Physics Laboratory Safety Manual

Georgia Gwinnett College

Introduction

Balancing Creativity and Safety: Experimental physics motivates teachers and students to create new techniques and apparatus and to use them to demonstrate both old and new ideas. It is impossible, therefore, to anticipate all of the specific hazards that might arise in the study of physics. While it is not desirable to eliminate creativity in the interest of safety, teachers should temper their creativity with a constant alertness to potential dangers. Common sense can go a long way toward providing a safe environment. This manual provides both general and specific rules for those activities frequently performed in the physics classroom.

Physics Laboratories Are Safe When:

- Activities are selected and planned with student safety in mind.
- Hazards are anticipated and cautions taken to ensure proper functioning of equipment.
- Students are instructed in the appropriate use of equipment.
- Protective equipment is available and used as necessary.

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Mechanical Hazards

A. Exposed Belts: Exposed belts and pulleys must be covered with a shield. This prevents the hazard of broken belts, and of fingers or clothing being caught between belts and pulleys.

B. Falling Masses: Heavy masses may be used in experiments involving Atwood's machine, free fall, Newton's laws, and momentum. Warning should be given to students to prevent hands and feet from being caught between a moving heavy mass and floor or table surfaces. Students may not anticipate how difficult it is move or support a lead brick or kilogram mass.

C. High-speed Rotation: Rotators are sometimes used to demonstrate centripetal force, circular motion, and sound phenomena. Any device attached to a rotator should be fastened securely and checked for tightness frequently. Observers should avoid contact with moving accessories such as toothed wheels, siren discs, etc. Loose clothing and long hair should be kept away from moving parts, and observers should not be in the plane of rotation. The use of safety goggles should be considered in student laboratories investigating centripetal force. Extremely high-speed rotation should be avoided when possible. High speeds may cause some objects to fly apart unexpectedly. A strobe light is sometimes used to illuminate a rotating object, making the object appear to be at rest. If the object is a fan blade, a toothed wheel, or anything else with sharp edges, there is danger of injury from touching or inserting an object into the apparently stationary object. Students should be alerted to this danger.

D. Magnets: Large permanent magnets and electromagnets may attract opposite poles or steel objects with unanticipated force. Students should be warned of the potential risk of pinching their hands between object and the magnet. In addition, exposed terminals on electromagnets should be insulated to prevent electric shock hazards.

E. Power Tools: It may be necessary for students constructing apparatus for physics experiments to use various power tools contained in a wood or metal shop. In these situations the machine shop personnel should be consulted for proper safety precautions necessary for each tool or machine.

F. Projectiles: In demonstrating the flight of any projectile, students should be kept clear of the path and impact area. The teacher should always pretest the projectile to determine the path it will follow and its range as well as the amount of variability to be expected. Sharp-pointed objects should not be used as projectiles. Use of safety goggles should be considered. A simple mechanical launcher (e.g., compressed spring, compressed air, stretched elastic) should be used. It should only be “loaded” at the specific time a flight is to be observed.

G. Springs: Stretched or compressed springs contain mechanical potential energy. A stretched spring, unexpectedly released, can pinch fingers. A compressed spring, when suddenly released, can send an object at high velocity toward an observer. Care should be taken to avoid unexpected release of the spring's energy when working with dynamics carts, spring-type simple harmonic oscillators, and springs used in wave demonstrations.

Electrical Hazards

A. Physiological Effects

1. Body Resistance: Students must be warned of the high death potential present even when the voltage is low. The severity of an electrical shock depends primarily on the amount of current to which a person is exposed. Since the current is related to the resistance and voltage, these two factors, as well as the part of the body involved and the duration of the contact, determine the extent of injuries to the victim. If the skin is wet or the surface broken, the resistance drops off rapidly, permitting the current to flow readily through the bloodstream and body tissues. *See chart below for relative hazards of electric shock.*

