UNITED STATES MARINE CORPS
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Marine Corps Engineer School
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Camp Lejeune, North Carolina 28542-5040

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APR 00

STUDENT HANDOUT

FUNDAMENTALS OF ELECTRICITY

1. **LEARNING OBJECTIVES**:

a. **Terminal Learning Objective**: Given a schematic, a faulty generator set electrical system, and applicable tools and test equipment, with the aid of references, repair the generator set electrical system so that it functions properly in accordance with the appropriate equipment technical manual. (1141.03.04)

b. **Enabling Learning Objectives**:

(1) Given electrical terms and characteristics, identify the characteristic of each electrical term in accordance with FM 11-60 and FM 11-61. (1141.03.04a)

(2) Given the resistance per 1000 ft. of wire, the length of wire, and the current moving through the wire, compute the voltage drop caused by the wire in accordance with FM 11-60. (1141.03.04b)

(3) Given a list of electrical symbols and a list of electrical components, match each symbol to its component in accordance with Electricity Concepts Unit 1. (1141.03.04c)

(4) Given a list of operating characteristics, identify the characteristics that apply to the operation of a relay, in accordance with FM 11-60. (1141.03.04d)

(5) Provided with an electricity concepts trainer, multimeter, lab manual, and a constructed circuit, measure the voltage across the circuit, in accordance with Electricity Concepts Unit 1. (1141.03.04e)

(6) Provided with an electricity concepts trainer, multimeter, lab manual, and a constructed circuit, measure the resistance of the circuit, in accordance with Electricity Concepts Unit 1. (1141.03.04f)

(7) Provided with an electricity concepts trainer, multimeter, lab manual, and a constructed circuit, measure the

current through the circuit, in accordance with Electricity Concepts Unit 1. (1141.03.04g)

(8) Given a description of an operating circuit and the amperage rating of a circuit breaker l, identify whether the circuit breaker will allow current to flow or not in accordance with FM 11-60. (1141.03.04h)

(9) Without the aid of references, identify the purpose of grounding electrical equipment, in accordance with FM 11-60 and MCI 11.41a. (1141.03.04i)

(10) Provided a selection of definitions, without the aid of references, identify the correct definition for a cycle, in accordance with FM 5-424. (1141.03.04j)

(11) Provided a selection of definitions, without the aid of references, identify the correct definition for frequency, in accordance with FM 5-424. (1141.03.04k)

(12) Provided a selection of definitions, without the aid of references, identify the correct definition for the effect of inductance on alternating current, in accordance with FM 5-424. (1141.03.04l)

(13) Provided a selection of definitions, without the aid of references, identify the correct definition for the effect of capacitance on alternating current, in accordance with FM 5-424. (1141.03.04m)

BODY

1. **The Structure of Matter:** Matter is defined as anything that occupies space and has weight. Matter may be found in any one of three states: solid, liquid, and gaseous.

EXAMPLE: Matter is air, water, automobiles, clothing, and even our own bodies.

a. Elements: An element is a substance that cannot be reduced to a simpler substance by chemical means. There are over 100 known elements. All the different substances we know about are composed of one or more of these elements.

EXAMPLE: Iron, gold, silver, copper, and oxygen.

b. Compounds: A compound is a chemical combination of elements that can be separated by chemical but not by physical means.

EXAMPLE: Water, which consists of hydrogen and oxygen, and table salt, which consists of sodium and chlorine.

c. Mixtures: A mixture is a physical combination of elements and compounds that can be separated by physical means.

EXAMPLE: Air, which is made up of nitrogen, oxygen, carbon dioxide, and small amounts of several rare gases, and sea water, which consists chiefly of salt and water.

d. Molecules: A molecule is a chemical combination of two or more atoms, (we will talk about atoms after we discuss molecules). In a compound the molecule is the smallest particle that has all the characteristics of the compound.

EXAMPLE: If we start with a quantity of water, divide this and pour out one half, and continue this process a sufficient number of times, we will eventually end up with a quantity of water which cannot be further divided without ceasing to be water. This quantity is called a molecule of water. If this molecule of water is divided, instead of two parts of water, there will be one part of oxygen and two parts of hydrogen (H_2O).

e. Atoms: Molecules are made up of smaller particles called atoms. An atom is the smallest particle of an element that retains the characteristics of that element. The atoms of one element, however, differ from the atoms of all other elements. Just as thousands of words can be made by combining the proper letters of the alphabet, thousands of different materials can be made by chemically combining the proper atoms.

f. Subatomic Particles: The atoms of each element are made up of the subatomic particles known as electrons, protons, and in most cases neutrons which are collectively called subatomic particles. The electrons, protons, and neutrons of one element are identical to those of any other element. The reason there are different kinds of elements is that the number and the arrangement of electrons and protons within the atom are different for the different elements.

(1) Electron: The electron is a small negative charge of electricity.

(2) Proton: The proton has a positive charge of electricity equal and opposite to the electron. The electron and proton each have the quantity of charge however; the mass of the proton is approximately 1837 times bigger than that of the electron.

(3) Neutron: In some atoms, there exist neutral particles called neutrons. The neutron has a mass approximately equal to that of the proton, but it has no electrical charge.

g. Shells: The difference between the atoms, insofar as their chemical activity and stability are concerned, is dependent upon the number and position of the electrons included within the atom. How are these electrons positioned within the atom? In general, the electrons reside in groups of orbits called shells. These shells are elliptically shaped and are assumed to be located at fixed intervals.

h. Shell Designators: The shells are identified with a letter designator. Starting with the shell closest to the nucleus and progressing outward, the shells are labeled K, L, M, N, O, P, and Q, respectively. The shells are considered to be full, or complete, when they contain the following quantities of electrons: two in the K shell, eight in the L shell, eighteen in the M shell, and so on. The number of electrons in each shell can be determined by using the formula $2n^2$,(n) being the shell number.

EXAMPLE: In the copper atom, which has an atomic number of 29, the K shell has 2 electrons, L has 8 electrons, M has 18 electrons, and N has 1 electron which totals out to 29.

i. Valence Shell: The outermost shell of an atom is called the valence shell; and the electrons contained in this shell are called valence electrons. The valence of an atom determines its ability to gain or lose electrons, which in turn determines the chemical and electrical properties of the atom.

2. **Electrical Terms and Characteristics**:

In working with electricity, there are several terms that you will be using. It is important that you understand these terms. These are a few of the more common terms that you, as future 1142's, will need to know.

a. Voltage is a difference of potential of one coulomb of charge between two points.

b. Current is the flow of electrons through a circuit.

c. Resistance is the opposition to current flow.

d. Directed drift is the directed movement of electrons due to a potential difference.

e. Random drift is the haphazard movement of electrons.

f. Energy is the ability to do work.

(1) Kinetic energy is the energy that a body possesses by virtue of its motion.

(2) Potential energy is the energy due to the position of one body with respect to another body.

g. Magnetism is the ability of a material to attract pieces of iron.

h. Conductors:

(1) Allow electrons to flow easily through them.

(2) Have from 1-3 valence electrons.

(3) Examples are silver, copper, gold, and aluminum.

i. Insulators:

(1) Oppose the flow of electrons because insulators do not allow electrons to move freely through them.

(2) Are usually compounds.

(3) Have 5-8 valence electrons.

(4) Examples are rubber, plastic, enamel, and glass.

j. Semiconductors:

(1) Are neither good conductors nor good insulators.

(2) Have 4 valence electrons.

(3) Examples are silicon and germanium.

k. The source is the device that provides (supplies) electrical energy to the circuit.

l. The conducting path is a route for electrons to follow from source to load and back to source.

m. The load is a device that changes electrical energy into a more useful form.

n. The switch is a device used to control electrical energy.

o. Power rating is the rate at which a device converts electrical energy into a more useful form of energy.

p. Direct current is current that only flows in on direction through a circuit.

