Safety in Academic Chemistry Laboratories

VOLUME 1

ACCIDENT PREVENTION FOR COLLEGE AND UNIVERSITY STUDENTS

7TH EDITION

A Publication of the American Chemical Society Joint Board–Council Committee on Chemical Safety

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American Chemical Society
Washington, DC

Foreword from the Chair

When the Committee on Chemical Safety of the American Chemical Society (ACS) published the first edition of *Safety in Academic Chemistry Laboratories* (*SACL*) almost 30 years ago, there was very little emphasis on teaching laboratory safety. During the intervening years, the distribution of the six prior editions approached a million copies. *SACL* is one of the most widely used laboratory safety guidance documents in print today. Although written as a guideline for safe practices in academic chemistry laboratories, its application is not limited to educational facilities. The information presented in this manual is adaptable to all laboratories and workplaces using chemicals, including research, analytical, quality control, clinical, and process development laboratories.

As we learn more about the hazards and risk of the chemicals in our laboratories, we must share this knowledge with our colleagues and our students. The ACS Division of Chemical Health and Safety disseminates current research and developments in its national meeting technical programs and through its journal, *Chemical Health and Safety*. Precollege science teachers have begun to include chemical safety in their classroom instruction. The Committee on Chemical Safety has prepared two companion publications to assist those involved in elementary and secondary school science education. Copies of *Safety in the Elementary (K–6) Science Classroom* and *Chemical Safety for Teachers and Their Supervisors: Grades 7–12* are available through the ACS Office of Society Services.

I am pleased to introduce the seventh edition of the committee's flagship publication and wish to thank the many individuals who generously contributed their time and wisdom to this and the previous editions. Their efforts have helped to make academic chemistry laboratories much safer places with fewer accidents and injuries. Jay Young has contributed to several editions of *SACL*; he was the major contributor and served as Editor of this edition. The comprehensiveness and lucidity of this volume are the direct result of his dedication and commitment. The Editor's Preface acknowledges those who contributed to the revisions and development of the seventh edition. The final draft was reviewed by Dan McDonald, Russ Phifer, and Rubye Torrey. Larry Funke coordinated the efforts of those ACS staff members involved in the production and distribution activities.

All comments are welcome. Please direct them to the Committee on Chemical Safety, American Chemical Society, 1155 16th St., NW, Washington, DC 20036.

Kenneth P. Fivizzani
Chair, ACS Committee on Chemical Safety
October 2002

Preface from the Editor

The first edition of this book was written in 1972 by members of the ACS Committee on Chemical Safety under the direction and urging of its chair, Howard H. Fawcett (now deceased). It was published as an 11-page, double-spaced, typed and mimeographed document. Since then, almost a million copies of the original and its five subsequent editions have been distributed. The objective has remained unchanged; however, the details have become more complex.

Our knowledge of chemical hazards has advanced; chemical safety has become an important part of both the precollege and the college and university undergraduate teaching curriculum. *Safety in Academic Chemistry Laboratories* is now published in three parts—*Safety in the Elementary (K–6) Science Classroom, Chemical Safety for Teachers and Their Supervisors: Grades 7–12,* and *Safety in Academic Chemistry Laboratories* (now in two volumes—this volume for students who work with chemicals in college and university laboratories, and a companion volume for faculty, graduate student teaching assistants, and administrators).

Younger students in the presecondary and secondary grades begin to learn by instruction. As students mature, their instruction is presented less passively, and they take a more active role in learning. By the time they reach the college or university level, students' active participation should be an essential part of the learning process. To reflect the active participation of the maturing student, we have added a subtitle, *Accident Prevention,* to this edition.

I wish to acknowledge the helpful suggestions and contributions of the members of the Joint Board–Council Committee on Chemical Safety, with particular thanks to Robert Alaimo, Charles Greenlief, Rubye Torrey, and George Wahl, members of the Revision Subcommittee, and to Eileen Segal, Russell Phifer, Stephen Sichak, Dan McDonald, and Bernard Blais.

Jay A. Young
Editor
October 2002

Disclaimer

The materials contained in this manual have been compiled by recognized authorities from sources believed to be reliable and to represent the best opinions on the subject. This manual is intended to serve only as a starting point for good practices and does not purport to specify minimal legal standards or to represent the policy of the American Chemical Society. No warranty, guarantee, or representation is made by the American Chemical Society as to the accuracy or sufficiency of the information contained herein, and the Society assumes no responsibility in connection therewith. This manual is intended to provide basic guidelines for accident prevention. Therefore, it cannot be assumed that all necessary warning and precautionary measures are contained in this document and that other or additional information or measures may not be required. Users of this manual should consult pertinent local, state, and federal laws and legal counsel prior to initiating any accident-prevention program.

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Introduction

The ACS Joint Board–Council Committee on Chemical Safety has prepared this

Occupational Safety and Health Act. However, accident prevention, not the regulations, is the essential component of all laboratory operations:

Doing things safely is not merely the right way to work —it is the *only* way.

1. Your Responsibility for Accident Prevention

Accident prevention is a collective responsibility that requires the full cooperation of everyone in the laboratory. Your safety is both your and your laboratory instructor's first concern. Everyone is responsible for accident prevention, especially you, the person actually carrying out the laboratory procedures. Accidents often result from

- an indifferent attitude,
- failure to use common sense, and
- failure to follow instructions, making a mistake.

You can be a victim of a mistake you have made. You can be a victim of a mistake some other student has made. If you are not doing it right, and a classmate points this out to you, be grateful—it could be that he or she has just saved your life. Conversely, if someone else is making a mistake, let him or her know. A safe laboratory is also your instructor's responsibility; report unsafe acts to him or her.

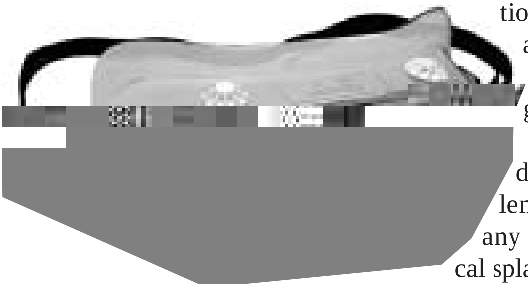
Become involved; participate in the practice of preventing accidents. Follow these general guidelines:

- Follow all safety instructions carefully.
- Never play tricks or indulge in horseplay in a chemical laboratory.
- Become thoroughly acquainted with the location and use of safety equipment and facilities such as exits, safety showers, and eyewash fountains.
- Before undertaking any laboratory work, become familiar with the hazards of the chemicals involved. Be sure you know and be sure that you follow the safety precautions that protect you and others from those hazards.
- Become familiar with the hazards of the apparatus and the operations involved. Learn what to do and what to avoid doing. Follow these safety precautions.

