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Basic Electrical Safety

Course FN000235

The material included in this handout must be studied before the training session. This booklet is for you to keep as a reference.

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TABLE OF CONTENTS

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Fermilab

BASIC ELECTRICAL SAFETY

Theory of Electricity

What is Electricity?

Though you cannot see electricity, you are aware of it every day. You see it used in countless ways. You cannot taste or smell electricity, but you can feel it. Basically, there are two kinds of electricity - static (stationary) and dynamic (moving). This module is about dynamic electricity because that is the kind commonly put to use. Electricity (dynamic) is characterized by the *flow of electrons through a conductor.* To understand this phenomenon, you must know something about chemical elements and atoms.

Elements and Atoms

Elements are the most basic of materials. Every known substance - solid, liquid, or gas - is composed of elements.

An atom is the smallest particle of an element that retains all the properties of that element. Each element has its own kind of atom; i.e., all hydrogen atoms are alike, and they are all different from the atoms of other elements. However, all atoms have certain things in common. They all have an inner part, the nucleus, composed of tiny particles called protons and neutrons. An atom also has an outer part. It consists of other tiny particles, called electrons, which orbit around the nucleus. Neutrons have no electrical charge, but protons are positively charged. Electrons have a negative charge. The atoms of each element have a definite number of electrons, and they have the same number of protons.

An aluminum atom, for example, has thirteen of each. The opposite charges - negative electrons and positive protons - attract each other and tend to hold electrons in orbit. As long as this arrangement is not changed, an atom is electrically balanced. This is illustrated in Figure 1 on the following page.

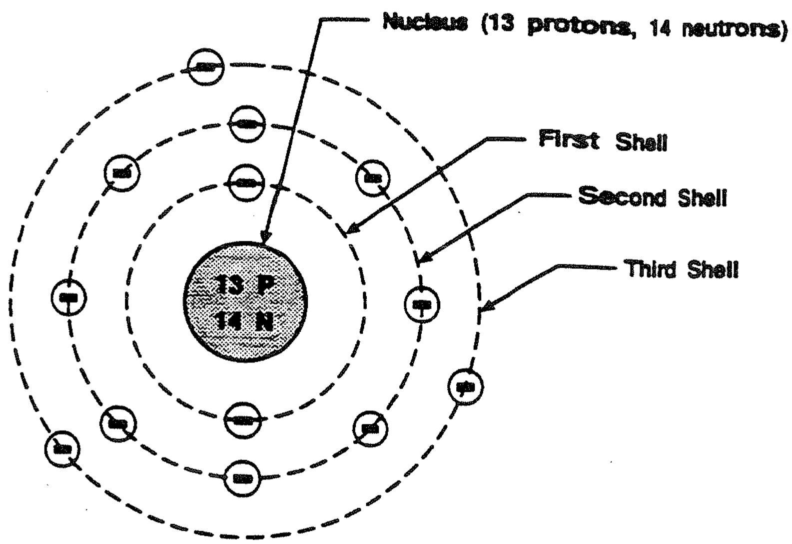


Figure 1: ALUMINUM ATOM

However, the electrons of some atoms are easily moved out of their orbits. This ability of electrons to move or flow is the basis of current electricity.

When electrons leave their orbits, they are referred to as free electrons. If the movement of free electrons is channeled in a given direction, a flow of electrons occurs. As previously stated, the flow of electrons through a conductor characterizes dynamic electricity.

Electrical Materials

A material that contains many free electrons and is capable of carrying an electric current is called a conductor. Metals and (generally) water are conductors. Gold, silver, aluminum and copper are all good conductors. Materials that contain relatively few free electrons are called insulators. Non-metallic materials such as wood, rubber, glass, plastic and mica are insulators. Conductors include the human body, earth, and concrete.

Generating Electricity

There are several ways to produce electricity. Friction, pressure, heat, light, chemical action, and magnetism are among the more practical methods used to make electrons move along a conductor.

To date, magnetism is the most inexpensive way of producing electrical power and is therefore of most interest to us. Because of the interaction of electricity and magnetism, electricity can be generated economically and abundantly. Electricity is produced when a magnet is moved past a piece of wire. Or, a piece of wire can be moved through a magnetic field. A magnetic field, motion, and a piece of wire are needed to produce electricity.

Voltage, Current and Resistance

Voltage

A force or pressure must be present before water will flow through a pipeline. Similarly, electrons flow through a conductor because of a force called electromotive force (EMF) is exerted. The unit of measure for EMF is the volt. The symbol for voltage is the letter E. A voltmeter is used to measure voltage.

Current

For electrons to move in a particular direction, it is necessary for a potential difference to exist between two points of the EMF source. The continuous movement of electrons past a given point is known as current. It is measured in amperes. The symbol for current is the letter I and for amperes, the letter A. It is sometimes necessary to use smaller units of measurement. The milliampere (mA) is used to indicate 1/1000 (0.001) of an ampere. An ammeter is used to measure current in amperes. Note: The established convention for the direction of current flow is actually the opposite direction of electron flow.

Resistance

The movement of electrons along a conductor often meets with some opposition. This opposition is known as resistance. Resistance can be useful in electrical work. Resistance makes it possible to generate heat, control current flow, and supply the correct voltage to a device. The symbol for resistance is shown in the accompanying symbol.

In general, resistance in a conductor depends on four factors: the *material* from which it is made, the *length*, the *cross-sectional area*, and the *temperature* of the material.

- *Material.* Different materials have different resistances. Some, such as silver, gold, aluminum and copper, have a low resistance, while others, such as iron have a higher resistance.

- *Length.* For a given material that has a constant cross-sectional area, the total resistance is *proportional* to the length. The longer the conductor, the greater the resistance.

- *Cross-Sectional Area.* Resistance varies inversely with the cross-sectional area of the conductor. In other words, the resistance *decreases* as the cross-sectional area *increases.*

- *Temperature.* Generally, in metals, the resistance increases as the temperature increases. For non-metals, the reverse is usually true.

- *Superconducting Materials.* Some materials, such as the niobium/titanium/copper alloy wire used in Tevatron magnets, are classified as superconductors. When cooled to very low temperatures, these materials exhibit virtually no resistance to the flow of electricity.

The symbol for resistance is the letter R. Resistance is measured by a unit called the ohm. The Greek letter *omega* (Ω) is used as the symbol for electrical resistance. Figure 2 summarizes the factors that affect resistance.

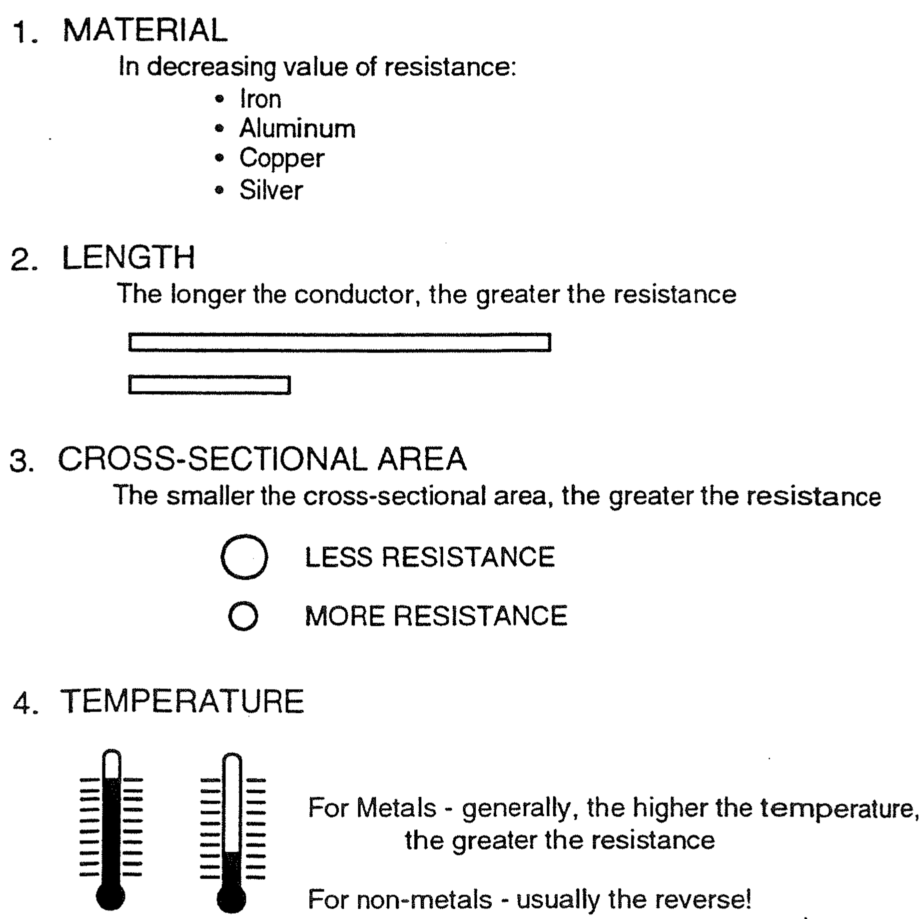


Figure 2: FACTORS THAT AFFECT RESISTANCE

Direct Current (dc) Circuits

Introduction

This section discusses the electrical relationships in direct-current circuits. Although alternating current is more commonly used in electrical work, direct current has its own unique applications and advantages and is used widely at the Laboratory. Direct current always flows in one direction.

Some dc motors, for example, have speed control characteristics that are better in some production operations. Direct current is used to charge storage batteries, for plating operations, for aluminum refining, and to operate electromagnetic lifting devices and most welding equipment. At Fermilab, direct current is used to power electromagnets that produce magnetic fields that steer and focus particle beams.

Complete Circuit

A complete circuit is necessary for the controlled flow or movement of electrons along a conductor. A complete circuit is made up of a source of electricity (e.g., battery), a conductor, and a consuming device (load). This is illustrated in the Figure 3 below.