3. **Conductors, Insulators, Semiconductors:** The electron theory states that all matter is composed of atoms and the atoms are composed of smaller particles called protons, electrons, and neutrons. It is the valence electrons that we are most concerned with in electricity. These are the electrons that are easiest to break loose from their parent atom.

a. Conductors: Conductive elements allow electrons to move freely through them. The atoms within these materials have from 1-3 electrons in their valence shell. Silver, copper, gold, and aluminum are materials with many free electrons and make good conductors. Silver is the best conductor followed by copper, gold, and aluminum. Copper is used more often because of cost. Aluminum is used where weight is a major consideration such as in high-tension power lines with long spans between supports. Silver is used on different types of contacts such as the lead contacts on generators, where good electrical conductivity is required. Gold is used where oxidation or corrosion is a consideration and a good conductivity is required. Conductors are usually found in the form of wire, but may be in the form of bars, tubes, or sheets.

b. Insulators: Nonconductive elements have few free electrons. There are from 5-8 electrons in their valence shell, which are held to the atom with a relatively strong force and cannot be moved about very easily. Some examples of these materials are rubber, plastic, enamel, glass, dry wood, paper, and mica. These materials are called insulators. They do not allow electrons to move freely through them. Keep in mind, there are no perfect insulators. If enough electrical pressure is applied, all insulators will break down and electric current will flow.

c. Semiconductors: Some materials are neither good conductors nor good insulators. If the valence shell is half-complete (contains four electrons), that material is classified as a semiconductor. Examples are silicon and germanium, which are used extensively in transistors and other solid-state devices.

d. Electrical Conductivity: The electrical conductivity of matter is dependent upon the atomic structure of the material from which the conductor is made. In any solid material, such as copper, the atoms which makes up the molecular structure are bound firmly together. At room temperature copper will contain a considerable amount of heat energy. When not under the influence of an external force, these electrons move in a haphazard manner within the conductor. When controlled by an external force, the electrons move generally in the same direction. The effect of this movement is felt almost instantly from one end of the conductor to the other. This electron movement is called an electric current.

4. **Electrostatics:** Electrostatics is simply defined as electricity at rest. Most of you are familiar with electrostatics, whether you realize it or not. Have you ever observed the way a person's hair stands on end after a vigorous rubbing? Have you ever walked across a carpeted room only to receive a slight shock when you touch the metal doorknob? Well, these are both examples of the effects of electrostatics.

a. History of Electrostatics: Interest in the subject of static electricity can be traced back to the Greeks. Thales of Miletus, a Greek philosopher and mathematician, discovered that when an amber rod is rubbed with fur, the rod has the amazing characteristics of attracting some very light objects such as bits of paper and shavings of wood.

(1) William Gilbert: Around 1600, William Gilbert, an English scientist, made a study of other substances that had been found to possess qualities of attraction similar to amber. Because of Gilbert’s work with electrics, a substance, such as amber or glass, when given a vigorous rubbing was recognized as being electrified or charged with electricity.

(2) Charles Dufay: In 1733, Charles Dufay, a French scientist, discovered that when a glass rod was rubbed with fur, both the glass rod and the fur became electrified. He systematically placed the glass rod and the fur near other electrified substances and found that certain substances, which were attracted to the glass rod, were repelled by the fur, and vice versa. From these experiments he concluded that there must be two exactly opposite kinds of charges.

(3) Benjamin Franklin: Benjamin Franklin, an American statesman, inventor, and philosopher, is credited with first using the terms positive and negative to describe the two opposite kinds of charges. The charge produced on a glass rod when it is rubbed with silk, Franklin labeled positive. He attached the term negative to the charge produced on the silk. Those bodies that were not electrified or charged, he called neutral.

b. Static Electricity: In a natural or neutral state, each atom in a body of matter will have the proper number of electrons in orbit around it. Consequently, the whole body of matter composed of the neutral atoms will also be electrically neutral. In this state, it is said to have a zero charge.

(1) If however, any electrons are removed from a body of matter, more protons will remain and the whole body of matter will become electrically positive.

(2) Should the positively charged body come in contact with another body having a normal charge, or having a negative (too many electrons) charge, an electric current will flow between them.

(3) Electrons will leave the more negative body and enter the positive body. This electron flow will continue until both bodies have equal charges. However, if they are not in contact, their charges cannot equalize. The existence of such an electric force, where current cannot flow, is referred to as

static electricity. (Static in this instance means not moving.) It is also referred to as an electrostatic force.

(4) One of the easiest ways to create a static charge is by friction. When two pieces of matter are rubbed together, electrons can be wiped off one material onto the other. When both materials being rubbed together are poor conductors, very little equalizing current can flow, and an electrostatic charge builds up. However, if the charge becomes great enough, current will flow regardless of the poor conductivity of the materials. This current can cause visible sparks and produce a crackling sound.

c. Nature of Charges: When in a natural or neutral state, an atom has an equal number of electrons and protons. Because of this balance, the negative charge of the electrons in orbit is exactly balanced by the positive charge of the protons in the nucleus, making the atom electrically neutral.

d. Ionization: When an atom loses or gains an electron it is said to be ionized. An atom becomes a positive ion whenever it loses an electron and has an overall positive charge. Conversely, whenever an atom acquires an extra electron, it becomes a negative ion and has a negative charge.

e. Charged Bodies: One of the fundamental laws of electricity is that like charges repel each other and unlike charges attract each other.

(1) In the atom, the negative electrons are drawn toward the positive protons in the nucleus. This attractive force is balanced by the electron's centrifugal force caused by its rotation about the nucleus.

(2) Electrons repel each other because of their like negative charges, and protons repel each other because of their like positive charges.

f. Coulombs Law of Charges: The relationship between attracting or repelling charged bodies was first discovered and written about by a French scientist named Charles A. Coulomb.

(1) Coulombs Law states that charged bodies attract or repel each other with a force that is directly proportional to the product of their individual charges and is inversely proportional to the square of the distance between them.

(2) Simply stated, this means the amount of attracting or repelling force which acts between two electrically charged bodies in free space depends on two things: the strength of their individual charges and the distance between them.

g. Electric Fields: The space between and around charged bodies in which their influence is felt is called an electric field of force. It can exist in air, glass, paper, or a vacuum.

(1) Electrostatic fields and dielectric fields are other names used to refer to this region of force.

(2) The field about a charged body is represented by lines that are referred to as electrostatic lines of force. These lines are imaginary and are used merely to represent the direction and strength of the field.

(3) The lines of force exerted by a positive charge are shown leaving the charge and for a negative charge they are shown entering.

5. **Magnetism:**

Magnetism is generally defined as that property of a material that enables it to attract pieces of iron. A material possessing this property is known as a magnet.

a. Magnetic Materials: The most important group of materials connected with electricity and electronics are the ferromagnetic materials. Ferromagnetic materials are those which are relatively easy to magnetize, such as iron, steel, nickel and cobalt.

(1) Natural Magnets: Magnetic stones such as those found by the ancient Greeks are considered to be natural magnets. These stones had the ability to attract small pieces of iron. However, the magnetic properties attributed to the stones were products of nature and not the results of the efforts of man. Natural magnets no longer have any practical use, for it is now possible to easily produce more powerful magnets.

(2) Artificial Magnets: Magnets produced from magnetic materials are called artificial magnets. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatuses.

(a) Artificial magnets are generally made from special iron or steel alloys that are usually magnetized electrically. The material to be magnetized is inserted into a coil of insulated wire and a heavy force of electrons is passed through the wire.

(b) Magnets can also be produced by stroking a magnetic material with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force, very similar in nature to electrostatic lines of force.

(c) Artificial magnets are usually classified as permanent or temporary. The classification is dependent upon their ability to retain their magnetic properties after the magnetizing force has been removed.

1 Reluctance: The opposition that a material offers to the magnetic lines of force.

2 Residual Magnetism: The amount of magnetism that remains in a temporary magnet.

3 Retentivity: The ability of a material to retain an amount of residual magnetism.

4 Permeability: The ease by which magnetic lines of force distribute themselves throughout the material.

b. Permanent Magnets: Permanent magnets are made from substances such as hardened steel and certain alloys which retain a great deal of their magnetism.

(1) Permanent magnets have high reluctance.

(2) Permanent magnets have low permeability.

c. Temporary Magnets: Temporary magnets are made of substances such as soft iron or annealed silicon steel which will retain only a small part of its magnetism.

(1) Temporary magnets have low reluctance.

(2) Temporary magnets have high permeability.

d. Magnetic Poles: The magnetic force surrounding a magnet is not uniform. There exists a great concentration of force at each end of the magnet and a very weak force at the center.

(1) The two ends, which are the regions of concentrated lines of force, are called the poles of the magnet.

