Electrical Hazards

What are electrical hazards?

Electrical hazards are caused by

- ❑ the improper use of machinery or apparatus
- ❑ the improper use of electrical outlets
- ❑ the improper use of electrical equipment, such as cables and power cords
- ❑ the improper maintenance of apparatus, outlets, and electrical equipment

When used or maintained improperly, electrical equipment or devices can overheat or produce electrical fires. Frayed cords or exposed wires can easily electrify you or your students. Examples of particular hazards are

- ❑ apparatus with deteriorated power cord insulation
- ❑ a bent or broken prong on a plug
- ❑ a broken prong on a plug protruding from an outlet
- ❑ an overloaded circuit
- ❑ flammable fumes near electrical apparatus
- ❑ metal tools used near energized conductors
- ❑ dangling jewelry near an energized conductor
- ❑ a circuit that someone is working on with both hands
- ❑ a water spill on electrical equipment

Safety Information

You may know that the extent of injury caused by an electric shock depends on the magnitude of current. (Current is the movement of charge.) However, remember $\Delta V = IR$. Hence, a circuit that has high voltage is also likely to have a large current. So, the best safety practice is to avoid high-voltage circuits.

Does the type of current matter?

Both **alternating current (AC)** and **direct current (DC)** can produce injury to living tissue and can destroy equipment. However, the AC (60 Hz and 120 V) that U.S. electric companies supply to most electrical outlets disturbs human nerve impulses more readily than DC of the same voltage or AC at other frequencies do because human nerve impulses resonate at approximately 60 Hz. In addition, the DC circuits often used in classroom experiments are relatively harmless. Yet, DC can still be dangerous, and burn hazards are created in many common uses of DC. So, all circuits should be treated cautiously.

Definitions

alternating current (AC)
a current in which charge moves in one direction and then in the opposite direction

direct current (DC)
a current in which charge moves in one direction

What are the dangers of electricity to living tissue?

Electrical hazards can burn equipment and cause a fire in your classroom. These hazards can also cause serious injuries to you or your students. Specifically, current passing through a body may produce one or more of the following symptoms:

- ❑ **Shock** Shock should not be confused with electric shock. Shock is an excitation or disturbance of the normal function of nerves or muscles.
- ❑ **Involuntary muscle reaction** A person who experiences an electric shock may not be able to control her or his muscles. In addition, muscles that a person normally does not control, such as the heart, may operate abnormally.
- ❑ **Muscle paralysis** An electric shock may prevent muscles from moving (for example, arm muscles cannot flex) or operating (for example, the heart cannot pump blood).
- ❑ **Burning of tissue and organs** Tissue and organs may be burned so badly that they hemorrhage.
- ❑ **Death (electrocution)** Death can result from electrocution, which is caused by electric shock.

SAFETY INFORMATION

Severe electric shocks may cause internal hemorrhages as well as tissue, nerve, and muscle damage. These injuries are often not visible and may not be obvious to onlookers. In addition, an electric shock is often only the beginning of a chain of events. A person who experiences an electric shock may fall and break a bone or get a cut.

Critical values of current and their corresponding physiological effects

Listed below are the critical values of current and their corresponding physiological effects. These approximate values are based on 60 Hz AC passing through the intact skin for one second.

Critical values of 60 Hz AC (mA) female	male	Physiological effects
0.7	1.1	threshold of sensation
1.2	1.8	threshold of painless shock
11	16	paralysis of voluntary muscles
19	30	respiratory arrest
50	75	ventricular fibrillation—the uncoordinated pumping of the heart chambers such that blood does not flow properly (can be fatal)
4000	4000	cardiac arrest
5000	5000	burns that are severe enough to be fatal

DID YOU KNOW?

Approximately 109 mA of DC will give a female respiratory arrest and approximately 170 mA of DC will give a male respiratory arrest. In contrast, only 19 mA of 60 Hz AC will cause respiratory arrest in a female, and 30 mA of 60 Hz AC will cause respiratory arrest in a male.

SAFETY INFORMATION

The critical values of 60 Hz AC and their corresponding physiological effects are taken from "The Effects of Electric Shock on Man" by Charles Dalziel. See the appendix for more information.