Mode of Electric Contact	R (Ω)	I (mA)
one dry finger on each electrode	100,000	1.1
one wet finger on each electrode	40,000	2.8
one salt/wet finger on each electrode	16,000	6.8
tight grip on each electrode	1,200	92.0

2. Current-Resistance Relationship: Ohm's law indicates that the amount of current in *amperes* flowing in a circuit varies directly with the electrical potential applied in *volts* (V) and varies inversely with the resistance (R) in *ohms*:

$$\mathbf{I} = \frac{\mathbf{V}}{\mathbf{R}}$$

Thus, one can calculate the expected current in a given situation. Example: Let R for a damp hand = 1,000 ohms. If an electrical potential of 110 volts is applied across the hand, the current would be:

$$\mathbf{I} = \frac{\mathbf{110\ V}}{\mathbf{1000\ \Omega}} = \mathbf{0.11\ A} = \mathbf{110\ mA}$$

The table below illustrates how the various current values affect human beings. The readings are approximate and vary among individuals. In view of the information below, it would be sound practice never to receive an electrical shock under any circumstances if it can be avoided.

Current (mA) AC (60 Hz)	Current (mA) DC	Effect
1-3	5	mild perception
6-9	70	paralysis, inability to let go
25	80	danger to life from heart and respiratory failure
100	100	fibrillation, death

3. Burns: Many electrical devices become quite hot while in use. In addition, “shorted” dry cells and batteries can produce very high temperatures. Students should never grasp a recently operated device or wiring without first checking for excess heat.

B. Electrical Apparatus

1. Batteries: A battery is an unregulated source of current capable of producing large currents when resistance is low. When short-circuited, connecting wires can become very hot, raising the risk of burns. Short-circuited mercury batteries may even explode. Chemical leakage from batteries is a potential hazard, especially in the case of wet cells that contain caustic chemicals such as sulfuric acid. Certain types of batteries are rechargeable while others are not. Carbon-zinc and nickel-cadmium type batteries can be recharged. Do not, however, attempt to recharge a completely dead carbon-zinc battery, a leaking or corroded battery, or any battery that carries a warning against recharging. Such batteries can cause damage to the charger and may explode, causing personal injury. Lead-acid batteries can be recharged but produce explosive hydrogen gas during the process. They should only be recharged in a well-ventilated area with an appropriate charger.

2. Capacitors: Capacitors are used to store electric charge. They may remain charged for long periods after power is turned off, and they therefore pose a serious shock/burn hazard. Before working on any circuit containing a capacitor, make sure that it is discharged by shorting its terminals with an insulated wire or screwdriver. Oil-filled capacitors may sometimes recharge themselves and should be kept shorted when not in use. Oil from older capacitors may be contaminated with dangerous PCBs. When installing electrolytic-type capacitors in a circuit, proper polarity rules must be followed (negative to negative and positive to positive). Improper connection can result in an explosion. Be on the lookout for capacitors in any apparatus with high voltage components such as oscilloscopes, TV sets, lasers, computers, and power supplies. Electrostatic generators and Leyden Jars are also capacitors and can be a source of unexpected shock.

3. Circuit Loads: Most laboratory electrical circuits have a maximum power rating of 1,500 watts (if fuses are 15 amp) or 2,000 watts (if fuses are 20 amp). The total power load on a circuit should not exceed these values. The total load is the sum of the power ratings of all apparatus plugged into that circuit. The individual power rating is usually found printed on a plate somewhere on the apparatus.

4. Electrostatic Generators: Electrostatic generators used in demonstrations of static electricity produce high voltages (about 105 volts) with very low currents. The danger of these generators depends on their size and capacity to produce enough current to be dangerous. In many cases the shock from such devices is very quick and not harmful. The startling effect, however, can be detrimental to persons with heart conditions. In general, experiments that use human subjects to demonstrate the effect of electrical shock should not be attempted due to the large variation in physical and physiological factors. Leyden jars -- which can be charged with electrostatic generators -- are especially dangerous because of their capacity to store a charge for long periods of time. An accidental discharge through a person can be avoided by properly shorting the devices after use.