(2) Magnets have two magnetic poles and both poles have equal magnetic strength.

(3) The law for magnetic poles are like poles repel, unlike poles attract.

e. Magnetic Fields: The space surrounding a magnet where magnetic forces act is known as the magnetic field. The magnetic field is very strong at the poles and weakens as the distance from the poles increases.

(1) Lines of force: Magnetic lines of force are imaginary lines used to illustrate and describe the pattern of the magnetic field. The magnetic lines are assumed to emanate

from the North Pole of a magnet, pass through the surrounding space, and enter the South Pole, thus completing the closed loop.

(2) Properties of Magnetic Lines of Force

(a) Are continuous and always form closed loops.

(b) Will never cross one another.

(c) Parallel lines of force traveling in the same direction repel one another. Parallel lines of force traveling in opposite directions tend to unite with each other and form into single lines traveling in a direction determined by the magnetic poles creating the lines of force.

(d) They tend to shorten themselves. Therefore, the magnetic lines of force existing between two unlike poles, cause the poles to be pulled together.

(e) Will pass through all materials, both magnetic and nonmagnetic.

(f) Are more concentrated at the poles.

f. Magnetic Flux: The total number of magnetic lines of force leaving or entering the pole of a magnet are called magnetic flux. The intensity of a magnetic field is directly related to the magnetic force exerted by the field.

g. Magnetic Induction: The magnetic effect of one body on another without any physical contact between them is called induction. Magnetism can be induced in a magnetic material by several means.

(1) The magnetic material may be placed in the magnetic field.

(2) Brought into contact with a magnet.

(3) Stroked by magnet.

h. Magnetic Shielding: There is no known insulator against magnetic lines of flux. If a nonmagnetic material is placed in a magnetic field, the flux penetrates the nonmagnetic material. The sensitive mechanisms of electric instruments and meters can be influenced by stray magnetic fields which will cause errors in their readings. Because these instruments cannot be insulated against magnetic flux, it is necessary to employ some means of directing the flux around the instruments. This is accomplished by placing a soft iron case, called a magnetic shield, around the instrument. Since the soft iron shield has high permeability, magnetic lines of flux will be drawn through it shielding an instrument.

6. **Electrical Energy**:

a. Energy is defined as the ability to do work. In order to perform any kind of work, energy must be expended (converted from one form to another). Energy supplies the required force or power whenever any work is accomplished.

(1) Kinetic energy: Energy that a body possesses by virtue of its motion.

EXAMPLE: When a hammer is set in motion in the direction of a nail, it possesses energy of motion. As the hammer strikes the nail, the energy of motion is converted into work as the nail is driven into the wood.

(2) Potential Energy: Energy due to the position of one body with respect to another body or to the relative parts of the same body.

EXAMPLE: If the hammer was suspended by a string one foot above the nail, as a result of gravitational attraction the hammer would feel a force pulling it downward. If the string is cut, the force of gravity will pull the hammer down against the nail, driving it into the wood. While the hammer is suspended above the nail it has the ability to do work because of its elevated position in the earth's gravitational field. Since energy is the ability to do work, the hammer contains energy.

b. Electrical Charges: From our previous discussion of electrostatics, you learned that a field of force exists in the space surrounding any electrical charge.

(1) The strength of the field is directly dependent on the force of the charge.

(2) The charge of one electron is so small that it is impractical to use. The practical unit adopted for measuring charges is the coulomb, named after the scientist Charles Coulomb.

(3) One coulomb is equal to the charge of 6,280,000,000,000,000,000 (six quintillion two hundred and eighty quadrillion) or (6.28×10^{18}) electrons.

c. Voltage: Electrical potential or potential differences are expressed in volts. When a difference of potential of one coulomb exists between two bodies, the difference of potential is one volt. Volts are the unit of measure for a difference of potential.

d. Electromotive Force: The force that moves or tends to move electric current. The term is often considered synonymous with voltage even though the technical definitions are different. (The National Electric Code considers the terms interchangeable).

e. Difference of Potential: When a charge or voltage exists between two bodies.

(1) Electrical charges are created by the displacement of electrons so that there exists an excess of electrons at one point and a deficiency at another point.

(2) Consequently, a charge must always have either a negative or a positive polarity.

(a) A lack of electrons has a positive polarity.

(b) An excess of electrons has a negative polarity.

(3) A difference of potential can exist between points, or two bodies, only if they have different charges.

EXAMPLE: If one body is deficient of 6 coulombs (representing 6 volts), and the other is deficient by 12 coulombs (representing 12 volts), there is a difference of potential of 6 volts.

(4) The potentials at various points in a circuit are generally measured with respect to the metal chassis on which all parts of the circuit are mounted.

(a) The chassis is considered to be at zero potential and all other potentials are either positive or negative with respect to the chassis.

(b) When used as the reference point, the chassis is said to be at ground potential.

(5) When a difference in potential exist between two charged bodies that are connected by a conductor, electrons will flow along the conductor.

(a) This flow is from the negatively charged body to the positively charged body, until the two charges are equalized and the potential difference no longer exists.

(b) A fundamental law of electricity is that the electron flow is directly proportional to the applied voltage. If the voltage is increased, the flow is increased. If the voltage is decreased, the flow is decreased.

7. **How Voltage is produced**:

a. To be a practical voltage source, the potential difference must not be allowed to dissipate, but must be maintained continuously.

b. A voltage source is a device that is capable of supplying and maintaining voltage while some type of electrical lead is connected to its terminals.

c. At present, there are six known methods for producing a voltage or electromotive force (emf). They are friction, pressure, heat, light, chemical action, and magnetism. We are going to focus on voltage produced using magnetism.

d. Generators employ the principle of electromagnetic induction to produce a voltage. Various generators will be discussed in detail when we get into the lesson that covers A. C. Characteristics. The important subject to be discussed at this time is the fundamental operating principle of all electromagnetic induction generators.

(1) There are three fundamental conditions which must exist before a voltage can be produced by magnetism.

(a) There must be a closed loop conductor in which the voltage will be produced.

(b) There must be a magnetic field in the conductors' vicinity.

(c) There must be relative motion between the magnetic field and conductor. The conductor must be moved so as to cut across the magnetic lines of force or the field must be moved so that the lines of force cut across the conductor.

(2) Since voltage and current are produced in the conductor, they are called induced voltage and induced current. Moving a conductor up or down through a magnetic field induces a voltage in the conductor.

(3) By using the left-hand rule for generators, we can determine the polarity of the induced voltage and the direction of current flow.

8. **Electric Current**:

Current is defined as the directed flow of electrons through a circuit. The direction of electron movement is from a region of negative potential to a region of positive potential. Therefore, electric current can be said to flow from negative to positive.

a. Directed Drift: The directed movement of electrons due to a potential difference is called directed drift.

(1) Associated with every charged body there is an electrostatic field. Bodies with like charges, repel one another and bodies with unlike charges, attract each other.

(2) An electron will be affected by an electrostatic field in exactly the same manner as any negatively charged body. It is repelled by a negative charge and attracted by a positive charge.

(3) If a conductor has a difference in potential applied across it, electrons will be repelled from the negative terminal and attracted to the positive terminal. This causes a movement of electrons from one end of the conductor to the other.

(4) Random drift is the haphazard movement of electrons. If some form of energy, such as heat, is applied to a material, some electrons acquire sufficient energy to move to a higher energy level. As a result, some electrons are freed from their parent atoms, which then become ions.

b. Magnitude of Current Flow: Current flow is the terminology most commonly used in indicating the directed movement of electrons. The magnitude of current flow is affected by the difference in potential applied across a conductor.

(1) If the potential difference is increased, the electrostatic field will become stronger and the current will be increased.

(2) If the difference in potential is decreased, the electrostatic field will become weaker and current flow will decrease.

c. Measurement of Current: Current is measured in amperes, and the letter used to represent the current flow is a lower case a.

(1) A current of one ampere is said to flow when one coulomb of charge passes a point in one second.

(2) Remember, one coulomb is equal to the charge of ($6.28 \text{ X } 10^{18}$) electrons.

oppose current flow. Now, we will cover the electrical property that deals with the opposition to current flow.

9. **DETERMINING THE VOLTAGE DROP IN A CONDUCTOR**:

The opposition to current flow is known as resistance.

a. The unit of measure is the ohm.

b. The symbol used to represent the ohm is the Greek letter Omega (⦸).