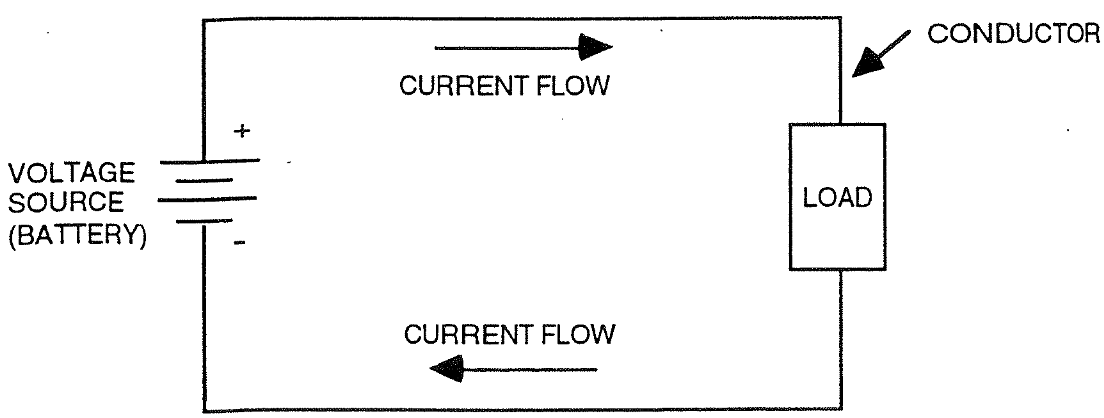


Figure 3: SIMPLE DC CIRCUIT

Current flow along the completed path provides energy. If the circuit is so arranged that the current has only one path, the circuit is called a *series circuit*. If there are two or more paths for the current, the circuit is called a *parallel circuit*.

Series Circuit

Figure 4 shows three loads (resistors) connected in series. The current flows through each of them before returning to the battery. For this circuit, voltages are developed across each of the resistors. The sum of the voltages across each of the resistors equals the battery voltage.

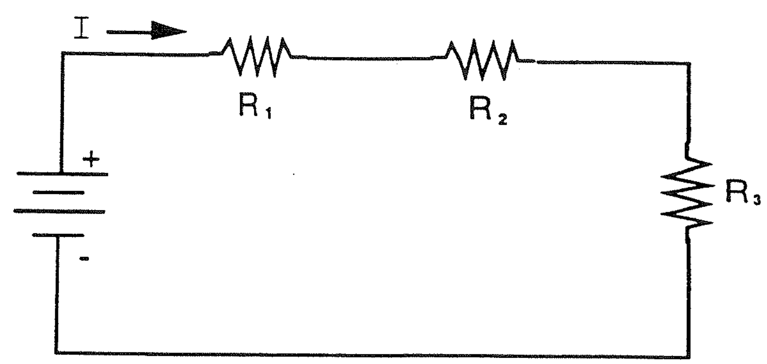


Figure 4: SERIES CIRCUIT

Parallel Circuit

In a parallel circuit, each load is connected directly across the voltage source. There are as many separate paths for current flow as there are branches. See Figure 5 below.

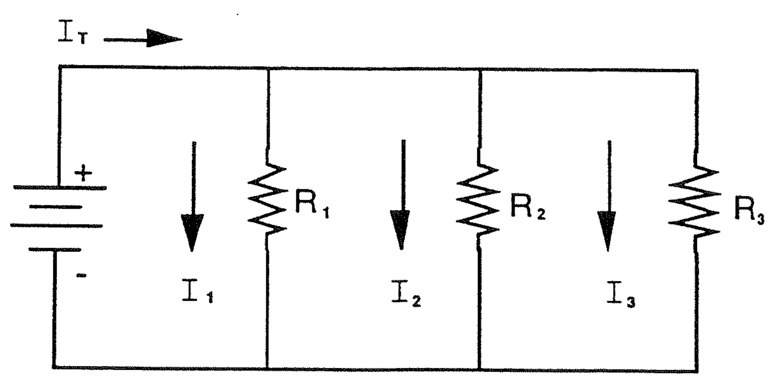


Figure 5: PARALLEL CIRCUIT

The voltage across all branches of a parallel circuit is the same. This is because all branches are connected across the voltage source. Current in each branch of a parallel circuit depends on the resistance of the branch.

Open Circuit

An open circuit is one which does not have a complete path for electrons to follow. Therefore, there is no current flow. Such an incomplete path is usually brought about by a loose connection or the opening of a switch. An open circuit caused by an open switch is illustrated in Figure 6.

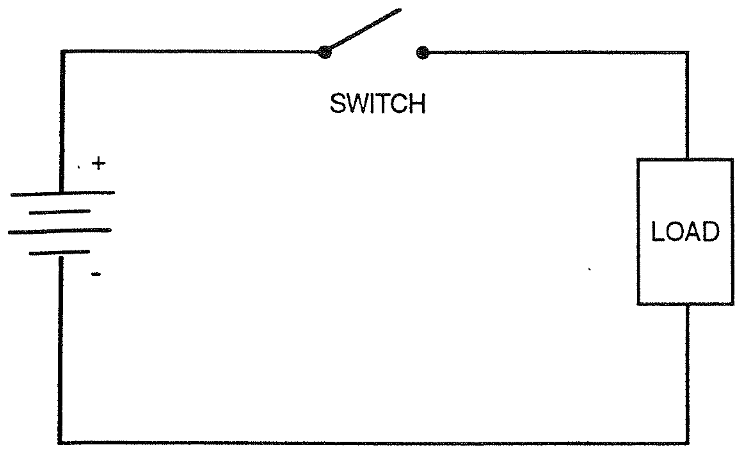


Figure 6: OPEN CIRCUIT

Short Circuit

A short circuit is one which has a path of low resistance to current flow. It is usually created when a low-resistance conductive path is placed across a consuming device. A greater current will flow through the path of least resistance rather than through the consuming device. A short usually generates an excess current flow which results in overheating, possibly causing a fire or other damage. Figure 7 illustrates a short circuit.

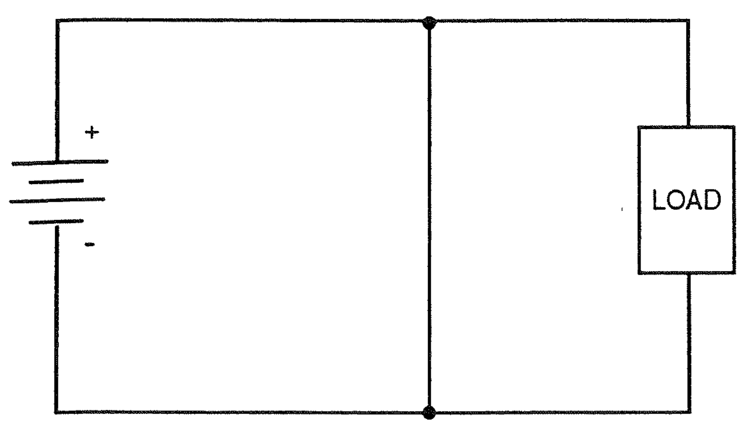


Figure 7: SHORT CIRCUIT

Ohm's Law

Ohm's Law states the relationship that exists among the three basic quantities of electricity: current, voltage, resistance. A physicist named Georg S. Ohm discovered the relationship in 1827. With this law you can calculate any one of the three quantities if you know the other two. *Ohm's Law* is the most important and most often applied law in electricity.

Simply stated, voltage (E) in volts is equal to the current (I) in amperes multiplied by the resistance (R) in ohms. In equation form:

$$E = I R$$

This is the formula to use in order to find the voltage when the current and resistance are known.

To find the current when the voltage and resistance are known, the formula becomes:

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

To find the resistance when the voltage and current are known, the formula becomes:

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

The best way to become accustomed to using *Ohm's Law* is to solve some basic problems, such as:

1. If the current is 5 amps and the resistance is 20 ohms, what is the applied voltage?

$$E = I R \qquad E = (5)(20) \qquad E = 100 \text{ volts}$$

2. If the voltage is 100 volts and the resistance is 25 ohms, what is the current in the circuit?

$$I = \frac{E}{R} \qquad I = \frac{100}{25} \qquad I = 4 \text{ amps}$$

3. If the current is 2 amps and the applied voltage is 100 volts, what is the resistance?

$$R = \frac{E}{I} \qquad R = \frac{100}{2} \qquad R = 50 \text{ ohms}$$

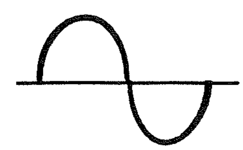
Power

Power is defined as the rate of doing work and is expressed in metric measurements in watts. The three most commonly used formulas are:

$$P = E\,I \qquad P = \frac{E^2}{R} \qquad P = I^2\,R$$

Alternating Current (ac) Circuits

Comparison of ac and dc



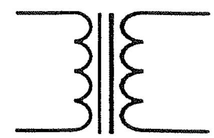
Direct current flows continuously in one direction through a circuit because the polarity of the voltage source never changes. But, alternating current changes rapidly in both direction and value because the polarity of the voltage source is changing likewise. These reversals typically occur at a rate of 60 times per second or 60 Hertz.

Advantages of Alternating Current

Power companies use ac generators, also called alternators, to produce electrical power more economically than was previously possible with dc generators. The main reason for this is that the power lost by the transmission of ac from the generating station to the user is very much less that with dc. Using ac, the power companies are able to efficiently transmit power by "transforming" the produced electrical energy into a higher voltage, but a lower current equivalent. The device used to conveniently raise or lower the ac voltage is called a *transformer.*

Conductors, or transmission lines, transport electrical power. All conductors have some amount of resistance. Although the amount of resistance for a one foot length of conductor may be small, this resistance is distributed along each foot of a transmission line, which can be hundreds of miles long. Over these long distances, the power losses, as given by $P=I^2R$, can become excessive due to the resistance of the transmission lines. Note, however, that even if the resistance could be cut in half, the power loss would also be only halved, as shown by $P=I^2R$. But because power is proportional to the *square* of the current, reducing the current by half reduces the power loss by *four times*. Another power formula, P=EI, tells us that we could indeed cut the current in half by doubling the voltage, and still transmit the same amount of power.

Powerful transformers operating on the principle of *mutual induction* can boost the voltage in accordance with these requirements. A transformer consists of two coils of wire wound on the same core. The input voltage is applied to one coil, called the *primary*, and the voltage output is taken from the other coil, called the *secondary*. When the secondary has twice as many turns of wire as the primary, the transformer has a *turns ratio* of 2:1. The rising and falling magnetic field in the primary coil cuts across twice as many conductors in the secondary, and the transformer is called a *step-up* transformer. By reversing this procedure, the original voltage can be obtained using a *step-down* transformer. The symbol for a transformer is shown at the right.



Transformers perform two functions in the transmission of ac. They step up and step down the voltage, and they isolate the generating station from the load. In this way, power companies can maintain low current levels in the transmission lines, and hold power losses to a minimum. Figure 8 represents the common means of generating, transmitting, and distribution electric power. Voltages utilized in the transmission of ac often range into the thousands and hundreds of thousands of volts. Fermilab is one of the few customers of electrical energy in Illinois that receives its power directly from the 345 kV high-voltage transmission lines of the electric utility company.

