DOCUMENT RESUME

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TITLE	Overcurrent and Electrical Shock Protection. Module SH-31. Safety and Health.
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SPONS AGENCY	Office of Vocational and Adult Education (ED). Washington, DC. Div. of National Vocational Programs.
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IDENTIFIERS	*Hazards; *Occupational Safety and Health; Shock

ABSTRACT

This student module on overcurrent and electrical shock protection is one of 50 modules concerned with job safety and health. This module discusses safety rules and techniques that may reduce the number of home and industrial fires and electrical accidents. Following the introduction, five objectives (each keyed to a page in the text) the student is expected to accomplish are listed (e.g., Describe systems and equipment grounding). Then each objective is taught in detail, sometimes accompanied by illustrations. Learning activities are included. A list of references and answers to learning activities complete the module. (CT)

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SAFETY AND HEALTH

OVERCURRENT AND ELECTRICAL SHOCK PROTECTION

MODULE SH-31

CORD

CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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CORD

The Center for Occupational Research and Development
601 Lake Air Drive, Suite C
Waco, Texas 76710

INTRODUCTION

Each year in the United States more than 1,000 people are killed and thousands more are injured as a result of misuse of electricity or by stray electrical currents resulting from defective equipment. Many of these fatalities and injuries could have been eliminated with proper grounding and ground-fault protection. Further, every year thousands of home and industrial fires are caused by incorrect electrical bonding and grounding procedures.

This module discusses safety rules and techniques that, if put into use, would reduce the number of home and industrial fires and minimize the number of injuries and fatalities that result from electrical accidents.

A person reading this module should have a basic understanding of electricity and the relationship between voltage, current, and resistance, or they should have successfully completed Module SH-03, "Fundamentals of Electrical Safety."

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Distinguish between series and parallel circuits and calculate voltage, amperes or resistance given two of the three variables. (Page 3)
2. Describe overcurrent protection devices. (Page 6)
3. Discuss factors that cause electrical shock and the effects of current on the human body. (Page 9)
4. Describe systems and equipment grounding. (Page 13)
5. Describe ground-fault circuit interrupters and how they work. (Page 18)

OBJECTIVE 1: Discuss current flow in parallel circuits.

All electric circuits have a source, a load, and connecting conductors. In addition, all electric circuits have a voltage that causes current to flow through the resistance of the conductors and the load. The current can be either d.c. (current which flows in one direction all the time, from a negative terminal to a positive terminal) or a.c. (current which changes direction back and forth at a specific rate with 60 cycles per second being typical). However, since circuits can have more than one load and more than one source, all circuits need not have the same arrangement.

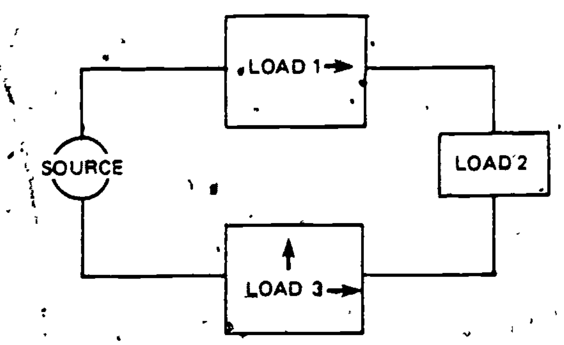


Figure 1. A simple series circuit.

There are two basic types of circuit arrangements; series and parallel. To understand the parallel circuit, which is the major type of circuit used for commercial power distribution, it is helpful to compare it to a series circuit. A series circuit is one with two or more loads but only one path for current to flow from the source through the loads and back to the source. Figure 1 shows a simple series circuit.

Ohms law states that the amount of current flowing through a load is dependent upon the amount of voltage and resistance. If the circuit has a source voltage of 15 volts and the load has a resistance of three ohms, then the current drawn will be five amperes. What happens if another load, this one with two ohms of resistance, is put in series with the first load? Could the circuit still have the same five amperes of current flow? No, to have five amperes of current flow through the two loads that total to five ohms of resistance; the voltage source would have to be 25 volts according to the equation:

$$E = I \times R$$

Thus, if the voltage remains at 15 volts, the current must drop to three amperes. Therefore, the series circuit is totally unsuitable for use if a constant voltage is desired across many loads that have different resistances. Another drawback to the series circuit is that if a break should occur at any point in the circuit, then all current stops flowing and all the loads are de-energized.

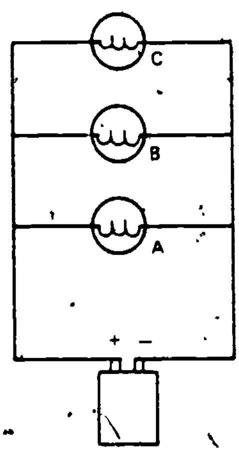
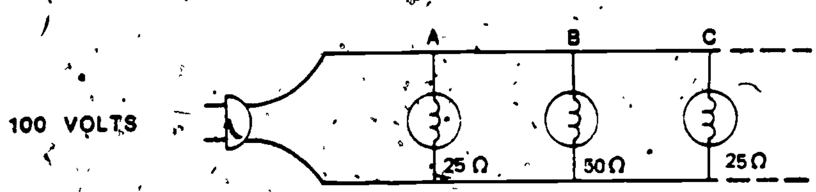


Figure 2. A simple parallel circuit.