How can electric shocks occur?

Most electric shocks are caused when people come in contact with defective power cords or with energized instruments whose cases are removed. A person receives an electric shock when he or she becomes part of a live electric circuit—when current enters the body at one point and exits at a different point. You will receive an electric shock if you are in contact with

- ❑ both energized receptacle slots of an outlet or power cord wires
- ❑ one energized wire and a ground
- ❑ a metallic piece that is in contact with an energized conductor and a ground

When instrument cases are open or electric components are exposed, an electric shock is likely to occur. Always make sure that an instrument is unplugged before you inspect the internal components of an instrument. Furthermore, always have a trained technician repair equipment. Students should never work on instruments that use AC and have exposed internal components.

Note that student-assembled circuits that use low-voltage and relatively safe DC power sources (such as D-cell batteries) are far less hazardous than activities in which AC is used, even though these student circuits are not enclosed in cases. Regardless, remain cautious about students working on electrical devices. (See the sections on resistive heating and on the prevention of electrical hazards.)

✔ DID YOU KNOW?

Capacitors should always be treated with caution because capacitors store charge and can deliver an unexpected electric shock.

What conditions affect the severity of electric shock?

Several factors, in addition to the magnitude and type of current, affect the severity of electric shock. Those factors include the following:

- ❑ **Current path through the body** Electric shocks are less severe if the current path does not include vital organs.
- ❑ **Length of time the electric shock acts on the body** The duration of the electric shock effects the extent of injury—the longer the duration of the electric shock on the body, the greater risk of severe injury. In addition, the electric shock can influence the duration of exposure if a victim cannot let go of the conductor of electricity that is causing the electric shock because of loss of voluntary muscle control.

- **Location on the body of the electrical contact** An electric shock that starts at a finger and exits through the grounded elbow on the same arm will do less damage than an electric shock that starts at a finger and exits through the victim's grounded feet. The latter scenario is more dangerous because more tissue is affected and the path of current is closer to internal organs.

  Current can burn vital organs even if the current does not pass through those vital organs. This type of damage may occur externally because of arcing or thermal contact (a vital organ is near tissue that is experiencing electric shock). The likelihood of this type of damage increases at high current levels.

DID YOU KNOW?

The severity of heart injury that an electric shock can cause depends on which stage of the pumping cycle the heart was in at the instant the electric shock occurred.

- **Skin resistance** The resistance of the body greatly affects the severity of the electric shock. Human tissue has very low resistance because the cellular fluid in tissue is a good conductor of electricity. However, dry skin has very high resistance—approximately a hundred thousand ohms ($10^5 \Omega$). Resistance of wet skin is low—a thousand ohms or less ($10^3 \Omega$). Skin resistance is even lower than the resistance of wet skin if a cut or deep abrasion is present. The exposure of moist and deeper skin layers increases the severity of injury that results from the electric shock.

  Because low resistance results in high current for a given potential difference ($I = \Delta V/R$), the current in wet skin can be several hundred times greater than the current in dry skin. Whether you have wet or dry skin can mean the difference between a harmless electric shock and an electric shock that causes serious burns and interferes with the functions of internal organs.

- **Other physiological and psychological factors** Age and physical condition affect the severity of an electric shock. Body resistance also varies according to muscular structure.

  Studies show that for a given current, a person concentrating on a task may not experience the same electric shock as a person who is daydreaming and then is startled when the electric shock occurs.

What should I do if someone is electrified?

If someone is electrified, tell a student to get another teacher to call for emergency personnel. Then, remove the person from contact with the energized conductor. Do not try to touch the person or you may be electrified as well. You can turn off the power of the device that is causing the electric shock if this can be done safely (for example, turning off the circuit breaker for the outlet in which the device is plugged). Or you can obtain an insulator, such as a wooden meterstick, and break the contact between the person who is being electrified and the energized conductor.