5. Extension Cords: Use extension cords only when there is no convenient way to connect equipment directly to a receptacle. If an extension cord must be used, it should be checked for damage, proper grounding, and electrical capacity. An extension cord should be marked with its capacity in amperes and watts and the total load should not exceed these values. If the cord is unmarked, assume that it is 9 amperes or 1,125 watts. If an extension cord becomes very warm to the touch, it should be disconnected and checked for proper size. In general, science laboratories should be equipped with sufficient receptacles to minimize extension cord use. *(See Circuit Loads)*

6. Fuses/Circuit Breakers: Replace blown equipment fuses with fuses of the same amperage. Replace fuses with the equipment unplugged. Failure to use the correct fuse can cause damage to equipment and overheating. Frequent blowing of circuit fuses or tripping of circuit breakers usually indicates that the circuit is overloaded or a short exists. Circuit breakers and fuses that are tripped or blown should be turned on or replaced only after the cause of the short or overload is removed from the circuit.

7. Grounding. Use grounded 3-prong plugs when available. If the outlet is 2-prong, use an adapter and secure the ground wire to the cover-plate screw on the outlet. Grounding is particularly important for the light sources used with ripple tanks since these lights are suspended above the water in the tanks. Any apparatus with a metallic case or exposed metal parts should be checked to make sure that the case is grounded. Such ungrounded appliances should be retrofitted with a ground wire and three-pronged plug. The use of ground-fault interrupters should be considered.

8. Power Cords: Any power cord should be inspected periodically and replaced immediately if frayed or damaged. Apparatus should be located to keep power cords away from student traffic paths. When removing the cord from an outlet, the plug should be pulled, not the power cord. Wet hands and floors present a hazard when connecting or disconnecting electrical apparatus.

Vacuum and Pressure Hazards

A. Vacuums

1. Suitable Containers: Many popular physics demonstrations utilize a small vacuum pump to evacuate a chamber such as a bell jar, a coin-feather tube, or a collapsing metal can. Under no circumstances should a standard thin-walled, flat-bottom jar be evacuated because of the likelihood of implosion. If students are to be allowed to pump out a well-designed chamber, make sure it is firmly mounted so it cannot tip over and implode when under vacuum. Any large evacuated chamber should be equipped with a screen shield to help provide protection following an implosion. Such implosions can result from long-term stresses in glass or may result from thermal effects if heating occurs without opportunity to expand. On small chambers where a screen is inconvenient or undesirable, the walls should be wrapped with tape to reduce the flying glass following an implosion. When bell jars are used in demonstrations, remind students that they are specifically designed to withstand atmospheric pressure, and that one should never pump on a conventional container. Full face shields should be worn whenever working with a system which could conceivably implode or explode.

2. Tubes and Implosions: Vacuum tubes, especially large ones, present a safety hazard if the tube breaks. Flying glass and electrodes can travel great distances when a tube implodes. This is a particular danger when tubes such as a cathode ray tube, a TV picture tube, or a Crookes tube are used in a demonstration or experiment that removes them from a protective housing. Under these conditions, safety goggles or shields should be worn by all observers. When an inoperable tube is to be discarded, it should be covered with a heavy canvas cloth and broken by striking the rear of the tube with a hammer. The broken tube should then be carefully disposed of.

3. Vacuum Pumps: Vacuum pumps equipped with belts and pulleys must have the belt and pulley system shielded to prevent clothing and hands from getting caught. This shield should also prevent injury from broken belts striking nearby observers. Students should be warned to be careful of the hot motor and other parts after operation.

B. Pressures

1. Compressed Air: Students in laboratories equipped with compressed air at lab stations or lecture tables should be warned of the danger of blowing dust or other debris into the eyes accidentally with compressed air. High pressure air directed at glassware for drying purposes can provide enough force to knock containers from the hands. The flow of air should be adjusted first to prevent this hazard.

