Chapter 6
Physical Hazards

OVERVIEW

Physical hazards include mechanical, electrical, heat, sound and radiation hazards that may occur in physics laboratory activities as well as a variety of other science activities. Hazards in each of these categories have the potential to cause injuries (or, in some extreme cases, even death), but by taking general precautions, such as using appropriate protective equipment and emphasizing routine safety, physical hazards can be easily minimized.

MECHANICAL HAZARDS

Mechanical hazards rarely exist in a well-maintained laboratory where equipment is commercially produced, approved and in good working order. In general, safety can be increased by ensuring that equipment is well-maintained, that all equipment is turned off before leaving the area for any reason, and that students use equipment only with teacher supervision. In addition, there are some risks and safety measures to keep in mind when using specific kinds of equipment or performing specific kinds of activities.

Rotating Machinery

Machinery with rotating parts can catch loose clothing, hands or hair, potentially causing serious injuries. Uncovered parts may also fly off, creating additional risk, especially for eye injuries. To minimize risks:

- ensure rotating shafts, belts and pulleys are covered by guards, lids or covers
- check devices attached to a rotor before use to ensure that they are tightly fastened
- wear (and have students wear) eye protection when using uncovered, rapidly rotating parts, as in the demonstration of centripetal force and circular or periodic motion
- have students stand back as much as possible.

Tools

Careless use of tools or use of tools in poor condition can cause injuries to the hands, eyes, head and limbs. To minimize risks:

- regularly check tools for defects or damage
- provide students with clear instructions on safe use before they have access to tools.

Cutting Tools (Scalpels, Razor Blades)

These instruments tend to be very sharp; careless use can quickly result in deep cuts on the fingers and hands. To minimize risks:

- use extreme caution in handling cutting tools, and ensure that students do the same
- replacement of blades is best done by teachers or technicians
- wear eye protection when using cutting tools in case blade breaks.

Magnets

Large, powerful magnets or electromagnets can attract other magnets or iron/nickel objects with surprising force, which can cause painful pinching of fingers or hands if caught between the two. To minimize risks:

- inform students of this hazard before such magnets are used.

Glassware

Any kind of glassware has the potential to break, thus creating the risk for cuts or spilled materials. To minimize risks:

- wear goggles for eye protection
- use heat-resistant glassware, which is less likely to crack when heated
- avoid using glass containers that are cracked or chipped, since they may crack further during the experiment
- clean up any broken glass immediately and dispose of in a special waste bin.

Projectile Launchers

Projectile launchers are often used in the study of motion—sometimes as demonstration devices and sometimes as equipment for student laboratories. Equipment used includes such devices as ballistic pendulums, commercially-available devices that launch plastic and steel balls, and teacher-constructed devices that launch a variety of materials. Decisions about devices to be used for this purpose—and who will use them and how—need to recognize factors that can affect potential risk. These factors include the power of the launcher, the nature of the projectile, and the maturity, skill and safety awareness of the user. It is also critically affected by the location and orientation of the launcher when the device is operated, relative to the location of students. These devices should never be oriented in a way that puts students in the line of fire.

Use of such equipment where potential injury is a concern, should only be allowed under the direct supervision of a teacher. To minimize risk:

- wear goggles for eye protection
- participants and spectators should be behind the line of fire
- avoid use of projectiles with sharp points
- ensure that misfiring does not place participants or spectators at risk.

Testing Structural Design to Failure

Studies of the physics of design technology frequently include activities in designing, constructing, and testing models for strength and/or efficiency of performance. Such testing, particularly for strength, often requires stress-to-failure determination, which may require some precautions.

To minimize risks:

- assess all inherent risks of testing to determine necessary precautionary measures
- wear goggles for eye protection
- minimize height at which testing is done on collapsing structures
- use of heavy weights should be closely supervised.

ELECTRICAL HAZARDS

The two major risks related to electricity are electrical shock and fire. Some specific hazards and precautions are described below.

Faulty Wiring

Loose or broken connections or frayed connecting cords may create a short circuit. This can result from contact of the lead-in wires or internal connections in the equipment. Fire, electrical shock or equipment damage may result. To minimize risks:

- check external wiring of equipment before use
- verify normal function before making equipment available for student use.