After the person who is suffering from electric shock has been removed from the source of the shock, check to see if this person is having breathing problems or is experiencing ventricular fibrillation. Artificial respiration or cardiopulmonary resuscitation should be performed on the person who experienced electric shock, if necessary. Also, use blankets to keep the person warm. Although a person who is electrified may appear unharmed, call emergency personnel because this person may have suffered internal injuries, such as burns to organs during the electric shock.

What is resistive heating?

Resistive heating is the thermal energy that current produces while moving through circuits. This type of energy is also known as *Joule heating* or I^2R *loss* and can be a hazard to you, your students, and your equipment. Charges colliding with (instead of moving smoothly through) atoms or ions of the conductor can produce resistive heating. When such collisions occur, the charges lose kinetic energy, but the conductor gains thermal energy. Resistive heating can occur if

- ❑ equipment components or conductors are not rated for the amount of current in their circuit
- ❑ outlets or circuits are overloaded
- ❑ electrical connections are poorly or improperly made
- ❑ apparatus is not properly ventilated

The effects of resistive heating are as follows:

- ❑ burns, if hot components are accidentally touched
- ❑ ignition of combustible materials in the vicinity of equipment that has resistive heating
- ❑ vaporization of or explosion of components

DEFINITIONS

resistive heating
the heating of electrical components due to the passage of current

Resistive heating is easy to prevent

Fortunately, resistive heating can be prevented easily by good laboratory technique and proper use of equipment. You should experience little resistive heating if you follow, in order, these simple steps.

- ✔ Before you start building your circuit, plan your circuit by drawing a schematic that identifies all components of the circuit.

- ✔ Estimate the current that each component of the circuit will have, based on the voltage of the power source.
- ✔ Compare your estimates of current with the ratings for the components you will use to prevent overloading the components.
- ✔ Connect all components in the circuit except the power source, and verify that all connections are properly made.
- ✔ Open the switch or turn the power source off while you connect the power source to the circuit.
- ✔ Leave the power source on only as long as necessary to perform the desired actions or functions.
- ✔ Open a switch or turn the power source off as soon as the necessary measurements or observations have been made.

SAFETY SUGGESTIONS

If a fire occurs because of an electrical hazard, try to extinguish the fire only if you believe that you can extinguish the fire safely. Do not use water to extinguish an electrical fire. Use a Class C fire extinguisher.

What are other electrical concerns?

Electric shock and resistive heating are not the only hazards associated with electrical equipment. Charges may move as a current spontaneously. Although these arcs and sparks typically create currents that exist for a short duration, these charges can still be hazardous.

Is static electricity a concern?

Static electricity is caused by an imbalance of electrons between two surfaces. The imbalance can be corrected by transferring electrons from one surface to another surface by conduction or induction. When the excess charge on a surface is discharged, a person standing near the discharge can be electrified. However, these electric shocks are not normally hazardous, so students do not have to report every instance of a shock by static electricity.

One serious concern related to static electricity is the accumulation of static electricity near a hazardous material such as a flammable gas or vapor. Static electricity can cause a flammable gas or vapor to ignite. Another concern is the potential for an injury to result from someone reacting to electric shock by, for example, rapidly pulling her or his hand away and knocking over a beaker.

Are there any other issues I should be concerned about?

You should be concerned about the following:

- ❑ **Sparks** Sparks are created when electricity jumps across a small gap in a circuit. Many types of electrical equipment are capable of creating sparks—thermostats, drills, and motors commonly produce sparks. Sparks are dangerous because they can ignite flammable materials or shock you or your students.

- ❑ **Electric arcs** Electric arcs are bands of sparks and may be created when a circuit is shorted, when the flow of a current is interrupted, or even when a switch is closed. Electric arcs are capable of causing electric shocks and combustion of materials. To prevent the occurrence of electric arcs, always ensure that components of circuits are properly connected before energizing the circuits and never close a switch or circuit breaker slowly.

What can I do to prevent electrical hazards?

You can prevent or minimize electrical hazards easily. Listed below are some steps you can take to minimize these hazards.

