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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ISBN 0-8412-3863-4
Printed in the United States of America

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 volume for the prevention of accidents in college and university educational chemistry laboratories. The information herein can be adapted to practices in all laboratories in which chemicals are used, including research, clinical, quality control, and development laboratories, as well as in other workplaces. The general recommendations herein can serve as a basis for preparing a chemical hygiene plan or other detailed instructions by those directly responsible for accident prevention in chemical laboratories.

There is a preferred way to perform work with chemicals that can reduce the probability of accidents, including toxic exposures, to a negligible level. To reduce the probability of accidents,

- practice the habit of accident prevention;
- use personal protective equipment (e.g., goggles, lab apron, or lab coat) at all times in the laboratory;
- use the smallest quantity of material necessary to accomplish the goal of the experiment;
- when possible, substitute a less hazardous chemical for a more hazardous one; and
- anticipate the possible consequences of the work you do in the laboratory.

Before you begin an operation or perform an experiment, ask yourself, "What would happen if ... ?" Answers to this question require an understanding of the hazards associated with the chemicals and equipment involved. The reactivity, flammability, corrosivity, and toxicity of the chemicals you use will dictate the precautions you take. Such precautionary information might well form an introductory section in all written routine procedures.

Effective safety programs require the active and enthusiastic support from the top administrative officer, the faculty and staff, and the students working in the laboratory facility. An accident-prevention program intended to achieve safe conditions for students and other laboratory workers must include

- regular safety inspections at intervals of no more than three months (more frequently for certain types of equipment, e.g., safety showers and eyewash fountains);
- regular monitoring of the performance of equipment and ventilation systems;
- formal and regular procedures to ensure that sufficient full-time personnel are trained in the proper use of emergency equipment and procedures; and
- procedures that ensure proper disposal of waste chemicals.

This volume is primarily for students in college and university chemistry laboratories, and the companion volume is for the faculty and administrators who develop and oversee the laboratory programs. This volume emphasizes the importance of knowing the hazards beforehand and the necessity of taking appropriate precautions. Later in their careers, whether as chemists or otherwise, students will encounter the challenges presented by various state and federal regulations. Accordingly, this volume addresses certain aspects of chemical laboratory work that involve regulations developed under the Resource Conservation and Recovery Act (RCRA); the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); and the

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.

This manual provides a basis from which individual safety policies and procedures can be developed. It is not intended to replace existing rules or regulations. It is a starting point for understanding accident prevention; further and more detailed information can be found in the references in Appendix 1. Most of the material presented here is the result of the many years of practical knowledge of the members of the Joint Board–Council Committee on Chemical Safety with additional information derived from regulatory sources.

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

[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).

shields, wear safety goggles to protect your eyes, and use face shields wide enough and long enough to protect your neck and ears.[2]

Clothing

Clothing worn in the laboratory should offer protection from splashes and spills; it should be easily removable in case of accident and should be at least fire-resistant. Nonflammable, nonporous aprons offer the most satisfactory and the least expensive protection. If you wear a lab jacket or coat instead of an apron, it should have snap fasteners rather than buttons so it can be readily removed.

In the laboratory, wear shoes with uppers made of leather or polymeric leather substitute. Do not go barefoot or wear sandals. Do not wear shoes that have high heels or open toes, uppers made of cloth, woven leather strips, or other woven material. Shorts, cutoffs, and miniskirts unnecessarily expose your skin to potential corrosives and are not safe. Constrain long hair and loose clothing. Do not wear jewelry such as rings, bracelets, and wristwatches in the laboratory. Jewelry can be damaged by chemical fumes and spills. Chemical seepage in between the jewelry and skin can put corrosives in intimate contact with your skin. Wearing jewelry increases the probability of accidental contact with electrical sources and consequent harmful electrical shock. Jewelry also can catch on equipment, causing accidents.

Gloves

Gloves are an important part of personal protection. Your instructor will require their use when appropriate. A variety of gloves and materials are available: latex, neoprene, butyl rubber, and many other materials. Different types of gloves have different gauntlet lengths; some cover the entire arm, some only the forearm, and some are only wrist-length. Individuals who are latex-sensitive should not wear gloves made of latex. Although cloth or leather gloves may protect against hot or cold objects, do not rely on them for protection against hazardous chemicals. Cloth gloves are porous; leather gloves are likely to be contaminated from prior use.

Use gloves correctly. Always check your gloves before each use to ensure the absence of cracks and small holes. To avoid unintentionally spreading chemicals, remove your gloves before leaving the work area and before handling such things as telephones, doorknobs, writing instruments, laboratory notebooks, and textbooks.

Be aware that no glove material can provide permanent protection. Eventually, liquids will permeate the glove. When certain glove materials are used with some liquids, permeation can take only a few minutes. Because the permeability of gloves made of the same or a similar material can vary by manufacturer, refer to the information provided by the manufacturer of the gloves for specific guidance. If a chemical diffuses through a glove, it is then held against your skin—you could receive more exposure than if you hadn't worn a glove at all.

Do not reuse gloves if they previously have been permeated by a harmful chemical; they cannot be reused safely because the chemical cannot be totally removed. Such gloves should be considered to be a hazardous waste material; dispose of them in the designated hazardous waste container as directed by your instructor. Otherwise, if they are clean, gloves may be reused.

[2]This combination of all three—laboratory bench shields, safety goggles, and a face shield—does not provide sufficient protection for any but the very smallest of explosions.