Modern homes, offices, cars, and factories are generally wired in parallel arrangement. A simple parallel circuit is shown in Figure 2. Three light bulbs are connected to the battery. Electrons leaving the battery can pass through either lamp A, B, or C. If lamp B is disconnected, electrons can still flow through A or C. The amount of current in the lamps depends upon the voltage of the battery and the resistance of each lamp. The example below illustrates this point.

Example 1: For the figure shown, what is the current drawn through each lamp and the total current drawn through the plug?



Lamp A: $I = \frac{V}{R} = \frac{100\ V}{25\ \Omega} = 4$ amps

Lamp B: $I = \frac{V}{R} = \frac{100\ V}{50\ \Omega} = 2$ amps

Lamp C: $I = \frac{V}{R}\ \ \frac{100\ V}{25\ \Omega} = 4$ amps

The total current through the plug:

$$I_{total} = 4a + 2a + 4a = 10 \text{ amps}$$

In the previous example, if a fourth lamp of 20 ohms were connected in parallel, it would draw an additional five amps since I = 100V/20 Ω = 5a, and a total of 15 amps would then be drawn through the plug and the wire delivering current to the plug.

The more appliances or lamps that are connected in parallel, the more current is drawn from the voltage source and the delivery wires. The higher the current in the delivery wire, the hotter the wire becomes. If the wire becomes too hot, it may melt or possibly cause a fire.

ACTIVITY 1:*

Fill in the blanks.

1. A circuit with only one path for the current to flow back to the source is known as a __________ circuit.
2. A circuit with more than one path back to the source is called a ____________ circuit.
3. The more appliances or lamps that are connected in parallel, the more _______ will be drawn from the voltage source and the delivery wires.

*Answers to Activities begin on page 23.

OBJECTIVE 2: Discuss overcurrent protection devices.

In order to protect wiring in a circuit from overheating because of high current, an overcurrent protection device is installed on the line (wire). Either a fuse or a circuit breaker may be used.

A fuse is made from a highly resistant type of material with a low melting point. If there is sudden surge of current greater than a certain safe amperage, the high current melts the fuse at once, thus opening the circuit and preventing further damage such as melting of wires or a fire. Figure 3 shows two types of fuses: (a) cartridge and (b) screw-in or plug. Each type of fuse should be used only in the type of circuit for which it is designed.

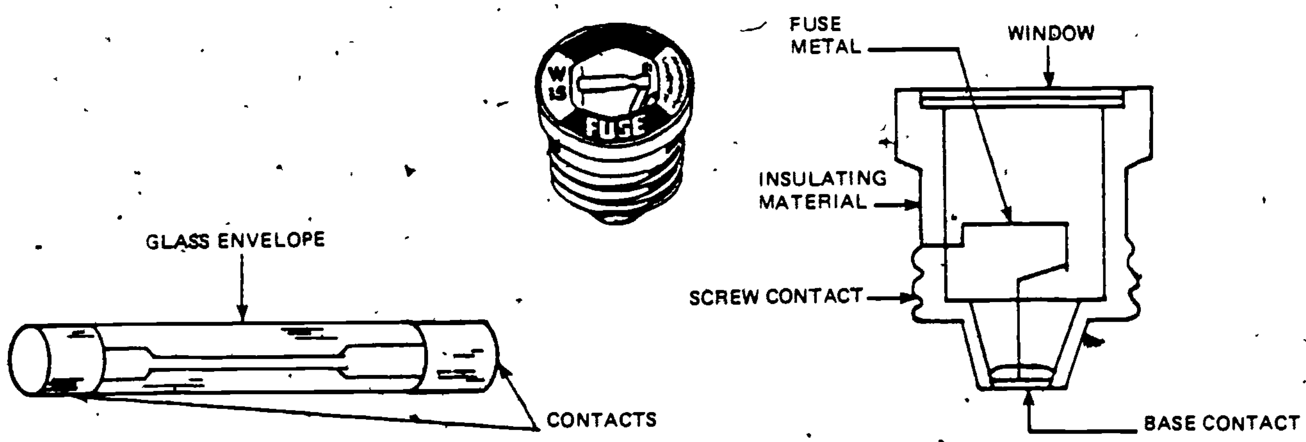


Figure 3. Fuse wire melts when current exceeds 15 amps, and current then stops.

In the circuit shown in Figure 4 the total current exceeds the limits of the fuse. The circuit is "overloaded," and the fuse "blows" because a total of 25 amps is attempting to pass through a 20 amp fuse.

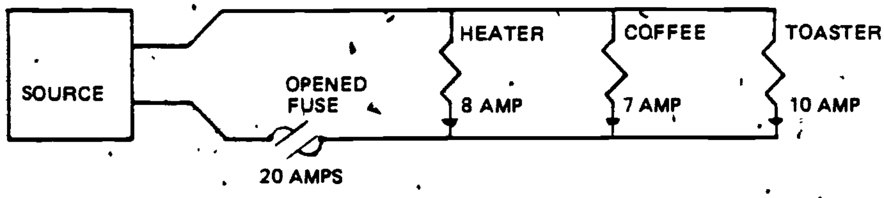


Figure 4. A total of 25 amps is attempting to pass through a 20 amp fuse; as a result the fuse blows.

In the circuit shown in Figure 5, the total current exceeds the limits of the fuse. In this case, a low resistant short occurs in the clock. Instead of traveling around the circuit, the large current encounters a path of low resistance and travels along this short circuit instead. The large current causes the fuse to blow.