- ✔ **Apparatus and Electrical Fixtures**
  - ✔ Often inspect the insulation on power cords, patch cords, and cables for deterioration. If a conductor is exposed, remove it from use or repair it immediately.
  - ✔ Do not splice equipment or cords. Do not use any equipment or cords that have splices.
  - ✔ Always use power cords rated for the device with which they are to be used. Ensure that connecting cords and cables are also rated for the magnitude of the current to be found in an activity.
  - ✔ Never remove the ground prong from a plug. If a plug is missing the ground prong, replace the plug immediately or stop using the apparatus with the broken plug.
  - ✔ Do not use three-to-two prong adapters.
  - ✔ Have any two-prong electrical outlets replaced as soon as possible. Two-prong outlets do not have the ground prong and are more dangerous than the three-prong outlets.
  - ✔ Do not overload circuits. Using extension cords often overloads circuits.
  - ✔ If a prong is broken off in an outlet, make certain the outlet is de-energized before attempting to remove the prong. Do not let students work in the immediate area until the outlet is de-energized and the prong is removed.
  - ✔ Have loose outlets repaired before allowing anyone to use them—they can cause electrical shorts.
  - ✔ Instruct students to report broken or damaged apparatus or fixtures immediately.

- ✔ Instruct students to warn you immediately if they touch any apparatus and feel a tingling sensation. Remove the suspect apparatus from use in experiments immediately.
- ✔ When replacing fuses, use only the type specified for the apparatus; do not attempt to substitute fuses whose current or voltage rating is different from the current or rating required.
- ✔ Never staple or nail power cords, patch cords, and cables, as is commonly done, to get them out of the way of students or equipment. Use cable ties or plastic wire keepers instead.
- ✔ Never use the power cord to move or carry apparatus.
- ✔ Provide adequate ventilation for electrical apparatus.
- ✔ If apparatus are used near chemicals, periodically check that connections and power cords are not degrading because of the chemicals.
- ✔ Electrical apparatus that must be used in hoods should be built to prevent sparks.
- ✔ Provide shielding between exposed vacuum tubes or cathode ray tubes and the students, and provide safety goggles to students. These tubes are potential implosion hazards.

✔ **Environmental**

- ✔ Always keep activity areas dry. Have any leaks repaired immediately, or have students work in an alternate area until repairs are made. Do not allow students to bring water bottles or drinks into the lab.
- ✔ Do not use any electrical apparatus near any water sources or around combustible materials. In particular, do not allow power cords or cables to lie under water faucets or in sinks.
- ✔ If you smell gas when you are entering a room, do not turn on the lights (or other electrical apparatus). A spark may be created by turning on any electrical equipment and may cause an explosion if the gas concentration is large.
- ✔ Do not leave windows open where rain may drop on equipment or create puddles on floors or benches.
- ✔ Make sure electrical panels on equipment are closed and latched, especially if they are accessible to students.
- ✔ Ensure that students have adequate lighting to perform activities.
- ✔ When arranging electrical equipment, take into account that not all students are the same height or that some students have visual or mobility impairments.

✔ **Work Practices**

- ✔ Know your limitations—do not attempt to repair apparatus if you are not certain what to do.
- ✔ Get students in the habit of working on energized electrical circuits (DC or AC) with one hand behind their back.
- ✔ Always construct a circuit, and then connect the circuit to the power source. Always disconnect the power source before disassembling the circuit.
- ✔ Always check that circuits are properly connected.
- ✔ Always have one student act as an observer when a group is working on a circuit. Never let any student work alone on a live circuit.
- ✔ Never allow students to wear jewelry, loose clothing, keys on a cord around the neck, or any other dangling conductors near an energized circuit.
- ✔ Never remove power cords, patch cords, and cables by pulling on the wire. Always use the plug or connector.
- ✔ Keep cords and plugs away from areas where they may be stepped on, pinched between objects, or tripped over.
- ✔ Do not use apparatus that have overextended power cords. Replace the power cord with a longer power cord, use closer outlets, or redesign the layout of the activity in the room.
- ✔ Do not store apparatus with the power cord wrapped tightly around it. A tightly wrapped cord adds stress to the cord at the point the cord enters the apparatus case and leads to the deterioration of the cord's insulation.