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 be aware of the hazards and may inadvertently commit unsafe acts. Obtain your laboratory instructor's approval before bringing visitors into the laboratory.

Comportment in the Laboratory

As a student, your duty to learn includes the duty to prevent accidents whenever you are in the chemical laboratory. These precepts are intended to help you fulfill this additional responsibility:

- Always wear eye protection when you or others nearby are working with chemicals or apparatus.
- Know beforehand the hazardous characteristics of the chemicals with which you plan to work.
- Wear chemically resistant lab coats or aprons. Do not wear shorts, cutoffs, or miniskirts. Do not wear high-heeled shoes, open-toed shoes, sandals, or shoes made of woven material.
- Confine long hair and loose clothing.
- Always wash your hands and arms with soap and water before leaving the laboratory, even if you wore gloves. Wash lab coats or jackets on which chemicals have been spilled separately from personal laundry.
- Never work alone in the laboratory.
- Do not prepare or store (even temporarily) food or beverages in a chemical laboratory. Never consume any food or beverage when you are in a chemical laboratory.
- Do not chew gum or tobacco, and do not smoke or apply cosmetics in the laboratory. Be aware that cosmetics and tobacco products in opened packages can absorb chemical vapors.
- Never wear or bring lab aprons or lab coats or jackets into areas where food is consumed.
- Never pipet by mouth. Always use a pipet aid or suction bulb.
- Do not handle contact lenses in the laboratory except to remove them when an emergency requires the use of the eyewash fountain or safety shower.
- Never perform unauthorized experiments.
- When moving about in the laboratory, anticipate sudden backing up or changes in direction by others. If you should stumble or fall while carrying glassware or chemicals, try to project them away from yourself and others.
- Never remove chemicals from the laboratory without proper authorization.
- Keep chemicals and apparatus well away from the edges of your laboratory bench or other workspace.
- Never engage in horseplay, pranks, or other acts of mischief in the laboratory.
- Report violations of your laboratory's safety rules to your instructor—you could save their lives and your own.

Housekeeping

In the laboratory and elsewhere, keeping things clean and neat generally leads to a safer environment. Avoid unnecessary hazards by keeping drawers and cabinets closed while working. Never store materials, especially chemicals, on the floor, even temporarily. Keep workspaces and storage areas clear of broken glassware, leftover chemicals, and scraps of paper. Keep aisles free of obstructions such as chairs, boxes, and waste receptacles. Avoid slipping hazards by keeping the floor clear of spilled liquids, ice, stoppers, glass beads or rods, and other such small items. Follow your laboratory's required procedure for the disposal of chemical wastes.

Cleaning Glassware

Clean your soiled glassware at the laboratory sink or in laboratory dishwashers. Use only environmentally acceptable cleaning agents, for example, soap or detergent. Use hot water if available. If necessary, use a mild scouring powder. Wear appropriate gloves. Use brushes of suitable stiffness and size. Avoid accumulating too many articles in the clean-up area. Usually, workspace around a sink is limited; piling up dirty or cleaned glassware can lead to breakage. Remember that the turbid water in a sink may hide the sharp, jagged edge of a piece of broken glassware that was intact when put into the water. If glassware in the sink is broken, drain out the standing water. Then use a pair of cut-resistant gloves, such as Kevlar or an equivalent, to remove the pieces of broken glass. To minimize breakage of glassware, sink bottoms should have rubber or plastic mats that do not block the drains.

Do not use strong cleaning agents such as nitric acid, chromic acid, sulfuric acid, or other strong oxidizers unless specifically instructed to use them, and then only when you wear proper protective equipment. Numerous accidents involving strong oxidizing cleaning solutions, such as chromic–sulfuric acid mixtures, have been reported. Do not use flammable solvents as cleaning agents unless your instructor specifically requires their use.

Inhaling Harmful Chemicals

Some people think that if they can smell a chemical, it is causing them harm. This is not necessarily correct. It is certainly correct that if you smell a chemical, you are inhaling it. However, some harmful chemicals have no odor; some paralyze the sense of smell; some have an odor but cannot be detected by the human nose at concentrations that are harmful; and some chemicals, even though they might have a decidedly noxious odor, are not harmful if inhaled. The long and short of it is simply that the presence of an odor is not a reliable indication of potential harm, and the absence of an odor is not a reliable indication of the absence of harm.

Many substances that may or may not have an odor are harmful if their vapors, dust, or mist are inhaled. The label on the container and the Material Safety Data Sheet for the chemical will carry a warning about inhaling, if appropriate (for a detailed description, see "Material Safety Data Sheets" on page 12). Do not work with such substances on a laboratory bench. Dispense and handle these substances in a laboratory hood. See "Laboratory Hoods" on page 27.

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 reinitiate 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 in laboratory operations are particularly susceptible to problems because their stoppers and/or stopcocks can be forced out, spilling the liquid. It is even possible for pressure to burst the vessel.

Use a separatory funnel correctly; if it is equipped with a glass stopcock, make sure that it is lubricated before using it in an extraction procedure. (Teflon stopcocks should not be lubricated.) When using a warm or hot extractant in a separatory funnel, wait until the extractant has cooled before continuing with the extraction. When using a volatile solvent in a separatory funnel, you should first swirl the unstoppered separatory funnel to allow some solvent to vaporize and expel air. Then close the funnel, invert it with the stopper held firmly in place, and immediately open the stopcock to release air and vapor. Do this with your hand and fingers firmly holding the barrel of the stopcock in place to keep the stopcock plug securely seated.