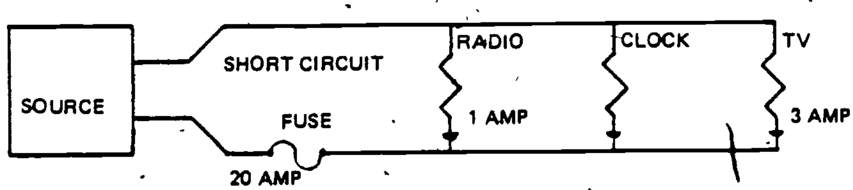


Figure 5. The current takes the short circuit.

Safety experts recommend that a switch be placed in any circuit that can be opened to deenergize the fuses to be handled. Insulated fuse pullers should be used as an added precaution. Fuses should never be inserted in a live circuit and blown fuses should be replaced with others of like size and type. Before any attempt is made to replace fuses, the circuit should be locked out and the cause of the overload should be discovered.

Circuit breakers are of two general types: thermal and magnetic. The thermal type works on the basis of temperature rise; therefore it is subject to variations in the temperature of the room in which it is installed. Magnetic-type circuit breakers are responsive to the amount of current passing through the circuit. Only qualified engineers should select circuit breakers for installation.

The plug receptacles in today's homes are generally wired with a 110 volt line (hot wire) and a zero voltage line (neutral wire). When an appliance is connected across the neutral and the hot line, a current is drawn. The appliance is the load. The greater the load, the smaller the resistance and the greater the current in the circuit. Normally, current flows through the hot wire and the loads, returning through the neutral wire. Remember that electricity runs in a closed loop system, and that current will flow where a complete path is provided.

To ensure that a good conductive path is maintained throughout an electrical circuit, connections between conductors must be secure. Good physical contact is necessary and can only be assured if approved conductors and connectors are properly joined.

ACTIVITY 2:

Circle the letter of the answer that best completes the statement:

1. Fuses and circuit breakers are examples of devices that provide...
   a. short circuits.
   b. voltage sources.
   c. overvoltage protection.
   d. overcurrent protection.
2. A fuse blows when...
   a. the circuit is overloaded.
   b. the total current exceeds the limit of the fuse.
   c. the fuse melts and opens the circuit.
   d. all of the above.

OBJECTIVE 3: Discuss the factors that cause electric shock and the effects of current on the human body.

The damaging effects of electrical shock are caused by current passing through the body. The hazardous and fatal levels of current are very small compared to the amount of current normally present in most circuits and appliances. In fact, hazardous levels are so small that the current values are expressed in milliamperes (1000 milliamperes = 1 amp). Currents as low as 60 milliamperes may kill a healthy person if they are allowed to continue for two or three seconds. A current of 333 milliamperes or one third of an amp lasting for as little as one-fourth of a second may be equally deadly.

The muscular reactions of persons experiencing nonlethal (not deadly) amounts of current (6 milliamperes to 25 milliamperes) are especially hazardous. The current can cause a contraction of muscles that "freeze" the person to the source of the shock. Thus, the current continues to travel through the body.

Normally the resistance of a person's dry outer skin is enough to limit currents to a safe level when handling low voltages. When handling the terminals of a 12-volt car battery, a person would not normally feel any current. A slight tingling sensation is felt at voltages of approximately 30 volts. However, if the skin is wet or moist, an uncomfortable shock can be experienced at even these low voltages.

Most fatal currents are the result of contact with the common 110 voltages and a wet grounded surface. There must be an electrical potential difference between one part of the body and another part in order for a person to receive an electrical shock. If a person were to come in contact with a high voltage line and were completely isolated, no current would flow. The squirrel standing on the high voltage line (see Figure 6) has no current flowing through it. Since both feet are at the same potential, there is no voltage between the squirrel's feet and, hence, no current flows through its body even though there may be current in the wire.

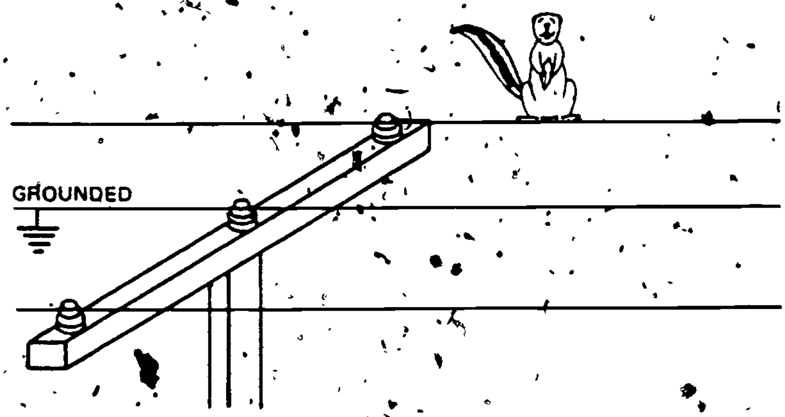


Figure 6. Both the feet are at the same potential, hence there is no current flow.

If the squirrel stood with one foot on one wire and one on the other, see Figure 7, a current would flow through its body. The amount of current would depend on the squirrel's resistance; if its feet were wet, there would be less resistance and, therefore more current.