Heavy-duty Usage of Lightweight Equipment

Equipment damage and overheating, and therefore fire, are always possible if equipment is in prolonged use at power ratings greater than for which the item was designed. To minimize risks:

- use equipment only as intended.

Electrical Equipment Near Water

Use of electrical equipment near water creates the potential for a shock hazard if water gets into the electrical system and a person makes contact with the water conducting current from the equipment. As well, there is potential for malfunction or failure of the equipment. To minimize risks:

- ensure equipment used near sinks or other water sources is properly insulated and grounded
- use ground-fault interrupter plugs where available
- switch off current at the wall outlet or unplug immediately if water gets into the electrical equipment, and do not use again until completely dry.

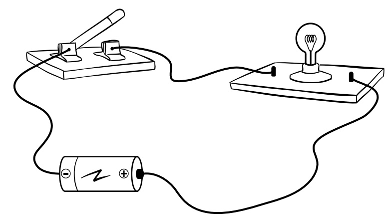
Electrical Equipment Near Flammable Liquids

The rotor of an electric motor generates sparks as it rotates past the brushes, which can ignite flammable vapours under poorly-ventilated conditions. To minimize risks:

- ensure that electrical equipment is used only in properly-ventilated areas, away from flammable liquids.

Shorting Dry Cell Circuits

Short circuits in devices not protected by a fuse can lead to overheating and to risk of fire or injury. Completing a circuit between terminals of a dry cell or dry cells without adding any resistance in the form of a bulb or other electrical device, will create such risks.



Contact with overheated wires can lead to skin burns or cause a fire if the wires are near flammable materials. Severe shorts can also cause dry cells to melt, give off toxic fumes and possibly explode. To minimize risks:

- ensure a circuit has at least one source of resistance; e.g., bulb, electric motor
- connect the battery/batteries last into a circuit if an open switch is not included.

Spark Timers

Spark timers are sometimes used in the study of motion in senior high school physics. This equipment uses a voltage surge to transfer carbon dots onto a ticker tape or paper sheet to mark the location of an object at preset time intervals. Spark timers that use ticker tape pose no significant hazard but spark timers attached to air tables do, since they use larger sheets of carbon paper that can transmit a minor electric shock to anyone who touches it. The shock itself is not the danger but the reaction to it can create unwanted hazards such as an elbow to the face of a by-stander. To minimize risk, warn students of the potential hazard.

High Voltage Equipment

Some student-wired laboratory set-ups and teacher-made demonstration equipment have the potential to deliver a high voltage discharge. Common risks include the following:

- capacitors that build up and store current can discharge on contact, generating a powerful shock in the process
- polarized capacitors can explode if incorrectly connected into a circuit
- tesla coils can cause severe skin burns
- electrostatic generators, particularly the Van de Graaf, can cause serious shocks if students join hands
- isolation transformers that use 120V AC current can be fatal since only one wire needs to be touched.

To minimize risks:
- ensure high voltage equipment is handled with extreme care
- ensure any use of such equipment is under the direct supervision and guidance of a qualified person
- ensure the equipment is in good working order before using it in the classroom.

HEAT HAZARDS

Heating devices create hazards of fire and injury. The potential risks posed by these devices vary with the heating device used and the way in which it is used. The analysis below identifies the pros and cons of using different devices and suggests procedures for minimizing risk.

In general, to reduce the risk of burns, students should:
- wear heat resistant gloves when handling heated objects or containers
- where possible, use test tube holders or tongs to handle hot equipment and containers
- never reach over an exposed flame or heat source
- use heat-resistance glassware for heating substances to prevent cracking and spilling of hot contents
- allow ample time for heated objects to cool before touching them.

Additional precautions for specific heat sources are listed below.

Bunsen Burners

Bunsen burners provide a direct and very efficient source of heat for laboratory purposes. However, there is a risk of burns particularly to student fingers and hands. As well, if the burner is used to heat water or a solution, the rapid heating can cause hot liquid to spurt out as it reaches its boiling point. To minimize risks:
- use Bunsen burners only if the activity requires high heat and if the maturity of the students is sufficient (in general, Bunsen burners would not be the preferred source of heat in elementary school and might also be avoided in junior high school)
- provide students with training on the use of Bunsen burners, particularly the routine of lighting and regulating flame intensity
- point the tube mouth away from anyone nearby when using Bunsen burners to heat a solution or water in a test tube
- do not use Bunsen burners or alcohol burners if flammable liquids are being used anywhere in the laboratory
- supervise students closely at all times during use.