Personal Protection

Eye Protection

Everyone in the laboratory, including visitors, must wear chemical splash goggles (not safety glasses or spectacles) at all times, even when not performing a chemical operation. Normal prescription eyeglasses do not provide appropriate laboratory eye protection, although they may meet the U.S. Food and Drug Administration standards for impact resistance.[1] Never rely on such eyeglasses for protection in the laboratory.



The type of eye protection you need depends on the circumstances. Contact lenses cannot provide adequate protection in any environment in which an accidental chemical splash can reasonably be expected. Appropriate eye protection requires safety goggles such as those shown in the illustration. Wear safety goggles at all times in the laboratory whether or not contact lenses are worn.

When working at reduced pressure or when some other potential exists for dynamic reactions, implosions, or enthusiastic splashing, use appropriate laboratory bench

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[1] The impact-resistant standard test for prescription spectacles, not safety goggles, is described in 21 CFR (Code of Federal Regulations) 801.410(d)(2).

Laboratory Protocol

The chemistry laboratory is a place for serious learning and working. Horseplay cannot be tolerated. Variations in procedures, including changes in the chemicals to be used or in the amounts that will be used, may be dangerous. Ask your instructor before you make any changes. Alterations may be made only with the knowledge and approval of your instructor.

Laboratory Visitors

All laboratory visitors, no matter how brief their visit, should wear eye protection. Chemists and other scientists visiting a laboratory should observe safe behavior. Other laboratory visitors, such as friends and relatives, particularly children, may not

Distillations

Distillation is a common method of separation and purification used in laboratory and industrial operations. Potential dangers arise from pressure buildup, the use of flammable materials, initiation of an exothermic chain (runaway) reaction, and the necessity to use heat to vaporize the chemicals involved. Various apparatus designs are used to accomplish distillations at atmospheric pressure, under inert atmospheres, at reduced pressure (vacuum distillation), or by the addition of steam to the distillation mixture (steam distillation).

Careful design and construction of the distillation system are required to accomplish effective separation and to avoid leaks that can lead to fires or contamination of the work area. It is desirable to ensure smooth boiling during a distillation and to avoid bumping, which can knock the distillation apparatus apart or cause other damage. Stirring the distillation mixture (e.g., with a magnetic stirrer) is one way to prevent bumping.

Alternatively, boiling stones can be effective for distillations performed at atmospheric pressure. Use fresh boiling stones to boil a liquid without stirring. Do not add boiling stones or any other solid material to a liquid that is near or at its boiling point, because the addition is likely to cause the hot liquid to suddenly erupt and boil over. Instead of boiling stones, use a short glass tube that has one end closed. Before starting the distillation, place the tube in the liquid to be heated in an approximately vertical orientation, open-end down. If the distillation is stopped and it is necessary later to re-initiate the distillation, you will need a second glass tube, or you can remove the original glass tube, drain out its contents, and then put it back into the liquid for use again.

The source of heat is an important accident-prevention factor in the distillation process. You can evenly heat best by using a ceramic cavity heater, steam coils, hot water, a nonflammable liquid bath, or an electric heating mantle. Before using a heating mantle, inspect it for rips, tears, loosened seams, and severe distortions of the covering cloth. Do not use a mantle with any of these defects. Silicone oil or another suitable high-boiling oil also can be used for even heating on a hot plate.

Commonly available hot plates are not necessarily spark-proof; make sure they are so labeled. When distilling a flammable liquid, do not use a hot plate unless you are certain it is spark-proof. Sometimes a distillation will go awry. When this happens, it is often desirable to remove the heat source from underneath the distillation apparatus. Therefore, support the distillation apparatus separately from the heat source to facilitate its removal if necessary.

An additional thermometer may be inserted very near the center bottom of the distilling flask to warn of dangerous exothermic reactions. To prevent such reactions, do not heat the material above the temperature directed in the procedure you are following.

Never distill organic compounds or evaporate them to dryness unless they are known to be free of peroxides. Most ethers, including cyclic ethers, form dangerously explosive peroxides on exposure to air and light. Many alcohols, unsaturated hydrocarbons, and other reagents also can form peroxides. See “Organic Peroxides and Peroxide Formers” on page 24. See “Working with Reduced Pressure” on page 31 for a brief discussion on distilling under reduced pressure. See “Using Steam” on page 28 for a brief discussion on steam distillation.

Extractions

Extractions can present a hazard because of the potential buildup of pressure from a volatile solvent and an immiscible aqueous phase. Glass separatory funnels used in0 Tc9 funnels

Some toxic chemicals can be absorbed directly through intact skin. If that is the case, both the label and the Material Safety Data Sheet will warn of this hazard. For such chemicals, be sure to wear gloves that are impervious to the chemical; discard the gloves after use as directed by your instructor. Wash your hands thoroughly after you have discarded the gloves.

If you spill a chemical on your skin or clothing, wash it off immediately and thoroughly. Always wash your hands thoroughly before leaving the laboratory.

There is only one other way that you can be exposed to a toxic chemical: by breathing. We all breathe and therefore could sometimes inhale the vapors, dust, and mist in the air in the laboratory. You will be in the laboratory for only a few hours

- emergency and first aid procedures;

Flammable limits are approximate values[6] expressed as percentage by volume in air, usually at atmospheric pressure and ambient temperature. Note that as the temperature increases, the lower flammable limit decreases and the upper flammable limit increases; increases in pressure also cause a decrease in the lower flammable limit and an increase in the upper flammable limit.

Recommended extinguishing media. Some chemicals that are on fire (e.g., magnesium) will burn even more vigorously if water or carbon dioxide is used in an attempt to extinguish the fire.

First aid. Describes the procedures for emergency first aid. Be sure you can perform the first aid properly; otherwise, move away so a qualified person can provide the necessary help. Meanwhile, you can summon the ambulance, if necessary.

Health hazard data. This includes one or more of the following:

LD_{50} (lethal dose fifty). This is the lethal single dose (usually by ingestion) in milligrams of chemical per kilogram (mg/kg) of animal body weight of a chemical that is expected to kill 50% of a test animal population within a specified time.

LC_{50} (lethal concentration fifty). This is the concentration of a chemical in air expressed as ppm for gases and vapors or as milligrams of material per liter (mg/L) of air for dusts and mists expected to kill 50% of a test animal population within a specified time by inhalation.

Permissible exposure limit (PEL). This number is the concentration of a hazardous chemical in the air expressed in units of ppm or mg/m^3. This number is established by OSHA after consultation with physicians, scientists, labor unions, and chemical manufacturers as the maximum concentration in the breathing air that can be inhaled without harm by an adult worker for 8 hours a day, 40 hours a week, during his or her working lifetime—provided that the worker is a person of average health.

