

Laboratory Safety

Introduction

Safety is a collective responsibility that requires the full cooperation of everyone in the laboratory. However, the ultimate responsibility for safety rests with the person carrying out a given procedure. In the case of an academic laboratory, that person is usually the student. Accidents often result from an indifferent attitude, failure to use common sense, or failure to follow instructions. Each student should be aware of what the other students are doing because all can be victims of one individual's mistake. Do not hesitate to point out to other students that they are engaging in unsafe practices or operations. If necessary, report it to the instructor. In the final assessment, students have the greatest responsibility to ensure their own personal safety.

This guide provides a list of do's and don'ts to minimize safety and health problems associated with experimental laboratory work. It also provides, where possible, the ideas and concepts that underlie the practical suggestions. However, the reader is expected to become involved and to contribute to the overall solutions. The following are general guidelines for all laboratory workers:

- 1) Follow all safety instructions carefully.
- 2) Become thoroughly acquainted with the location and use of safety facilities such as safety showers, exits, and eyewash fountains.
- 3) Become familiar with the hazards of the chemicals being used, and know the safety precautions and emergency procedures before undertaking any work.
- 4) Become familiar with the chemical operations and the hazards involved before beginning an operation.

Personal Protection

Eye Protection

All people in the laboratory including visitors must wear eye protection at all times, even when not performing a chemical operation. Wearing of contact lenses in the laboratory is normally forbidden because contact lenses can hold foreign materials against the cornea. Furthermore, they may be difficult to remove in the case of a splash. Soft contact lenses present a particular hazard because they can absorb and retain chemical vapors. If the use of contact lenses is required for therapeutic reasons fitted goggles must also be worn. In addition, approved standing shields and face shields that protect the neck and ears as well as the face should be used when appropriate for work at reduced pressure or where there is a potential for explosions, implosions, or splashing. Normal prescription eyeglasses, though meeting the Food and Drug Administration's standards for shatter resistance, do not provide appropriate laboratory eye protection.

Clothing

Clothing worn in the laboratory should offer protection from splashes and spills, 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. Lab jackets or coats should have snap fasteners rather than buttons so that they can be readily removed.

High-heeled or open-toed shoes, sandals, or shoes made of woven material should not be worn in the laboratory. Shorts, cutoffs, and miniskirts are also inappropriate. Long hair and loose clothing should be constrained. Jewelry such as rings, bracelets, and watches should not be worn in order to prevent chemical seepage under the jewelry, contact with electrical sources, catching on equipment, and damage to the jewelry.

Gloves

Gloves can serve as an important part of personal protection when they are used correctly. Check to ensure the absence of cracks or small holes in the gloves before each use. In order to prevent the unintentional spread of chemicals, gloves should be removed before leaving the work area and before handling such things as telephones, doorknobs, writing instruments, computers, and laboratory notebooks. Gloves may be reused, cleaned, or discarded, consistent with their use and contamination.

A wide variety of gloves is available to protect against chemical exposure. Because the permeability of gloves of the same or similar material varies from manufacturer to manufacturer, no specific recommendations are given here. Be aware that if a chemical diffuses through a glove, that chemical is held against the worker's hand and the individual may then be more exposed to the chemical than if the glove had not been worn.

Personal Hygiene

Everyone working in a chemistry laboratory should be aware of the dangers of ingesting chemicals. These common sense precautions will minimize the possibility of such exposure:

- 1) Do not prepare, store (even temporarily), or consume food or beverages in any chemical laboratory.
- 2) Do not smoke in any chemical laboratory. Additionally, be aware that tobacco products in opened packages can absorb chemical vapors.
- 3) Do not apply cosmetics in a laboratory.
- 4) Wash hands and arms thoroughly before leaving the laboratory, even if gloves have been worn.
- 5) Wash separately from personal laundry, lab coats or jackets on which chemicals have been spilled.
- 6) Never wear or bring lab coats or jackets into areas where food is consumed.
- 7) Never pipette by mouth. Always use a pipette aid or suction bulb.

Laboratory Protocol

The chemistry laboratory is a place for serious learning and working. Horseplay cannot be tolerated. Variations in procedures including changes in quantities or reagents may be dangerous. Such alterations may only be made with the knowledge and approval of the instructor.

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. Work spaces and storage areas should be kept 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 ice, stoppers, glass beads or rods, other small items, and spilled liquids. Use the required procedure for the proper disposal of chemical wastes and solvents.

Cleaning Glassware

Clean glassware at the laboratory sink or in laboratory dishwashers. Use hot water, if available, and soap or other detergent. If necessary, use a mild scouring powder. Wear appropriate gloves that have been checked to ensure that no holes are present. Use brushes of suitable stiffness and size. Avoid accumulating too many articles in the cleanup area. Usually work space around a sink is limited and piling up dirty or cleaned glassware leads to breakage. Remember that the turbid water in a sink may hide a jagged edge on a piece of broken glassware that was intact when put into the water. A pair of heavy gloves may be useful for removing broken glass, but care must be exercised to prevent glove contamination. To minimize breakage of glassware, sink bottoms should have rubber or plastic mats that do not block the drains.

