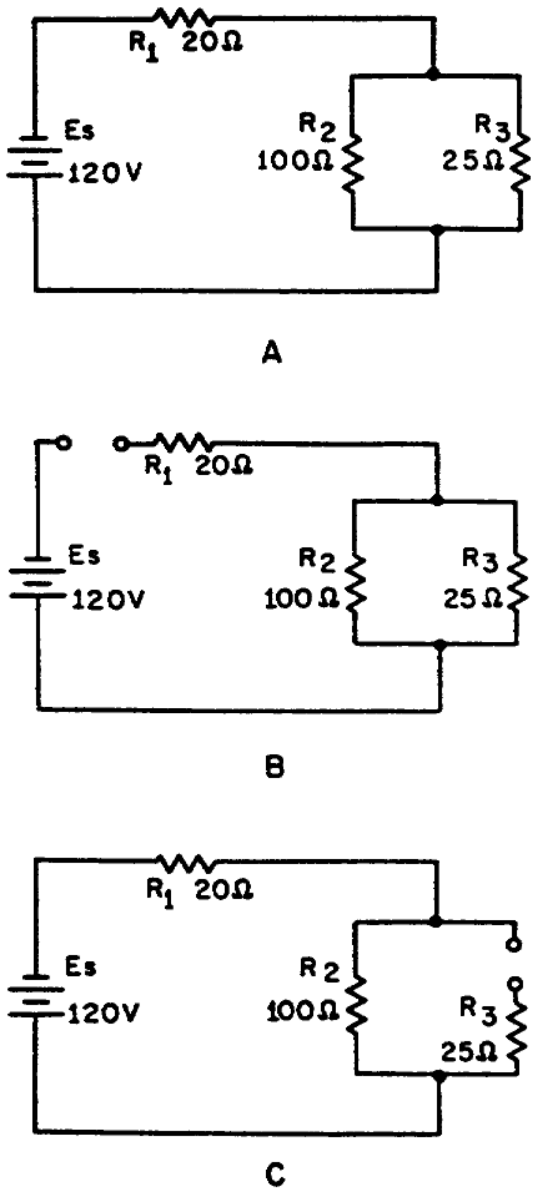
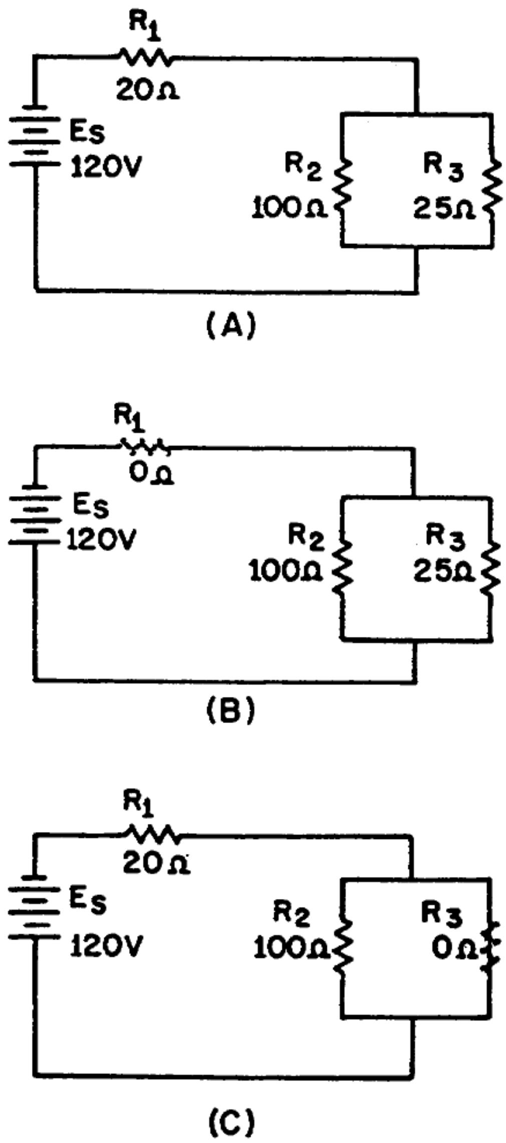


FIGURE 59. SERIES-PARALLEL WITH SHORTS.



In view C, R_3 has shorted. With R_3 shorted, there is a short circuit in parallel with R_2. The short circuit routes the current around R_2, effectively removing R2 from the circuit. Total circuit resistance is now equal to the resistance of R_1, or 20 Ohms.