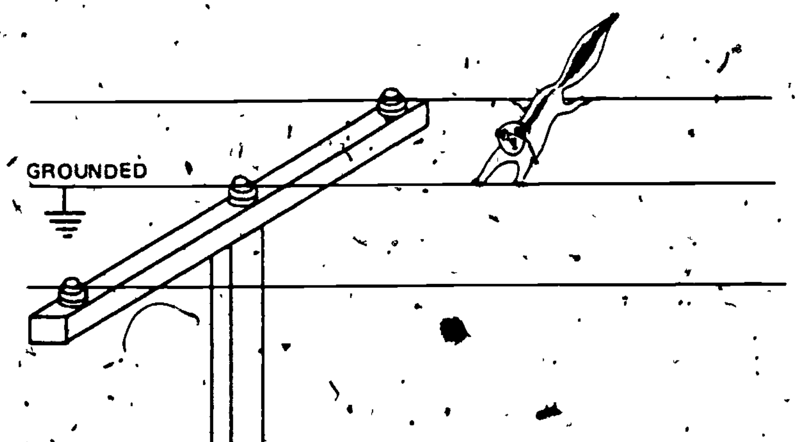


Figure 7. Current would flow through the body.

It is possible for exposed metal parts of a system to become energized through contact with the 110 volt "hot" line. In the absence of adequate grounding, a potential hazard is present. If a person were to touch a faulty 110 volt appliance with one hand and both feet were on the ground, there would be a voltage between the hand and ground of 100 volts. Normally the resistance is high enough between one's feet and ground that any current that does flow is not great enough to do serious harm. However, if someone's hands and feet are wet and the ground is wet, the overall resistance is greatly reduced, and harmful current may be created. Often the victims of electrical shock are contacting a wet surface with the feet or hands: the bathtub, water faucet, or standing on the wet ground or floor with wet shoes.

A serious electrical shock affects the nervous system and results in a loss of muscle control. Table 1 lists the effects of 60 hertz ac currents on the nervous system. Note that the number of milliamperes varies with resistance. In turn, skin resistance varies with moisture. For example, if body resistance were 1000 ohms when wet and 50 volts were across the body, 50 milliamperes, a fatal amount, would flow.

TABLE 1. EFFECTS OF ELECTRIC SHOCKS.

Ac 60 Hz	Effects on Nervous System
2 - 5 ma	painful - muscle control retained
5 - 20 ma	painful - loss of muscle control - cannot let go
20 - 75 ma	very painful - paralysis of breathing muscles
50 - 100 ma	ventricular fibrillation results
Over 100 ma	heart stops (3-4 minutes - permanent stoppage)

SAFETY RULES

When working with electrical equipment, a person should be familiar with basic handling procedures. The following is a brief list of some of these important procedures:

1. Know the location of the ON/OFF switches.

2. Never handle electrical equipment when hands, feet, or body are wet or perspiring, or when standing on wet floor.

3. With high voltages, regard all floors as conductive and grounded unless they are covered with well-maintained and dry rubber matting of suitable type for electrical work.

4. Whenever possible, use only one hand when working on circuits or control devices.

5. When touching electrical equipment, (for example, when checking for overheated motors), use the back of the hand. Thus, if accidental shock were to cause muscular contraction, you would not "freeze" to the conductor.

6. Wear safety glasses where sparks or arcing may occur.

7. Avoid wearing rings, metallic watchbands, etc., when working with electrical equipment or when in the vicinity of strong induced fields.

8. Learn the rescue procedures for helping a victim of electrocution. When anyone is working with exposed possibly fatal or hazardous voltages, a second person should be present who is able to help in an emergency. The following is a set of procedures for helping a victim of electrocution:

   a. Don't touch victim until he is separated from the energized circuit.

   b. Kill the circuit (know location of power switches).

   c. Remove victim with a nonconductor if still in contact with an energized circuit or if status of circuit is unknown. Use laboratory coat or shirt or trousers as a loop, but hurry!

   d. If an energized power line is on victim, remove it with a nonconductor such as a stick or broom handle.

   e. Begin artificial (mouth to mouth) respiration. A course in first aid for respiratory and circulatory emergency (CPR) is recommended. The local Red Cross has such courses.

   f. Have someone call for emergency medical aid.

9. There are several electrical components that offer unique possible hazards. For example, capacitors can be extremely hazardous even after the power is shut off. Do not handle these electrical components unless properly trained.

ACTIVITY 3:

Circle one: True or False

1. Hazardous and fatal levels of current are very large compared to the amount of current present in most circuits. True False

2. There must be an electrical potential difference between one part of your body and another part in order for you to be "shocked.". True False

3. If someone's hands and feet are wet, overall resistance is greatly increased. True False

4. A rescuer using bare hands may safely remove the victim of electrical shock from the current source. True False

OBJECTIVE 4: Describe systems and equipment grounding.

A wiring system must be so designed that it will protect life and property against faults caused by electrical failures, power surges, and natural disasters. This protection can be achieved by ensuring that all metal enclosures of the wiring system and the noncurrent-carrying or neutral conductors are connected to a common earth potential. This connection to the earth potential is commonly referred to as grounding. One method of grounding a device is to bond it to the local cold water supply, between supply and meter.

Whether it occurs intentionally or accidentally, a ground is a conducting connection between an electric circuit or piece of equipment and the earth or to some conducting body that serves in place of the earth. There are two distinct divisions of grounding: systems grounding and equipment grounding.