Physical/chemical properties. This section usually includes some of the following items:

Boiling point. The value may be expressed either in degrees Celsius or Fahrenheit, usually at atmospheric pressure but, if so stated, may be at reduced pressure.

Melting point. Either in degrees Celsius or Fahrenheit.

Vapor pressure. Usually in torr at a specified temperature or at approximately room temperature if the temperature is not specified.

Specific gravity. Density with respect to water at a specified temperature or, if not specified, understood to be approximately room temperature.

Solubility. The value given is usually the approximate solubility in water and is at room temperature unless stated otherwise.

Appearance and odor. Liquid, solid, or gas (at room temperature); color, crystalline, or amorphous; odoriferous or not; and other characteristics.

Evaporation rate. Usually relative to *n*-butyl acetate or other named volatile substance.

Precautions for spills and cleanup. This section describes the procedures for proper cleanup of a spill or release. An appropriate waste disposal method, including whether the material can be put in a landfill or an EPA-approved disposal facility, is sometimes described in this part.

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[6] Flammable limits are determined by measurements in a laboratory under controlled conditions. Generally, the conditions under which these values are determined are not the same as the conditions existing in the laboratory where the flammable liquid is being used. Consequently, the numerical values of the flammable limits of a liquid only approximate the true values of the flammable limits under the actual existing laboratory conditions.

Reactivity. Some chemicals react vigorously with other chemicals; some are self-reactive; and others are unstable and decompose vigorously if disturbed. Reactivity includes all these characteristics. A chemical's reactivity is described in its MSDS.

Short-term exposure limit (STEL). This number is the concentration in ppm or mg/m^3 that should not be exceeded for more than a short period (usually 15 minutes). If measurements show that the concentration of the hazardous chemical exceeds this limit for more than the specified time period, the TWA (see below) is rendered useless and the PEL or TLV has been violated.[7]

Target organ. The name of an organ or organs (kidney, liver, skin, eyes, etc.) or system or systems (respiratory system, central nervous system, etc.) that are likely to be adversely affected by an overexposure to the chemical.

Time-weighted average (TWA). In practice, worker exposures must be measured and averaged over an 8-hour day. If the TWA does not exceed the PEL or TLV for a worker, then he or she is not harmed. It is possible, of course, that for one or more short time periods during the working day the PEL or TLV limit could be exceeded even though the TWA is not exceeded; for such an event, see STEL, above.

Threshold limit value (TLV). This number is a concentration limit. It is similar to the PEL, although it was established by the American Conference of Governmental Industrial Hygienists (ACGIH) instead of OSHA. ACGIH updates its TLV list annually, whereas the PEL list is rarely revised. The list of chemicals for which a TLV has been established includes all of the chemicals for which a PEL has been established, plus several more. Some of the TLV limits for the same chemicals differ in numerical value from the PEL limits. The PEL limit is a legal limit; the TLV limit is a voluntary, recommended limit. Because the TLV limits are subject to frequent revision, most

- instructions in case of fire, if applicable;
- methods to handle spills or leaks, if appropriate;
- instructions if the chemical requires unusual handling and storage procedures; and
- the name, address, and telephone number of the manufacturer or supplier.

Reading MSDSs and Labels

MSDSs and labels use words or phrases such as “avoid contact,” “use with adequate ventilation,” and other precautions whose significance may not be immediately obvious. See the table for descriptions of many of these phrases and the precautions you should take.

Common words used in MSDSs and labels

Phrase or term	Description	Precautions
(May cause) allergic skin reaction	Repeated or prolonged skin contact may cause an allergic reaction if you are susceptible.	Avoid prolonged and/or repeated contact. Wash thoroughly after using or handling, even if you are sure there was no skin contact.
(May cause) allergic respiratory reaction	Repeated or prolonged inhalation may cause an allergic reaction if you are susceptible.	Use only in a laboratory hood. Do not breathe dust, mist, or vapors. Keep the container closed.
Avoid breathing (vapor, mist, dust)	May cause harm if inhaled.	Exercise care when using or handling to avoid inhaling vapor, mist, or dust. Keep the container closed when not in use.
Avoid contact with eyes	Irritating to the eyes and in some cases could cause blindness.	Wear safety goggles. If the chemical gets in your eyes, immediately flush your eyes with plenty of water for at least 15 minutes while a physician is called. If contact lenses are worn, remove them while flushing.
Avoid contact with skin or clothing	Contact with skin may cause harm; if it gets on clothing, it can transfer to the skin.	In case of contact, immediately flush skin with water. Remove contaminated clothing, shoes, wristwatch straps, etc., and launder clothing separately from all other garments before wearing again. Dispose of contaminated shoes, leather and fabric wristwatch straps, etc., as hazardous waste.
Carcinogen	Suspected or known to cause cancer.	Exercise extreme care when using and handling, and do so only in a designated area in the laboratory. Do not breathe vapors and avoid all contact with skin, eyes, and clothing by wearing suitable protective equipment and using appropriate confining apparatus.

Causes (severe) eye burns	Can cause serious injury or blindness if it gets in the eyes.	Wear both safety goggles and a face shield. If the chemical gets in your eyes, immediately flush your eyes with plenty of water for at least 15 minutes while others call a physician. If contact lenses are worn, remove them while flushing.
Combustible	Gives off vapors that can ignite under usual working conditions.	Keep the container closed. Since the vapors are invisible and will travel several feet, keep these liquids and solids several feet away from heat, sparks, flames, and other sources of ignition.
Corrosive	Contact destroys living tissue as well as equipment.	Wear safety goggles. Do not breathe vapors and avoid contact with your skin, eyes, and clothing. Use other protective equipment, such as a face shield, as appropriate.
Danger	Can have serious harmful effects (e.g., loss of a limb or digit, loss of sight, loss of life) if precautions are not taken.	Follow the precautions described in the MSDS and on the label. Handle with extreme care.
Do not get in eyes	Can cause irritation or even blindness if it gets in the eyes.	Wear both safety goggles and a face shield. If the chemical gets in your eyes, immediately flush your eyes with plenty of water for at least 15 minutes while others call a physician. If contact lenses are worn, remove them while flushing.
Do not get on skin	Can cause harm by damaging skin and/or by penetrating intact skin.	Before using, put on clean gloves made of material known to be impervious to this chemical for at least several minutes. Remember that no glove material is impervious to a chemical for long periods. If this chemical does get on your skin, wash it off immediately.
Explosive	Known to explode under some conditions.	Handle with care. Avoid impact shock (hitting or dropping), friction, sparks, flames, and heat.
Extremely flammable	Gives off vapors that very readily ignite under usual working conditions.	Keep the container closed when not in use. Since the vapors are invisible and will travel several feet, keep these liquids and solids several feet (or the recommended distance) away from heat, sparks, flames, and other sources of ignition.
(May be) fatal if inhaled	Has caused the death of 50% or more of a population of test animals who inhaled this substance.	Do not breathe air containing vapors, dust, or mist from this substance. Use only in a laboratory hood. Alternatively, if you have been certified by a physician to use a respirator and have been trained in its proper use and maintenance, you may use a respirator known to be appropriate for this substance.