2. Gas Bottles: One of the most common items to be found in any science laboratory is a container of compressed gas. The pressures in gas containers may vary from atmospheric pressure to 10,000 psi, with most tanks essentially designed as shipping containers (with a minimum weight and wall thickness). A container of gas should not be kept around if the gas and its characteristics are unknown. Any gas cylinder should be anchored to the wall or mounted in a well-designed holder. When a gas cylinder tips over and is damaged, it can become a high powered, massive rocket capable of going through many walls and people. Large tanks should be carefully moved in a wheeled cart with a tie-down chain safety cap in place, and should never be pulled by the threaded cap or rolled on the floor. Almost all cylinders have internal pressures greatly

exceeding what is needed for an experimental apparatus. Small laboratory lecture bottles may be controlled with a needle valve as long as they are not discharging into a system allowing pressure to build up to bottle pressure. Large cylinders should be controlled by a single or double stage regulator of a suitable pressure range. When a regulator is being used, the main cylinder valve should still be closed each time an experiment is shut down since regulators are not made to be reliable shut-off valves. If compressed gas is used as a propellant, students should remain clear of the gas exhaust and propelled objects. (*See Projectiles*)

3. Generating Gases: A pressure relief safety valve of some type should be an integral part of any system constructed to generate gas or steam.

Heat and Cryogenic Hazards

A. Heat

1. Heating Procedures: Often it is necessary to heat liquids and solids in physics experiments and demonstrations. It is safer to use water baths and hot plates than to heat directly with open flames such as with Bunsen burners. Below are guidelines for heating and handling hot objects.

   - Any glass apparatus that is to be heated should be made of Pyrex® brand or Kimax® brand. It must be free of chips and cracks.
   - Gas burners should be kept away from the body at all times. The pressure of the gas should be adjusted to allow proper ignition. Too high a pressure tends to blow the flame out. Do not allow gas to accumulate if ignition is delayed for any reason.
   - Never heat a closed container if there is no means of pressure relief.
   - Many substances, especially glass, remain hot for a long time after they are removed from the heat source. Always check objects by bringing the back of the hand near them before attempting to pick them up without tongs, hot pads, or gloves.
   - Never set hot glassware on cold surfaces or in any other way change its temperature suddenly, because uneven contraction may cause breakage.

2. Steam: Live steam is generated in experiments to determine coefficients of thermal expansion and the heat of vaporization of water. Potential hazards can be avoided by following a few simple guidelines.

   - Produce steam only in a container with a direct open line to the atmosphere.
   - Instruct students that steam has a very high heat capacity and is invisible (the visible “vapor” is already condensed droplets). Caution them not to aim steam outlets at their own skin or at other students.
   - Production of steam under pressures higher than atmospheric pressure should be limited to teacher demonstrations. The teacher should take necessary precautions associated with the higher temperatures of this steam and the explosion hazards.

3. Thermometers: Thermometers present several possible hazards in the laboratory related to breakage and spillage of mercury. Following the guidelines below will minimize the hazards.

   - Use alcohol thermometers in place of mercury thermometers to eliminate the hazards associated with mercury spills.
   - Consider the range of temperatures to be measured when choosing a thermometer. If heated beyond its capacity, a thermometer may break.
   - Mount a thermometer in a safety rubber stopper whenever possible. When using other types of stoppers, use a lubricant on the glass or a split stopper. If necessary to free the thermometer from the stopper, split the stopper with a single-edge razor blade. Teachers should ensure that students use the thermometer in such a way that the equipment does not become unstable.
   - If a mercury thermometer is used, be alert to the potentially serious hazard of a mercury spill. Instruct students that they must report any such breakage immediately and remove any source of heat which is present. Each laboratory where mercury is used should be equipped with a mercury-spill kit. Follow the directions that come with the kits.

4. Burns: A common cause of student injury is a burn from recently heated glassware. To avoid such burns, check the glassware by bringing the back of the hand close before attempting to pick it up. In case of an accidental burn, administer first aid and then seek additional health care if needed.