(1) The standard of measurement for one ohm is the amount of resistance that develops 0.24 calories of heat when one ampere flows through a material for one second.

(2) A conductor has one ohm of resistance when an applied voltage of one volt produces a current of one ampere.

(3) Resistance is determined by the physical structure of a material. More specifically there are four factors that affect the resistance of a material:

(a) Physical structure.

(b) Length: The resistance of a length of conductor is given in ohms per 1000 feet. For the ⦸ per 1000 Feet of different size conductors, refer to pp. 3-6 in your Electricity Concepts Unit 1. The resistance of a length of conductor can be determined by the following formula:

$$R = \frac{\Omega/1000\text{FEET} \times \text{LENGHT} \times 2}{1000}$$

(x2 conductors, because: There is one per side. One runs from the source to the load and the other, then runs from the load back to the source)

1 By using this formula, we will see that as the length is doubled the resistance is doubled.

EXAMPLE: If we take a length of #8 conductor, 50' long, with a resistance of .628 ohms per 1000 feet, it will have a resistance of

$$R = \frac{0.628 \times 50 \times 2}{1000}$$

Step One:	**Step Two:**	**Step Three:**
.628 x50 = 31.4	31.4 x2 = 62.8	62.8÷1000=0.0628

R=0.0628Ω

2 If we now double the length of the conductor, the resistance is doubled.

$$\boldsymbol{R} = \frac{0.628X100X2}{1000}$$

Step One: **Step Two:** **Step Three:**

Step One	Step Two	Step Three
.628	62.8	125.6÷1000=0.1256
x100	x2	
62.8	125.6	

R=0.1256Ω

3 Ohm's Law (which will be covered later) states that a precise relationship exists between current, voltage, and resistance. If you calculate the resistance in a conductor and you know how much current is flowing through the conductor, then you can calculate the amount of voltage drop of the conductor by simply multiplying the current and the resistance.

EXAMPLE: Using the resistance of the first conductor (.0628Ω) with 50a of current, the voltage drop across the conductor would be:

$$\boldsymbol{R} = \frac{0.628X50X2}{1000} X50a=3.14v$$

Step One	Step Two	Step Three
.628	31.4	62.8÷1000=0.0628
x50	x2	
31.4	62.8	

Step Four:

.0628
x50
3.14

Voltage Drop is: 3.14v

EXAMPLE: Using the resistance of the second conductor (.1256Ω) with 50a of current, again, the voltage drop is equal to:

$$R = \frac{0.628 \mathrm{X} 100 \mathrm{X} 2}{1000} \mathrm{X} 50a = 6.28v$$

Step One:

0.628
x100
62.8

Step Two:

62.8
x2
125.6

Step Three:

125.6÷1000=0.1256

Step Four:

0.1256
x50
6.28

Voltage Drop is: 6.28v

(c) Cross Sectional Area: The diameter of wire is usually expressed in mils. As the cross sectional area of a wire increases, the resistance decreases.

(d) Temperature: It effects the resistance of materials in different ways. In some materials, an increase in temperature causes an increase in resistance. In others, it causes resistance to decrease. The amount of change of resistance per change in temperature is known as the temperature coefficient.

<u>1</u> If the temperature increases and the resistance of the material increases, it is said to have a positive temperature coefficient.

2 If the temperature increases and the resistance of the material decreases, it is said to have a negative temperature coefficient.

3 Most conductors have a positive temperature coefficient. Carbon, a material used to make resistors, has a negative temperature coefficient.

Note: Conductance is the ease at which a material will pass electrons and is the opposite of resistance.

10. **Electrical Resistors**:

Resistors are components manufactured to possess specific values of resistance. There are two basic types of resistors: composition and wire wound.

a. Composition Resistors: One of the most common types of resistors is the carbon resistor. These resistors are made of powdered carbon and clay. Clay is used as a binder. The resistor is then encased in a tubular plastic case for sealing and wire leads are attached for circuit connection.

(1) The chemical composition of the resistor determines its ohmic value and is controlled by the manufacturer. They are manufactured with resistance values of one ohm to twenty million ohms and are used where large currents are not involved.

(2) Carbon resistors come in 1/8, ¼, ½, 1, and 2 watt sizes. The larger the wattage rating, the larger the physical size of the resistors.

b. Wire Wound Resistors: These resistors are very accurate and can handle more current than carbon resistors. Wire wound resistors are made of German silver (copper, nickel, and zinc) or nichrome. One disadvantage of wire wound resistors is the cost of the wire to make them. There are two types of wire wound resistors, fixed and variable.

(1) Fixed: There are two types of fixed wire wound resistors, power and precision.

(a) Power type

1 Can carry high currents and dissipate large amounts of heat.

2 Very large in size to handle these large currents and heat.

3 Made with a value of a few ohms to thousands of ohms with a tolerance of 10-20%.

(b) Precision type

1 Used when resistances with very small tolerances are required.

2 Made with ohmic values as low as .1 ohms and tolerances a small as .1%.

(2) Variable Resistors: There are two types of variable resistors, rheostat and potentiometer.

(a) The rheostat has two electrical connections, is used as a current control device, and is wired in series. An example of a rheostat would be the dimmer control for the dash lights on your car.

(b) The potentiometer has three electrical connections, is used as a voltage control device, and is wired in parallel. An example of a potentiometer would be the balance control on your radio.

c. Resistor Wattage Rating: A rating expressing the maximum power that a resistor can safely handle.

(1) When current flows 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.

(2) The heat dissipating capability of a resistor is measured in Watts (w). The unit of watts will be discussed in more detail later when we talk about power.

d. Resistor Color Code

(1) Order of colors and memory aid

COLOR	MEMORY AID	1ST DIGIT	2ND	MULTIPLIER	RESISTANCE TOLERANCE
Black	Bad	0	0	1	-
Brown	Boys	1	1	10	-
Red	Run	2	2	100	-
Orange	Over	3	3	1,000	-
Yellow	Yellow	4	4	10,000	-
Green	Gardenias	5	5	100,000	-
Blue	Behind	6	6	1,000,000	-
Violet	Victory	7	7	10,000,000	-
Gray	Garden	8	8	100,000,000	-
White	Walls	9	9	1,000,000,000	-
(Gold)	(Gold)	-	-	.1	+/- 5%
	(Silver)	-	-	.01	+/- 10%

(NO COLOR)	-	-	-	+/- 20%

(2) The resistor is marked by a series of colored bands. Their color and position indicate the ohmic value of the resistor.

(a) First color band: The first color band indicates the first number of the value of the resistor (the first significant digit).

(b) Second color band: The second color band indicates the second number in the value of the resistor (second significant digit).

(c) Third color band: The third color band indicates the multiplier factor.

(d) Fourth color band: The fourth color band is known as the tolerance; it tells you how accurate the resistor is. If the band is gold, the tolerance is 5%, if the band is silver, the tolerance is 10%, and if there is no band then the tolerance is 20%.

(e) Fifth color band: The fifth color band, which is not illustrated on the chart, indicates the failure or reliability level. This level is expressed in 50% rated wattage in percent per 1000 hours. The following gives the reliability level for the colors of the fifth band:

COLOR	RELIABILITY LEVEL
Brown	1%
Red	.1%
Orange	.01%
Yellow	.001%

11. **The Basic Electric Circuit**:

The basic electric circuit consists of a source, conducting path, load, and a switch.

a. The Source: The device that supplies the electrical energy used by the load in the form of voltage and can be called the voltage source. Examples of voltage sources are dry cell, storage batteries, power supplies, and generators.

b. Conducting Path: Electrons must have a complete path to move through in order to reach the load and return back to the source. The path is usually supplied by wires that connect all the parts of the circuit together.

c. The Load: Any device through which electric current flows, that changes the electrical energy into a more useful form.

(1) The load dissipates (or uses) the electrical energy supplied by the source.

(2) Examples of loads are:

(a) Light bulbs, which change electrical energy to light energy.

(b) An electric motor which changes electrical energy into mechanical energy.

(c) Speaker in a radio which changes electrical energy into sound energy.

d. The Switch: A control device, which interrupts the flow of current, delivered to the load.