(May be) fatal if swallowed	Will cause death if a sufficient quantity is swallowed. For some very toxic chemicals, less than a gram is a sufficient quantity.	Handle with extreme care. Wash your hands thoroughly, and clean under your fingernails before leaving the laboratory. If swallowed or if swallowing is suspected, call a physician immediately. Do not induce vomiting unless directed to by a physician.
Flammable	Gives off vapors that readily ignite under usual working conditions.	Keep the container closed when not in use. Since the vapors are invisible and will travel several feet, keep these liquids and solids several feet (or the recommended distance) away from heat, sparks, flames, and other sources of ignition.
Harmful if inhaled	Has harmed test animals exposed to this substance in the air they breathed.	Avoid breathing air containing this substance.
Harmful if swallowed	Can cause serious discomfort, nausea, fainting, or other harm if swallowed.	Handle with care. Wash your hands thoroughly before leaving the laboratory. If swallowed or if swallowing is suspected, call a physician. Do not induce vomiting unless directed to by a physician.
Irritant	Has an irritant effect on skin, eyes, respiratory tract, etc.	Do not breathe vapors, dust, or mist and avoid contact with skin and eyes.
Keep away from heat, sparks, and flame	Vapors can explode and/or burn.	Keep the container closed. Eliminate all sources of ignition that are within a radius of several feet before using or handling this chemical.
Lachrymator	Has an irritant or burning effect on the eyes and is dangerous in very small quantities (merely opening the cap can immediately cause tears to form).	Only open in a laboratory hood! Do not breathe vapors. Avoid contact with skin and eyes. Avoid heating.
Mutagen	Causes damage to chromosomes.	Exercise extreme care when using and handling and do so only in a designated area in the laboratory. Do not breathe vapors and avoid all contact with skin, eyes, and clothing by wearing suitable protective equipment and by using appropriate confining apparatus.
Oxidizer	Will oxidize any oxidizable substance, e.g., a substance that can burn, such as a reducing agent, and may set it on fire.	Keep from contact with clothing and reducing agents. Keep container closed when not in use.

Peroxide former	Forms peroxides or hydroperoxides on standing or when in contact with air.	Many peroxides are explosive! Do not open a container of a peroxide former without your instructor’s permission. The act of opening the container can cause the contents to explode.
Poison	Has very serious and often	Avoid all contact. Exercise extreme care when using and handling and do so only in a designated area in the laboratory. Do not breathe vapors and avoid all contact with skin, eyes, and clothing by wearing suitable protective equipment and using appropriate confining apparatus.
Pyrophoric		Only expose to air if you have taken suitable precautions beforehand.
Reproductive hazard		Exercise extreme care when using and handling and do so only in a designated area in the laboratory. Do not breathe vapors and avoid all contact with skin, eyes, and clothing by wearing suitable protective equipment and using appropriate confining apparatus.
Sensitizer		Avoid the first exposure.
Skin		Do not allow contact with skin, eyes, or clothing. In case of skin contact, immediately flush the affected area.
Teratogen		Exercise extreme care when using and handling and do so only in a designated area in the laboratory. Do not breathe vapors and avoid all contact with skin, eyes, and clothing by wearing suitable protective equipment and using appropriate confining apparatus.
Toxic		Avoid all contact with the body. Do not breathe vapors, dust, or mist. When using or handling, use suitable protective equipment.

istics. If you intend to prevent accidents when working with chemicals in the laboratory, then you need to know the hazardous characteristics of the chemicals with which you will work. As a student, you will work with several dozen or more chemicals. How can you be expected to know the hazardous characteristics of so many different chemicals?

The answer: classification. The hazardous characteristics of all chemicals can be sorted into just a few classes. The important classes to consider in accident prevention include those listed in the box.

Solvents and Their Hazards

Of course, water is the most common solvent. As noted previously, many chemicals can react with water, some of them violently. Organic solvents (e.g., acetone, hexane, petroleum ether, trichloroethylene) are also often used, even though they present flammability hazards. It is interesting to note that a flammable liquid itself cannot burn; it is the vapor from the liquid that burns. The rate at which a liquid produces flammable vapors depends on its rate of vaporization, which increases as the temperature increases. Consequently, a flammable liquid is more hazardous at elevated temperatures than at normal temperatures. All flammable liquids and solids must be kept away from oxidizers and from inadvertent contact with ignition sources.

Some organic solvents can penetrate intact skin. When in contact with the skin, all organic solvents cause dryness and cracking. The vapors of all organic solvents are toxic, some more so than others. Typical symptoms from overexposure to organ-

Acids and Bases

All strong acids and bases and some weak acids and slightly soluble bases (e.g., glacial acetic acid, hydrofluoric acid, hydrobromic acid, calcium hydroxide) are corrosive. When in contact with the eyes or the skin, they irreversibly destroy living tissue. The more concentrated the acid or base and/or the longer the contact, the greater the destruction. Some acids and bases start damaging within 15 seconds of contact.

All of the hydrogen halides are acids; their aqueous solutions are toxic, and their vapors are serious respiratory irritants. Hydrogen fluoride poses a special danger.

Both gaseous hydrogen fluoride and its aqueous solution, hydrofluoric acid, are toxic and are rapidly absorbed through the skin, penetrating deeply and destroying the underlying tissues. Contact with a dilute solution of hydrofluoric acid is usually painless for several hours, but then serious burns appear along with adverse internal effects and *excruciating* pain. First aid procedures for hydrofluoric acid exposures are complex, requiring prior preparation of a special gel and other measures. The details are described in the MSDS for hydrofluoric acid. Before you use or handle this acid, be sure you are thoroughly familiar with the information provided in a currently valid MSDS for this acid. Your instructor should know the name of the hospital emergency room or the physician prepared in advance to treat hydrofluoric acid burns.

Concentrated sulfuric acid is a very strong dehydrating agent. All except very dilute solutions are oxidizing agents. Sulfuric acid is also available as fuming sulfuric acid (oleum). In this form, which contains “extra” SO_3, it is a strong oxidizing agent. When preparing aqueous solutions, always slowly add the acid to water while stirring the mixture. Remember that the heat of the solution will greatly increase the temperature—sometimes enough to cause it to boil and splatter.