Alcohol burners

Use of alcohol burners creates a significant burn hazard especially if there is any risk of the burner falling and breaking while it is lit or if it is turned upside down. The use of hot plates in place of alcohol burners is thus recommended as it creates a lower risk for students. Given the risks associated with use of alcohol burners, the National Science Teachers Association (NSTA) has taken a similar position with a recommendation that they should no longer be used in the science classroom or laboratory.

If alcohol burners are used, the following steps can be taken to minimize risks:

- use burners that are leak proof; i.e., do not leak if turned upside down
- supervise students closely during use
- avoid moving alcohol burners while lit
- never place burners on sloping surfaces
- place the burner well away from the edge of the table or counter on which it is set.

Hot plates

Electric hot plates with thermostatic controls provide a safer, controllable and reliable source of heat that meets the needs of science courses. However, they can still cause burns to skin. In addition, coiled hot plates, which might still be in use in some schools, have greater potential to cause burns because of the exposed coils. To minimize risks:

- ensure hot plates, as well as the heated materials and containers, are handled with care using proper techniques
- avoid coiled hot plates if possible, and take extra care if they must be used.

Primus Cartridge Burners

These also have a significant burn hazard associated with their use, much like that of the Bunsen and the alcohol burner. One major drawback of this heat source is the inability to control the air supply to the flame, thus the heat intensity of the flame is high (flame blue in colour) regardless of the size of the flame. Butane cartridges tend to be narrow and uniform in diameter and thus must be stabilized when in use. For these reasons, butane cartridges are not a good choice of heating at any grade level. To minimize risks:

- supervise students closely during use
- stabilize the cartridge while in use.

Butane Burners

These burners are relatively easy to use and function much like a Bunsen burner. They have separate adjustments for gas and for air. One drawback to their use is that the gas cartridges are not rechargeable and must be replaced once the gas is used up, making them more expensive to use than Bunsen burners.

Candles

Candles provide low intensity heat and thus are limited in their usefulness. However, they can be a good source of heat for activities where low intensity is required. The main problem with candles is their instability that can lead to tipping. To minimize risk:

- secure the candle firmly to a base to prevent tipping. For example, impaling the bottom of the candle onto a nail protruding from a board base is effective. Setting the candle into a small amount of melted wax that then solidifies is generally not adequate.

ROCKETRY HAZARDS

Rockets are devices containing combustible propellants that produce thrust by expelling hot gases. Depending on their physical size and the size of the motor(s), rockets are classified as model rockets or high powered (model) rockets. The guidelines and regulatory requirements that must be met for each of these are quite different.

Model Rockets

No special training or certification is required for building, installing and firing model rockets made of lightweight materials weighing 1.5 kg or less. Rockets in this category are restricted to types A to G motors producing up to a maximum of 160 Newton-seconds impulse, which in combination cannot exceed 320 Newton-seconds total impulse. For less powerful A to F motors, the person must be over the age of 12 years and be supervised by an adult. However, to purchase "G" level motors, a person must be 18 years old or older. Model rockets use premanufactured solid propellant rocket motors with black powder or composites as propellants.

Flying of model rockets should be done in accordance with the Canadian Rocketry Association safety code. These can be found at http://www.canadianrocketry.org. Also check with local authorities for bylaws regulating the firing of such rockets. Currently, in Calgary, for example, bylaw 36/74 prohibits firing of rockets from park lands that includes green spaces, school and park reserves, city parks, as well as school yards. In Edmonton, a permit is required to launch model rockets from public-owned or controlled land, including any local park. Launching on private land does not require a permit as long as the rocket lands on the same private land.

Rocketry clubs and associations in Alberta that can be contacted for more information on rocketry include the Edmonton Rocketry Club, Calgary Rocketry Association, Lethbridge Rocketry Association, and the Cold Lake Rocketry Club.