12. **Basic Diagrams**:

There are three types of diagrams—pictorial, schematic, and wiring.

a. Pictorial: Shows the actual physical location, size, and hookup of the components as would be seen by the human eye.

b. Schematics: The technician's primary aid in troubleshooting an electrical circuit is the schematic diagram.

1 The schematic diagram is a picture of the circuit.

2 It uses symbols to represent the various circuit components.

3 Physically large or complex circuits can be shown on relatively small diagram.

c. Wiring: Similar to a pictorial diagram, except that components are shown as rectangles or circles. The location of parts is correct and all connecting wires are shown connected from one component to another.

13. **Electrical Symbols and Component Identification**:

What are electrical symbols?

a. Symbols serve as a convenient method of identifying electrical components on an electrical schematic.

b. Symbols often look like the component itself, but are greatly simplified.

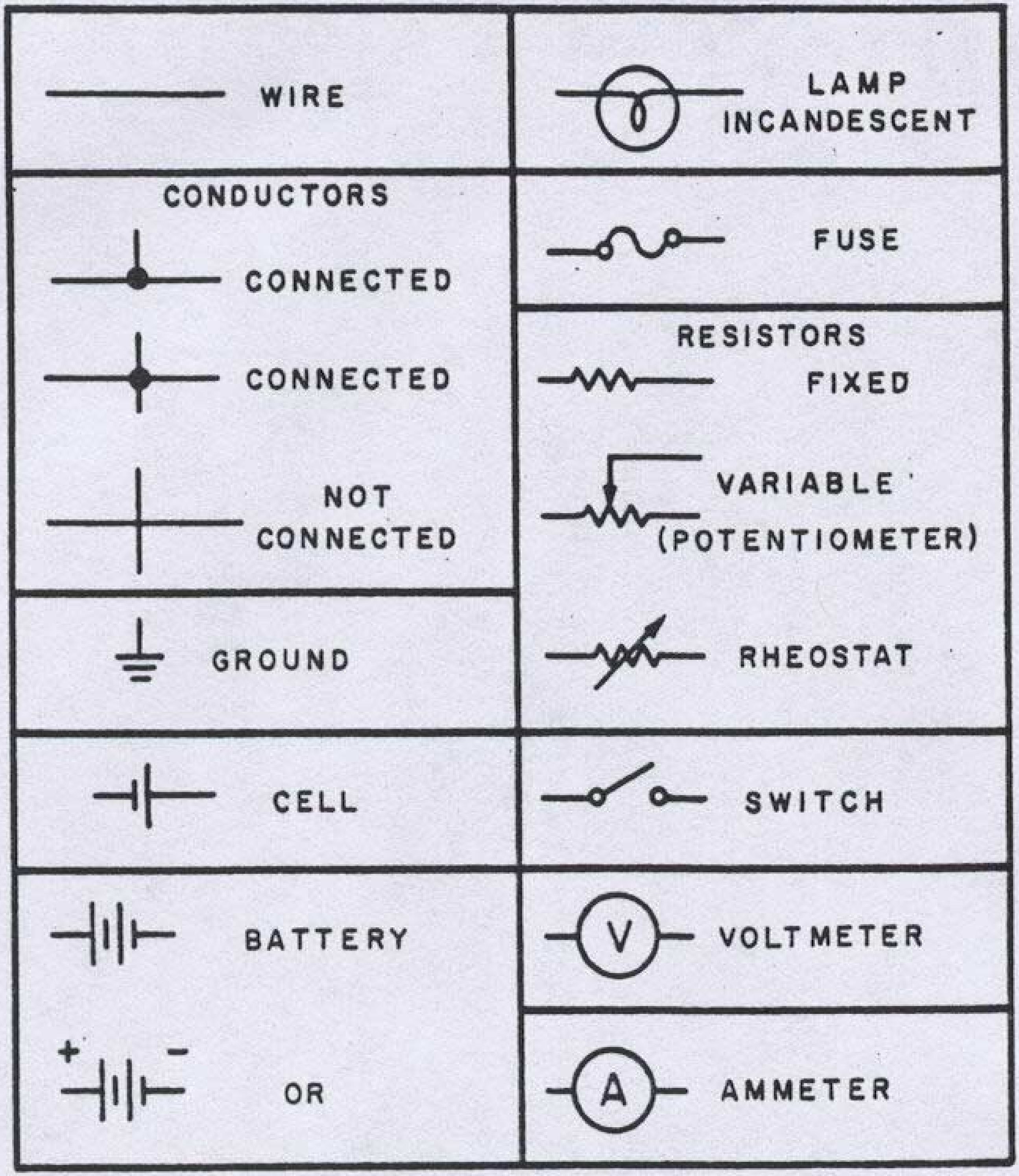


Figure 3-1.—Symbols commonly used in electricity.

(1) Wire: A solid or stranded group of solid, cylindrical conductors having low resistance to current flow, with any associated insulation.

(2) Conductor: A material with a large number of free electrons that easily permits electric current to flow. Where conductors are connected on a schematic, the connection will be indicated by a dot. Where not connected conductors will cross over or one conductor will be shown looping over the other.

(3) Ground: : A safety precaution to protect against electrical shock. It prevents a significant difference of potential from developing between the chassis of any electrical device and the earth.

(4) Cell: A single unit that transforms chemical energy into electrical energy. Batteries are made up of cells.

(5) Battery: A device for converting chemical energy into electrical energy.

(6) Lamp Incandescent: Changes electrical energy into light and heat energy.

(7) Fuse: A device used to limit the amount of current flow in a circuit. They are generally grouped into three broad categories—plug, cartridge, and blade type.

(a) Plug- 0-30 amps.

(b) Cartridge- 30-60 amps.

(c) Blade- 60-600 amps.

(8) Resistors Fixed: Opposes current flow. Its ohmic value is fixed when it is manufactured.

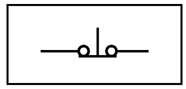
(9) Variable (Potentiometer): A variable resistor used as a voltage control device.

(10) Rheostat: A device for controlling the amount of voltage,(example: a dimmer switch).

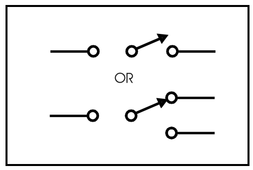
(11) Switch: A device to connect, disconnect, or change the connections in an electrical circuit.

(12) Voltmeter: A device for measuring voltage.

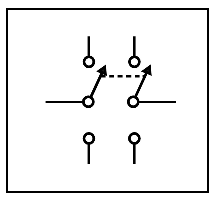
(13) Ammeter: An instrument for measuring the amount of electron flow in amperes.



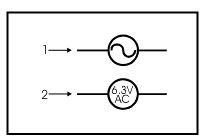
(14) Switch-Pushbutton: Has momentary contacts to complete the circuit and release to open the circuit.



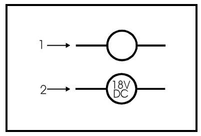
(15) Switch-single pole, Double Throw: Operates in only one of two positions.



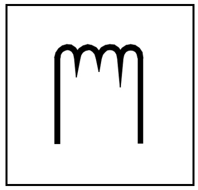
(16) Switch double pole, double throw: Has two sets of contacts that open and close.



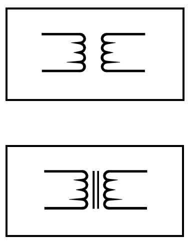
(17) A. C. Power Supply: Supplies alternating current to the load.



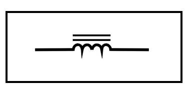
(18) D.C. Power Supply: Supplies direct current to the load.



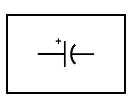
(19) Coil: Has an air core, it is an inductor and opposes changes in alternating current.



(20) Transformer: A device which takes voltage and current of one level and changes it to voltage and current of another level. Usually used in alternating current circuits.



(21) Inductor Iron Core: Used primarily in alternating current circuits, has two electrical connections, and offers opposition to changes in alternating current.



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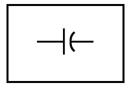
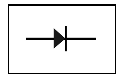
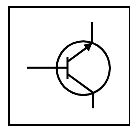
(22) Capacitor - Polarized: A device that stores an electrical charge. Must be mounted in the circuit by observing the circuit polarity.



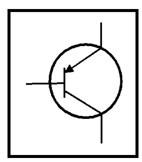
(23) Capacitor - Non-polarized: May be mounted in a circuit without regard to polarity.