Do not vent the separatory funnel near a flame or other ignition source. And of course, direct the vapors away from yourself and other people; preferably direct them into a laboratory hood. Then close the stopcock, and with the separatory funnel inverted the entire time, shake with a swirl and immediately open the stopcock to vent the air and vapor. Repeat as necessary, following the same venting procedure. If it is necessary to use a separatory funnel larger than 1 liter for an extraction with a volatile solvent, the force on the stopper may be too great and expel it. Consider performing the extraction in several smaller batches.

Refrigerators

Refrigerators used for low-temperature storage of laboratory chemicals should be labeled for such use and must be explosion-proof. Never use household refrigerators for chemical storage.

Laboratory chemicals stored in refrigerators should be placed on a spill tray with edges sufficiently high to contain the spilled contents of any containers that are placed in the tray. Always seal and, if possible, double-package all chemicals to be stored in refrigerators; label each chemical legibly with the name of the material, the date placed in the refrigerator, and the name of the person who stored the material. Dispose of old chemicals after a specified storage period.

Store radioactive materials only in a designated refrigerator that can be locked and is properly labeled for such storage.

Never under any circumstances store food or beverages in a refrigerator used for laboratory chemicals or radioactive materials.

Disposal

Properly handling reaction byproducts, surplus, waste chemicals, and contaminated materials is a major element of accident prevention. Every student is responsible for ensuring that these wastes are handled in a manner that minimizes personal hazard and recognizes the potential for environmental contamination.

Typically, your reaction byproducts and surplus chemicals will be neutralized or deactivated as part of your procedure. Alternatively, your instructor will direct you to use designated, labeled waste containers; most likely, different containers are used for different classes of chemicals. Handle your waste materials in the specific ways designated by your instructor.

General Disposal Guidelines

- When disposing of chemicals, put each class of waste chemical in its specifically labeled disposal container.
- Never put chemicals into a sink or down the drain unless your instructor has told you that these substances are allowed by local regulations to be put into the sanitary sewer system. For example, water and dilute aqueous solutions of sodium chloride, sugar, and soap from a chemistry laboratory may be disposed of in the sink.
- Put ordinary waste paper in a wastepaper basket separate from chemical wastes. If a piece of paper is contaminated, such as paper toweling used to clean up a spill, put the contaminated paper in the special container that is marked for this use. Such paper must be treated as a chemical waste.
- Broken glass belongs in its own marked waste container. Broken thermometers may contain mercury in the fragments; they belong in their own labeled container.

Unattended Operation of Equipment

Reactions that are left to run unattended overnight or at other times are prime sources for fires, spills, and explosions. Do not let equipment such as power stirrers, hot plates, heating mantles, and water condensers run overnight without fail-safe provisions and your instructor's consent. Check unattended reactions periodically. Always leave a note plainly posted with a phone number where you and the instructor can be reached in case of emergency. Remember that in the middle of the night, emergency personnel are entirely dependent on accurate instructions and information.

2. Guide to Chemical Hazards

Chemicals can cause harm if they are not handled properly. For example, they can be *toxic*, *flammable*, *corrosive*, or *reactive*. Some chemicals are hazardous in only one of these ways, some in more than one. Every chemical, even water,[3] is hazardous in at least one way. The degree of hazard varies; it can be great or small, or in-between. For example, both gasoline and alcohol are flammable, but gasoline is much more flammable. Gasoline is easier to ignite and more likely to burn vigorously or explode than alcohol. In all cases, you can work safely by taking the precautions that are described on the label and in the Material Safety Data Sheet (see page 12). The instructor in charge of your laboratory can explain the precautions that you will follow in your laboratory work.

Toxicity

This discussion is a brief introduction to the topic of toxicity. It has long been known that anything ingested in sufficient quantity can be lethal. In the 16th century, a military surgeon and alchemist known as "Paracelsus" (whose real name was Philippus Aureolus Theophrastus Bombast von Hohenheim) wrote: "What is it that is not poison? All things are poison and nothing is without poison. It is the dose only that makes a thing not a poison."

Any substance could be harmful to living things. But complex relationships exist between a substance and its physiological effect in humans. The major factors include the dose (the amount of a substance to which one is exposed and the length of time of exposure to the substance), the route of exposure (by inhalation, ingestion, absorption through the skin or eyes, or injection), and myriad other factors such as gender, stage in the reproductive cycle, age, lifestyle, previous sensitization, allergic factors, genetic disposition, and even whether is has been a "good day" or a "bad day" for the victim. These and other factors can affect the severity of an exposure. If you don't know these details, as is often the case, *it is prudent to act as though you could be susceptible to serious toxic consequences and to therefore follow the necessary precautions when working with chemicals in the laboratory*.

The toxic effects can be immediate or delayed, reversible or irreversible, local or systemic. The toxic effects vary from mild and reversible (e.g., a headache from a sin-

Toxic chemicals can enter the body by four routes:

Inhalation through the respiratory tract (lungs) by breathing.
Ingestion through the digestive tract. This can occur through eating; chewing gum; applying cosmetics or smoking in the laboratory; using a contaminated beaker, say, as a cup for drinking coffee; or eating lunch without washing your hands after working in the laboratory.
Absorption through body openings such as the ears or eyeball sockets, through cuts in the skin, or even through intact skin.
Injection of a toxic substance through a cut made in the skin by a sharp, contaminated object. Possibilities include mishandling a sharp-edged piece of a contaminated broken glass beaker or misuse of a sharp object such as a knife or hypodermic needle.