As you know, R_2 and R_3 form a parallel network. Resistance of The network can be calculated as follows:

Given:

R_2 = 100 Ohms

R_3 = 0 Ohms

Solution:

$$R_{eq} = \frac{R_2 \times R_3}{R_2 + R_3}$$

$$R_{eq} = \frac{100 \text{ Ohms} \times 0 \text{ Ohms}}{100 \text{ Ohms} + 0 \text{ Ohms}}$$

The total circuit current with R_3 shorted is 6 amps. All of this current flows through R_1 and would most likely damage R_1. Notice that even though only one portion of the parallel network was shorted, the entire parallel network was disabled.

Opens and shorts alike, if occurring in a circuit, result in an overall change in the equivalent resistance. This can cause undesirable effects in other parts of the circuit due to the corresponding change in the total current flow. A short usually causes components to fail in a circuit which is not properly fused or otherwise protected. The failure may take the form of a burned-out resistor, damaged source, or a fire in the circuit components and wiring.

Fuses and other circuit protection devices are installed in equipment circuits to prevent damage caused by increases in current. These circuit protection devices are designed to open if current increases to a predetermined value. Circuit protection devices are connected in series with the circuit or portion of the circuit that the device is protecting. When the circuit protection device opens, current flow ceases in the circuit.

7. Batteries

A battery is a voltage source that uses chemical action to produce a voltage. In many cases the term battery is applied to a single cell, such as the flashlight battery. In the case of a flashlight that uses a battery of 1.5 volts, the battery is a single cell. The flashlight that is operated by 6 volts uses 4 cells in a single case, and this is a battery composed of more than one cell. There are three ways to combine cells to form a battery.

a. *Capacity and Rating of Batteries.* The capacity of a battery is measured in ampere-hours. The ampere-hour capacity is equal to the product of the current in amperes and the time in hours during which the battery will supply this current. The ampere-hour capacity varies inversely with the discharge current. For example, a 400 ampere-hour battery will deliver 400 amperes for 1 hour or 100 amperes for 4 hours.

Storage batteries are rated according to the rate of discharge and ampere-hour capacity. Most batteries are rated according to a 20-hour rate of discharge. That is, if a fully charged battery is completely discharged during a 20-hour period, it is discharged at the 20-hour rate. Thus, if a battery can deliver 20 amperes continuously for 20 hours, the battery has a rating of 20 amperes x 20 hours or 400 ampere-hours. Therefore, the 20-hour rating is equal to the average current that a battery is capable of supplying without interruption for an interval of 20 hours.

NOTE

Aircraft batteries are rated according to a one-hour rate of discharge.

All standard batteries deliver 100 percent of their available capacity if discharged in 20 hours or more, but they will deliver less than their available capacity if discharged at a faster rate. The faster they discharge, the less ampere-hour capacity they have.

The low-voltage limit, as specified by the manufacturer, is the limit beyond which very little useful energy can be obtained from a battery. This low-voltage limit is normally a test used in battery shops to determine the condition of a battery.

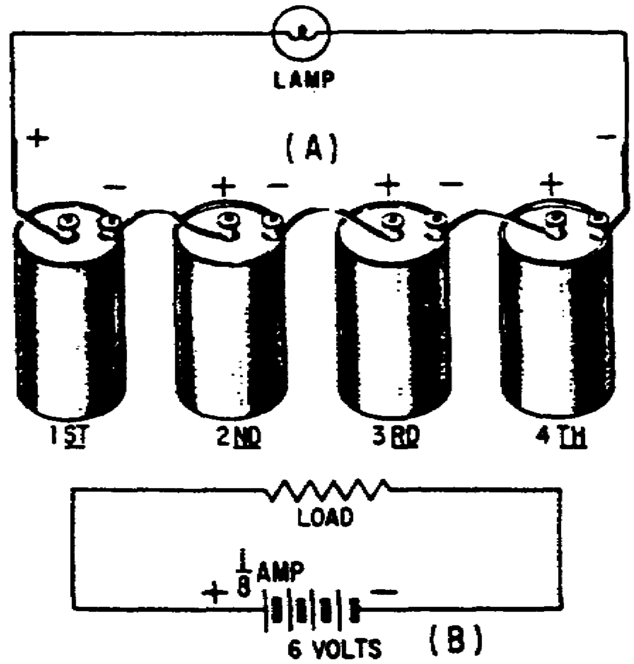
b. *Combining Cells.* In many cases, a battery-powered device may require more electrical energy than one cell can provide. The device may require either a higher voltage or more current, and in some cases both. Under such conditions, it is necessary to combine or interconnect a sufficient number of cells to meet the higher requirements. Cells connected in series provide a higher voltage, while cells connected in parallel provide a higher current capacity. To provide adequate power when both voltage and current requirements are greater than the capacity of one cell, a combination series-parallel network of cells must be used.