Avoid the use of strong cleaning agents such as nitric acid, chromic acid, sulfuric acid, strong oxidizers, or any chemical with a "per" in its name (such as perchloric acid, ammonium persulfate, etc.) unless specifically instructed to use them, and then only when wearing proper protective equipment. A number of explosions involving strong oxidizing cleaning solutions, such as chromic sulfuric acid mixtures, have been reported. The use of flammable solvents should be minimized and, when they are used, appropriate precautions must be observed.

Unattended Operation of Equipment

Reactions that are left to run unattended overnight or at other times are prime sources for fires, floods, and explosions. Do not let equipment such as power stirrers, hot plates, heating mantles, and water condensers run overnight without fail-safe provisions and the 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.

Fume Hoods and Ventilation

A large number of common substances present acute respiratory hazards and should not be used in a confined area in large amounts. They should be dispensed and handled only where there is adequate ventilation, such as in a hood. Adequate ventilation is defined as ventilation that is sufficient to keep the concentration of a chemical below the threshold limit value or permissible exposure limit.

If you smell a chemical, it is obvious that you are inhaling it. However, odor does not necessarily indicate that a dangerous concentration has been reached. By contrast, many chemicals can be present at hazardous concentrations without any noticeable odor.

Refrigerators

Chemicals stored in refrigerators should be sealed, double packaged if possible, and labeled with the name of the material, the date placed in the refrigerator, and the name of the person who stored the material. A current inventory should be maintained. Old chemicals should be disposed of after a specified storage period. Household refrigerators should not be used for chemical storage.

If used for storage of radioactive materials, a refrigerator should be plainly marked with the standard radioactivity symbol and lettering, and routine surveys should be made to ensure that the radioactive material has not contaminated the refrigerator.

Food should never be stored in a refrigerator used for chemical storage. These refrigerators should be clearly labeled "No Food". Conversely food refrigerators, which must be always outside of, and away from, the chemical work area, should be labeled "Food Only—No Chemicals".

Radioactive Materials

Radioactive materials are used in the Environmental Engineering laboratories. Doors of rooms containing radioactive materials are clearly labeled. Areas where radioactive materials are used are clearly delineated with labeling tape and signs. All equipment within areas labeled radioactive are potentially contaminated and should not be touched or removed. Do not place anything into or take anything from an area labeled radioactive.

Working Alone

Avoid working alone in a building or in a laboratory.

Use of Chemicals

Before using any chemical you need to know how to safely handle it. The safety precautions taken are dependent on the exposure routes and the potential harmful effects.

Routes of Exposure

- 1) ingestion
- 2) inhalation
- 3) absorbed through skin
- 4) eye contact

Each potential exposure route requires different precautions. Chemical exposure may have acute (immediate, short term) or chronic (long term potentially cumulative) effects. Information on health hazards can be found on chemical labels and in Safety Data Sheets.

Safety Data Sheets (SDSs)

SDS can be found online with simple search queries. MSDS provide extensive information on safe handling, first aid, toxicity, etc. The following is a list of terms commonly used in SDS:

TLV—Threshold Limit Value—are values for airborne toxic materials that are to be used as guides in control of health hazards. They represent concentrations to which nearly all workers (workers without special sensitivities) can be exposed to for long periods of time without harmful effect. TLV's are usually expressed as parts per million (ppm). TLV's are also expressed as mg of dust or vapor/m³ of air.

TDLo—Toxic Dose Low—the lowest dose of a substance introduced by any route, other than inhalation, over any given period of time and reported to produce any toxic effect in humans or to produce carcinogenic, neoplastigenic, or teratogenic effects in animals or humans.

TCLo—Toxic Concentration Low—the lowest concentration of a substance in air to which humans or animals have been exposed for any given period of time and reported to produce any toxic effect in humans or to produce carcinogenic, neoplastigenic, or teratogenic effects in animals or humans.

TDLo—Lethal Dose Low—the lowest dose (other than LD50) of a substance introduced by any route, other than inhalation, over any given period of time in one or more divided portions and reported to have caused death in humans or animals.

LD50—Lethal Dose Fifty—a calculated dose of a substance that is expected to cause the death of 50% of an entire defined experimental animal population. It is determined from the exposure to the substance by any route other than inhalation of a significant number from that population.

LCLo—Lethal Concentration Low—the lowest concentration of a substance in air, other than LC50, that has been reported to have caused death in humans or animals. The reported concentrations may be entered for periods of exposure that are less than 24 hours (acute) or greater than 24 hours (subacute and chronic).

LC50—Lethal Concentration Fifty—a calculated concentration of a substance in air, exposure to which for a specified length of time is expected to cause the death of 50% of an entire defined experimental animal population. It is determined from the exposure to the substance of a significant number from that population.