[3]From one point of view, water is the most dangerous single chemical known. Considering all known industrial accidents involving chemical reactions, those involving water as a chemical reactant have caused more fatalities than any other single chemical compound.

When you work with chemicals in the laboratory,

- remember to read and heed the labels before using chemicals,
- follow the precautions recommended in the Material Safety Data Sheets, and
- *always* follow your instructor's directions.

gle episode of inhaling the vapors of ethyl acetate that disappears when the victim inhales fresh air) to serious and irreversible (e.g., birth defects from excessive exposure to a teratogen during pregnancy or cancer from excessive exposure to a carcinogen).

Some important details about toxic effects:

- **Acute poisoning** is characterized by rapid assimilation of the substance.[4] Often, but not always, the effect is sudden and can be painful or severe and even fatal. Normally, a single exposure is involved. Examples: carbon monoxide or cyanide poisoning.
- **Chronic poisoning** is characterized by repeated exposures with a duration measured in months, or years.[4] Symptoms may not be immediately apparent. Examples: lead or mercury poisoning, pesticide exposures.
- **Substances in combination** may result in the synergistic effect. When two or more hazardous materials are present, the resulting effect can be greater than the effect predicted for the individual substances. Example: exposure to alcohol and chlorinated solvents. The opposite is also possible; two poisonous substances can lessen each other's effects, called the antagonistic effect. Example: cyanide and amyl nitrite.
- **Allergens** are agents that produce an immunologic reaction, and you may encounter them in the laboratory. Asthma-like symptoms or dermatitis are typical allergic reactions. Not everyone is susceptible to allergens. A susceptible individual will not suffer an allergenic reaction unless he or she has been sensitized by at least one previous exposure. For some allergens, an individual must be exposed several times before suffering an allergenic response. Tell your instructor if you know or suspect that you are allergic to a chemical in your laboratory.

Except for allergenic exposures, the toxic effects from exposure to a chemical depend on the severity of the exposures. Generally, the larger or more frequent the exposure, the more severe the result. Consequently, you can reduce or even avoid harm by keeping exposures to a minimum. The following section explains how.

Exposure Limits

Toxic chemicals can cause harm if they are ingested. Therefore, do not eat or drink anything in the lab, and do not put your hands or fingers in your mouth. A toxic chemical can also enter your body in other ways. Until you have washed your hands and have left the laboratory, keep your hands away from your eyes, ears, and nose. Keep your hands away from any cuts, bruises, or other places where your skin has been broken. If it is necessary to use needles or to handle broken glass, exercise care to avoid puncturing your skin or cutting yourself.

[4]Strictly, an acute exposure is an exposure to a toxic substance that lasts 24 hours or less; a chronic exposure is a repeated exposure that takes place for a duration of three months or longer. Repeated exposures that occur for a period of less than one month are called sub-acute exposures, and those lasting from one to three months are called sub-chronic exposures.

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 each week, and if your instructor ensures that the concentrations of toxic vapors, dusts, and mists are kept well below the threshold limit value (TLV) or permissible exposure limit (PEL), you are unlikely to be harmed by an inhalation exposure. The terms TLV and PEL are defined in the "Understanding an MSDS" section at right.

Sources of Information

Material Safety Data Sheets (MSDSs)

The U.S. Occupational Safety and Health Administration (OSHA) has defined a hazardous chemical as any chemical that presents a hazard either under normal use or in a foreseeable emergency. (As you probably have guessed, almost all chemicals are hazardous chemicals as defined by OSHA.) The MSDS for a hazardous chemical describes its hazards and the precautions you must take to avoid harm. OSHA requires that employers provide an MSDS for a hazardous chemical on the premises to any employee who requests it. Although students are usually not employees, most educational institutions provide them with MSDSs; an MSDS can be educational, even though some of them may be difficult to fully understand.[5]

OSHA does not require or prefer any particular format or ordered presentation of topics for an MSDS. OSHA only mandates that the MSDS be in English and that it include

- the name of the hazardous chemical (and if it is a mixture, the names of the hazardous components present at 1% or greater levels—0.1% if the component is a carcinogen);
- some of the physical and chemical properties of the chemical (e.g., vapor pressure, boiling point, density);
- the physical hazards of the chemical (e.g., if it can catch fire or explode);
- the health hazards of the chemical (e.g., whether it is corrosive, an irritant, or harmful to the kidneys, and how it can enter the body [called "routes of entry," e.g., inhalation, ingestion]);
- the PEL and TLV, if established (see "Understanding an MSDS" at right);
- whether or not the chemical can cause cancer as determined by certain authorities (e.g., the National Toxicology Program);
- the precautions to take when using the chemical;
- the control measures, work practices, and personal protective equipment you should use;

[5]You may wish to study the Chemical Laboratory Information Profile (CLIP) for a chemical before trying to understand the MSDS for that chemical. CLIPs are written in plain English and are published in the *Journal of Chemical Education*.

- emergency and first aid procedures;
- the date of preparation or, if revised, the date of the revision; and
- the manufacturer's name and address.

An MSDS is divided into sections, which discuss the OSHA-required topics listed above. Typical names of the sections: Product identification, Hazardous components, Physical data, Health hazard information, Fire and explosion hazard data, Reactivity data, Protective equipment to be used, Spill or leak procedures, Special information, Other precautions, and Comments. The order of the sections and their content vary with the manufacturer. Some manufacturers of hazardous chemicals use an MSDS format prescribed by the American National Standards Institute (ANSI), known as ANSI Z400.1, which is a voluntary standard. Other manufacturers prefer different formats.