5. Asbestos: Many older hot plates, hair dryers and other heating elements contain wires or parts insulated with asbestos. Since the dangers of asbestos are well documented, all efforts should be made to replace this equipment with non-asbestos-insulated apparatus.

B. Cryogenics: Dry ice (solid carbon dioxide) is used in some low-friction pucks, as a source of carbon dioxide gas, and as a cooling agent. A mixture of dry ice and alcohol or liquid nitrogen might also be used as low-temperature baths. The temperatures of these materials are low enough to cause tissue damage from a cryogenic “burn.” This is not likely to occur if contact is brief, because the vapor layer formed between the cryogen and the tissue is not a good conductor of heat. Follow the guidelines below to avoid a dry ice “burn.”

- Flush the skin that came into contact with the dry ice with water. Water should always be readily available during cryogenic experiments.
- In preparing a dry ice/alcohol mixture, pour the alcohol over the dry ice rather than dropping the dry ice into the alcohol to avoid spattering. When storing alcohol that has been used in a dry ice/alcohol mixture, the alcohol should be returned to room temperature to allow the escape of excess dissolved gas before placing in a closed container.
- When dry ice is used in a confined space, provide sufficient ventilation to eliminate the risk of asphyxiation. This risk is caused when the more dense carbon dioxide gas released produces an oxygen-deficient layer.
- Used to produce a special effect (such as fog in a drama production), dry ice may produce large amounts of carbon dioxide. Students and other teachers should be warned of this risk and informed about avoiding it.
- Cryogens should be kept in double-walled containers such as Thermos bottles or Dewars. Any fluid which gets between the walls at low temperatures may become trapped and vaporize at higher temperatures, building up pressure and exploding the container. The outer wall should be heavily wrapped to avoid this hazard.

Chemical Hazards in Physics

A. Carbon Dioxide: The use of dry ice in cryogenic experiments must be accompanied by precautions against production of an oxygen-deficient atmosphere. Carbon dioxide, which is more dense than air, easily collects in a non-ventilated area. (*See Cryogenics*)

B. Carbon Monoxide: Do not allow carbon monoxide from incomplete combustion to collect in a closed area. Always conduct demonstrations using small internal combustion engines under a vented hood or outdoors.

C. Explosives: Do not attempt to make explosive compounds such as those that might be used in model rocketry. Only factory-made, pre-loaded rocket engines should be used for this purpose.

D. Flammables: Do not use flammable substances near an open flame unless the purpose is to demonstrate flammability. Many flammables produce toxic fumes and should be burned only under a vented hood. Large containers of flammable liquids should be opened, and liquids transferred, in a room free from open flames or electrical arcs and, preferably, under a fume hood.

E. Mercury: Do not use mercury in the classroom. Use alternate equipment not requiring mercury in place of mercury. There are many reasons for this recommendation: The vapors from free mercury are cumulatively toxic. Mercury is absorbed through the skin. The vapors it forms are absorbed by inhalation. Complete clean up of any mercury spill, which is absolutely necessary, is difficult to accomplish. *NOTE:* As stated earlier, each laboratory where mercury is used should be equipped with a mercury-spill kit. Follow the directions that come with these commercially available kits.

F. Other Heavy Metals/Solder: Highly toxic cadmium oxide may be produced when silver solder containing cadmium is overheated. Some solders contain flux, which may produce noxious fumes. Use fume hoods when working with these materials.

Radiation Hazards

A. Infrared Radiation: Caution students that, beyond a limited exposure, infrared waves (heat waves) entering the eye can cause burns to the cells of the retina. Infrared lamps and the sun are concentrated sources of these waves.

- Follow manufacturer's instructions when using any infrared lamp.
- The sun should never be viewed directly, especially at times when its visible light is partially obscured. (The visible light triggers the body's natural defenses of avoidance and pupil constriction.) Lenses and sunglasses do not offer protection from this radiation. Safe viewing of the sun can be done by projecting an image of it through a very small hole onto a white piece of paper about one-half meter behind the hole.