Systems grounding is the connection of the neutral wire to the earth. This is done by bonding the neutral wire to the metal pipe coming into the building from an underground cold water supply. There should be at least 10 feet or more of buried pipe. Before the connection is made, there should be an assurance that the metal pipe has no insulated couplings or changes to nonmetallic piping. Plastic piping systems are not conductors and cannot be used for grounding.

Underground gas piping has been used in the past to ground electrical circuits because of its earth contact. There exists a clear, hazard in this type of grounding. If an improper connection is made, an arc of electrical discharge may occur if the current flowing in the system is large enough. This arc can not only ignite a gas leak, it can burn a hole in the pipe that could result in an explosion and fire. Grounding to gas pipes is unacceptable.

When no satisfactory cold water pipe is available, one or more ground rods may be used. These rods must be driven into the ground at such locations and at such depths to ensure a connection of no higher than 25 ohms of resistance between them and the earth. The National Electrical Code should be consulted for the necessary conditions for this type of grounding.

Equipment grounding helps to eliminate electrical fire hazards and removes the dangers of electrical shock. Dangerous shock results when a person comes in contact with the metal frame or casing of electrical apparatus that has become energized due to a breakdown or failure of the insulation or current-carrying wires. All equipment grounding should be connected to the metal frame or casing of electrical equipment and to the metal conduits carrying service wiring to electrical apparatus.

Exposed metal parts of fixed equipment that are not designed to carry current, as well as portable cord and plug connected equipment that is likely to become energized, shall be grounded under conditions specified in section 250 of the National Electrical Code.

There are certain conditions when an exception to equipment grounding may be made. One of these exceptions is for listed portable tools and listed appliances protected by an approved system of double insulation or by an equivalent system. These items shall not be required to be grounded. Where such a system is employed, the equipment shall be distinctively marked.

GROUNDING FOR HAZARDOUS LOCATIONS

Special precautions must be made when grounding an electrical system or piece of equipment in locations where there are flammable or combustible vapors, liquids or gases, or combustible dusts or fibers. These fire hazards may be found in gasoline stations, paint-finishing process plants, health care facilities, agricultural storage areas, marinas, petroleum and chemical processing plants, as well as many other locations.

The Occupational Safety and Health Administration (OSHA) of the U.S. Department of Labor has assigned certain classifications and wiring procedures for these hazardous locations. Electrical wiring in these locations should be done in a manner to ensure that electrical sparks or arcing will be isolated from the combustible materials. For example, switches can produce arcing, primarily when they are opened.

Further, static electricity can be a serious hazard in these locations because of possible arcing. To eliminate this possibility, special procedures are recommended in addition to grounding. These procedures are covered more thoroughly in Module SH-30 entitled, "Safe Handling and Use of Flammable and Combustible Materials."

The National Electrical Code contains guidelines for determining the type and design of equipment and installations which meet this requirement.

There are a variety of methods for grounding conduits and electrical equipment. Grounding is often accomplished by running a third wire, called the "grounding wire," along with the conduit wires and connecting the grounding wire to all exposed metal enclosures, frames, conduits, raceways, etc., with which a person may come in contact. Portable electrical equipment that is grounded will have what is commonly called a three prong plug (see Figure 8). Since the "U" grounding blade is longer than the current-carrying blades, it ensures a ground connection while the cord is inserted or removed from the receptacle. The green grounding wire in a flexible cord is connected to the hex screw in the plug cap and thus to the "U" grounding blade.

Grounding is also accomplished by using metal conduit as a means of supplying a possible path for electricity to flow from electrical equipment metal housing to the ground potential (see Figure 9).

The grounding wire and metal conduit do not normally carry current. They provide a path of low resistance to ground when any faulty leak age current develops. If the current is high enough, the circuit may try to draw currents in excess of the circuit breaker or fuse limits. When this happens, the fuse will blow or the circuit breaker will trip and electrical power will be cut off to the appliances.

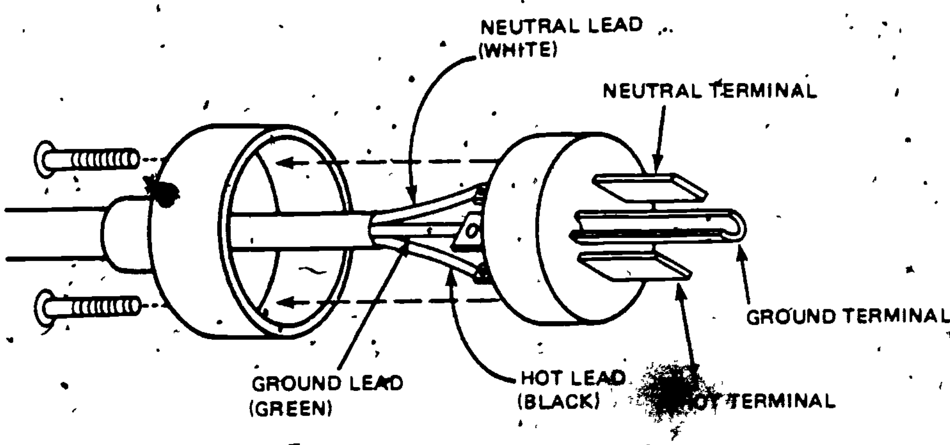


Figure 8. Disassembled three prong plug.