Understanding an MSDS

As you attempt to read and understand an MSDS, you may find these comments helpful. The terminology below is used in many MSDSs. Reading the descriptions can help you understand MSDSs.

CAS registry number. The ACS Chemical Abstracts Service (CAS) assigns a unique number to each known, discovered, or synthesized chemical, called the CAS registry number.

Ceiling limit. Some very hazardous chemicals are characterized by a ceiling limit in addition to a permissible exposure limit (PEL) or threshold limit value (TLV) (see below). The ceiling limit is a concentration in parts per million (ppm) or milligrams per cubic meter (mg/m^3) that must not be exceeded in a specified time period, typically 15 minutes.

Chemical name. Usually, the International Union of Pure and Applied Chemistry (IUPAC) or CAS chemical name is given, but a trade or common name for the chemical may be given instead (e.g., "ethylene glycol" is acceptable instead of the IUPAC name, "1,2-ethanediol").

Composition of mixtures. This includes all hazardous components present in concentrations greater than 1% and all carcinogens in concentrations greater than 0.1%.

Control measures. Lists types of protective clothing, gloves, and respiratory protection. If the material should be handled in a laboratory hood, in a glovebox, or with extra ventilation, that recommendation might be stated under this heading. (Note that use of most respirators requires training and an examination by a physician.)

Fire and explosion hazard data. The information in this section usually includes the following:

Flash point. The lowest temperature at which the vapor of the chemical can be ignited by a flame when the chemical is slowly heated in a special apparatus. Several methods exist to establish the flash point; the method used should be specified but often is not.

Autoignition temperature. The lowest temperature at which a chemical ignites spontaneously in the air.

Flammable limits. All volatile flammable chemicals have minimum and maximum vapor concentrations in air below and above which they cannot be ignited.

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.

[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 authorities opine that to protect against overexposure, one should rely on the TLV limits rather than the PEL limits.

Danger signifies that the hazards can cause serious injury (e.g., blindness, loss of a limb) or death.
Warning signifies that the hazards can cause less than serious injuries.
Caution warns users to be careful when using, handling, or storing the chemical.

Labels

Almost all of the labels on the bottles of chemicals you will use conform to the requirements of the current edition of the voluntary ANSI Standard for Hazardous Industrial Chemicals—Precautionary Labeling, Z129.1. This standard requires that every label contain

- the name of the chemical that is in the labeled container;
- one of three signal words, Danger, Warning, or Caution (see box), to indicate the relative degree of severity of the hazard(s) of the chemical;
- the principal foreseeable hazard(s) the chemical presents when used in the industrial workplace;
- the precautionary measures that will protect users from the harmful effects of those hazards;
- first aid instructions if the measures described could mitigate or prevent further serious injury before professional medical assistance is available;

[7]Additional details not pertinent to this discusion are desribed in 29 CFR 1910.1000.

- 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 irreversible toxic effects on the body. These substances are hazardous when inhaled, swallowed, or in contact with the skin, and in sufficient quantities may lead to death. Usually, but not always, there will be a skull and crossbones on the label.	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	Catches fire spontaneously upon exposure to air.	Only expose to air if you have taken suitable precautions beforehand.
Reproductive hazard	A teratogen or mutagen.	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	Can cause an allergic reaction on a second, third, or later exposure.	Avoid the first exposure.
Skin	A notation for substances that can be absorbed directly through intact skin and produce toxic effects.	Do not allow contact with skin, eyes, or clothing. In case of skin contact, immediately flush the affected area.
Teratogen	Causes birth defects and/or fetal death and can affect fetal development.	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	Hazardous to health when inhaled, swallowed, injected, or in contact with the skin. Can cause serious damage in a short or prolonged exposure.	Avoid all contact with the body. Do not breathe vapors, dust, or mist. When using or handling, use suitable protective equipment.

Use with adequate ventilation	Inhaling the vapors, mist, or dust of this chemical can be harmful.	Keep the concentration of this chemical in your breathing air below the PEL or TLV (whichever is lower). Unless you know that the ventilation in the laboratory is sufficient to maintain the concentration in your breathing air below the PEL or TLV, use and handle this chemical 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.

The Properties of Chemicals

In addition to safety matters, MSDSs provide other useful information. You can learn about solubilities, volatility, and other properties and how manufacturers classify chemicals. The possibilities are only limited by the time and energy you wish to expend in studying the details in many MSDSs.

Learning Chemistry from an MSDS

The practical information found in the reactivity section of an MSDS can be useful when you plan an experimental procedure. For example, you can use the section of an MSDS that describes chemical reactivity, which includes information on the incompatibility of chemicals, as the basis for practical decisions involving the handling of chemicals.

Thus, if you plan to add acetic acid to chromic oxide, nitric acid, perchloric acid, potassium permanganate, or some other oxidizing agent as part of an experimental procedure, you can learn from the MSDSs for the acetic acid and other chemicals you plan to use that the reaction will be vigorous; if the quantities are not minimized, the vigor of the reaction could be disastrous. You could discover that you shouldn't mix a waste containing acetic acid with a waste containing nitric acid. If you had to bring together acetic acid and any one or more of its incompatible compounds, you now know that it would be important to carefully control experimental conditions. With respect to safe storage, you learn from the reactivity section that acetic acid should not be stored near chromic oxide, nitric acid, perchloric acid, potassium permanganate, or any other oxidizing agent.