(1) *Series-Connected Cells.* Assume that a load requires power supply of 6 volts and a current capacity of 1/8 ampere. Since a single cell normally supplies a voltage of only 1.5 volts, more than one cell is needed. To obtain a higher voltage, the cells are connected in series as shown in figure 60 on the following page.

View B in figure 60 is schematic representation of the circuit shown in view A. The load is shown by the resistance symbol and the battery is indicated by one long and one short line per cell.

In a series hookup, the negative electrode (cathode) of the first cell is connected to the positive electrode (anode) of the second cell, the negative electrode of the positive of the third, etc. The positive electrode of the first cell and the negative electrode of the last cell then serve as the terminals of the battery. In this way, the voltage is 1.5 volts for each cell in the series line. There are four cells, so the output terminal voltage is 1.5 x 4, or 6 volts. When connected to the load, 1/8 ampere flows through the load and each cell of the battery. This is within the capacity of each cell. Therefore, only four series-connected cells are needed to supply this particular load.

FIGURE 60. PICTORIAL AND SCHEMATIC VIEWS OF SERIES CONNECTED CELLS.



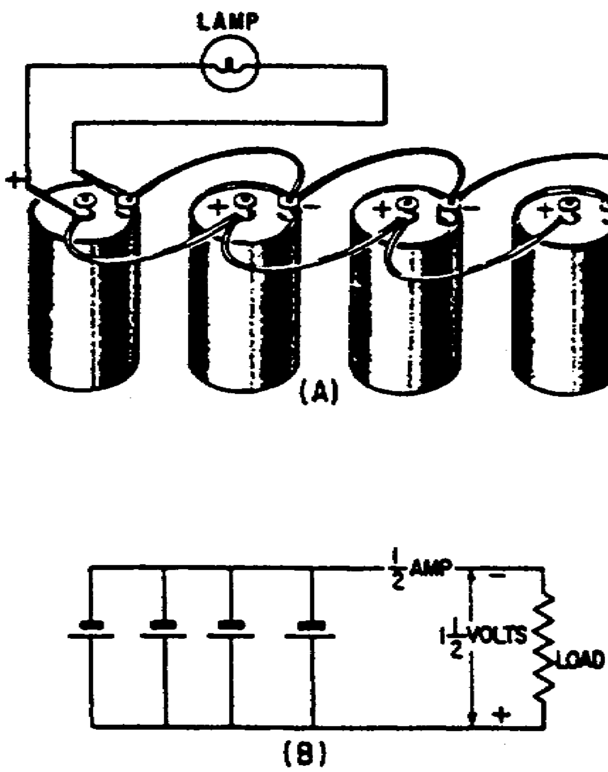
CAUTION

When connecting cells in series, connect alternate terminals together (- to +, - to +, etc.). Always have two remaining terminals that are used for connection to the load only. Do not connect the two remaining terminals together as this is a short across the battery and would not only quickly discharge the cells, but could cause some types of cells to explode.

(2) *Parallel-Connected Cells.* In this case, assume an electrical load requires only 1.5 volts, but will require 1/2 ampere of current. Assume that a single cell will supply only 1/8 ampere. To meet this requirement, the cells are connected in

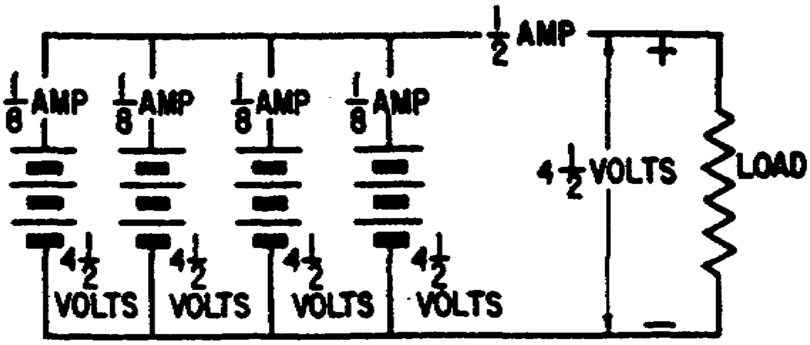
parallel as shown in figure 61, view A, and schematically represented in view B. In a parallel connection, all positive cell electrodes are connected to one line, and all negative electrodes are connected to the other. No more than one cell is connected between the lines at any one point; so the voltage between the lines is the same as that of one cell, or 1.5 volts. However, each cell may contribute its maximum allowable current of 1/8 amperes to the line. There are four cells, so the total current is 1/8 x 4 = 1/2 ampere. In this case, four cells in parallel have enough capacity to supply a load requiring 1/2 ampere at 1.5 volts.