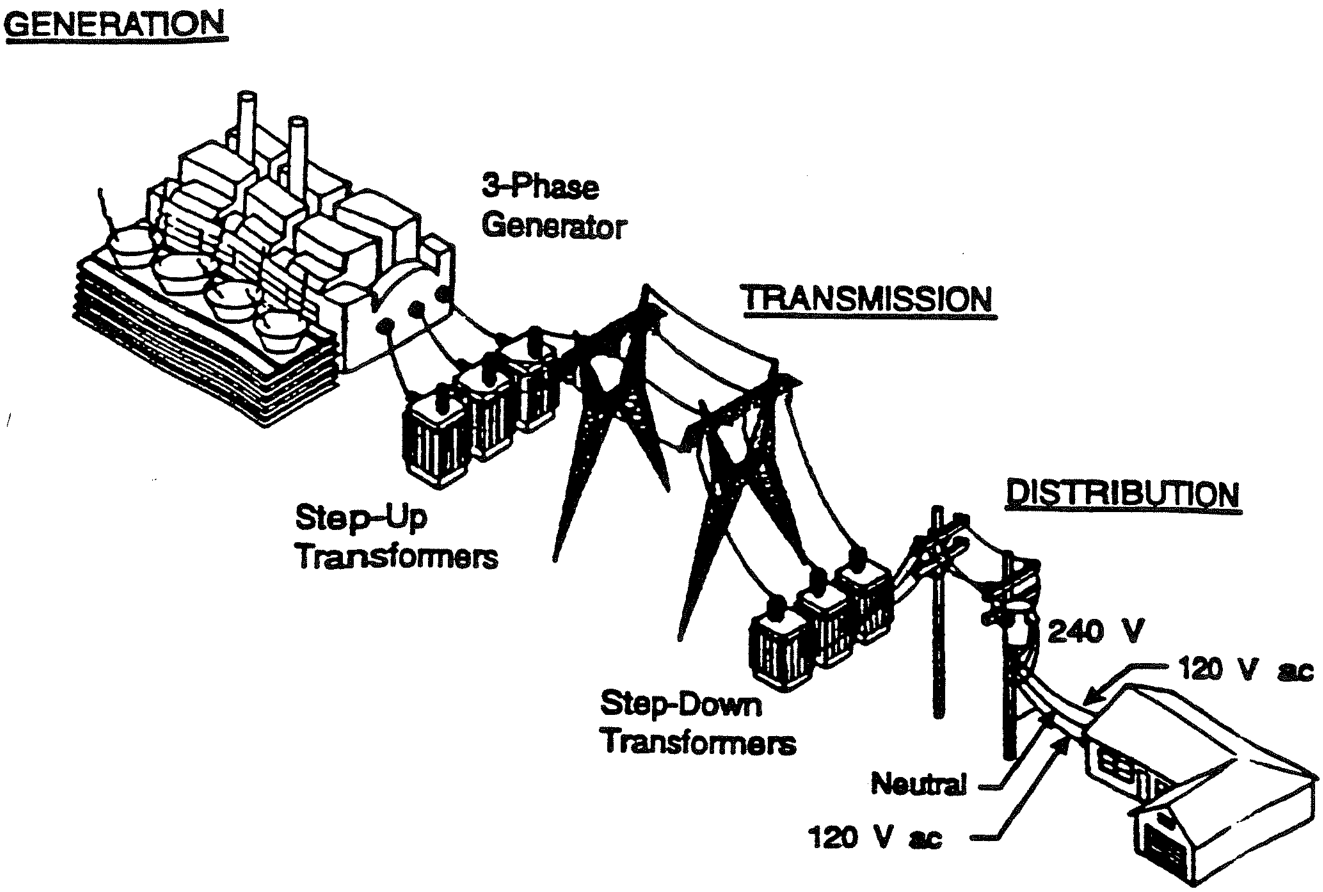


Figure 8: ELECTRIC POWER GENERATION, TRANSMISSION AND DISTRIBUTION

Hazards of Electricity

The primary hazards associated with electricity and its use are:

- **SHOCK.** Electric shock occurs when the human body becomes part of a path through which CURRENT can flow. The resulting effect on the body can be either *direct* or *indirect.*

    - **Direct.** Injury or death are possible consequences of electric current flowing through the human body. A thorough coverage of the effects of electricity on the human body is contained in a following section.

- **Indirect.** Although electric current through the human body may be well below the values required to cause noticeable injury, human reaction can result in falls from ladders or scaffolds, or movement into operating machinery. Such reaction can result in serious injury or death.

- **BURNS.** Burns can result when a person touches electrical wiring or equipment that is improperly used or maintained. Electrical burns are typically from the inside of the body out and require special treatment.

- **ARC-BLAST.** Arc-blasts occur from high-amperage currents arcing through air. This abnormal current flow (arc-blast) is initiated by contact between two energized points. This contact can be caused by persons who have an accident while working on energized components, or by equipment failure due to fatigue or abuse. Temperatures as high as 35,000° F have been recorded in arc-blast research. The three primary hazards associated with an arc-blast are:

  - **Thermal Radiation.** In most cases, the radiated thermal energy is only part of the total energy available from the arc. Numerous factors, including skin color, area of skin exposed, type of clothing have an effect on the degree of injury. Proper clothing, work distances and overcurrent protection can reduce the adverse consequences of burns resulting from thermal radiation.

  - **Pressure Wave.** A high-energy arcing fault can produce a considerable pressure wave. Research has shown that a person 2 feet away from a 25 kA arc would experience a force of approximately 480 pounds on the front of their body. In addition, such a pressure wave can cause serious ear damage and memory loss due to mild concussions. In some instances, the pressure wave may propel the victim away from the arc-blast, reducing the exposure to the thermal energy. However, such rapid movement could also cause serious physical injury.

  - **Projectiles.** The pressure wave can propel relatively large objects over a considerable distance. In some cases, the pressure wave has sufficient force to snap the heads of 3/8 inch steel bolts and knock over ordinary construction walls.

  The high-energy arc also causes many of the copper and aluminum components in the electrical equipment to become molten. These "droplets" of molten metal can be propelled great distances by the pressure wave. Although these droplets cool rapidly, they can still be above temperatures capable of causing serious burns or igniting ordinary clothing at distances of 10 feet or more. In many cases, the burning effect is much worse than the injury from shrapnel effects of droplets.

- **EXPLOSIONS.** Explosions occur when electricity provides a source of ignition for an explosive mixture in the atmosphere. Ignition can be due to overheated conductors or equipment, or normal arcing (sparking) at switch contacts. OSHA standards, the National Electrical Code and related safety standards have precise requirements for electrical systems and equipment when applied in such areas.

- **FIRES.** Electricity is one of the most common causes of fire both in the home and workplace. Defective or misused electrical equipment is a major cause, with high resistance connections being one of the primary sources of ignition. High resistance connections occur where wires are improperly spliced or connected to other components such as receptacle outlets and switches. This was the primary cause of fires associated with the use of aluminum wire in buildings during the 1960s and 1970s.

  As an example, consider a bad connection at a receptacle that has a resistance of 2 ohms. If there is a current of 10 amperes flowing through that resistance, the power developed at the bad connection would be:

$$P = I^2R = 10^2 \times 2 = 200 \text{ watts}$$

  If you have ever touched an energized 200 watt light bulb, you will realize that this is a lot of heat to be concentrated in the confined space of a receptacle. Situations similar to this can contribute to electrical fires.

Effects of Electricity On The Human Body

The effects of electric shock on the human body depend on several factors. The major factors are:

1. Current and Voltage, 2. Resistance, 3. Path through body, and 4. Duration of shock

The muscular structure of the body is also a factor in that people having less musculature and more fat typically show similar effects at lesser current values.

Current and Voltage

Although high voltage often produces massive destruction of tissue at contact locations, it is generally believed that the detrimental effects of electric shock are due to the *current* actually flowing through the body. Even though Ohm's law (I = E/R) applies, it is often difficult to correlate voltage with damage to the body because of the large variations in contact resistance usually present in accidents. Any electrical device used on a house wiring circuit can, under certain conditions, transmit a fatal current. Although currents greater than 10 mA are capable of producing painful to severe shock, currents between 100 and 200 mA can be lethal.

With increasing alternating current, the sensations of tingling give way to contractions of the muscles. The muscular contractions and accompanying sensations of heat increase as the current is increased. Sensations of pain develop, and voluntary control of the muscles that lie in the current pathway becomes increasingly difficult. As current approaches 15 mA, the victim cannot let go of the conductive surface being grasped. At this point, the individual is said to "freeze" to the circuit. This is frequently referred to as the "let-go" threshold.

As current approaches 100 mA, ventricular fibrillation of the heart occurs. Ventricular fibrillation is defined as "very rapid uncoordinated contractions of the ventricles of the heart resulting in loss of synchronization between heartbeat and pulse beat." Once ventricular fibrillation occurs, it will continue and death will ensue within a few minutes unless stopped. Use of a special device called a de-fibrillator is required to save the victim.

Heavy current flow can result in severe burns and heart paralysis. If shock is of short duration, the heart stops during current passage and usually re-starts normally on current interruption, improving the victim's chances for survival.

It is important to note that a typical household 20 amp branch circuit can easily supply 20,000 mA of current.

Resistance

Studies have shown that the electrical resistance of the human body varies with the amount of moisture on the skin, the pressure applied to the contact point, and the contact area. The outer layer of skin, the epidermis, has very high resistance when dry. Wet conditions, a cut or other break in the skin will drastically reduce resistance. Shock severity increases with an increase in pressure of contact. Also, the larger the contact area, the lower the resistance.

Whatever protection is offered by skin resistance decreases rapidly with increase in voltage. Higher voltages have the capability of "breaking down" the outer layers of the skin, thereby reducing the resistance by "punching through" to more conductive parts of the human body.

Path Through Body

The path the current takes through the body affects the degree of injury. Current through a single extremity is generally lesser in consequence of injury. Nonetheless, there have been many cases where an arm or leg was almost burned off when the extremity came in contact with electrical current and the current only flowed through a portion of the limb before it went out into the other conductor without going through the trunk of the body. Had the current gone through the trunk of the body, the person would almost surely have been electrocuted. A small current that passes from one extremity through the heart to the other extremity is capable of causing severe injury or electrocution. A large number of serious electrical accidents in industry involve current flow from hands to feet. Since such a path involves both the heart and the lungs, results can be fatal.

Duration of Shock

The duration of the shock has a great bearing on the final outcome. If the shock is of short duration, it may only be a painful experience for the person.

If the level of current flow reaches the approximate ventricular fibrillation threshold of 100 mA, a shock duration of a few seconds could be fatal. This is not much current when you consider that a small light duty portable electric drill draws about 30 times as much.