Another example: differing solubilities in water. Which chemicals are soluble in water? All nitrates, but only some chlorides and sulfides. Some of the insoluble chlorides are slightly soluble in warm water, others are not. The solubility of some sulfides varies depending on the pH. Knowledge of differing solubilities in water and other solvents is useful to analytical chemists.

Some salts are neutral, others are acidic or basic. Look for these details and others in the MSDSs for the chemicals you use. The properties of chemicals are unique and differ for many reasons. Remembering these reasons is useful to serious students of chemistry.

Classifying Hazardous Chemicals

There are millions of individual chemicals, and each has its own hazardous character-

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.

Class	Examples
Oxidizing agents	Nitrates, permanganates, chromates
Reducing agents	Hydrogen, carbon, hydrocarbons, organic acids
Corrosive chemicals	Strong and some weak acids and bases, halogens
Water-reactive chemicals	Alkali metals, some hydrides, phosphides, carbides
Air-reactive chemicals	Alkali metals
Highly toxic chemicals	Carcinogens, cyanides, phenol
Less toxic chemicals	Ethanol, *n*-hexane, acetic acid
Self-reactive chemicals	Picric acid, TNT, diazo compounds
Incompatible pairs*	Acid vs base, oxidizing agent vs reducing agent

*Appendix 2 lists a few examples of incompatible pairs of compounds, and examples of pairs of compounds that, if allowed to react with each other, will produce harmful toxic products. For a complete list of all such known pair combinations, see *Bretherick's Handbook of Reactive Chemical Hazards;* Urben, P. G.; 6th ed.; Butterworth-Heinemann: London, 2000; book and CD-ROM.

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 organic solvent vapors include dizziness, slurred speech, unconsciousness and, rarely, death. Typically affected are the central nervous system, the liver, and the kidneys. Avoid skin contact with these liquids. When present in your breathing air, their vapors must be at concentrations less than the PEL or TLV, whichever is lower.

A few organic solvents (e.g., ethers, some non-aromatic unsaturated cyclic hydrocarbons) can form potentially explosive peroxides. These solvents are particularly dangerous if they are evaporated close to dryness. Your instructor can provide details. Always consult the MSDS before proceeding with laboratory work involving any organic solvent.

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 vapor passes through the paper or cloth bag. Such redispersed mercury vapor or aerosol droplets would spread the vapor contamination further. Call your instructor for help; a mercury clean-up unit is necessary to properly clean up the spill. Mercury spilled into floor cracks can be made nonvolatile by amalgamation with zinc dust or finely powdered tin—that is, if you could ever be sure that the particles of metal will penetrate far enough into narrow cracks to reach the very tiny mercury droplets.

Strong bases. These substances are all corrosive and can cause serious, destructive chemical burns, including blindness. Strong bases are insidious; even a concentrated solution of a strong base often causes no pain until the corrosive damage is quite severe. Although correctly classified as "dilute," saturated solutions of strong bases, such as $Ca(OH)_2$, also are extremely corrosive.

Formaldehyde. Formaldehyde is a colorless, water-soluble, pungent, and irritating gas. It is typically available as "formalin," an aqueous solution of formaldehyde at concentrations varying from 37 to 56% and often also containing up to 15% methanol. Formaldehyde is also sold in a polymeric form called "paraformaldehyde." Paraformaldehyde decomposes into the monomer on heating. Inhalation of formaldehyde vapors from formalin or paraformaldehyde can result in severe irritation of the upper respiratory tract and lead to edema.

Do not breathe formaldehyde vapors; they are suspected to be carcinogenic and are

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.

3. Recommended Laboratory Techniques

Working with Chemicals and Apparatus

Following these recommendations will help make your work easier and equipment use safer.

- Plan your work before starting a laboratory procedure. Be sure you know what to do if you or another laboratory worker has an accident.
- Keep your workspace free of clutter.
- Set up clean, dry apparatus, firmly clamped and away from the edge of the lab bench, paying attention to the proximity of reagent bottles to burners and to other workers and their equipment. Choose sizes that can properly accommodate the operation to be performed, allowing at least 20% free space.
- Except for glass tubing, stirring rods, and graduates, use borosilicate glassware (e.g., Pyrex). Examine your glassware closely for flaws such as cracks and chips. Damaged glassware should be repaired (see your instructor) or discarded in a waste container labeled for broken glass.
- Other equipment also should be free of flaws such as cracks, chips, frayed wire, and obvious defects. Check with your instructor if you have questions.
- A properly placed pan under a reaction vessel or container will act as a secondary containment to confine spilled liquids in the event of glass breakage.
- Use shields when working with reactive mixtures. Place the shields in suitable positions to protect yourself and others. Be sure that the shields are stabilized with weights or fasteners so that they cannot be knocked over. Also wear both eye and face protection when using shields.
- When working with flammable gases or liquids:
  - Do not allow burners or other ignition sources in the vicinity unless your instructor directs otherwise.
  - Use appropriate traps, condensers, or scrubbers to minimize release of material to the environment.
  - If you will be using a hot plate or heating mantle, do not proceed with your laboratory work until you know the autoignition temperatures of the chemicals likely to be released and can ensure that the temperatures of all exposed surfaces are less than those autoignition temperatures.
  - Make certain that the temperature control device and the stirring/ventilating motor (if present) do not spark.
- Whenever possible, use an enclosed, nonsparking electric heater or hot plate or use steam in place of a gas burner. Use only nonsparking motors (e.g., air motors) in the chemical laboratory when flammables are present.
- Support and orient large separatory funnels so that the stopcock will not be loosened by gravity. Use retainer rings on stopcock plugs.
- Use securely positioned clamps to support condensers; secure attached water hoses with wire or clamps.
- Secure stirrer motors and vessels firmly to maintain proper alignment. Magnetic stirring is preferable, except for viscous materials.
- Position apparatus that is attached to a ring stand so that the center of gravity of the system is over the base and not to one side. Arrange the apparatus so that burners and baths can be removed quickly. Standards bearing heavy loads should be firmly