Nitric acid is also a strong oxidizing agent. It generally reacts more rapidly than sulfuric acid. If dilute nitric acid gets on the skin and is not washed off completely, it causes the exposed skin to become yellowish brown as a protein denaturing reaction occurs.

Phosphoric acid is a weak acid. The concentrated acid is a viscous liquid and, like sulfuric acid, is a strong dehydrating agent. When preparing aqueous solutions, always add the acid to water slowly while stirring the mixture. Unlike most acids, which have a sour taste, dilute solutions of phosphoric acid taste sweet. In fact, dilute phosphoric acid is used as a sweetening agent in almost all soft drinks. Do not taste or swallow the phosphoric acid that is available in the laboratory.

Perchloric acid is a very powerful oxidizing agent, particularly at elevated temperatures. It can react explosively with organic compounds and other reducing agents. Perchloric acid must be used only in a specially constructed water-wash-down laboratory hood that has been designated to be used only for this purpose. Do not use this hood until you have been instructed in the operation of the wash-down facility. Never work with perchloric acid on laboratory benches made of wood or other combustible material. Keep perchloric acid bottles on glass or ceramic secondary containment trays with edges that are high enough to hold all the acid if the bottle breaks. Always digest organic matter with nitric acid before adding perchloric acid. Note that if sulfuric acid is added to dehydrate perchloric acid, an excessive dehydration may produce anhydrous perchloric acid, which is explosive at ordinary temperatures. Do not mix sulfuric or phosphoric acid with perchloric acid. Perchlorate esters have the same shattering explosive effect as nitroglycerine. Transition-metal perchlorates also can explode.

Dry picric acid is highly explosive; you should only use it when necessary and if you thoroughly understand its hazards. Although picric acid is not explosive when wet, water may evaporate and leave it a dry, hazardous solid. Be certain that the picric acid contents are moist before opening a bottle of picric acid; of particular concern is the possibility that explosive peroxides may have formed in the cap threads. If there is any question about the safety of opening a bottle of old picric acid, immerse the bottle in water and slowly twist the cap to allow water to dissolve any crystals. Water can then be safely added to moisturize the picric acid.

The most common bases used in academic laboratories are the alkali metal hydroxides and aqueous solutions of ammonia. Sodium and potassium hydroxides are strong bases and are extremely destructive to the skin and the eyes. Be cautious when you prepare concentrated solutions of these bases. The high heat of the solution can raise the temperature to dangerous levels—high enough to cause boiling and splattering. Ammonia in aqueous solution is a weak base, sometimes erroneously called "ammonium hydroxide." The vapors of aqueous ammonia solutions are irritating and toxic.

A Few Examples of Toxic Materials

Halogens. All halogens are toxic oxidizing agents—especially fluorine. It is too reactive to use as a reagent in a teaching laboratory. Chlorine also is a strong oxidizing agent; only if you have received special instructions should you work with chlorine. Bromine is a corrosive volatile liquid that causes serious burns on skin contact. It is a lachrymator. Use it only in a laboratory hood.

Mercury. Spilled mercury evaporates, filling the air with toxic vapors. Mercury vapor is a cumulative poison. If spilled, mercury will roll when it hits a hard surface, usually breaking into droplets, some of which are too tiny to be seen. Even visible droplets can adhere to smooth vertical surfaces; therefore, cleanup must be thorough.

Spilled mercury should be immediately and thoroughly cleaned up using an aspirator bulb or a special vacuum device. Do not use an ordinary vacuum cleaner; mercury a severe eye irritant, causing delayed effects that are not appreciably eased by eye washing. Skin sensitization can result from repeated exposure to liquid solutions. Because repeated exposure to formaldehyde solutions can lead to a formaldehyde allergy, avoid skin contact with solutions by wearing neoprene, butyl rubber, or polyvinyl chloride gloves. Note that these gloves can resist permeation of formaldehyde for only a limited time. Formaldehyde should be used and handled only in a designated laboratory hood.

Cyanides and nitriles. Cyanides and nitriles are rapidly acting toxic substances. Overexposures can be fatal. Symptoms of toxicity occur if these materials are swallowed, inhaled, or absorbed through the skin. A few inhalations of hydrogen cyanide can cause mental deterioration; a few more can be fatal. Some metal cyanides are hydrolyzed in aqueous solution and form hydrogen cyanide; all are converted to hydrogen cyanide in the presence of acid. Before you work with cyanides, make sure that amyl nitrite pearls are on hand as a first aid antidote. Also be sure that your instructor knows the name of a physician who can treat overexposures to cyanide and can administer sodium nitrite and sodium thiosulfate solutions, as appropriate.

Organic Peroxides and Peroxide Formers

Organic peroxides are a special class of compounds that pose unusual stability problems. These peroxides are among the most dangerous chemicals normally handled in chemical laboratories and manufacturing. As a class, organic peroxides are low-power explosives. They are hazardous because of their extreme sensitivity to shock, sparks, heat, or other forms of accidental explosive initiation. Many peroxides that are routinely handled in laboratories are more sensitive to shock than primary explosives such as TNT. Peroxides have a specific half-life, or rate of decomposition, under any given set of conditions. A low rate of decomposition may autoaccelerate into a violent explosion, especially in bulk quantities of peroxides. They are sensitive to heat, friction, impact, light, and strong oxidizing and reducing agents. Never open a container if you suspect that the contents are contaminated with a peroxide—the contents may explode. All organic peroxides are extremely flammable, and fires involving bulk quantities of peroxides should be approached with extreme caution. A peroxide present as a contaminating reagent in a solvent can change the course of a planned reaction.

The following types of compounds form peroxides:

- Aldehydes.
- Ethers, especially cyclic ethers, and ethers derived from primary and secondary alcohols. It is especially important to label the containers of ethyl or isopropyl ether with the date they are received, so that the user can destroy the contents of the container within three months after receipt. Never distill an ether unless it is known for certain to be free of peroxides, and even then do not distill to dryness.
- Compounds containing benzylic hydrogen atoms. Such compounds are especially susceptible to peroxide formation if the hydrogens are on tertiary carbon atoms [e.g., cumene (isopropyl benzene)].
- Compounds containing the allylic ($CH_2 = CHCH_2 –$) structure, including most alkenes.
- Ketones, especially cyclic ketones.
- Vinyl and vinylidene compounds (e.g., vinyl acetate and vinylidene chloride).