At relatively high currents, death is inevitable if the shock is of appreciable duration. However, if the shock is of short duration, and if the heart has not been damaged, interruption of the current may be followed by a spontaneous resumption of its normal rhythmic contractions.

Summary of Effects

We can sum up the lethal effects of electric current as follows:

- Current flow greater than the "let-go" threshold of an individual may cause a person to collapse, become unconscious and can result in death. The current flow would most often have to continue for longer than five seconds. Although it may not be possible to determine the exact cause of death with certainty, asphyxiation or heart failure are the prime suspects.

- Current flow through the chest, neck, head or major nerve centers controlling respiration may result in a failure of the respiratory system. This is usually caused by a disruption of the nerve impulses between the respiratory control center and the respiratory muscles. Such a condition is dangerous since it is possible for the respiratory failure to continue even after the current flow has stopped.

- The most dangerous condition can occur when fairly small amounts of current flow through the heart area. Such current flow can cause ventricular fibrillation. This asynchronous movement of the heart causes the heart's usual rhythmic pumping action to cease. Death results within minutes.

- When relatively large currents flow through the heart area, heart action may be stopped entirely. If the shock duration is short and no physical damage to the heart has occurred, the heart may begin rhythmic pumping automatically when the current ceases.

- Extensive tissue damage, including internal organ damage due to high temperatures, occurs when very large currents flow through major portions of the body.

- There are recorded cases of delayed death after a person has been revived following an electrical shock. This may occur within minutes, hours or even days after the event has occurred. Several assumptions for such delayed effects are:

    - internal or unseen hemorrhaging
    - emotional or psychological effects of the shock
    - aggravation of a pre-existing condition

In many accidents, there is a combination of the above effects, or additional effects may develop after the initial accident, thus making an accurate diagnosis quite difficult.

Common Workplace Circuits

Following are simplified diagrams of typical circuits that supply electrical energy to which individuals are most commonly exposed. Electrical energy is transmitted in different "phases." The changing voltage of each of the phases is displaced (by 120°) from the other phases. Most electrical energy is utilized by connections to a single phase. Larger loads, such as large appliances and motors, require two or three phases for energization.

The circuit described by Figure 9 usually supplies several lights and four to six duplex receptacles in a typical residence.

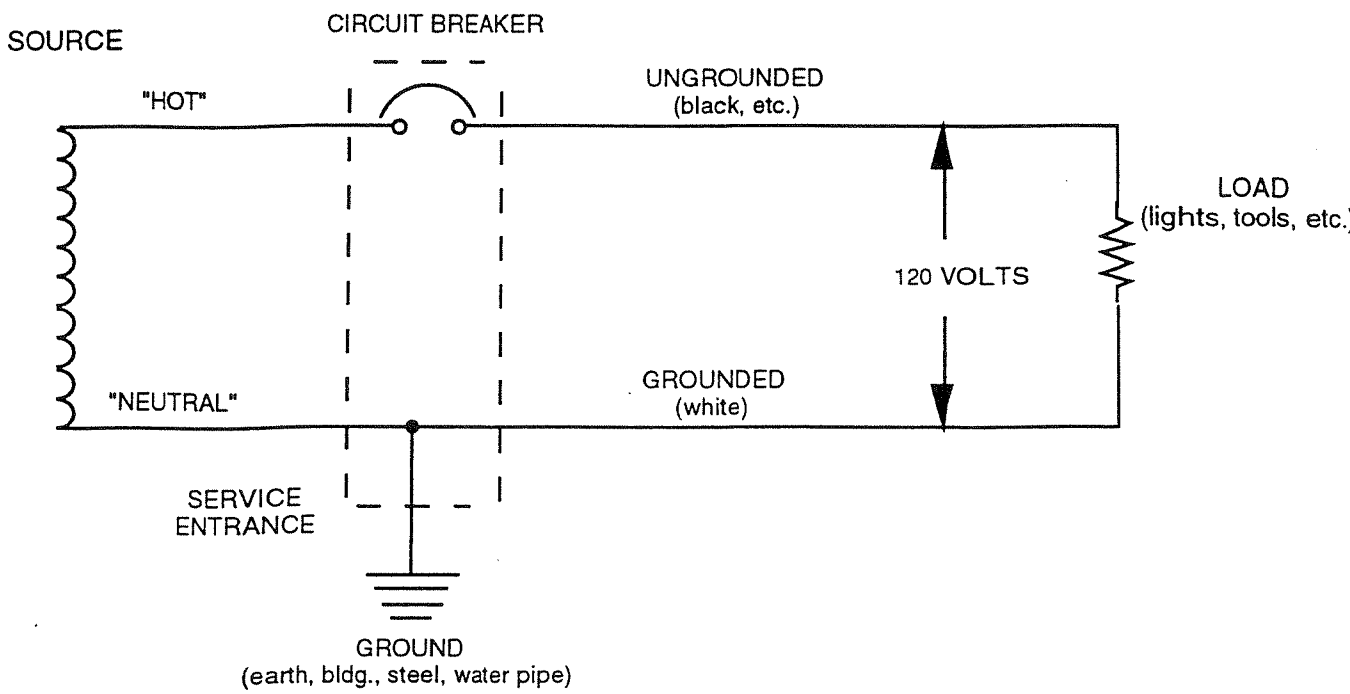


Figure 9: SINGLE-PHASE 2-WIRE CIRCUIT

Figure 10 represents the general electrical service for a residence. It usually supplies a number of 120 volt 2-wire circuits for lights and receptacles and also 220 volts for larger appliances.

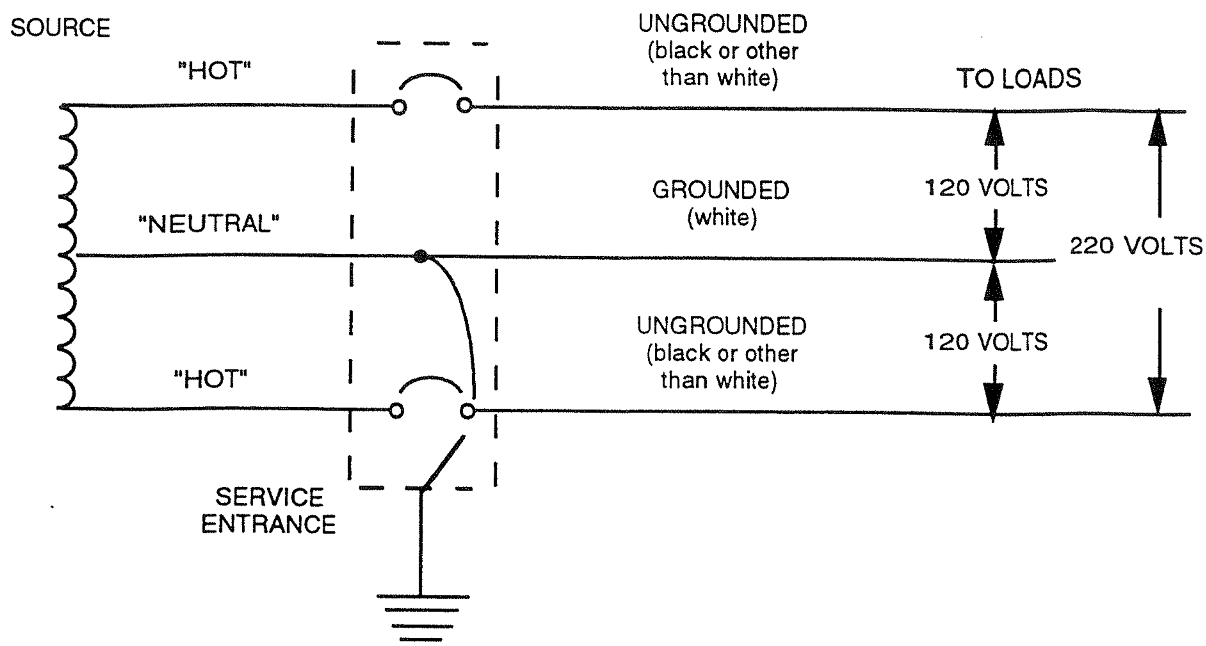


Figure 10: TWO-PHASE 3-WIRE CIRCUIT

Electrical Protective Devices

Introduction

The *electrical protective devices* we will discuss include fuses, circuit breakers, and ground fault circuit interrupters (GFCIs). These devices are critically important to electrical safety. *Overcurrent devices* should be installed where required. They should be of the size and type to interrupt current flow when it exceeds the capacity of the conductor. Proper selection takes into account not only the capacity of the conductor, but also the rating of the power source and potential short circuits.

Types of Overcurrent

There are two types of overcurrent:

1. Overload - When you ask a 10 hp motor to do the work of a 12 hp motor, an overload condition exists. The overcurrent may be 150 percent of normal current.

2. Fault - When insulation fails in a circuit, fault current can result that may be from 5 times to 50 times that of normal current.

When a circuit is overloaded, the plasticizers in the insulation are vaporized over a long period of time, and the insulation becomes brittle. Movement of the conductors due to magnetic or other forces can crack the insulation, and a fault can result. Conductors should be protected from overload and the eventual damage that results.

Faults occur in two ways. Most of the time a fault will occur between a conductor and a grounded electrical enclosure or another conductive component not part of the intended circuit. This is called a *ground fault.* Infrequently, a fault will occur between two conductors. This is called a *short circuit*, and was described earlier.

In order to predict what will happen in a normal circuit and a ground-fault circuit, we first need to understand the terminology used to describe electrical systems. Figure 11 should aid in this discussion. The dashed lines represent the enclosures surrounding the electrical system. These enclosures include the service panel, conduit, and boxes enclosing switches, controllers, equipment terminals, etc. The conduit bonds all of the enclosures together such that there is no electrical potential between them. It also provides an emergency path for ground-fault current to return to the voltage source which in this case is shown as secondary windings of a transformer.