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:

- Ethyl ether (3 and 4)
- Acetone (3 and 4)
- Butanone (3 and 4)

Of course, other liquids that are both quite flammable and volatile (3 and 4) are unsuitable for use as cooling bath liquids. One of these would be a better choice:

- 60% Ethylene glycol, 40% water (2)
- 60% Propylene glycol, 40% water (2)
- Isopropyl alcohol (3)
- Ethanol (1 and 3)

After selecting a liquid, add a few small pieces of dry ice one at a time, or add the liquid in small increments to dry ice. Either way, wait for the foaming to stop before proceeding with the next addition.

Cryogenic Liquid Cooling Baths and Cold Traps

Exercise caution when using liquid cryogenic coolants. Follow the precautions described in the MSDS for the cryogenic liquid you will be using. Be aware that very low temperature coolants, such as liquid nitrogen, will condense oxygen from the air on standing and can then cause an explosion if they come in contact with combustible materials. These precautions are essential:

- Use gloves and face shields. Immerse the object to be cooled slowly to avoid too vigorous boiling and overflow of the coolant.
- Use only properly vented containers when handling cryogenic liquids.
- Glass Dewar flasks should be made of borosilicate glass and protected by covering with cloth-backed friction or duct tape or by encasing in a metal sheath to contain flying pieces in the event of implosion.
- The edge of a glass Dewar flask is fragile. Avoid pouring cold liquid onto the edge of a glass Dewar flask when filling because the flask may break and implode. For the same reason, do not pour a cryogenic liquid out of a glass Dewar flask; use a siphon. Consider using a metal or plastic Dewar flask to eliminate this problem.
- Never use a household Thermos bottle or other insulated container in place of a Dewar flask. Thermos bottles and other insulated containers are designed to keep consumable liquids cold; they are not sturdy enough for laboratory use.

Working with Reduced Pressure

Protect vacuum desiccators by covering with cloth-backed friction or duct tape or by enclosing in a sturdy box or in an approved shielding device to restrict flying fragments in case of an implosion. Store only chemicals being dehydrated or protected from moisture in a desiccator. Before opening a desiccator that is under reduced pressure, make sure that atmospheric pressure has been restored. Occasionally, a vacuum desiccator lid will be found to be "frozen" after atmospheric pressure has been restored. Try using a single-edge razor blade as a wedge; tap it gently with a wooden block to loosen the lid.

Surround apparatus that is under reduced pressure with shielding. If you use vacuum pumps, place a cold trap between the apparatus and the vacuum pump so that volatiles from a reaction or distillation neither get into the pump oil nor out into the

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 induce an explosion in the hot system. Pure nitrogen or other inert gas is preferable to air during distillation and for cooling the system.

4. Safety Equipment and Emergency Procedures

General Information

Chemistry laboratories are equipped with one or more eyewash fountains and safety showers. Each person who uses such laboratories must be familiar with the locations of this equipment and know how to use it. Properly equipped laboratories will also have fire extinguishers; do not attempt to use a fire extinguisher unless you have been trained in its use by a qualified firefighter.

Your laboratory has a plan for everyone to follow if an evacuation is necessary. Be sure that you know both the main and the alternate evacuation routes as well as the procedures for assembling outside the building and accounting for each person who was in the laboratory.

In case of an emergency, as much as possible, follow procedures that have been established and that you have practiced. The first and most important step in any emergency procedure is this:

Before you help another person, evaluate the potential danger to yourself. If you try to help and are injured, you cannot be of much further help to someone else.

When an emergency occurs, the following actions are recommended:

- Report the nature and location of the emergency to your instructor and, if necessary, to the appropriate fire or medical facility. State your name, your location, and the telephone number of the telephone you are using. Tell where you will meet the emergency vehicle. If individuals are involved, report how many; whether they are unconscious, burned, or trapped; whether an explosion has occurred; and whether there is or has been a chemical or electrical fire.
- Tell others in the area about the nature of the emergency.
- Do not move any injured individuals unless they are in immediate danger from chemical exposure or fire. Keep them warm. Unnecessary movement can severely complicate neck injuries and fractures.
- Meet the ambulance or fire crews at the place you indicated. Send someone else if you cannot go.
- Do not make any other telephone calls unless they relate directly to the control of the emergency.

Fires

Fire Prevention

The best way to fight a fire is to prevent it. You can prevent fires and reduce their severity considerably through proper housekeeping and thoughtful reflection about what you are doing. This includes

- maintaining unobstructed aisles and exits,
- storing only limited quantities of flammable material,
- promptly disposing of waste, and
- separating flammable liquids from combustible materials, such as cardboard boxes and paper towels.