Examples of chemicals that can form dangerous concentrations of peroxides when exposed to air:

- Cyclohexene
- Cyclooctene
- Decalin (decahydronaphthalene)
- *p*-Dioxane
- Ethyl ether
- Isopropyl ether
- Tetrahydrofuran (THF)
- Tetralin (tetrahydronaphthalene)

Be sure that your instructor knows in advance if you plan to work with any of these compounds.

attached to the bench top. Anchor equipment racks securely at both the top and the bottom.

- Never place any apparatus, equipment, boxes (empty or filled), containers of chemicals, or any other objects on the floor.
- Never heat a closed container. Make sure the heating apparatus has a vent.
- Before you heat more than a few milliliters of a liquid in an unstirred vessel, add some boiling stones or a short glass tube with one end closed (as described in "Distillations," page 7). If, as in some distillations, there is the possibility of a dangerous exothermic reaction or decomposition, use a thermometer with its bulb in the liquid. This will provide a warning and may allow time to remove the heat and apply external cooling.
- Use an appropriate gas trap whenever evolution of hazardous gases or fumes is possible.
- Laboratory hoods are recommended for all operations in which toxic or flammable vapors are evolved. Most flammable vapors have a density greater than that of air and will settle on a bench top or floor where they may diffuse to a distant burner or other ignition source and "flash back." That is, if the flammable vapors are not controlled—within a hood, for example—they can evolve, expanding up and out over the containing vessel rim. Then they can travel undetected at floor level over astonishingly long distances. If there is a source of ignition at that distant point, the train of vapor will instantly flash back all the way to the container and either ignite the liquid in the container or cause the vapors near the container to explode.
- Use a laboratory hood when working with a system under reduced pressure (which may implode). Close the sash of the hood to provide a shield. Note that unless designed and built for the purpose, hoods are *not to be relied on for protection* in case of an explosion.

Equipment Use

Laboratory Hoods

Laboratory hoods control exposures to toxic, offensive, or flammable vapors. They protect users from implosions but *not* from explosions. If it is necessary to perform a procedure that could result in an explosion, conduct such work behind sturdy barriers that are designed and built for the purpose. Ordinary laboratory hoods are not strong enough to withstand the forces released in any but the mildest of explosions.

Before each use, be sure that the hood is working properly. If you have questions, ask your instructor. Do not rely on a monitoring device such as a strip of tissue paper held inside the hood to flutter in the breeze. At best, such a device can only indicate that the hood fan is pulling some air into the duct. A properly operating laboratory hood requires both an adequate airflow and the absence of excessive turbulence.

Never block, even partially, exhaust ports or slots in the rear wall and ceiling of the hood; do not change the size of the vent openings in the rear and ceiling of a hood. Never alter the supply air vents to the room, especially air vents in the ceiling of the room that are near the hood. A hood's airflow can also be disrupted by drafts from windows or doors and even by a change of position of the worker at the hood. Therefore, when you use a hood, keep the sash closed, or open it only the minimum amount necessary.

Keep your face outside the plane of the hood sash. Place your equipment and do your work within the hood, at least 15 cm (6 in.) from the front edge of the fume hood.

That is, work as far back in the hood as practical, but do not block the rear vent openings.

When it is necessary to contain or collect waste solvents or toxic vapors, the apparatus used in a hood should be fitted with condensers, traps, or scrubbers, as appropriate. Hoods are not an appropriate means for disposing of hazardous waste chemicals or evaporating solvents. Only hoods designed for the purpose may be used for work with perchloric acid.

A laboratory hood is not a storage cabinet. Chemicals stored in the hood can interfere with efficient hood operation, and, in the event of an accident or fire, every item in the hood may become involved.

Precautions for Using Electrical Equipment

Electrical currents of low amperage and voltage under certain circumstances may result in fatal shock. Voltages as low as 24 V AC can be dangerous and present a lethal threat. Comparably low-voltage DC circuits do not normally present a hazard to human life, although severe burns are possible. The longer contact with a live circuit lasts, the worse the damage, especially for burns. Follow these recommendations:

- Only individuals qualified by training or experience should maintain or repair electric or electronic equipment.
- Do not use electric wires as supports. Never pull on live wires.
- Immediately report any electrical failure or any evidence of equipment overheating.
- Inspect all electrical equipment periodically to be certain the insulation on the cords is not frazzled, tattered, cracked, or damaged. Inspect the plugs; make sure they are not bent or damaged. Make sure that only 3-wire grounded, double-insulated, or isolated wiring is used for 110–115 V AC applications.

Centrifuges

Bench-top centrifuges should be anchored securely so that if vibration occurs, they will not “walk” off the edge of the bench or knock over bottles and equipment. These rules apply to the safe operation of centrifuges:

- If vibration occurs, stop the centrifuge immediately and check the counterbalance load. If present, check the swing-out buckets for clearance and support.
- Always close the centrifuge lid before operating the centrifuge; keep it closed while the centrifuge is running.
- Do not leave the centrifuge until full operating speed is attained and the machine appears to be running safely without vibration.
- If the centrifuge has no brake, allow the centrifuge to coast to a stop. If it has a brake, use the brake, not your hand, to stop the centrifuge.
- If requested by your laboratory instructor, clean centrifuge rotors and buckets regularly; use a noncorrosive cleaning solution.

Using Steam

Some laboratories are equipped with steam outlets at the laboratory benches; in other laboratories, students set up their own steam-generating equipment as needed. Steam is very hot and can severely burn the skin and underlying tissues. Wear thick cloth or leather gloves, safety goggles, a face shield, and a laboratory apron or coat when you work with steam. Never direct steam toward any person.

When carrying out a steam distillation, minimize the accumulation of condensate in the distillation flask. Remember that the heat of condensation of steam is very high. Overfilling of the flask is less likely if condensation from the entering steam line is trapped and if the flask is heated or insulated to prevent excessive condensation. Do not flood the condenser by running the steam in too fast.

Using High-Pressure Air

Many laboratories are equipped with outlets for pressurized air. Air under the pressures available in the laboratory is a hazardous material. If air under pressure is directed toward intact skin, it can penetrate without making any visible opening and cause the nearby skin area to expand like a balloon. The pain from such an event can be severe, and the damage to the tissues can require hospitalization. Never direct air under pressure toward yourself or any other person.

Ultraviolet Lamps

Two categories of hazards are involved in the use of UV lamps: those inherent in the radiation itself and those associated with the operation of the lamps.

All radiation of wavelengths shorter than 250 nm should be considered dangerous. Operate UV irradiation systems only in a completely closed radiation box. Wear protective safety goggles with UV-absorbing lenses; your eyes can be accidentally exposed to light in this wavelength region. Wear slacks and a long-sleeved shirt to protect your skin. Skin areas exposed to illumination from UV lamps can be painfully burned, similar to severe sunburn.