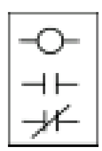
(24) Diode: A solid state electronic device that allows current to flow in one direction only.



(25) Transistor NPN: A solid state electronic device that acts like a switch and consists of three parts—base, emitter, and collector. It takes a positive potential (voltage) on its base in order for it to act like a switch and conduct.



(26) Transistor PNP: A solid state device that also acts like a switch. Takes a negative potential (voltage) on its base in order to conduct.



(27) Relay: A device that consists of a coil and a set of normally open and normally closed contacts.

(INSTRUCTORS NOTE: GIVE STUDENTS A 10-MINUTE BREAK.)

TRANSITION: What is the difference between the schematic symbol for a polarized capacitor and a non-polarized capacitor? What is the purpose of a fuse? Now that we know some of the more important electrical schematic symbols, let's look at some basic electrical circuit diagrams.

14. **Electrical Circuits:**

An electrical circuit is a path or group of paths capable of carrying electrical currents. There are three basic types of electrical circuits—series, parallel, and compound.

a. Series Circuit: A circuit that provides only one path for current to flow through.

(1) Current flow is the directed movement (drift) of electrons. The movement of electrons is determined by the polarity of the voltage source.

(2) The polarity of the voltage source is negative to positive.

(3) Since electrons move from an area of excess charge to an area of deficient charge, they move from negative to positive.

(4) In a series circuit electrons leave the negative terminal of the battery (voltage source) travel through the load and return to the positive battery terminal.

b. Parallel Circuit: A circuit, which provides more than one path for current to flow through. Electrons leave the negative battery terminal and when they reach a junction in the circuit, current will divide and flow through each circuit branch according to the resistance.

c. Compound/combination Circuit: A combination circuit consisting of the features of both series and parallel circuits.

(1) The series portion of the circuit will have one path for current to flow through.

(2) The parallel portion of the circuit will have more than one path for current to flow through.

d. Electrical Circuit Measurements: It is important to be able to effectively measure circuit voltage, current, and resistance in order to better understand electrical circuits and to be able to effectively troubleshoot the circuits.

(l) The voltmeter is used to measure electrical difference in potential.

(2) The ammeter is used to measure current flow.

(3) The ohmmeter is used to measure circuit resistance.

(4) The multimeter combines all three types of meters.

(a) The multimeter contains a function/range switch.

1 This switch selects the correct function D.C. volts, D.C. amps, and D.C. resistance.

2 Also, selects the correct range which is illustrated on the face of the meter.

(b) The meter also contains two test leads, one black, which is the common or negative lead and one red or positive lead.

1 These leads fit into the appropriate jacks marked "com" for the black lead and V-⦸ for the red lead.

2 The common test lead remains in the com jack for all measurements.

3 The red test lead is placed in the V-⦸ jack when measuring voltage or resistance. When measuring current the red test lead is placed in the jack marked A for amps.

(c) Making circuit measurements:

NOTE: The peak hold switch must be off for direct current measurements and the power switch must be on.

1 Measuring voltage:

a De-energize the circuit.

b Select the correct function and range.

c When measuring an unknown voltage, start at the highest range.

d Observe circuit polarity, negative to positive.

e Place the meter in parallel with the component to be measured.

f Energize the circuit.

2 Measuring current

a De-energize the circuit.

b Select the correct function and range.

c When measuring an unknown current, start at the highest range.

d Observe circuit polarity, negative to positive.

e Place the meter in series with the component to be measured by physically breaking into the circuit.

f Energize the circuit

3 Resistance measurements

a De-energize the circuit.

b Select the correct function and range.

c Isolate the component to be measured.

d Place the meter in parallel with the component to be measured.

e In order to take a continuity check, place the function/range switch on the musical note indicated on the face of the meter. Place the test probes across the wire or component. If the wire or component is good, a beeping sound will be given by the meter.

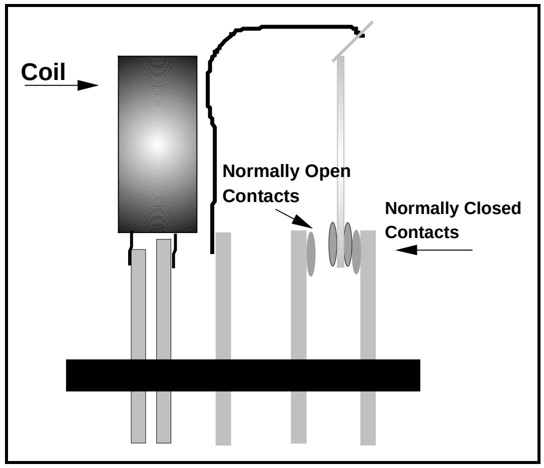
15. **Electromagnetic Devices:** An electrically excited magnet capable of exerting mechanical force or performing mechanical work.

(1) An electromagnet is a switch in the form of a coil which when energized causes mechanical motion by attraction. The mechanical motion is used to produce a switching action in an external circuit. In some cases the coil is also called a solenoid.

(2) The inside of the coil is called the core and it may be air or a type of magnetic material. If a piece of soft iron is placed within the coil the magnetic properties are greatly increased. The increase in magnetic strength is due to the improved magnetic path that the soft iron provides.

(3) Two types of electromagnetic devices are the relay and the circuit breaker.

(a) The Relay is a magnetically operated switch. The basic relay has a single coil controlling one set of contacts, however in most cases a coil will control many contacts.



1 The coil of wire is wrapped around a soft iron core. When current flows through the coil, a magnetic field is created around the coil. The coil is said to be energized when current flows through it and de-energized when no current is flowing through it.

2 The mechanical arm, or sometimes referred to as an armature, is made of a ferromagnetic material. Since the mechanical arm is made of a ferromagnetic material it can be affected by a magnetic field.

3 When the coil is energized the magnetic field that is created will attract the mechanical arm causing the contacts to open or close.

4 The contacts are labeled normally open (NO) and normally closed (NC) due to their positions when the coil is de-energized.

5 When the coil is de-energized a normally open contact will not allow current to flow through it. However, the normally closed contact will allow current flow.

(b) The Circuit Breaker functions like a fuse that prevents excessive current from flowing in a circuit.

1 The coil of the electromagnet and the contacts are connected in series with the source and the load.

2 If the load draws more than a predetermined value of current, the electromagnet becomes energized and attracts the armature (moveable contact) opening the contacts, thus opening the circuit.

EXAMPLE: Again, using Ohm's Law, current is equal to the voltage divided by the resistance. If the total voltage is 120v and the total resistance is 6Ω, then the total current would be 20a. The current rating for the circuit breaker must be at least 20a. If the current rating were less, the circuit breaker would trip and no current would flow through the circuit.

3 The circuit breaker is held open by a latching device and must be reset so the circuit can become operational again.

16. **Ohm's Law:** In the early part of the 19th century, George Simian Ohm proved by experiment that a precise relationship exists between current, voltage, and resistance. This relationship is called Ohm's Law and is stated as follows:

a. The current in a circuit is directly proportional to the applied voltage and inversely proportional to the circuit resistance.

1 If a flashlight contains a battery rated at 1.5 volts and a lamp has a resistance of 5 ohms, then the current in the circuit can be determined. Using this equation and substituting values:

$$I = \frac{E}{R} = \frac{1.5 \text{ volts}}{5 \text{ ohms}} = .3 \text{ ampere}$$

2 If the flashlight were a two-cell flashlight, we would have twice the voltage, or 3.0 volts, applied to the circuit. Using this voltage in the equation:

$$I = \frac{3.0 \text{ volts}}{5 \text{ ohms}} = .6 \text{ ampere}$$

You can see that the current has doubled as the voltage has doubled. This demonstrates that the current is directly proportional to the applied voltage.

3 If the value of resistance of the lamp is doubled, the equation will be:

$$I = \frac{E}{R} = \frac{3.0 \text{ volts}}{10 \text{ ohms}} = .3 \text{ ampere}$$

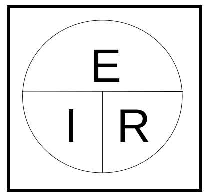
The current has been reduced to one-half of the value of the previous equation, or .3 ampere. This demonstrates that the current is inversely proportional to the resistance. Doubling the value of the resistance of the load reduces circuit current value to one-half of its former value.

b. Ohm's Law applies to all electrical circuits.

c. Ohm's Law applies to the source and the individual circuit components.

d. Ohm's law also tells us that in an electrical circuit, the current is directly proportional to the voltage as long as the resistance is held constant and indirectly proportional to the resistance as long as the voltage is held constant.