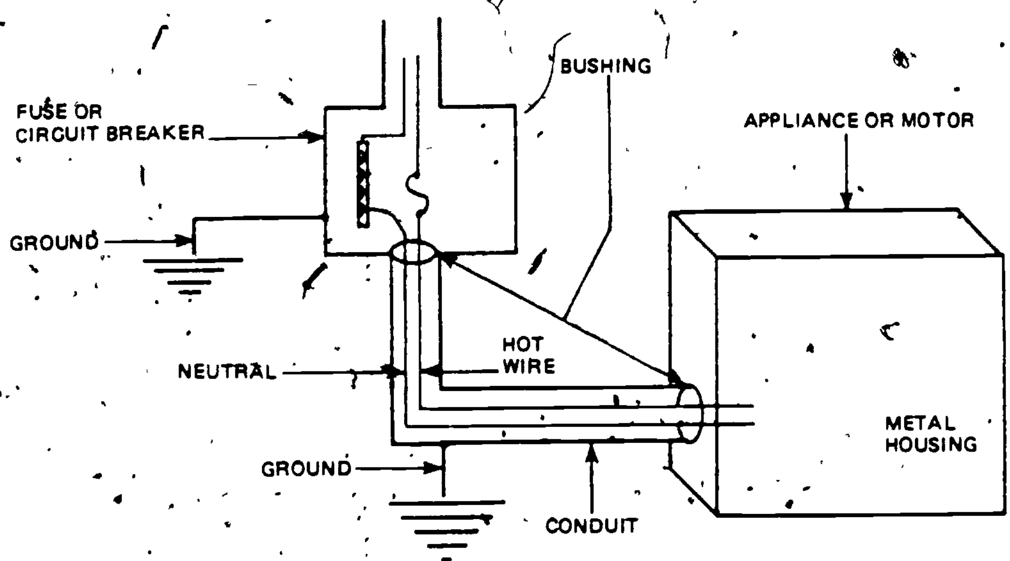


Figure 9. Grounding using metal conduit.

In Figure 10, the frame of the motor (or appliance) is not grounded. As a result, contact between the motor winding and the frame causes the

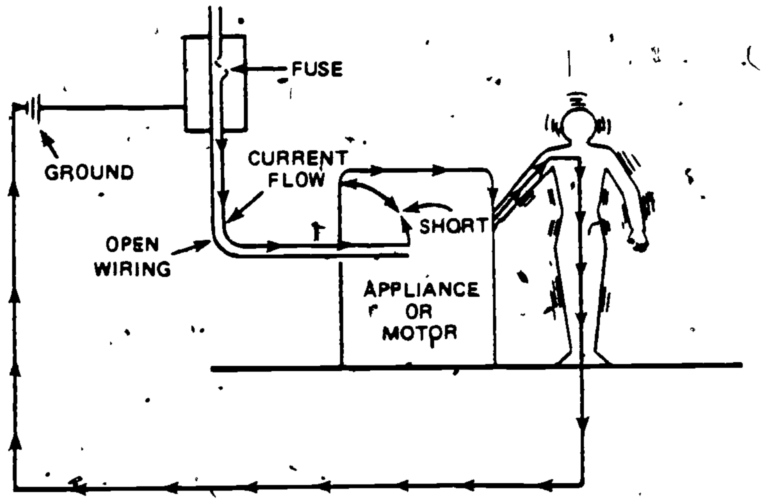


Figure 10. Appliance that has not been grounded.

current to flow through the person's body to the ground, thus making a complete circuit. Such a shock can cause serious harm or prove fatal.

In Figure 11, the frame of the motor (or appliance) is grounded through the steel conduit. A similar fault current therefore causes the overcurrent protective device to open.

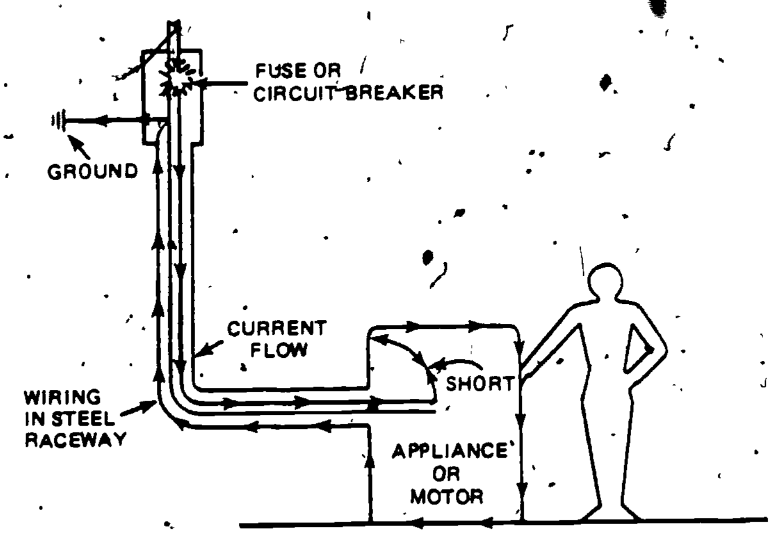


Figure 11. Grounded appliance.

ACTIVITY 4:

1. Fill in the blanks:

   a. Connecting of the neutral wire to the earth is ______________________.

   b. Equipment grounding is not necessary for tools or appliances having __________ __________.

   c. The part of electrical equipment that needs to be grounded is ______________________.

2. Identify three industries in which particular care must be taken in grounding systems or equipment.

   a. ______________________

   b. ______________________

   c. ______________________

3. Explain why this is so. ______________________

____

____

OBJECTIVE 5: Describe ground fault circuit interrupters and how they work.