Mercury arc lamps should be adequately cooled and operated within an enclosure designed to prevent damage by explosion of glass fragments and leakage of mercury vapor; make sure that the lamp you use is so equipped.

Do not handle mercury arc lamps with your bare hands. Deposits of oil from your skin damage the outer glass surface. If these oily residues are not thoroughly removed, they will burn into the glass, causing localized buildup of heat during the operation of the lamp. The lamp may then overheat, and the outer envelope may crack.

At the end of the useful life of a mercury arc lamp, buildup of UV-absorbing films on the interior glass walls may cause the temperature to rise above the safe operating point. Therefore, make sure that the running-time meter on the lamp works, so you can know the total time the lamp has been operated.

Controlling Temperature

Many reactions must be initiated by heating. Because the rates of most chemical reactions increase as the temperature increases, highly exothermic reactions can become dangerously violent unless provisions are made for adequate cooling. Some exothermic reactions have an induction period. In such reactions, if too much reagent was added initially, the reaction can become too vigorous for effective condensation of vapors once the induction period is completed; a cooling bath must be prepared in advance and be ready to be applied promptly to the reaction vessel. Remember that viscous liquids transfer heat poorly and require special precautions.

Many reactions require some temperature control. Assemble your apparatus in such a way that both heating and cooling can be controlled, that is, readily applied and withdrawn. For example, when heating the contents of a test tube in a burner flame, it is easy to overheat and cause the contents to boil up and out. To prevent this, hold the test tube with a test tube holder and heat it *gently* along the side, not at the bottom. Or, heat the contents of a test tube by placing it in a hot water bath. Never point a heated test tube toward yourself or any other person.

Oil and Sand Baths

When you use hot oil or sand for heating, take care to avoid hazardous splattering if water or another organic liquid falls into the hot oil or sand.

Avoid overheating an oil bath. Watch for smoking of the oil; oil that is smoking is too hot and may burst into flames at any moment. If an oil bath starts to produce smoke, turn off the heat immediately and call your instructor. Do not leave an operating sand or oil bath unattended unless it is equipped with a high-temperature shutoff and with a warning label (“Hot Oil” or “Hot Sand”).

Ensure that glassware that is to be used in an oil or sand bath is free of cracks and other imperfections. Do not use a sand or oil bath unless it is equipped with a thermometer or other temperature-indicating device. In addition, an oil bath must be labeled with the name of the oil and its maximum safe working temperature. Take precautions to contain any spills of hot oil or hot sand caused by breakage or overturning of the baths.

Cooling Baths and Cold Traps

When ice water is not cool enough for use as a bath or cold trap, salt and ice may be used. For lower temperatures, dry ice or dry ice with an organic liquid may be used. Still lower temperatures require cryogenic liquids.

Dry Ice Cooling Baths and Cold Traps

Follow these precautions when using dry ice. It is often but incorrectly said that dry ice can “burn” the skin. Correctly stated: Unless precautions are taken, dry ice will damage fingers or hands, for example, by freezing them. Do not handle dry ice with bare hands; if your skin is even slightly moist, severe freezing can result. Use tongs or a folded cloth pad, or wear leather or cryo-gloves. Never put dry ice in your mouth. Wear goggles while chipping dry ice. Dry ice sublimes, forming gaseous carbon dioxide, an asphyxiating gas. Be sure that you are protected by an adequate ventilation system when using or handling dry ice. Do not lower your head into a dry ice chest; no oxygen is present, and suffocation can result.

Sometimes it may be desirable to use a dry ice–organic liquid cooling bath. Additional precautions are then necessary. For example, to be used safely with dry ice, an organic liquid ideally should have the following five characteristics:

1. Nontoxic vapors
2. Low viscosity
3. Nonflammability
4. Low volatility
5. Suitable freezing point

The final choice of a liquid will also depend on the temperature requirements. No liquid meets all of the above criteria. The following are examples of liquids that should *never* be used (numbers in parentheses signify which of the above criteria are *not* met); they are too flammable and volatile:

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atmosphere of the laboratory. When possible, vent exhausts from pumps to a laboratory hood. Vacuum pumps with belt drives must be equipped with belt guards.

Water aspirators for reduced pressure are used for filtration purposes and for some rotary evaporations. Use only equipment that is approved for these purposes. For example, use only a heavy-walled filter flask designed for the purpose; never apply reduced pressure to other flat-bottomed flasks. When you use a water aspirator for reduced pressure, place a trap and a check valve between the aspirator and the apparatus so that water cannot be sucked back into the system if the water pressure should fall unexpectedly while filtering.

Superheating and consequent bumping (sudden boiling) frequently occur when you use reduced pressure for distilling. Therefore, it is important that the assembled apparatus is secure and that heat is distributed more evenly than is possible with a flame. Use a heating mantle whenever possible. See the “Distillations” section on page 7. Evacuate the assembly gradually to minimize the possibility of bumping. Stirring or using a nitrogen or other inert gas (never use air) bleed tube often can provide good vaporization while preventing bumping or overheating and decomposition. Use standing shields to surround the apparatus for protection in the event of an implosion. After you finish a reduced-pressure distillation, allow the system to cool before slowly bleeding in air; the oxygen in air that is introduced into a still-hot apparatus may

Stand back, take a look, and ask:

- Are there any frayed wires?
- Is a stirrer with a sparking motor being used to stir a flammable liquid?
- Are those bottles too close to the edge of the bench?
- Is the workspace cluttered?
- Do I understand each of the potential hazards in what I am about to do?
- Am I prepared in advance to take preventive steps?

Dealing with a Fire

When a fire occurs, the following actions are recommended:

- A fire contained in a small vessel often can be suffocated. For example, use a watch glass to suffocate a fire in a beaker by covering the mouth of the beaker. Do not pick up a vessel that is on fire. Do not cover it with dry towels or cloths; use a wetted material. Remove nearby flammable materials to avoid spreading the fire.
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Chemicals on Skin, Clothing, and Eyes

For small liquid spills that only affect a small area of skin, immediately flush with flowing water for at least 15 minutes. Remove any jewelry to facilitate removal of possible residual liquid. If there is no visible injury, wash the entire area with warm water and soap. Check the MSDS to see whether any delayed effects should be expected. It is advisable to seek medical attention for even minor chemical burns. Hydrofluoric acid spills require special treatment; see “Acids and Bases” on page 22.

Solid chemicals that are spilled on the skin can usually be brushed off with no adverse consequences. The brushed-off solid should, of course, be put into the appropriate hazardous waste container. If the solid adheres to your skin, call your instructor.