High Powered (Model) Rockets

Rockets in this category have motors with an impulse over 160 Newton-seconds but not exceeding 40 960 N-s. Installing and firing such rockets is restricted to individuals over the age of 18, requires Canadian Association of Rocketry High Power certification and is restricted to approved launches. Transport Canada has set out requirements for launching high powered model rockets in Canada. These can be found at the Canadian Association of Rocketry Web site at http://www.canadianrocketry.org/.

The major inherent risks associated with firing rockets include possible burns and the potentially lethal impact of misguided rockets.

SOUND HAZARDS

Prolonged exposure to sound in excess of 85 decibels★ (dBA) causes cumulative damage to inner ear hair cells, which results in permanent loss of hearing at the specific frequencies to which the lost hair cells were sensitive. Such volumes might be created, for example, by loud music at school dances or by large generators in mechanical rooms. By contrast, high impact noise causes eardrum perforation. Such noise is generated by pneumatic tools such as jack hammers. The eardrum perforations will heal, but each time this happens scar tissue builds up on the eardrum and makes it less sensitive to sound waves. Any equipment or instruments generating significant sound should be monitored for loudness to ensure they do not exceed allowable occupational exposure limits set out in the *Occupational Health and Safety Code*.

★**Note**: A dBA is a measure of sound level in decibels using a reference sound pressure of 20 micropascals when measured on the “A” weighting network of a sound level meter.

RADIATION HAZARDS

Radiation is an insidious hazard associated with the decay of radioactive materials such as isotopes of uranium and thorium, as well as emissions from electronic equipment or other sources. Radiation is the emission of energy in either particulate or electromagnetic form and is generally classified into two distinct categories, ionizing and nonionizing.

Ionizing Radiation

Ionizing radiation has the potential to damage human tissue by breaking chemical bonds, removing electrons from atoms, or even breaking up the nucleus of atoms. It can affect the cells of the body, increasing risk of harmful genetic mutations, cancer, or, at worst, massive tissue damage leading to death within a few weeks. For this reason, possession and use of materials that emit such radiation is tightly controlled by the Atomic Energy Control Board (AECB) through the enforcement of several sets of regulations.

It should be noted that there is no readily-applicable standard specifying what amount of radiation exposure is safe. Perceptions range from zero tolerance to acceptable exemption levels set out in Schedule 1 of the Nuclear Substances and Radiation Devices Regulations for a variety of radioactive substances. These exemption levels, given in becquerels, do not require licensing as long as the possession limit of such sealed sources does not exceed 10 in any one calendar year.

In general, the level of radioactivity in materials considered acceptable for senior high school activities is so small that it approaches the level of normal background radiation. Such low levels do not require special licensing from the AECB, since potential health risks are minimal. These low-level sources are readily available through science supply companies. These have radioactivity levels measured in microcuries and can generally be disposed of via the local landfill. One should check with the district office to ensure this is the case. Furthermore, no elaborate safety equipment or protective measures are necessary.

Radioactive decay rates are given in curies or in the International System of Units in becquerels. A curie (Ci) is defined as 37 billion disintegrations per second as measured in 1 gram of radium. A becquerel equals one disintegration per second.

Special handling and shielding of radioactive materials is required in instances where activity levels exceed the exemption quantities set out in Schedule 1 of the Nuclear Substances and Radiation Devices Regulations. Materials that have such high levels of radioactivity are not recommended for school use. See http://www.nuclearsafety.gc.ca/eng/regulatory_information/Regulations/index.cfm for more information on these regulations and exemption limits in Schedule 1.

Radioactive materials available for purchase come in both sealed and unsealed containers. Sealed containers have the radioactive material permanently embedded within a metal, plastic or other medium. Such sources are easier to handle and are generally safer to use than the unsealed sources of the same material. Sealed sources in license-exempt quantities are also readily disposable.

The term “ionizing” radiation refers to radiation in several forms:

- alpha particles
- beta particles
- gamma rays
- ultraviolet radiation, particularly at higher frequencies.

Each of these forms of radiation has sufficient energy to break chemical bonds and damage human tissue. Potential harm is proportional to the energy absorbed which in turn is affected by the amount of exposure.

Although alpha particles can be stopped by a sheet of paper and beta particles by a layer of clothing, both are much more hazardous if ingested or inhaled. On the other hand, both gamma and x-rays easily pass through the human body. Lead shielding is necessary to protect against such rays.