FIGURE 61. PICTORIAL AND SCHEMATIC VIEWS OF PARALLEL-CONNECTED CELLS.



(3) *Series-Parallel-Connected Cells.* Figure 62 on the following page depicts a battery network supplying power to a load requiring both a voltage and current greater than one cell can provide. To provide the required 4.5 volts, groups of three 1.5 volt cells are connected in series. To provide the

FIGURE 62. SCHEMATIC OF SERIES-PARALLEL CELLS.



required 1/2 ampere of current, four series groups are connected in parallel, each supplying 1/8 ampere of current.

8. Conclusion

In the previous task, we covered a great deal of information concerning electricity. First, we learned the elements of electricity. Then we covered the safety requirements to be used when working around electricity, voltage, current, resistance functions. We also learned about Ohm's law and the color code system for resistors.

In this task, we put to work some of the information learned in task one. We learned about measuring and computing voltage, the different types of circuits (series, parallel, and series-parallel). In addition, we covered the connection of batteries in all three types of circuits.

Immediately following this task, there is a practical exercise which is designed to test your retention of the information presented in this subcourse. When you feel that you sufficiently understand the information presented in this text, turn the page and begin the practical exercise. If you have difficulty with any portion of the practical exercise, turn back to the text and re-review the information.

PRACTICAL EXERCISE 1

1. Instructions

Read the scenario and respond to the requirements that follow the scenario.

2. Scenario

You have been assigned to the military advisory group (MAG) located at Riyadh, Saudi Arabia. While stationed at Riyadh, you have worked extensively with the Saudi Arabian Army Ordnance Corps (SAAOC).

You have been tasked with assisting SSG Abdul Ibn Saud with developing a course in basic electronics to be taught to Fire Control Instrument Repairmen at the Saudi Arabian Army Ordnance School (SAAOS), Taif. On Monday morning you fly to Taif and meet with SSG Abdul. The two of you have decided that the best course of action is for each of you to develop a lesson plan and test questions. You then will sit down and combine both lesson plans and test questions to make one.

You fly back to Riyadh and begin developing your lesson plan. You have worked all week and through the weekend developing the lesson plan. Tomorrow is Monday and you are scheduled to meet with SSG Abdul. All that remains is to prepare an answer sheet for the test items.

3. Requirement

Using your knowledge of electricity and electronics, and this subcourse, provide an answer sheet for the following questions.

a. State the difference between conductors and insulators.

b. What two agents should be used to extinguish an electrical fire?

c. Define ampere, voltage, and resistance.

d. What is meant by the term efficiency of an electrical device?

e. Define a series circuit.

f. Define an open circuit.

g. Define a short circuit.

h. Define a parallel circuit.

LESSON 1. PRACTICAL EXERCISE - ANSWERS

Requirement

a. A conductor is defined as any material that will permit the flow of electricity through it, while an insulator is defined as any material that blocks the flow of electricity through the material.

b. The two types of agents used to extinguish a fire are carbon dioxide (CO_2) and potassium chloride or purple K (PKP).

c. Ampere is defined as the basic unit of electrical current. Voltage is the term used to signify electrical pressure. Voltage is a force which causes current to flow through an electrical conductor. Resistance is defined as the opposition which a device or material offers to the flow of current.

d. The term efficiency of an electrical device is the ratio of power converted to useful energy divided by the power consumed by the device.

e. A series circuit is defined as a circuit that contains only one path for current flow.

f. A circuit is said to be an open circuit when a break exists in a complete conducting pathway.

g. A short circuit is an accidental path of low resistance which passes an abnormally high amount of current.

h. A parallel circuit is defined as a circuit having more than one current path connected to a common voltage source.

REFERENCES

REFERENCES

The following documents were used as resource materials in developing this subcourse:

FM 11-60