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.
- Activate the fire alarm. Notify co-workers and your instructor. Call the fire department.
- If the fire is burning over an area too large for the fire to be suffocated quickly and simply, everyone should evacuate the area except those trained and equipped to fight fires. Use the stairs to leave the building, do not use the elevators. Follow evacuation procedures that have been established and that you have practiced during prior fire drills.
- It is easy to underestimate a fire. *Never* attempt to use a fire extinguisher unless you have been trained in its use and know that it is likely to extinguish the fire. If you have been trained in the use of a fire extinguisher, locate yourself between the fire and an escape route (e.g., a door) and fight the fire from this position, but be sure you can escape. Small fires just starting often can be extinguished, but not always. If not extinguished, a fire can quickly threaten your life and those of your co-workers.

Personal Injuries Involving Fires

When a person's clothing is on fire, you may need to lead him or her to the safety shower. Some people instinctively run randomly if their clothes are on fire, which fans the flames and increases their injuries. If possible, stop an individual from running.

If the shower is not readily available, douse the individual with water. Get him or her to stop, drop, and roll; that is, to lie down and roll to put out the fire. Then, try to extinguish any small, still-burning flames by patting them out. Beat out the flames around the head and shoulders, then work downward toward the feet. Next, cover the victim with a coat, blanket, or whatever is available but leave the head uncovered. Do not use fire blankets until the fire is extinguished.[8] While wearing gloves if necessary, remove any clothing contaminated with chemicals. To prevent contamination of the eyes, use scissors when removing pullover shirts or sweaters. Place clean, wet, cold cloths on burned areas. Wrap the victim to avoid shock and exposure. Get medical attention promptly.

[8]If the victim is standing, wrapping the body with a fire blanket or other material can force flames toward the face and neck and, if wrapped tightly, can press melted globs of what once was polymeric clothing fabric into the flesh, thereby accentuating the severity of injury to the victim.

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.

For splashes into the eye, immediately flush the eye with temperate potable water from a gently flowing source for at least 15 minutes. Use your thumb and forefinger to hold your eyelids away from the eyeball, move your eyes continuously—up and down and sideways—to flush out thoroughly behind the eyelids and behind the eyeball itself. An eyewash fountain should be used, but if one is not available, injured persons should be placed on their backs and water gently poured into the corners of their eyes for at least 15 minutes. After any first aid treatment to the eyes, promptly visit a member of a medical staff or an ophthalmologist who is acquainted with the management of chemical injuries to the eyes.

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

Other Personal Injury Accidents

Anyone overcome with smoke or fumes should be removed to fresh air and treated for shock. Remember to evaluate and describe the possibility of harm to the rescuer before the rescuer enters or continues to remain in a toxic environment.

If hazardous chemicals have been ingested, follow the first aid treatment shown on the label or in the MSDS. Never give anything by mouth to an unconscious person. Attempt to learn exactly what substances were ingested and inform the medical staff promptly (perhaps while the victim is en route to a hospital). Refer to the MSDS for information regarding treatment.

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 absorbent retaining material. Commercially available or homemade spill control kits can be useful. If possible, use an absorbent material that will neutralize the liquids (limestone or sodium carbonate for acids, sodium thiosulfate solution for bromine, etc.). Commercial absorbents (e.g., Oil-Dri and Zorb-All), vermiculite, or small particles (about 30 mesh) of kitty litter or other satisfactory clay absorbents can be used. Dry sand is less effective.

Use a dustpan and brush, and wear protective gloves to clean up dry spills and liquid spills that have been absorbed by an absorbent. Wear leather or other protective gloves when cleaning up broken glass. Then, while wearing protective gloves, clean the contaminated area with soap and water, and mop it dry. Place a warning sign that says "Wet and slippery floor," or sprinkle some absorbent on the spot. However, note that vermiculite, kitty litter, and some other absorbents can create a slipping hazard if scattered on a wet surface.

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.

Appendix 2. Incompatible Chemicals

Use this table only as a guide. Specific incompatibilities are listed in MSDSs. Consult *Bretherick's Handbook of Reactive Chemical Hazards* (Urben, P. G.; 6th ed.; Butterworth-Heinemann: London, 2000; book and CD-ROM) for an extensive listing and thorough discussion of chemical incompatibilities.

Chemical	Incompatible with
Acetic acid	Oxidizing agents, e.g., chromic acid, nitric acid, hydroxyl compounds, ethylene glycol, perchloric acid, peroxides, permanganates
Acetone	Nitric acid, sulfuric acid, other oxidizing agents
Acetylene	Chlorine, bromine, copper, fluorine, silver, mercury
Alkali and alkaline earth metals	Water, carbon tetrachloride, other chlorinated hydrocarbon compounds, carbon dioxide, halogens
Ammonia (anhydrous)	Mercury (e.g., in manometers), chlorine, calcium hypochlorite, iodine, bromine, hydrofluoric acid
Ammonium nitrate	Acids, powdered metals, flammable liquids, chlorates, nitrites, sulfur, finely divided organic or combustible materials
Aniline	Nitric acid, hydrogen peroxide
Arsenical materials	Reducing agents
Azides	Acids
Bromine	See Chlorine
Calcium oxide	Water
Carbon (activated)	Calcium hypochlorite, other oxidizing agents
Chlorates	Ammonium salts, acids, powdered metals, sulfur, finely divided organic or combustible materials
Chlorine	Ammonia, acetylene, butadiene, butane, methane, propane (or other petroleum gases), hydrogen, sodium carbide, benzene, finely divided metals, turpentine
Chlorine dioxide	Ammonia, methane, phosphine, hydrogen sulfide
Chromium trioxide (chromic acid)	Acetic acid, naphthalene, camphor, glycerol, alcohol, flammable liquids
Copper	Acetylene, hydrogen peroxide
Cyanides	Acids

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

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