Equipment grounding, fuses, and circuit breakers cannot be solely relied upon to protect people from dangerous electrical shocks, nor are they totally effective in eliminating possible electrical fires.

Overcurrent protection devices are effective only when fault currents exceed fuse and circuit breaker current ratings. Most fuses and circuit breakers in the home are rated at 15 amps and higher. Many small, strong fault current can be extremely harmful to people, and such currents may have sufficient power to ignite combustible materials. These small fault currents may not activate the overcurrent protection devices and in these cases, electrical power would continue to the electrical appliance.

A ground fault interrupter (GFI), also known as a ground fault circuit interrupter (GFCI), is a device that provides protection against stray fault currents even when these currents are small. The GFCI will respond as soon as the fault current exceeds five milliamps, which is slightly above the threshold of sensation. The power will then be disconnected within approximately 1/40 of a second. A ground fault interrupter monitors the current flow through the hot wire and in the grounded neutral. When there is an equal amount of current in both wires, the circuit is safe. When a ground fault occurs, part of the current from the hot wire will flow in the grounded neutral, and a part will flow in the ground-fault. Consequently, there will be a difference in current in the hot wire and in the grounded neutral. The GFCI will detect this difference and in a very short time cut off current in the circuit. (See Figure 12).

Figure 13 shows a typical GFCI sensor installed on a circuit for the detection of fault currents. The line conductors (neutral and hot) are passed through a coil of wire and connected to a tripping device. As long as the current in each conductor remains equal, the device remains in a closed position. If one of the conductors comes in contact with a grounded object, some of the current returns by an alternative path and an imblance in the current is detected by the sensing coil or sensing transformer. The imbalance in the circuit is sensed by the coil, and a current is established in the coil. The current will flow to the tripping device that opens or disconnects the circuit.

In summary, GFCI sensors may be installed in several different locations. For permanent applications, wired-in models can be installed around all circuit conductors, or around the bonding jumper conductor only. Portable GFCIs (see Figure 14) can offer protection at the point-of-use; plug-in units are small enough to be carried in a toolbox. Portable units have a test switch so that the unit can be checked periodically to ensure proper continuous operation. Equipment should be selected carefully according to intended use. Regulations regarding location and installation of GFCIs are discussed in the National Electrical Code section 210.8.