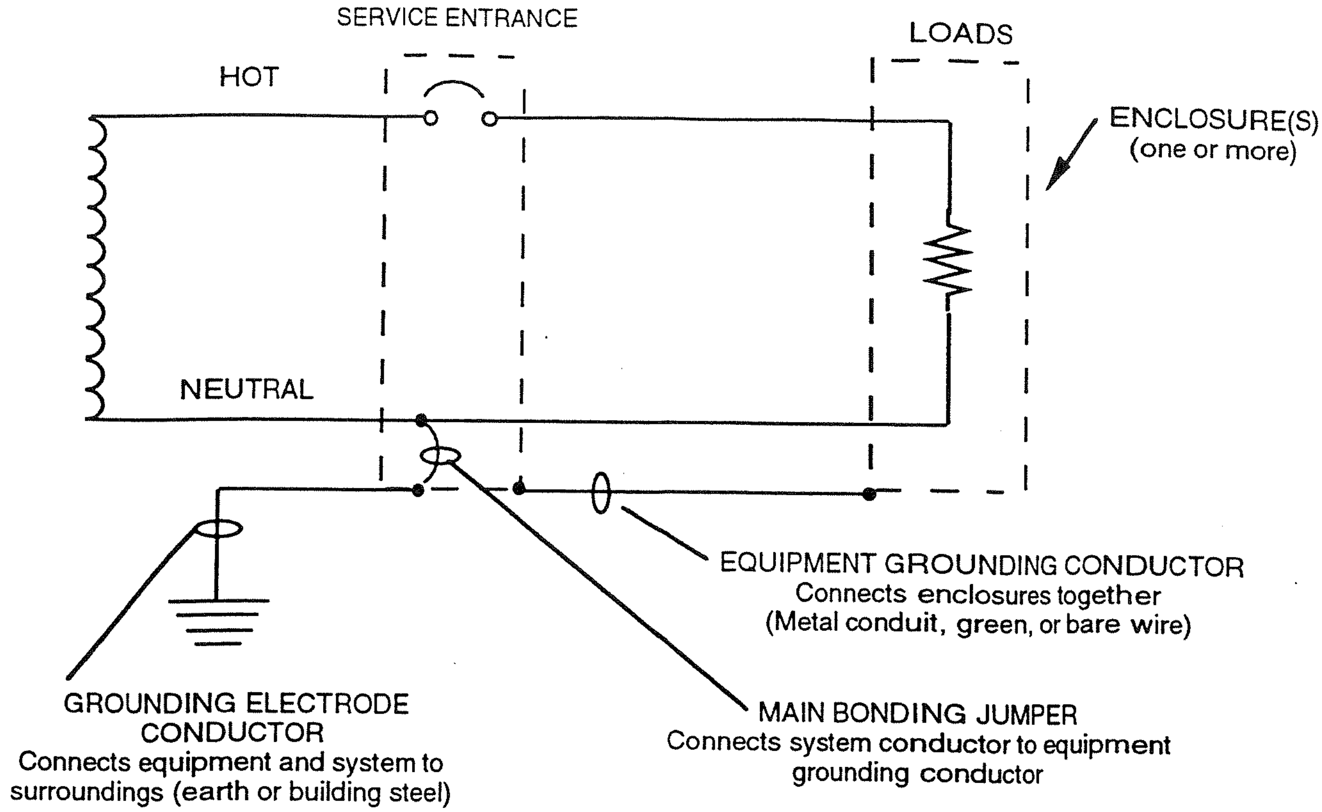


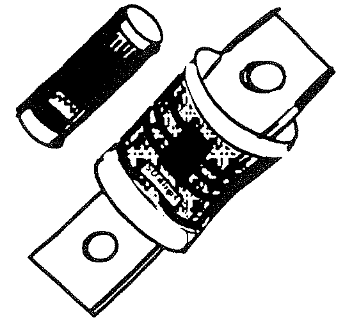
Figure 11: A PROPERLY GROUNDED SINGLE-PHASE CIRCUIT

Notice that there must be a wire between the grounded conductor and the enclosure to allow the fault current to return to its source. This wire is called the *main bonding jumper.* If there is no wire, then the electrical system is isolated and requires extra safety features.

The basic idea of an overcurrent protective device is to make a weak link in the circuit. In the case of a fuse, the fuse is destroyed before another part of the system is destroyed. In the case of a circuit breaker (as depicted in Figure 11), a set of contacts opens the circuit. Unlike a fuse, a circuit breaker can be re-used by re-closing the contacts. Fuses and circuit breakers are designed to protect equipment and facilities, and in so doing, they also provide considerable protection against shock in most situations. However, the only electrical protective device whose sole purpose is to protect people is the ground fault circuit interrupter.

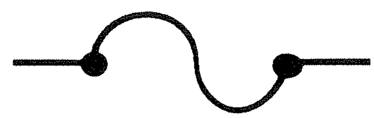
Fuses

A fuse is an electrical device that opens a circuit when the current flowing through it exceeds the rating of the fuse. The "heart" of a fuse is a special metal strip (or wire) designed to melt and *blow out* when its rated amperage is exceeded.



Overcurrent devices (fuses, circuit breakers) are always placed in the "hot side of a circuit (usually a black wire) and in series with the load, so that all the current in the circuit must flow through them.

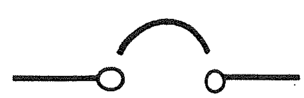
If the current flowing in the circuit exceeds the rating of the fuse, the metal strip will melt and open the circuit so that no current can flow. A fuse cannot be re-used and must be replaced after eliminating the cause of the overcurrent.



Fuses are designed to protect equipment and conductors from excessive current. It is important to always replace fuses with the proper type and current rating. Too low a rating will result in unnecessary blowouts, while too high a rating may allow dangerously high currents to pass. The symbol for a fuse is shown in the accompanying figure.

Circuit Breaker

Circuit breakers provide protection for equipment and conductors from excessive current without the inconvenience of changing fuses. Circuit breakers *trip* (open the circuit) when the current flow is excessive.



There are two primary types of circuit breakers based on the current sensing mechanism. In the *magnetic* circuit breaker, the current is sensed by a coil that forms an electromagnet. When the current is excessive, the electromagnet actuates a small armature that pulls the trip mechanism - thus opening the circuit breaker. In the *thermal-type* circuit breaker, the current heats a bi-metallic strip, which when heated sufficiently bends enough to allow the trip mechanism to operate. The symbol for a circuit breaker is shown in the accompanying figure. Circuit breakers are available for one, two, and three phase-circuits.

Ground Fault Circuit Interrupter

A ground fault circuit interrupter is not an overcurrent device. A GFCI is used to open a circuit if the current flowing to the load does not return by the prescribed route. In a simple 120 volt circuit we usually think of the current flowing through the "hot" (black, ungrounded) wire to the load and returning to the source through the "neutral" (white, grounded) wire. If all the current does not return through the neutral wire, then it must have gone somewhere else, usually to ground. The GFCI is designed to limit electric shock to a current- and time-duration value below that which can produce serious injury. The operation of the GFCI will be discussed later in this module.

Grounding

Grounding must be taken into account wherever electrical current flows. It can never be stressed too strongly that proper grounding and bonding must be correctly applied if the system, the equipment, and the people that come in contact with them are to be protected.

Effective grounding means that the path to ground: (1) is permanent and continuous, and (2) has ample current-carrying capacity to conduct safely and currents liable to be imposed on it, and (3) has a resistance sufficiently low to limit the potential above ground and to facilitate the operation of the overcurrent devices in the circuit.

The requirement for effective grounding is one of the most frequently cited violations of OSHA's electrical standards. *Effective grounding has no function unless and until there is contact and current flow from a current-carrying conductor to its grounded enclosure.* When such a *ground fault* occurs, the equipment grounding conductor goes into action to provide the following:

- It *prevents voltages* between the electrical enclosure and other enclosures or surroundings.
- It *provides a path* for large amounts of fault or overload current to flow back to the service entrance, thus blowing the fuse or tripping the circuit breaker.

How does grounding do its job?

Proper grounding requires connecting all of the enclosures (equipment housings, boxes, conduit, etc.) *together, and back to the service entrance enclosure.* This is accomplished by means of the green wire in the cord (portable equipment), and the conduit system or a bare wire in the fixed wiring of the building.

When a ground fault occurs, as in a defective tool, *the grounding conductor must carry enough current to immediately trip the circuit breaker or flow the fuse.* This means that the ground fault path must have low resistance. The only low resistance path is the green wire (in portable cord) and the metallic conduit system (or an additional bare wire if conduit is not used).

Note that the normal useful current flows in the "current-carrying" loop from the transformer over the black wire, through the tool or other load and back over the white wire to the transformer. The grounding conductor carries no current. This case is shown in Figure 12.

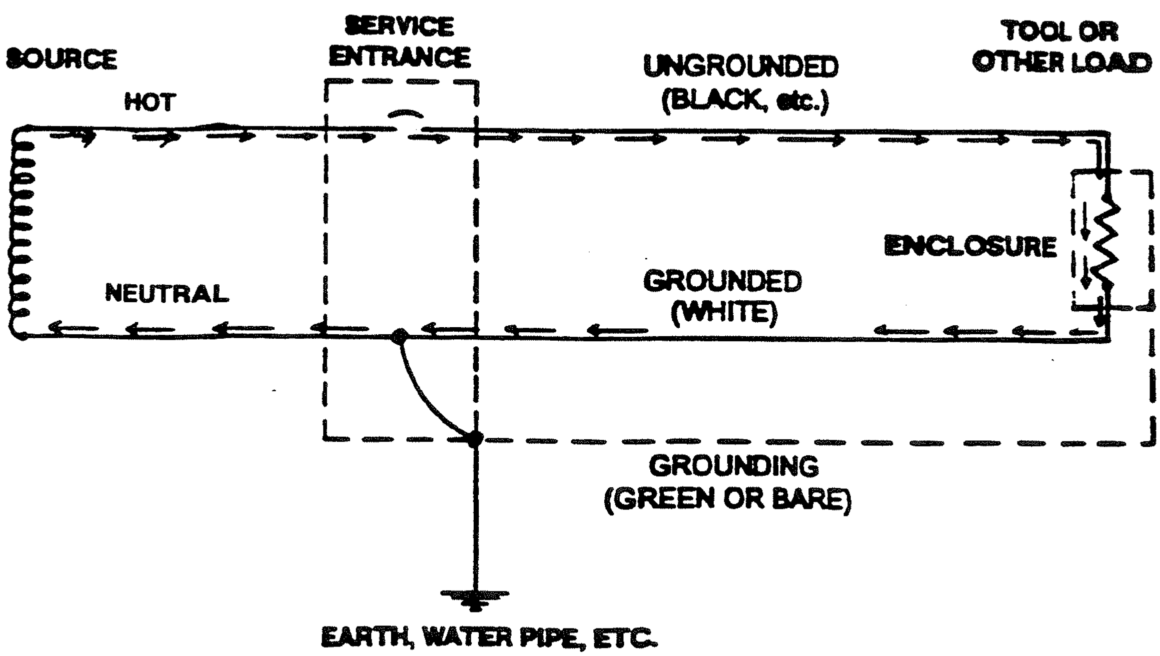


Figure 12: CURRENT FLOW IN A PROPERLY GROUNDED CIRCUIT

However, when the insulation on the black (ungrounded) conductor fails and the copper conductor touches the case of the tool, the ground-fault current flows through the green (grounding) conductor and the conduit system back to the service entrance. This situation is shown in Figure 13.