Accident Scenario

Electrical Plugs

In a chemistry classroom, students are using hot plates to heat solutions. One student wants to move his hot plate to the other side of his laboratory table and tries to unplug his hot plate without first turning off the hot plate. The plug will not separate from the outlet, so the student uses a metal spatula to free the plug from the outlet. The student experiences an electric shock as a result of his actions.

Tips to avoid electrical plug accidents

- ✔ Remind students of safe practices in the classroom, such as turning off electrical equipment before unplugging the equipment.

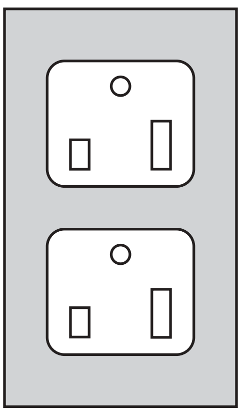
- ✔ If possible, do not use metal instruments such as spatulas during experiments that require electrical equipment.
- ✔ Do not let students move laboratory equipment during an experiment.
- ✔ Place warning signs and reminders near equipment.

What kind of outlets do I need?

Outlets (receptacles) in your classroom should have the standard three-prong design as shown in the diagram. This design has a ground connection. Plugs and outlets are wired in a standard way:

- ❑ The short slot of the outlet (black-wired prong on a plug) is the hot connection.
- ❑ The longer slot of the outlet (longer, white-wired prong on a plug) is the neutral connection.
- ❑ The round opening of the outlet (green-wired prong on the plug) is the ground.

The potential between the hot connection and the neutral connection is approximately 120 V. The ground connection protects users by ensuring that the equipment is at the same potential as Earth, which is neutral. You will not experience an electric shock if you and the equipment that you touch are at the same potential as Earth. (For apparatus that need 240 V, their cords will have a plug with a third wire at a potential of –120 V.)



This figure shows a three-prong outlet in the proper orientation.

Receptacles are usually oriented so that the slots form an inverted triangle. This inverted triangle is not the safest arrangement for outlets located on the skirt of the laboratory table because students commonly lean against laboratory tables while they are working. A student may repeatedly lean against a plug, gradually work the plug loose from the receptacle, and partially expose the energized prongs of the plug. A better arrangement in these cases would be to install the outlets as shown in the diagram on the previous page. The first prong to be exposed would be the ground prong, which is not energized (unless there also happens to be a short in the case of the equipment).

Receptacles should be equipped with a ground fault circuit interrupt (GFCI or GFI). Receptacles located near sinks or other water sources must have a GFCI. Receptacles for hoods should be located outside the hoods. This placement prevents ignition of vapors that may be present in the hood because of a plug sparking while being inserted or removed from an outlet.

If there are absolutely no other outlet alternatives and adapters must be used to connect three-prong plugs to a two-prong outlet, be certain to connect the ground on the adapter to a grounded screw on the outlet plate (or other suitable ground). Make sure the outlet panel screw is actually grounded, however. Also ensure that the ground wire is insulated, because if the wire is not truly a ground wire, someone could unknowingly touch it and receive an electric shock.

Dangers of using too much equipment with too few outlets

Receptacles must never be overloaded. Overheating of outlets may cause a fire, especially if combustible material is near the overloaded outlet. To ensure that an outlet is not overloaded, perform the following steps:

- ✔ Calculate the total load on the outlet or on the entire circuit from the wattage ratings for each device plugged into the outlet or for each component in the circuit.
- ✔ If the sum of the currents exceeds the current rating (the circuit breaker or fuse rating) for that outlet or circuit, then some devices or equipment must be moved to different outlets.

Do not use multiple outlet plugs that allow more than one apparatus to be plugged into an outlet simultaneously. If you are not careful about what equipment is plugged into the outlet, the outlet may overload and create a serious fire hazard.

For the following reasons, extension cords should never be used.

- ❑ Although extension cords are intended for temporary use, they have a tendency to become permanent.
- ❑ Extension cords are fire hazards because they are typically overloaded.
- ❑ The wires in extension cords are often not rated for their applied loads.
- ❑ These cords are trip hazards.