B. Microwaves: A microwave apparatus is often used to demonstrate various wave behaviors of electromagnetic radiation. Microwave devices designed for school use have sufficiently low power to be free of radiation hazards when the manufacturer's instructions are followed. Microwave ovens that are in good working order and used properly do not pose any safety hazard in a classroom. Follow these guidelines:

- Check the apparatus for radiation leakage before use if there are any doubts about its safety.
- Inspect ovens periodically to ensure they are clean and the door, hinges, vision screen, seals, and locks are secure and working properly.
- Do not place metal objects in the heating cavity.
- Do not permit students to stand close to an oven during operation.

C. Radioisotopes: Radioisotopes produce biological injury (cell damage) resulting from their ionizing properties. Gamma rays and beta particles are hazardous both inside and outside the body. Alpha particles cannot penetrate skin and are not hazardous if kept outside the body. The use of license-exempt quantities, especially sealed sources, will create minimum hazard because of the small amount of radiation present. Safe handling requires these protective measures:

- Time - Minimize contact time with samples.
- Distance - Use tongs, forceps, etc., to avoid direct contact.
- Shielding - Use shielding appropriate for the radiations encountered.
- Storage - Store radioactive materials so that people are not in frequent close proximity to them and they are not damaged accidentally.

D. Ultraviolet Radiation: Ultraviolet light can be absorbed in the outer layers of the eye, producing an inflammation known as conjunctivitis. The effect usually appears several hours after exposure and, unless the exposure is severe, will disappear within several days. Sources of harmful ultraviolet light likely to be encountered in physics include mercury vapor lamps, electrical arcs (e.g., the carbon arc lamp), incandescent ultraviolet lamps, and the sun.

- Mercury vapor lamps and electric arcs should not be observed without elimination of their ultraviolet emissions.
- Plastic or glass sheets which transmit poorly in the ultraviolet region offer good protection for the viewer of these sources.

- Use black paper with caution because, while it absorbs well in the visible range, it may be highly reflective in the ultraviolet range.
- The sun should never be observed directly. (*See Infrared Radiation*)
- Incandescent ultraviolet lamps present a minimal danger from their ultraviolet emissions, as the energy of this radiation is very low. These bulbs, however, get extremely hot when in use and must be given plenty of time to cool before handling.

E. Visible Light (including Lasers): Intense sources of visible light are usually not hazardous due to the inability of the human eye to remain focused on an intense source. Infrared and ultraviolet radiation sometimes present along with visible light provides a greater hazard. (*See Laser Safety*)

F. X-ray Radiation: X-rays may be produced in any situation in which high-speed electrons strike a target. These conditions may exist in evacuated tubes where the accelerating voltages are in the range of 10,000 volts or more. Crookes tubes and other cold cathode discharge tubes are potential sources of X-rays in the classroom. (Spectrum tubes used to observe spectra of elements and compounds are not a source of X-rays if the tubes are in good condition because the enclosed gases prevent electrons from achieving high enough energies.) To minimize possible X-ray exposure, three rules should be observed by teachers and students:

- Minimize the voltages used to operate vacuum tubes.
- Maximize the distance between the tube and the observers.
- Minimize the time during which the tube is operated.

If any tube or apparatus is suspected of emitting X-rays, it should be checked for dangerous amounts of radiation. Commercial companies listed in the yellow pages should be able to provide this service.