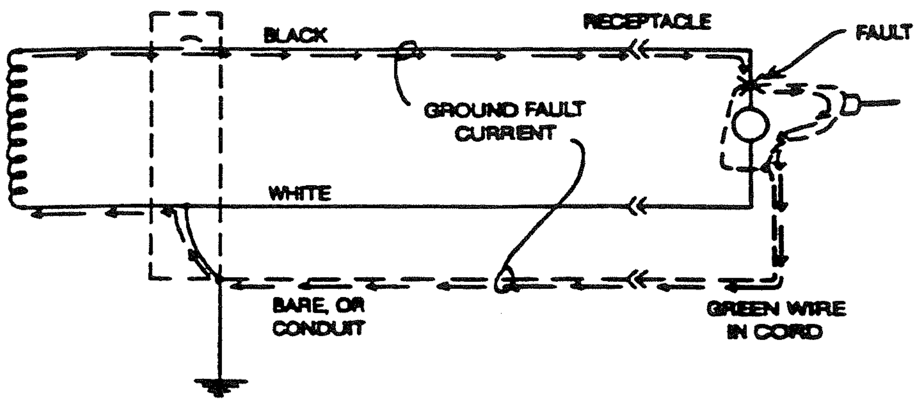


Figure 13: THE GROUND FAULT LOOP

If the equipment-grounding conductors are properly installed, this current will be perhaps 10 times or more greater than normal current, so the circuit breaker will trip out immediately.

But what happens if the grounding does not do the job?

If the ground-fault path is not properly installed, it may have such high resistance that it does not allow a sufficiently large amount of current to flow. Or, if the grounding conductor continuity has been lost (as when the grounding prong has been broken or cut off the plug), no fault current will flow. In these cases, the circuit breaker will not trip out, the case of the tool will be energized, and *persons touching the tool may be shocked* as shown in Figure 14.

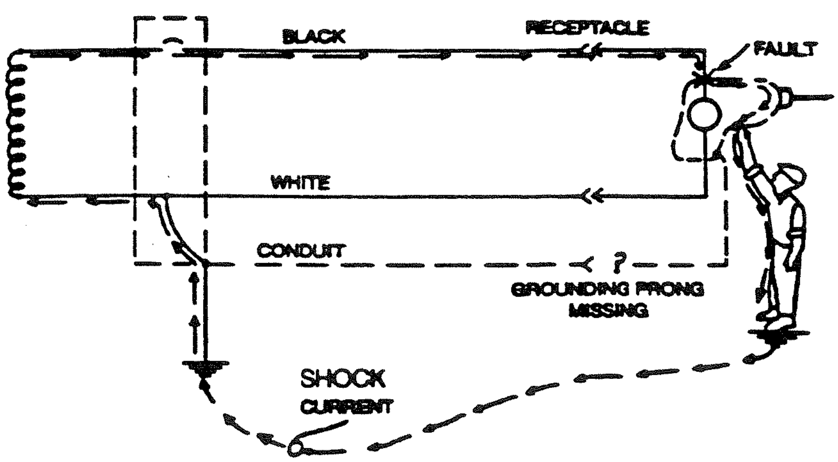


Figure 14: SHOCK FROM IMPROPERLY GROUNDED TOOL

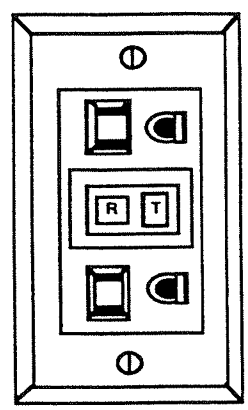
For the case shown, the person has become a parallel part of the circuit. The shock current can be substantial for the person, even lethal. But, the shock current is not high enough to trip the circuit breaker. Because the grounding prong is missing, the person is not protected.

Ground Fault Circuit Interrupters

Introduction

As we have discussed, effective grounding along with overcurrent devices (fuses and circuit breakers) are used to protect equipment and facilities, and in so doing, they may also provide considerable protection against shock in most situations. However, the only protective device whose sole purpose is to protect people is the ground fault circuit interrupter.

In most cases, *insulation* and *grounding* are used to prevent injury from electrical wiring systems or equipment. However, there are instances when these recognized methods do not provide the degree of protection required. To help appreciate this, let's consider a few examples of where ground fault circuit interrupters would provide additional protection.



- Many portable hand tools, such as electric drills, are now manufactured with non-metallic cases. If approved, we refer to such tools as *double insulated.* Although this design method assists in reducing the risk from grounding deficiencies (as shown in Figure 14), a shock hazard can still exist. In many cases, persons must use such electrical equipment where there is considerable moisture or wetness. Although the person is *insulated* from the electrical wiring and components, there is still the possibility that water can enter the tool housing. Ordinary water is a conductor of electricity. Therefore, if the water contacts energized parts, a path will be provided from inside the housing to the outside, bypassing the *double insulation.* When a person holding a hand tool under these conditions touches another conductive surface in their work environment, an electric shock will result.

- Double-insulated equipment or equipment with non-metallic housings, that does not require grounding under the National Electrical Code, is frequently used around sinks or in situations where the equipment could be dropped into water. Frequently, the initial human response is to grab for the equipment. If a person's hand is placed in the water and another portion of their body is in contact with a conductive surface, a serious or deadly electric shock can occur.

Since neither *insulation* (double insulation) nor *grounding* can provide protection under these conditions, it is necessary to use other protective measures. One acceptable method is a ground fault circuit interrupter, commonly referred to as a GFCI.

How Ground Fault Circuit Interrupters Work

A ground fault circuit interrupter is not an overcurrent device like a fuse or circuit breaker. (An exception here is the circuit-breaker type GFCI, which is discussed later.) GFCIs are designed to sense an imbalance in current flow over the normal path. If the current flowing in the *black wire* is within 5 (±1) milliamperes of the current flowing in the *white wire* at any given instant, the GFCI circuitry considers the situation normal. All the current is flowing in the normal path. If, however, the current flow in the two wires differs by more than 5 mA, the GFCI will quickly open the circuit.

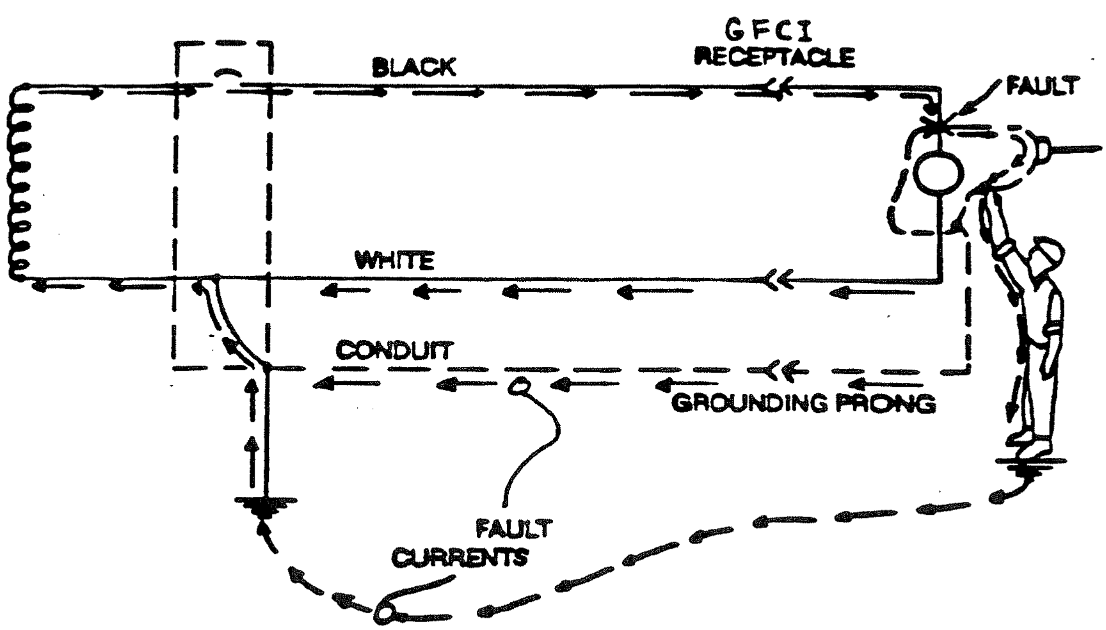


Figure 15: FAULT CONDITIONS SENSED BY A GFCI

Figure 15 demonstrates fault conditions for which the GFCI will open the circuit. Currents flowing through the grounding prong and conduit or through the person due to the fault will lessen the current normally flowing in the white wire. The GFCI will sense this condition and open the circuit.

Types of Ground Fault Circuit Interrupters

There are several types of GFCIs available, with some variations to each type. Although all types will provide ground-fault protection, the specific application may dictate one type over another.

- **Receptacle Type**
  The receptacle style GFCI incorporates, within one device, one or more receptacle outlets, protected by the GFCI. Such devices are becoming very popular because of their low cost (approximately $10). Most are of the duplex receptacle configuration and can provide GFCI protection for additional non-GFCI type receptacles connected "down stream" from the GFCI unit.

- **Cord Connected Type**
  The power supply cord type GFCI consists of an attachment plug which incorporates the GFCI module. It provides protection for the cord and any equipment attached to the cord. The attachment plug has a non-standard appearance and is equipped with test and reset buttons. It incorporates a no-voltage release device which will disconnect power to the load if any supply conductor is open.

- **Circuit-Breaker Type**
  The circuit-breaker type includes the functions of a standard circuit breaker with the additional functions of a GFCI. It is installed at the service entrance panelboard and can protect an entire branch circuit with multiple outlets. It is a direct replacement for a standard circuit breaker of the same rating.

Testing Ground Fault Circuit Interrupters

Due to the complexity of a GFCI, it is necessary to test the device on a regular basis. For permanently wired devices, a monthly test is recommended. Portable type GFCIs should be tested each time before use. GFCIs have a built-in test circuit which imposes an artificial ground fault on the load circuit to assure that the ground-fault protection is still functioning. Test and reset buttons are provided for testing.

Wiring For Proper Polarity

One potentially dangerous aspect of alternating current electricity is the fact that many pieces of equipment will operate properly even though the supply wires (hot, neutral, and ground) are not connected in the proper order. It is extremely important to recognize that improper termination of *any* conductor can introduce a serious hazard.