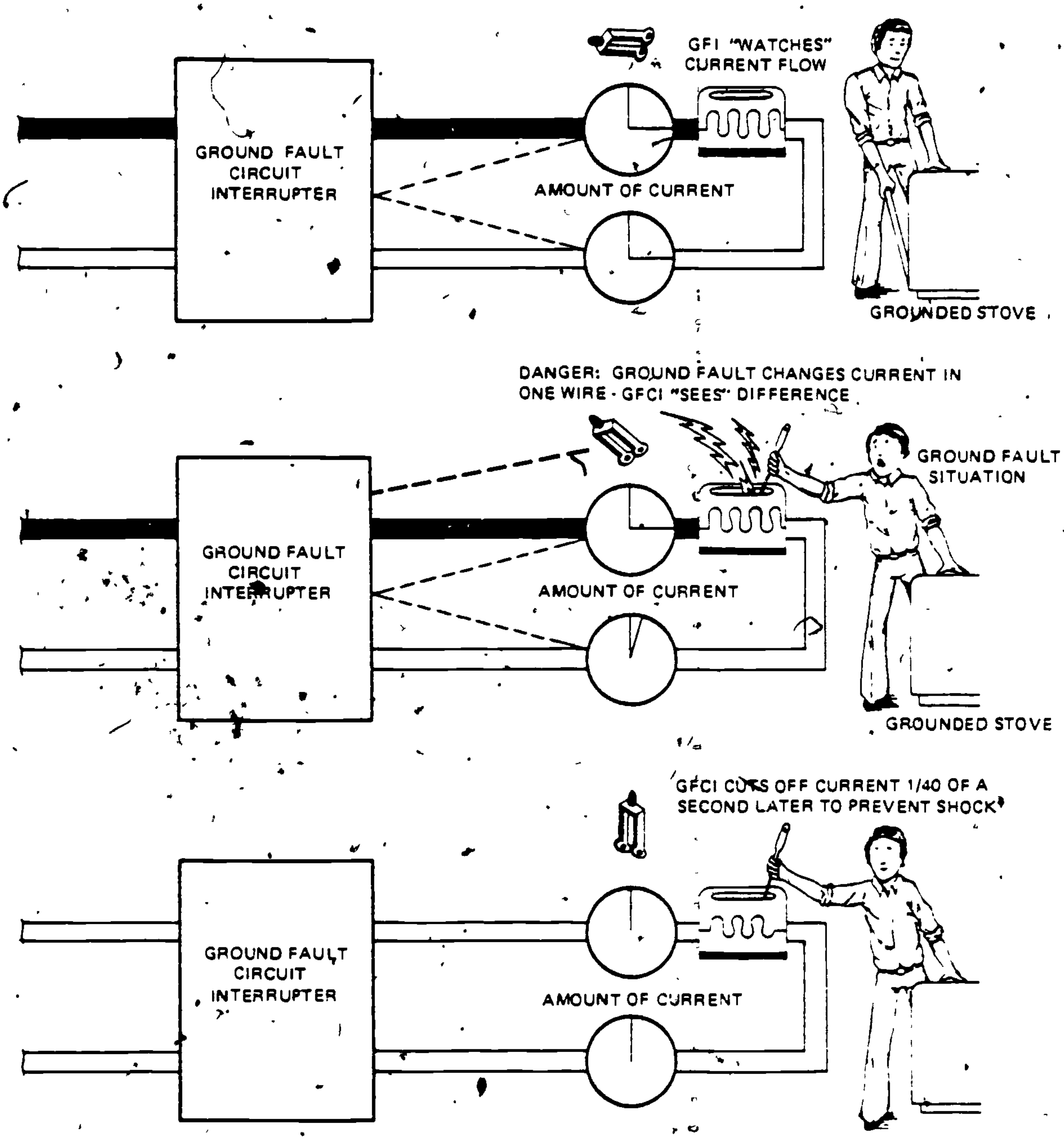


Figure 12. Ground fault circuit interrupter cuts off current about 1/40 of a second after ground fault occurs.

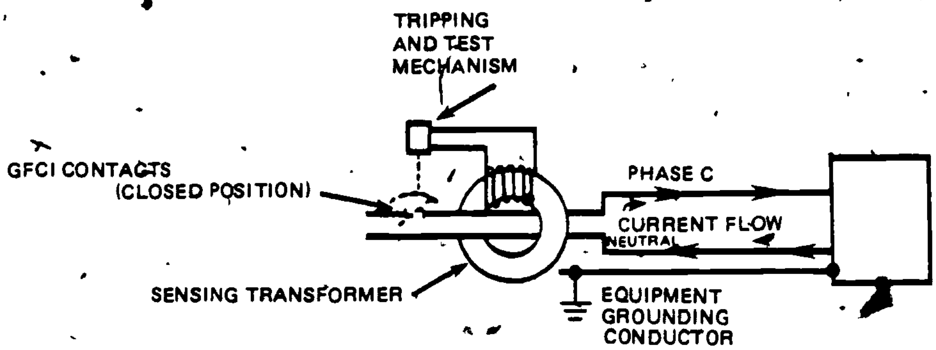


Figure 13. The circuitry and components for a typical ground-fault circuit-interrupt.

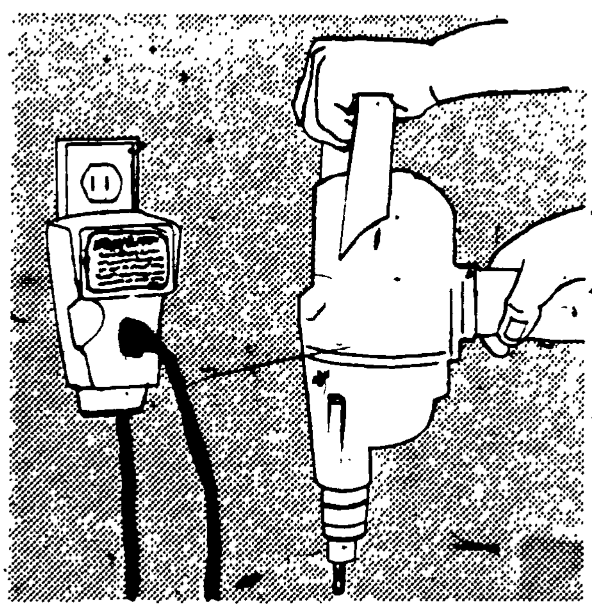


Figure 14. Plug-in ground fault circuit interrupter.

The Occupational Safety and Health Administration put into effect on April 16, 1981, the revision of 29 CFR Part 1910, Subpart S on Electrical Standards. The requirement on the use of ground-fault circuit interrupters is based upon section 210-8 of the National Electrical Code.

The law specifies the locations in plants and dwelling units that must have ground fault circuit protection. Where used, GFCIs will provide protection against line-to-ground shock hazard. Because a ground fault interrupter does an entirely different job from other overcurrent protection devices, it should be used in addition to fuses or circuit breakers and not in place of them.

ACTIVITY 5:

1. A ground-fault circuit interrupter is different from a fuse or circuit-breaker in all except which one of the following ways:
   a. GFCIs can detect small, strong fault currents (five milliamps and above).
   b. GFCIs react to ground faults rather than short circuits.
   c. GFCIs break or open the circuit to stop current flow.
   d. GFCIs react to an imbalance of current between hot and neutral wires.
2. Ground fault circuit interrupters react (open the circuit) to which one of the following:
   a. A short circuit.
   b. An imbalance of current between hot and neutral wires.
   c. An equal amount of current in the hot and neutral wire.
   d. A current in the neutral wire.

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ANSWERS TO ACTIVITIES

ACTIVITY 1

1. Series.
2. Parallel.
3. Current.

ACTIVITY 2

1. d.
2. d.

ACTIVITY 3

1. False.
2. True.
3. False.
4. False.

ACTIVITY 4

1. a. Systems grounding.
   b. Double insulation.
   c. The metal casing that is not designed to carry current safely.
2. a,b,c, may be chosen from this list: gasoline stations (flammable gasoline), paint-finishing plants (flammable liquids), health care facilities (flammable gases such as oxygen), agricultural storage areas (combustible dusts and vapors), petroleum and chemical processing plants (combustible liquids).
3. Because of the double hazard of electrical shock and fire or explosion hazard.

ACTIVITY 5

1. c.
2. b.