Cathode ray tubes (CRTs) do not normally pose a radiation risk but can emit x-rays when a current is present and there is a potential of at least 5000 volts. To produce an appreciable x-ray beam requires 10 000 volts or more.

Protection from Ionizing Radiation

To minimize the potential hazards of ionizing radiation, consider the following precautions that limit exposure to the radioactive material.

- Use low-level radioactive material with emissions in millicuries.
- Keep the time for potential exposure to a minimum.
- Stay as far from the radiation source as possible. As a rule, if the distance is doubled, exposure is deduced by a factor of four.
- Monitor radiation levels throughout time of exposure with the use of a Geiger counter.
- Store in a suitably shielded container; e.g., a lead storage pot in a properly marked cabinet not frequently used by people.

Nonionizing Radiation

Radiation that has enough energy to move atoms in a molecule around or cause them to vibrate, but not enough to change them chemically, is referred to as nonionizing radiation. Examples of this kind of radiation are sound waves, visible light rays, lower frequency ultraviolet rays and microwaves.

Nonionizing radiation increases kinetic energy of molecules in body tissue, which leads to heat production. When short wavelength radiation, such as ultraviolet rays, is absorbed by the skin or eyes at a high enough intensity or for a long enough time, the result can be sunburn and painful “welder’s flash” burns of the eye. Prolonged or chronic exposure to ultraviolet radiation may also lead to premature skin aging. At sufficiently high intensities, nonionizing radiation can disrupt essential physiological processes. However, in normal school laboratory practices, where low intensity radiation sources are used and exposure is minimized, levels will be well below specified limits and it is generally not necessary to measure actual field strengths.

Protection from Nonionizing Radiation

The best way to minimize the potential hazards of nonionizing radiation is to limit exposure to radiation sources by taking precautions such as the following.

- Keep the time for potential exposure to a minimum.
- Stay as far from the radiation source as possible (note that this is not the case with laser beams, which do not significantly change in intensity within the space of a typical school laboratory).
- Use appropriate shielding or protection, such as UV goggles or protective gloves.
- Never look directly into a laser beam, ultraviolet radiation source or bright light.
- Instruct students in proper operating and handling procedures, and ensure that they follow these procedures.

Potentially Hazardous Sources of Nonionizing Radiation

Ultraviolet radiation

Ultraviolet rays are high-energy rays that can produce skin burns and “welders flash burns” of the eye with enough exposure and light intensity. To reduce these risks:

- minimize skin exposure
- never look directly at a source of ultraviolet rays without appropriate eye protection.

Potential sources of ultraviolet rays include lasers, stethoscopes, microwave ovens, UV bulbs, welders, fluorescent bulbs, gas discharge tubes and burning magnesium ribbon.

Visible light and lasers

The direct or reflected viewing of any intense visible light source—electric arcs, burning magnesium ribbon, the Sun, or even collimated or focused beams from ordinary tungsten lights—can cause retinal damage. For example, looking at the sun requires the use of a solar filter equivalent to that of a welding mask.

The visible beam of light from a laser is focused by the lens of the eye and can cause severe retinal damage with very brief exposure if the laser is of sufficient power. For this reason, the Canadian Radiation Emitting Devices Regulation specifies that demonstration lasers for educational institutions be limited to 1 milliwatt beam power and be within the wavelength range of visible light (400 to 780 nanometres). For lasers meeting these criteria, the normal blink response time of 0.25 seconds is sufficient to prevent retinal damage. To further reduce risks:

- do not allow students to use lasers without close supervision
- use lasers in a well-lit room so that the pupils of the eye are small
- position lasers so that the beam cannot enter the eyes directly or by reflection.

Stroboscopes
Rhythmical pulses of light, especially in the range of 3 to 7 Hertz, can cause unpleasant or dangerous physiological effects in some people, including nausea and epileptic seizures. To minimize these risks:

- avoid the range of 3 to 7 Hertz
- warn students of potential effects and monitor them closely for unusual behaviour or onset of nausea during use of stroboscopes
- excuse students who know that flashing light has a negative effect on them.

Microwaves
All microwave ovens produced since 1971 are covered by a federal radiation standard that assures such ovens are safe. This standard limits leakage of microwaves to values well below the level at which heating or burning of human tissue would occur, even at distances as close as 5 cm.