Figure 16 illustrates a duplex receptacle correctly wired. Terminals are designated and identified to avoid confusion. An easy way to remember the correct polarity is "white to light" - the white (grounded or "neutral") wire should be connected to the light or nickel-colored terminal; "black to brass" - the black or multi-colored (ungrounded or "hot") wire should be connected to the brass terminal; and "green to green" - the green or bare (grounding) wire should be connected to the green hexagonal head terminal screw. Note that the grounded contact opening which connects to the "Neutral" wire is larger than that for the ungrounded contact opening which connects to the "Hot" wire. This design accommodates the wider blade on "polarized" plugs and enhances safety.

There are economical devices available that you can use to test duplex receptacles for proper wiring polarity. Deficiencies should be brought to the attention of an electrician or other qualified person.

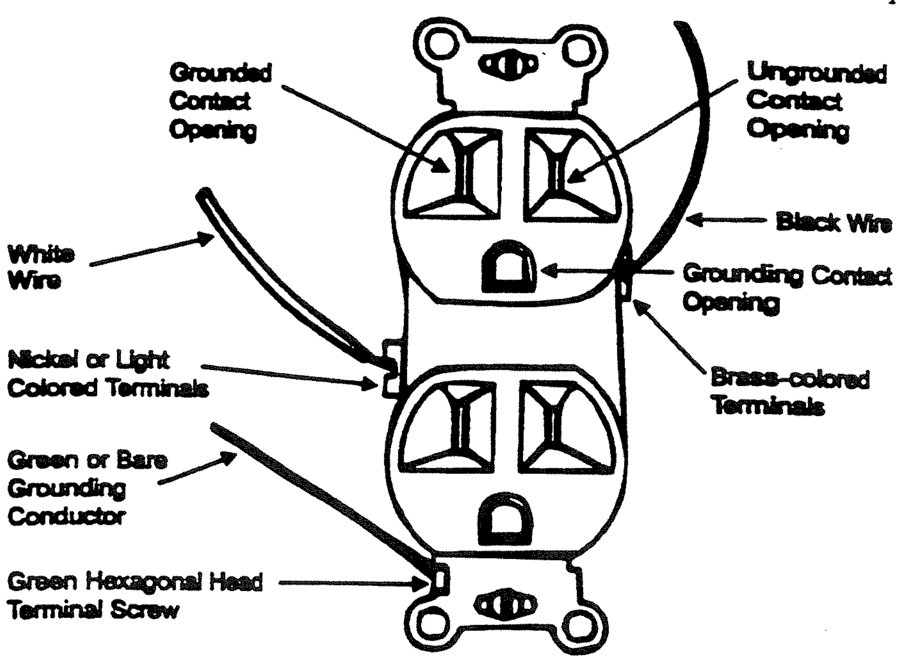


Figure 16: CORRECTLY WIRED DUPLEX RECEPTACLE

Electrical Safety

Basic Electrical Safety

Rafael Coll,
Environment Safety and Health Section

Health& Safety Group

Ext. 8518

Electrical Safety

Basic Electrical Safety

- √ **Course not designed to teach you to work on electrical equipment.**
- √ **You will not be qualified to work on electrical equipment.**
- √ **If you spot problems with electrical equipment you should report it to your supervisor.**

Electrical Safety

Objectives

- Be familiar with the fundamental concepts of electricity.
- Be familiar with the effects of electricity on the human body.
- Be able to recognize common electrical hazards.

Electrical Safety

Objectives

- Be familiar with electrical protective devices.
- Be familiar with PPE used by qualified electrical workers.

Electrical Safety

Electrical Terminology

- Voltage
  - electrical pressure (water pressure)
- Amperage
  - electrical flow rate (gallons/min)
- Impedance
  - restriction to electrical flow (pipe friction)

Electrical Safety

Electrical Terminology

- Circuit
  - path of flow of electricity
- Circuit Element
  - objects which are part of a circuit and through which current flows.
- Fault
  - current flow through an unintended path.

Electrical Safety

Electrical Terminology

- What is Grounding?
  - Protection from electric shock
    - normally a secondary protection measure
- A ground is a conductive connection
  - between electrical circuit or equipment and earth or ground plane
  - creates a low resistance to the earth.

Electrical Safety

Electrical Terminology

Electrical Safety

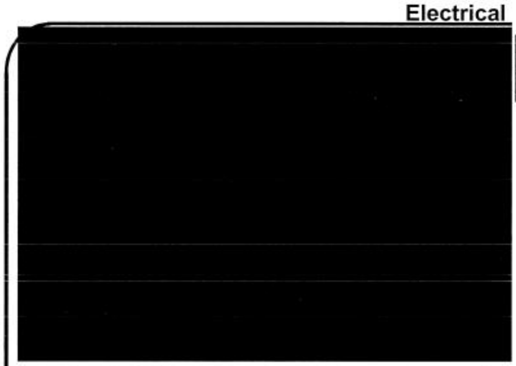
Basic Rules of Electrical Action

- Electricity isn't live until current flows
- Electrical current won't flow until there is a complete loop, out from and back to the power source.

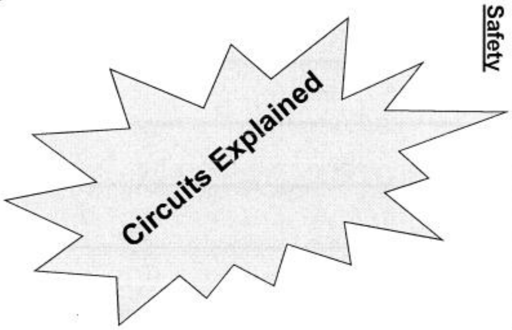
Fundamentals of Electrical Hazards

- To flow electricity must have a complete path.
- Electricity flows through *conductors*
  - water, metal, the human body
- Insulators are non-conductors
- The human body is a conductor.

Electrical Safety



Electrical Safety



Electrical Safety

Electrical Grounding

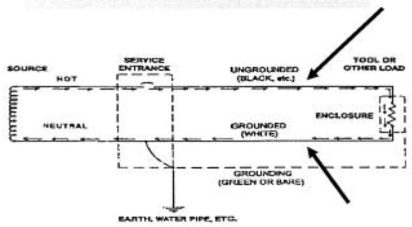
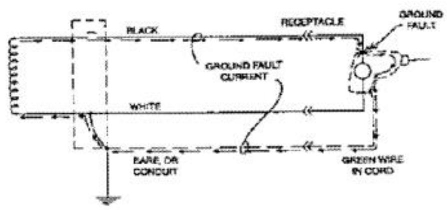


Figure 12: CURRENT FLOW IN A PROPERLY GROUNDED CIRCUIT

Electrical Safety



Circuit with a ground fault

Electrical Safety

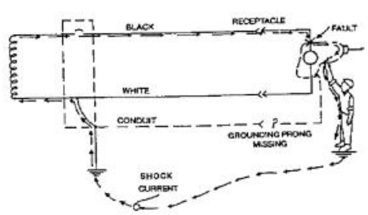


Figure 14: SHOCK FROM IMPROPERLY GROUNDED TOOL

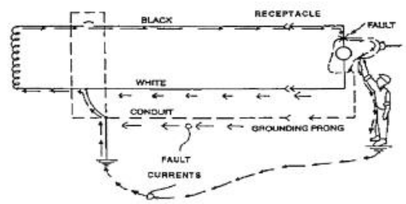


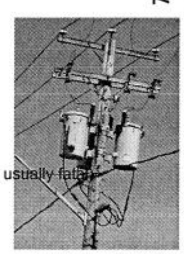
Figure 15: FAULT CONDITIONS SENSED BY A GFCI

Fundamentals of Electrical Hazards

Have You Ever Been Shocked?

THE BASICS

Fundamentals of Electrical Hazards



- √ **More than 3 ma**
  painful shock
- √ **More than 10 ma**
  muscle contraction "no-let-go" danger
- √ **More than 30 ma**
  lung paralysis- usually temporary
- √ **More than 50 ma**
  possible ventricular fib. (heart dysfunction, usually fatal)
- √ **100 ma to 4 amps**
  certain ventricular fibrillation, fatal
- √ **Over 4 amps**
  heart paralysis; severe burns. Usually caused by >600 volts

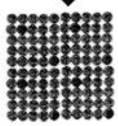
Fundamentals of Electrical Hazards

To place in perspective

150 squares like the one below is the tripping point of a circuit breaker


One penny= 1 ma
Perception level

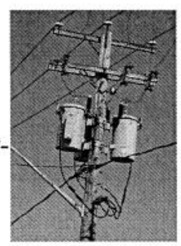

50 pennies= 50 ma
Heart dysfunction, possible Ventricular fib, usually fatal


100 pennies = 100 ma or 1/10 amp

At this level the human body goes into ventricular fib and death

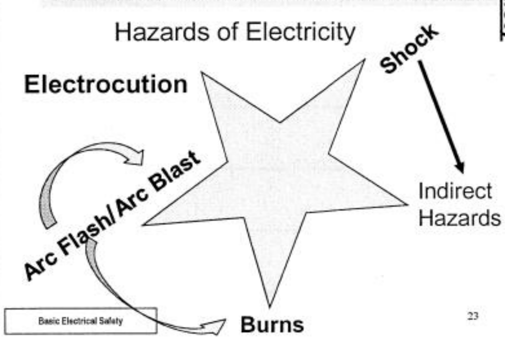
Fundamentals of Electrical Hazards

- Current can kill or injure a worker
- Voltage determines how- either by burning or electrocution



Fundamentals of Electrical Hazards

Hazards of Electricity



Fundamentals of Electrical Hazards

Arc Flash/Arc Blast

Time Duration of Event	30 ms to 500 ms
Temperatures as high as	35,000 °
Pressure Wave	15 tons/m²
Projectiles	Vaporized copper expands 67,000 x volumetrically

Some Consequences of an Arc Flash

Shrapnel

Human Projectile

Loss of Hearing

Loss of Sight

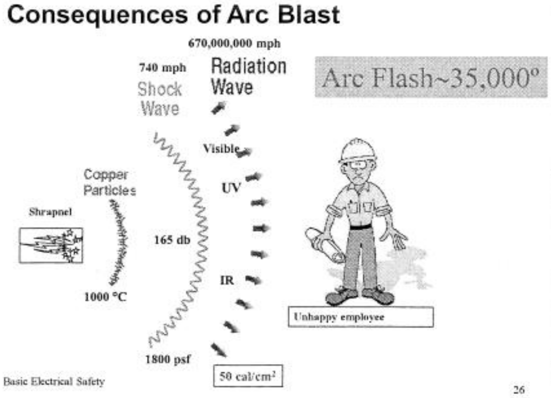
Death

Loss of Limb

Clothing Ignition

Tissue Burning

Consequences of Arc Blast



Electrical Safety

How Do We Protect Ourselves from the Flash?