(1) Mathematically, Ohm's Law is expressed by the following formulas:



(2) E represents voltage, I represents current, and R represents resistance.

(3) When the values of any two of these units are known, the third can be determined by one of these formulas.

17. **Series Circuits:** As we said before, in a series circuit, current has only one path to flow through.

a. There are three laws that apply to series circuits.

(1) The current flowing in the circuit is the same anywhere in the circuit.

(2) The same current flows through each component that is connected within the circuit.

(3) This is mathematically expressed by the formula:

$$I_T = I_1 = I_2 ...$$

b. The total resistance is equal to the sum of the individual resistance, mathematically expressed by the formula:

$$R = R_1 + R_2 ...$$

c. The total voltage is equal to the sum of the individual voltage drops.

(1) Mathematically expressed by the formula:

$$E = E_1 + E_2 ...$$

(2) The term voltage drop, is defined as the potential difference developed between two points in an electrical circuit.

d. Power in a Series Circuit: Power, whether electrical or mechanical pertains to the rate at which work is being done. Work is done whenever a force causes motion.

(1) Voltage is the electrical force that causes current (electrons) to flow in a closed circuit.

(2) When voltage causes electrons to move, work is done.

(3) When voltage exists, but current does not flow because the circuit is open, no work is done.

(4) The instantaneous rate at which electrical work is done is called the electric power rate and is measured in watts.

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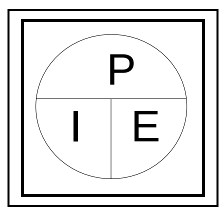
(5) The basic power formula is expressed:

$$P = I \times E$$



(6) P represents power, I represents current, and E represents voltage.

(7) Additional power formulas:

$$P = E^{2} \lozenge R$$
$$P = I^{2}R$$

e. Power Rating: Electrical components are often given a power rating. The power rating, in watts, indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or motion.

(l) The higher the wattage rating of a light bulb the more electrical energy that can be converted to light energy.

(2) Power used by electrical devices is measured in watt-hours.

(3) One watt hour is equal to 1 watt of power used continuously for one hour.

(4) The term kilowatt hour (KWH) is used more extensively and is equal to l000 watt-hours.

(5) The efficiency of an electrical device is the ratio of the power actually converted to useful energy to the power delivered to the device.

EXAMPLE: If 100 watts of power are delivered to a device and only 95 watts are converted to useful power, then the ratio is:
95 WATTS OF USEFUL POWERA100 WATTS OF POWER = 95% EFFICIENCY

f. Series Aiding and Opposing Sources: Many practical circuits contain more than one voltage source.

(l) Sources of voltage that cause current to flow in the same direction are considered to be series aiding voltages and the voltages are added.

(2) Sources of voltage that would tend to force current in opposite directions are said to be series opposing.

(a) The effective voltage is the difference between opposing voltages.

(b) When two opposing voltages are inserted into a circuit, current will flow in the direction determined by the largest source.

g. Reference Point: A reference point is an arbitrarily chosen point to which all other points in the circuit are compared.

(l) Any point can be chosen as a reference.

(2) Electrical potential at all other points is determined in relation to the reference point.

(3) The reference point of a circuit is always considered to be at zero potential.

(4) The term ground is used to denote a common electrical point of zero potential.

(5) In most electrical equipment the metal chassis is the common ground.

(6) Common points of the circuit are connected directly to the metal chassis thereby eliminating a large amount of connecting wire.

(7) Electrons pass through the metal chassis (a conductor) to reach the loads in the circuit.

(8) Most voltage measurements used to check proper circuit operation are taken in respect to ground. One meter lead

is connected to ground (negative lead) and the other meter lead (positive lead) is moved to various test points.

18. **Circuit Problems**:

(l) Short Circuit: A short is an accidental path of low resistance, which passes a high amount of current. When a short circuit occurs, the circuit or component resistance will drop sharply. The symptoms of a short circuit are:

(a) Zero resistance across the component.

(b) Higher than normal current flow.

(c) Zero voltage across the component.

(2) Open Circuit: Exists when a break exists in a complete conducting path. The symptoms of an open circuit are:

(a) Current ceases to flow.

(b) Zero voltage across the component.

(c) Normal resistance across the component.

(d) If there is a break in the wire the ends of the wire become an extension of the voltage source and voltage can be measured across the open spot in the wire.

(e) An open circuit will have an infinite, (too high to measure), resistance.

19. **Parallel Circuits**:

Circuits in which current has more than one path to flow through. There are three laws that apply to parallel circuits.

a. Voltage in a parallel circuit is the same anywhere in the circuit. Mathematically expressed by the formula:

$$E_T = E_1 = E_2 ...$$

b. Total circuit current is equal to the sum of the individual branch currents. Mathematically expressed by the formula:

$$I_T = I_1 + I_2 ...$$

c. Total circuit resistance will always be smaller than the smallest component resistance. Mathematically expressed by the following formulas:

(l) Equal resistors:

R_T = RAN

(2) Product over the sum:

$R_T = (R_1 \times R_2)A(R_1 + R_2)$

(3) Reciprocal method:

$R_T = 1A(1AR_1)+(1AR_2)+(1AR_3))$

d. Power formulas: You will use the same power formulas for parallel circuits that used for series circuits.

20. **Grounding Equipment for Electrical Safety**:

a. Safety precautions must always be observed by persons working around electrical circuits and equipment to avoid injury from electric shock. As you begin your laboratory work here in class and when you begin working on generators at your future duty stations, you must practice safe working habits. Failure to do so can result in lost job time, painful injuries, and needless deaths.

b. Shock Hazards: Most electrical sources have a set of terminals (usually two) that are connected to a load. The source may be a battery, a power supply, or a generator, which supplies electrical energy to the load. The load converts the electrical energy to a more useful form of energy.

EXAMPLE: A light bulb converts electrical energy to light energy, a motor converts it to mechanical energy, and a soldering iron converts it to heat energy.

c. A short circuit is an accidental path of low resistance. There is a balance between the energy supplied by the source and the energy used by the load. If this balance is upset, the source will try to deliver unlimited amounts of energy. This energy appears as intense heat at the point of contact and along the connecting wires.

EXAMPLE: A simple short circuit is when two bare wires have touched each other. With a battery as a source, the hazard of a short is not great, but a short across electric power lines can be extremely dangerous and can cause intense heat, sparks, and possibly a fire.

d. Personal Injury: The human body is a good conductor of electrical energy. When a person touches an electrically live (or short circuit) point, electric current tries to flow from the point of contact to ground. When this happens, the person experiences an electrical shock.

e. Safe Work Habits: Exposed metal and wet surfaces are good conductors of electrical energy, so it is good practice to avoid work surfaces combining water or metal and electricity. A cluttered work area is also a shock hazard. Spilled liquids, extra test equipment, loose electrical components, and test leads are potential hazards also. Along with bare wires, worn or wet insulation, and metal terminals.

f. Grounding Equipment: Improper grounding can make equipment unsafe. If there is insufficient ground connections, then the electrical energy from a shorted circuit within the equipment could flow through the metal chassis, through your body touching the equipment, to ground, and become a shock hazard.

g. Earth-Ground Connection: All equipment should have an adequate earth-ground connection. A proper earth-ground connection is obtained when the metal chassis of the equipment is physically connected to the earth. This connection provides an electrical path for current should any short circuits occur within the unit.

21. **Effects of Opens and Shorts**:

a. Open: The major difference between an open in a parallel circuit and an open in a series circuit is that in a parallel circuit the open would not necessarily disable the circuit.

(1) If the open occurs before the parallel branches:

(a) The circuit becomes disabled.

(b) The total circuit current is zero amps.

(c) The total circuit resistance is infinite.

(2) If the open occurs in one of the branches, that branch will be disabled but current will continue to flow in the remaining branches.

(a) Total circuit current decreases.

(b) Total circuit resistance increases.

b. Short:

(1) Total current is infinite.

(2) Total resistance is zero resistance.