Laser Safety

The laser produces an intense, highly directional beam of light that, if directed, reflected, or focused upon an object, is partially absorbed, raising the temperature of the surface and/or the interior of the object. Potentially, this can cause an alteration or deformation of the material. These properties can cause adverse biological effects in tissue. Photochemical effects are also a danger when the wavelength of the laser radiation is sufficiently short (i.e., in the ultraviolet or blue light region of the spectrum). Low-power lasers may emit levels of light that are not a hazard, or are no more hazardous than an electric light bulb. Some lasers concentrate visible light to an extent that retinal damage can occur in a very short time. Fortunately, these lasers are not often found in school science laboratories. Most lasers used in school laboratories are the continuous wave, low power (0.5 - 3.0 mW.), helium-neon lasers. The only optical danger is possible damage to the retina if a subject looks directly into the beam or non-diffused reflection. The diameter of the beam, the time of exposure, blink response time, and retina spot size all can affect the probability of injury. Since some of these lasers in this range are considered Class III lasers (see chart below), certain safety precautions are important to teach and use when working with lasers.

A. Biological Effects: The human body is vulnerable to the outputs of some lasers and can, under certain circumstances, incur damage to the eye and skin. The human eye is almost always more vulnerable to injury than human skin. In the near ultraviolet region and in the near-infrared region at certain wavelengths, the lens of the eye may be vulnerable to injury. Of greatest concern, however, is laser exposure in the retinal hazard region of the optical spectrum, approximately 400 nm (violet light) to 1400 nm (nearinfrared). Within this special region, collimated laser rays focus in a very tiny spot on the retina. This hazard only exists if the eye is focused at a distance; reflecting the laser light off diffuse surfaces also prevents the hazard. Higher levels of laser radiation would be necessary to cause injury. Since this ocular focusing effect does not apply to the skin, the skin is far less vulnerable to injury from these wavelengths. The light entering the eye from a collimated beam in the retinal hazard region is concentrated by a factor of 100,000 times when it strikes the retina.

B. Safety Standards: A system of laser hazard categories has been developed based on millions of hours of laboratory and industry laser use. Each laser is placed into one of at least four separate classes, or risk categories. The safety measures to reduce or eliminate accidents depend upon which class of laser is being used. See the chart below for laser risk classes and their hazards.

Class	Power Output (mW)	Hazard	Comments
I	<0.39	**inherently safe**	*Exempt lasers.* Considered incapable of producing damaging radiation and therefore exempt from control measures. Do not exceed maximum exposure levels.
II	<1.0	**low risk**	*Low-power lasers.* Hazardous if looked at continuously. May be viewed directly; avoid continuous intrabeam viewing. Emission limited to 1 mW for less than 0.25 seconds between 400 and 700 nm; hazards are prevented by aversion reflexes.
IIIa	<5.0	**low risk**	Limit up to five times that for Class II. Viewing by the unaided eye is safe, but the use of optical instruments may be hazardous. Requires control measures that prevent viewing of the direct beam.
IIIb	<500	**medium risk**	*Higher emission limit.* Direct viewing may be hazardous; but viewing by diffuse reflection is safe. Requires control measures that prevent viewing of the direct beam.
IV	>500	**high risk**	*High powered systems.* Emission limit higher still; even viewing by diffuse reflection may be hazardous. Skin injuries and fire hazard are also possible. Requires the use of controls that prevent exposure of the eye and skin to the direct and diffusely reflected beam.

C. Laser Guidelines: Lasers can be used safely through the use of suitable facilities, equipment, and well-trained personnel. Class II lasers require no special safety measures. However, as in the case of a movie projector, a person should not stare directly into the projection beam. Safety training is desirable for those working with Class III systems. Eyewear may be necessary if intra-beam viewing cannot be precluded. Operation within a marked, controlled area is also recommended. Finally, for Class IV lasers or laser systems, eye protectors are almost always required; facility interlocks and further safeguards provide additional protection. The following general guidelines for safe laser use in the classroom are excerpted from *Laser Fundamentals and Experiments*.