- Recognize when energized electrical work is ongoing.
  - Barriers
  - Warning Tape
  - Safety observer (verbal warnings)
  - Signs
  - Personal Protective Equipment in <u>use</u>
- Stay 10 feet away when possible, but in all cases stay no closer than 4 feet away (Flash Protection Boundary).

Electrical Safety

How Do We Protect Ourselves From the Flash?

- Recognize the personal protective equipment used by electricians when conducting LOTO or energized work (testing and troubleshooting)

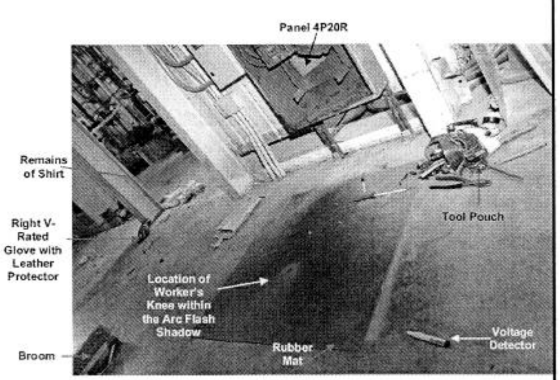


Figure 2-3. The insulating mat with the outline of BSE-1's knee in the arc flash shadow

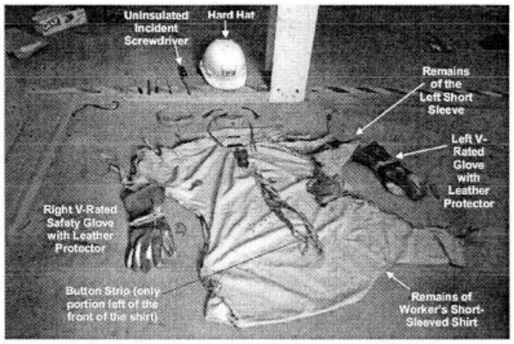
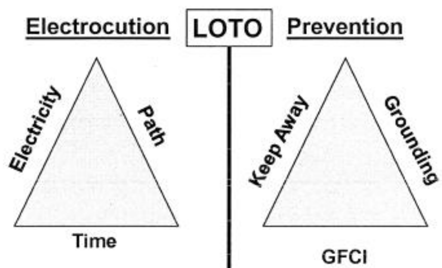


Figure 2-6. BSE-1's burned shirt and his flash-damaged PPE and tools

Preventing Accidental Electrical Contact (Shock and Electrocution)



Safe Practices

- Inspect any electrical cord for frayed conductors and missing grounding pins.
- Before plugging equipment to a GFCI make sure you test the receptacle.
- No daisy chaining of cords.

Electrical Safety

Safe Practices

- Damp areas and electrical equipment don't mix.
- Do not handle electrical equipment with wet hands.

Electrical Safety

Safe Distances- Transmission Lines (For Unqualified Workers)

- If working in an elevated position near overhead lines (Village) you must stay at least 10 feet away.
- With a conductive object in your hands (elevated or not) the closest distance from the conductive object to the energized line is also 10 ft.

Electrical Safety

Electrical Protection

- **Circuit Breakers**
  - **Provided to protect EQUIPMENT not people**
  - **Do not reset breakers with a line voltage higher than 120V and only reset if you know why it tripped**
- **GFCI's**
  - Provided to protect people
  - Trip range 4-6ma
  - Monthly test
- **Receptacles properly grounded.**

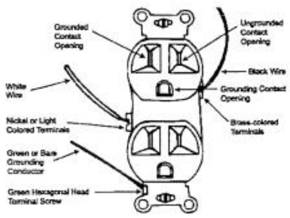


Figure 16: CORRECTLY WIRED DUPLEX RECEPTACLE

Electrical Protection

- **Distance**
  - If you sense the presence of an electrical hazard or exposed conductors that may be energized, keep your distance and STAY AWAY

Electrical Protection

- Inspect all electrical tools and equipment
  - ☑ Frayed, cut, broken wires
  - ☑ grounding prong missing
  - ☑ Improper use of cube taps
  - ☑ Improperly applied or missing strain relief

Electrical Safety

Do's and Don'ts

- **Do plug** power equipment into wall receptacles with power switches in the Off position.
- **Do** check the receptacle for missing or damaged parts.
- **Do** unplug electrical equipment by grasping the plug and pulling. Do not pull or jerk the cord to unplug the equipment.

Electrical Safety

Do's and Don'ts

- **Do** check for frayed, cracked, or exposed wiring on equipment cords.

- **Do not** plug equipment into defective receptacles.

Electrical Safety

Do's and Don'ts

- **Do not** drape power cords over hot pipes, radiators or sharp objects.
- **Do not** use extension cords in office areas unless for temporary use. Generally, extension cords should be limited to use by maintenance personnel.

Electrical Safety

Do's and Don'ts

- **Do not** use "Cheater plugs", extension cords with junction box receptacle ends or other jury-rigged equipment.
- **Do not** use consumer electrical equipment or appliances if not properly grounded. (Look for the UL Label)

Electrical Safety

Do's and Don'ts

- Employees should know the location of electrical circuit breaker panels that control equipment and lighting in their respective areas. Circuits and equipment disconnects must be identified.

Electrical Safety

Do's and Don'ts

- Temporary or permanent storage of any materials are not be allowed within 3 feet of any electrical panel or electrical equipment. Why??
- Any electrical equipment causing shocks or with high leakage potential must be tagged with a Danger tag or equivalent.

Electrical Safety

Myths and Misconceptions

- Electricity takes the path of least resistance.
- Electricity wants to go to ground.
- If an electric tools falls into a sink or tub of water, the item will short out.

Basic Electrical Safety 45

Electrical Safety

Myths and Misconceptions

- AC reverse polarity is not hazardous.
- It takes high voltage to kill; 120 volts is not dangerous.

Basic Electrical Safety 46

Electrical Safety

Basic Electrical Safety 47

8 cal/cm^2

Coverall

Electrical Safety

Full Gear

Basic Electrical Safety

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Home Safety Checklist: Electrical Safety

By Lore Postman and Laura Coyne

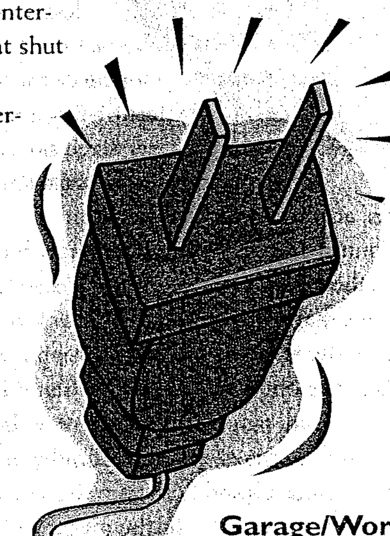
Even as technology improves, the electrocution hazards of the past can resurface and pose a danger to consumers, says the U.S. Consumer Product Safety Commission. Overall, the commission estimates about 200 consumer product-related electrocution deaths each year. Here's a room-by-room guide to keep you safe.

Kitchen/Bathroom:

✓ Outlets around sinks should have ground-fault circuit interrupters or outlets that shut off when a current is flowing through a person. Consumers can buy interrupter adapters that plug into existing outlets in most hardware stores for $20-$30. Electricians must install permanent interrupters.

✓ Clean behind and underneath the refrigerator periodically to prevent dust and dirt buildup on coils and cords.

✓ Never touch an electrical device if you're in contact with water.



Bedrooms:

✓ An electric blanket that is "tucked in" or covered with another blanket may overheat and catch fire.

✓ Make sure light-bulb wattages match the specifications on lighting fixtures throughout the house.

✓ Keep items that are stored in closets a safe distance from light bulbs. Certain materials near a hot bulb may catch fire.

Living/Family Room:

✓ Install safety covers on outlets (in entire house).

✓ Keep cords out of walkways.

✓ Don't cover cords with carpeting or rugs. The cords could overheat.

Laundry/Utility Room:

✓ Periodically vacuum your dryer's lint trap and exhaust hose. Lint buildup is a fire hazard.

✓ Make certain washer and dryer cords aren't pinched.

✓ Keep a 3-foot area around gas appliances, including dryers, water heaters and furnaces, clear of any clutter.

Garage/Workshop:

✓ Use an adapter to plug three-prong plugs into a two-hole receptacle. Replace tools without a three-prong plug or whose cords aren't double insulated.

✓ Never use a power tool if the grounding pin has been removed.

For more information on electrical safety, contact the National Fire Protection Agency at www.nfpa.org and the National Electrical Safety Foundation at www.nesf.org.

Top 10 Electrical Safety Tips

1 **Check it out.** Check your home's electrical panel for a "last-inspected" date. Get another inspection if it has been more than 10 years.

2 **Get unplugged.** Unplug heat-producing appliances when not in use. According to the National Fire Protection Association, you can leave a light burning for security, as long as the lamp is operating properly and the bulb is the correct wattage.

3 **Watch the wattage.** Burning a 100-watt bulb in a lamp designed for 60 watts is a fire hazard. Most lamps have wattage instructions written along the socket.

4 **Use cords with caution.** Extension cords are meant for short-term use and shouldn't be used to plug more items into a single outlet.

5 **The urge to surge.** Use surge protectors wherever possible.

6 **Give them a test.** Test ground-fault circuit interrupters monthly. Turn on a nightlight plugged into the outlet. Depress the "test" button. If the light turns off, the outlet is working properly. If the "reset" button pops out but the light stays on, the interrupter isn't working. Press the reset button to return the outlet to normal.

7 **High and dry.** Keep appliances away from water. Never reach into water for a plugged-in appliance. Unplug it first. Have the item inspected before using it again.

8 **Nice and tight.** Screw bulbs in securely. Loose bulbs can overheat.

9 **No yanking.** Unplug appliances by the gripping area next to the outlet. Yanking or tugging can damage the cord wire or insulation and could cause electrical shock or fire, according to the National Electrical Safety Foundation.

10 **Forget the pennies.** Pennies may be a quick fix for blown fuses, but they could cause the electrical panel to overheat and catch fire.

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Electrical Safety Foundation	http://www.esfi.org/cms/
Electrical Safety Forum	http://www.electrical-safety.com/
Electric League Kansas-Missouri	http://www.electricleague.org/safetyp.htm
US DOE Electrical Safety	http://www.hss.energy.gov/CSA/Analysis/electrical.html
Arc Flash Videos	http://www.westexinc.com/

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