(3) The voltage drop in all the parallel branches will be zero.

22. **Compound Circuits**:

Often referred to as a combination circuit and may also be called a complex circuit.

a. In order to solve these circuits, the rules for both series and parallel circuits must be applied.

(1) The rules for series circuits apply to the series portion of the circuit.

(2) The rules for parallel circuits apply to the parallel portion of the circuit.

(3) The circuit will be simplified to a simple series circuit containing one load.

b. In order to solve these circuits the rules for both series and parallel circuits must be applied.

(1) Start at the negative potential of the source and follow it to the positive potential of the source.

(2) Whenever the current has one path to flow through, the circuit is series and series circuit laws will apply to the components.

(3) Whenever the current divides and there is more than one path for current to flow through, the circuit is parallel and parallel circuit laws will apply to the components.

23. **Rheostat and Potentiometer**:

a. The Rheostat: As you remember from basic electricity, the rheostat is a variable resistor

(l) Is a current control device.

(2) Has two electrical connections.

(3) Is wired in series.

(4) Consists of a coil of wire wound on a circular insulating core.

(5) The movable arm makes contact with the coil of wire.

b. The Potentiometer: The potentiometer is another type of variable resistor.

(l) Is a voltage control device.

(2) Has three electrical connections

(3) Is used as a voltage divider.

24. **Alternating Current Characteristics**

a. Cycle- When the rotating coil of a basic 2 pole generator completes one revolution it is said to have completed one cycle.

b. Alternation- Alternation is defined as on half of a cycle.

c. Period- is the time required to complete a cycle.

d. Frequency- number of cycles per second is expressed in hertz (Hz).

e. Inductance- Is the property of an electrical circuit that opposes a change in current.

(1) The symbol for inductance is L.

(2) The basic unit of measurement for inductance is the Henry (H).

(3) The Henry is equal to the inductance required to induce one volt in an inductor by a change of one ampere per second.

(4) Inductance has the same effect on current that inertia has on the movement of a mechanical object. (Analogy) If you have ever pushed a heavy load like your car, you know it takes more work to start the load moving than it does to keep it moving. Once the load is moving it is easier to keep it moving than to stop it again. This is because the load possesses the property of inertia.

f. Capacitance-Is the property of an electrical circuit or component that opposes a change in voltage across it.

(1) The basic unit of measure is farads.

GLOSSARY

A.C. POWER SUPPLY: Supplies alternating current to the load.

AMMETER: An instrument for measuring the amount of electron flow in amperes.

ATOMS: The smallest particle of an element that retains the characteristics of that element.

BATTERY: A device for converting chemical energy into electrical energy.

CAPACITANCE: The property of an electrical circuit or component that opposes a change in voltage across it.

CAPACITOR-NONPOLARIZED: May be mounted in a circuit without regard to polarity.

CAPACITOR-POLARIZED: A device that stores an electrical charge.

CELL: A single unit that transforms chemical energy into electrical energy. Batteries are made up of cells.

COIL: Has an air core, it is an inductor and opposes changes in alternating current.

COMPOUND/COMBINATION CIRCUIT: A combination circuit consisting of the features of both series and parallel circuits.

COMPOUNDS: A chemical combination of elements that can be separated by chemical but not by physical means.

CONDUCTING PATH: A route for electrons to follow from source to load and back to source.

CONDUCTOR: A material with a large number of free electrons that easily permits electric current to flow.

CURRENT: The directed flow of electrons through a circuit.

CURRENT FLOW: The directed movement (drift) of electrons.

CYCLE: is a complete of positive and negative values.

D.C. POWER SUPPLY: Supplies direct current to the load.

DIFFERENCE OF POTENTIAL: When a charge or voltage exists between two bodies.

DIODE: A solid state electronic device that allows current to flow in one direction only.

DIRECT CURRENT: Current that only flows in one direction through a circuit.

DIRECTED DRIFT: The directed movement of electrons due to a potential difference.

ELECTROMOTIVE FORCE: The force that moves or tends to move electric current.

ELECTRON: A small negative charge of electricity.

ELECTROSTATICS: Electricity at rest.

ELEMENTS: A substance that cannot be reduced to a simpler substance by chemical means.

ENERGY: The ability to do work.

FREQUENCY: The amount of cycles per second. Is expressed in Hertz (HZ).

FUSE: A device used to limit the amount of current flow in a circuit.

GROUND: A safety precaution to protect against electrical shock. It prevents a significant difference of potential from developing between the chassis of any electrical device and the earth.

INDUCTANCE: Is the property of an electrical circuit that opposes a change in current.

INDUCTOR IRON CORE: Used primarily in alternating current circuits, has two electrical connections and offers opposition to changes in alternating current.

KINETIC ENERGY: Energy, which a body possesses by virtue of its motion.

LAMP INCANDESCENT: Changes electrical energy into light and heat energy.

LINES OF FORCE: Imaginary lines used to illustrate and describe the pattern of the magnetic field.

LOAD: A device that changes electrical energy into a more useful form.

MAGNETIC FIELDS: The space surrounding a magnet where magnetic forces act.

MAGNETIC FLUX: The total number of magnetic lines of force leaving or entering the pole of a magnet.

MAGNETIC INDUCTION: The magnetic effect of one body on another without any physical contact between them.

MAGNETISM: The ability of a material to attract pieces of iron.

MATTER: Anything that occupies space and has weight.

MIXTURES: A physical combination of elements and compounds that can be separated by physical means.

MOLECULES: A chemical combination of two or more atoms.

NEUTRON: Has a mass approximately equal to that of the proton, but it has no electrical charge.

OPEN CIRCUIT: Exists when a break exists in a complete conducting path.

PARALLEL CIRCUIT: A circuit, which provides more than one path for current to flow through.

PICTORIAL: Shows the actual physical location, size, and hookup of the components, as would be seen by the human eye.

POTENTIAL ENERGY: Energy due to the position of one body with respect to another body or to the relative parts of the same body.

POWER RATING: The rate at which a device converts electrical energy into a more useful form of energy.

PROTRON: Has a positive charge of electricity equal and opposite to the electron.

RANDOM DRIFT: The haphazard movement of electrons.

REFERENCE POINT: An arbitrarily chosen point to which all other points in the circuit are compared.

RELAY: A device that consists of a coil and a set of normally open and normally closed contacts.

RELUCTANCE: The opposition that a material offers to the magnetic lines of force.

RESIDUAL NAGNETISM: The amount of magnetism that remains in a temporary magnet.

RESISTANCE: The opposition to current flow.

RESISTORS FIXED: Opposes current flow.

RESISTOR WATTAGE RATING: A rating expressing the maximum power that a resistor can safely handle.

RETENTIVITY: The ability of a material to retain an amount of residual magnetism.

RHEOSTAT: A device for controlling the amount of voltage, (example: a dimmer switch).

SCHEMATICS: The technician's primary aid in troubleshooting an electrical circuit is the schematic diagram.

SERIES CIRCUIT: A circuit that provides only one path for current to flow through.

SHELL DESIGNATORS: Letters used to identify the shells.

SHELLS: When groups of electrons reside in-groups of orbits that are elliptically shaped.

SHORT CIRCUIT: An accidental path of low resistance which passes a high amount of current.

SOURCE: A device that provides electrical energy to the circuit.

SWITCH: A device used to control electrical energy. It is used to connect, disconnect, or change the connections in an electrical circuit.

TRANSISTOR NPN: A solid state electronic device that acts like a switch and consists of three parts-base, emitter, and collector. It takes a positive potential (voltage)on its base in order for it to act like a switch and conduct.

TRANSISTOR PNP: A solid state device that acts like a switch. Takes a negative potential (voltage) on its base in order to conduct.

TRANSFORMER: A device which takes voltage and current of one level and changes it to voltage and current of another level. Usually used in alternating current circuits.

VALENCE SHELL: The outermost shell of an atom.

VARIABLE (POTENTIOMETER): A variable resistor used as a voltage control device.

VOLTAGE: A difference of potential of one coulomb of charge between two points.

VOLTMETER: A device for measuring voltage.

VOLTAGE SOURCE: A device that is capable of supplying and maintaining voltage while some type of electrical lead is connected to its terminals.

WIRE: A solid or stranded group of solid, cylindrical conductors having low resistance to current flow, with any associated insulation.