- Before operation, warn all individuals present of the potential hazard.
- In conspicuous locations inside and outside the work area and on doors giving access to the area, place hazardous warning signs indicating that a laser is in operation and may be hazardous.
- Do not at any time look into the primary beam of a laser.
- Do not aim the laser with the eye. Direct reflection can cause eye damage.
- Do not look at reflections of the beam. These, too, can cause retinal burns.
- Do not use sunglasses to protect the eyes. If laser safety goggles are used, be certain they are designed for use with the laser being used.
- Report any afterimage to a doctor, preferably an ophthalmologist who has had experience with retinal burns. Retinal damage is possible.
- Do not leave a laser unattended.
- View holograms only with a diverged laser beam. Be sure the diverging lens is firmly attached to the laser.
- Remove all watches and rings before changing or altering the experimental setup. Shiny jewelry can cause hazardous reflections.

- Practice good housekeeping in the lab to ensure that no device, tool, or other reflective material is left in the path of the beam.
- Before a laser operation, prepare a detailed operating procedure outlining operation.
- Whenever a laser is operated outside the visible range (such as a CO_2 laser), a warning device must be installed to indicate its operation.
- A key switch to lock the high voltage supply should be installed.
- Use the laser away from areas where the uninformed and curious might be attracted by its operation.
- Illuminate the area as brightly as possible to constrict the pupils of the observers.
- Set up the laser so that the beam path is not at normal eye level (i.e., so it is below 3 feet or above 6½ feet).
- Use shields to prevent strong reflections and the direct beam from going beyond the area needed for the demonstration or experiments.
- The target of the beam should be a diffuse material capable of absorbing the beam and reflection.
- Cover all exposed wiring and glass on the laser with a shield to prevent shock and contain any explosions of the laser materials. Be sure all non-energized parts of the equipment are grounded.

Rocketry

A. Local Regulations: Before beginning a model rocket program, check local regulations on the use of model rockets. Be sure also to check regulations about launch sites and fire codes in your area.

B. Model Rocketry Safety Code: Follow the guidelines for safe launching and recovery of model rockets outlined below.

- Construction - In making model rockets, use only lightweight materials such as paper, wood, plastic, and rubber; use no metal as structural parts.
- Engines - Use only pre-loaded, factory-made model rocket engines in the manner recommended by the manufacturer. Do not alter or attempt to reload the engines.
- Flying Conditions - Do not launch a rocket in high winds or near buildings, power lines, tall trees, low flying aircraft, or under any conditions that might endanger people or property, such as the threat of lightning.
- Jet Deflector - The launcher must have a jet deflector device to prevent the engine exhaust from hitting the ground directly.
- Launch Area - Always launch rockets from a cleared area that is free of any easy-to-burn materials; use non-flammable recovery wadding.
- Launch Rod - To prevent accidental eye injury, always place the launcher so the end of the rod is above eye level, or cap the end of the rod with the hand when approaching it. Never place head or body over the launching rod. When the launcher is not in use, always store it so that the launch rod is not in an upright position.
- Launch Safety - Do not let anyone approach a model rocket on a launcher until making sure that either the safety interlock key has been removed or the battery has been disconnected from the launcher.
- Launch Targets and Angle - Do not launch a rocket so its flight path will carry it against a target on the ground; never use an explosive warhead nor a payload that is intended to be flammable. The launching device must always be pointed within 30 degrees of vertical.
- Launching System - The system used to launch model rockets must be remotely controlled and electrically operated, and must contain a switch that will return to “off” when released. All persons should remain at least 10 feet from any rocket that is being launched.
- Power Lines - Never attempt to recover a rocket from a power line or other dangerous places.
- Pre-Launch Test - When conducting research activities with unproven designs or methods, try to determine their reliability through pre-launch tests. Conduct launching of unproven designs in complete isolation from persons not participating in the actual launching.
- Recovery - Always use a rocket system with model rockets that will return them safely to the ground so that they may be flown again.
- Stability - Check the stability of model rockets before their first flight, except when launching models of proven stability.
- Weight Limits - Model rockets must weigh no more than 453 grams (16 ozs.) at liftoff, and the engine must contain no more than 113 grams (4 ozs.) of propellant.

For further information about model rockets and model rocket safety, contact: Estes Rocket Industries, P.O. Box 227, Penrose, CO 81240