Larger spills of a liquid on the skin and any spills of liquid on clothing can have serious consequences. Do not waste time by attempting to wipe or flush off the spill; *get to the safety shower immediately*. Quickly step under the showerhead and in the falling water spray; remove all contaminated clothing, shoes, and jewelry while the safety shower is on. Seconds count, so don’t waste time with modesty. Try to avoid spreading the chemical further over your skin, especially into your eyes. Don’t contaminate your eyes by removing pullover shirts or sweaters—someone else should cut the garment off with scissors while you are still in the shower. Flood the affected body area with temperate water for at least 15 minutes. Resume if pain returns. Do not use creams, lotions, or salves. Get medical attention without delay.

Launder contaminated clothes separately from other clothing or discard, as recommended in the MSDS.

Never work with chemicals in a laboratory unless it is equipped with a safety shower that has been tested within the past six weeks. A record, usually a tag affixed to the safety shower, should state the most recent test date and the tester’s initials.

If the injured person is not breathing, provide mouth-to-mouth resuscitation. If there is no pulse, administer cardiopulmonary resuscitation (CPR).

If an individual is bleeding severely, control the bleeding by compressing the wound with a cloth or whatever is available. If possible, elevate the injury above the level of the heart. If blood is spurting, place a pad directly on the wound and apply firm pressure. Take reasonable precautions to avoid contact with blood. Wrap the injured person to avoid shock and get immediate medical attention. In the case of a less severe cut, wrap the injured person to avoid shock (except in case of a trivial cut), and get medical attention. A pressure pad should be applied firmly on the wound. Only individuals trained in first aid should use tourniquets.

Do not touch a person in contact with a live electrical circuit. Disconnect the power first! Otherwise, you too may be seriously injured.

Spill Cleanup

Clean up all spills promptly, efficiently, and properly. Call your instructor for help. Warn all individuals who may be at risk to spare them exposure to the hazard and minimize its spread. Often the toxicity of the substance is more important than the volume spilled.

If a flammable material is spilled, immediately warn everyone to extinguish all flames, to turn off spark-producing equipment such as brush-type motors, and leave the area. You should do any work with a flammable toxic material in a laboratory hood; if a spill occurs, close the hood window sash and call your instructor.

Promptly contain spills on laboratory benches and floors. The smaller the area involved, the less the damage and the easier the cleanup. Follow your instructor's directions.

Many small liquid spills on the floor or laboratory bench (e.g., less than 200 mL) can be absorbed with paper towels, sand, or special absorbent. Of course, whatever is used becomes contaminated and must be handled as a hazardous waste. Be particularly careful that flammable liquids absorbed during cleanup do not present a fire hazard. Most spills of solids can be brushed up and disposed of in appropriate solid waste containers, but exercise care to avoid reactive combinations with a chemical that was put in the container earlier. Do not leave materials used to clean up a spill in open trashcans. Follow your instructor's directions.

Dike larger liquid spills on the floor by surrounding the involved area with an

Appendix 1. The Web as a Source of Safety Information

The Web offers many safety resources. Unfortunately, many contain a mixture of accurate and inaccurate information. A few are outright unreliable, being little more than expressions of ill-founded opinions concerning chemical safety matters and the environment.

Recommended Websites

The ACS Division of Chemical Health and Safety's (CHAS) webpage is accessible through the ACS website at chemistry.org (click on Tech Divisions, then Division Home Pages). The latter site links to other safety websites that have been evaluated and found to be reasonably reliable by CHAS members who have reviewed them and found the chemical safety information there generally sound. This site links to federal agencies that promulgate safety-related regulations and to foundations, companies, and other societies that have an interest in chemical safety.

Click on the link to OSHA, or go directly to www.osha.gov for a current outline of what is happening in OSHA, including statistics, a description of the agency, its Newsroom (speeches, news releases, testimony, publications), and OSHA regulations. Of special interest are Standards—29 CFR (indicating that they were published in Volume 29 of the *Code of Federal Regulations*. Section "1910.1450—Occupational Exposure to Hazardous Chemicals in Laboratories," known more commonly as the "Laboratory Standards," is of particular relevance. To find this information, enter "1910.1450" in the search field.

Other Useful Sites

- The Canadian Centre for Occupational Health and Safety, www.ccohs.ca
- The U.S. Environmental Protection Agency, www.epa.gov
- The National Institute for Occupational Safety and Health, www.cdc.gov/niosh/homepage.html
- The National Library of Medicine, www.nlm.nih.gov

Of course other reliable sites exist, for example, those of some universities and colleges and various others under the aegis of public-spirited associations and organizations; however, it isn't possible here to sort them all out from unreliable ones. You may wish to rely on personal recommendations for other resources.

Chemical	Incompatible with
Flammable liquids	Ammonium nitrate, chromic acid, hydrogen peroxide, nitric acid, sodium peroxide, halogens
Hydrocarbons (e.g., butane, propane, benzene)	Fluorine, chlorine, bromine, chromic acid, sodium peroxide, other oxidizing agents
Hydrocyanic acid (anhydrous)	Alkali
Hydrofluoric acid	Potassium permanganate, sulfuric acid
Hydrogen sulfide	Metal oxides, powdered copper, oxidizing gases
Hypochlorites	Acids, activated carbon, ammonia
Iodine	Acetylene, ammonia (aqueous or anhydrous), hydrogen
Mercury	Acetylene, fulminic acid, ammonia
Nitrates	Powdered metals and non-metals, metal sulfides, flammable/combustible liquids
Nitric acid	Acetic acid, aniline, sulfuric acid, chromic acid, hydrocyanic acid, hydrogen sulfide, flammable/combustible liquids and gases, copper, brass, heavy metals, alkalis
Nitrites	Ammonium salts, amides, phosphides, reducing agents
Nitroparaffins	Acids, bases, amines, halides
Oxalic acid	Silver, chlorites, urea
Oxygen	Oils, grease, hydrogen, and other reducing agents, including flammable liquids, solids, and gases
Perchlorates	See Chlorates
Perchloric acid	Reducing agents such as acetic anhydride, bismuth and its alloys, alcohols, paper, wood, grease, oils
Phosphorus (white)	Air, oxygen, alkalis, halogens, halogen oxides, oxidizing agents
Potassium	Carbon tetrachloride, carbon dioxide, water
Potassium permanganate	Glycerol, ethylene glycol, benzaldehyde, other reducing agents, sulfuric acid
Sodium	Carbon tetrachloride, carbon dioxide, water
Sodium peroxide	Ethyl and methyl alcohol, glacial acetic acid, acetic anhydride, benzaldehyde, carbon disulfide, glycerin, ethylene glycol, ethyl acetate, methyl acetate, furfural
Sulfides	Acids
Sulfuric acid	Permanganates, water, aqueous solutions, reducing agents, chlorates, perchlorates, nitric acid