Chemical Labels

All chemicals must be labeled. Unlabeled containers of mystery chemicals or chemical solutions are a nightmare for disposal as well as a potential safety hazard. The OSHA Hazard Communication Standard and the OSHA Lab Standard have specific requirements for the labeling of chemicals. In a laboratory covered under the Lab Standard, if a chemical is designated as a hazardous material, that is having the characteristics of corrosivity, ignitability, toxicity (generally meaning a highly toxic material with an LD50 of 50 mg/kg or less), reactivity, etc., and if it is made into a solution or repackaged as a solid or liquid in a concentration greater than 1% (0.1% for a carcinogen) it needs to have a so called Right-To-Know (RTK) label that duplicates the hazard warnings, precautions, and first aid steps found on the original label. All other chemicals must have at minimum a label with the full chemical name (not just the chemical formula), concentration, and date prepared. Right-To-Know labels will be made available for your use when necessary.

National Fire Protection Association (NFPA) ratings are included to indicate the types and severity of the hazards. The NFPA ratings are on a scale of 0-4 with 0 being nonhazardous and 4 being most hazardous. The ratings are described in Table 1-1.

Table 1-1. NFPA hazard code ratings.

Code	Health	Fire	Reactivity
4	Very short exposure can cause death or major residual injury	Will rapidly or completely vaporize at normal pressure and temperature	Capable of detonation or explosive reaction at normal temperatures and pressures
3	Short exposure can cause serious temporary or residual injury	Can be ignited under almost all ambient temperatures	Capable of detonation or explosive reaction but requires a strong initiating source or must be heated under confinement before initiation
2	Intense or continued exposure can cause temporary incapacitation or possible residual injury	Must be moderately heated or exposed to high temperature before ignition	Undergoes violent chemical change at elevated temperatures and pressures or reacts violently with water.
1	Can cause irritation but only minor residual injury	Must be preheated before ignition	Normally stable but can become unstable at elevated temperatures and pressures.
0	During a fire offers no hazard beyond combustion	Will not burn	Stable even under fire conditions.

Chemical Storage

There has been much concern, and some confusion, about the proper storage of laboratory chemicals. Here “proper” means the storage of chemicals in such a manner as to prevent incompatible materials from being accidentally mixed together in the event of the breakage of one or more containers in the storage area or to prevent the formation of reactive vapors that may require vented chemical storage areas. Below is a concise guide to the storage of common laboratory chemicals.

- 1) Perchloric acid is separated from all other materials.
- 2) Hydrofluoric acid is separated from all other materials.
- 3) Concentrated nitric acid is separated from all other materials.
- 4) Highly toxic materials (LD_{50} of 50 mg/kg or less) are stored separately.
- 5) Carcinogenic chemicals are stored separately.
- 6) Inorganic acids (except for 1, 2, 3 above) are stored separately.

- 7) Bases are stored separately.
- 8) Strong oxidizing agents are stored separately.
- 9) Strong reducing agents are stored separately.
- 10) Water reactive, pyrophoric and explosive materials are stored separately.
- 11) Flammable organic materials (solvents, organic acids, organic reagents) are stored separately.

Guidelines for separating incompatible chemicals:

- 1) Place the chemicals to be stored separately in a heavy gauge Nalgene (or similar plastic) tub. Plastic secondary containers must be compatible with the material being stored.
- 2) Strong acids, especially perchloric, nitric, and hydrofluoric are best stored in plastic containers designed to store strong mineral acids. These are available from lab equipment supply houses.
- 3) Bottle-in-a-can type of containers are also acceptable as secondary containment. Small containers of compatible chemicals may be stored in a desiccator or other secure container. Secondary containment is especially useful for highly toxic materials and carcinogens.
- 4) Dry chemicals stored in approved cabinets with doors may be grouped together by compatibility type on separate shelves or areas of shelves separated by taping off sections of shelving to designate where chemicals of one type are stored. Physically separated cabinets may be used to provide a barrier between groups of stored incompatible chemicals. Strong mineral acids may be stored in one cabinet and strong bases stored in a second cabinet, for example. Flammable solvents should be stored in a rated flammable storage cabinet if available.

If you are uncertain of the hazardous characteristics of a particular chemical refer to the SDS for that material. A good SDS will not only describe the hazardous characteristics of the chemical, it will also list incompatible materials.

Transporting Chemicals

Transport all chemicals using the container-within-a-container concept to shield chemicals from shock during any sudden change of movement. Large containers of corrosives should be transported from central storage in a chemically resistant bucket or other container designed for this purpose. Stairs must be negotiated carefully. Elevators, unless specifically indicated and so designated, should not be used for carrying chemicals. Smoking is never allowed around chemicals and apparatus in transit or in the work area itself.

When moving in the laboratory, anticipate sudden backing up or changes in direction from others. If you stumble or fall while carrying glassware or chemicals, try to project them away from yourself and others.

When a flammable liquid is withdrawn from a drum, or when a drum is filled, both the drum and the other equipment must be electrically wired to each other and to the ground in order to avoid the possible buildup of a static charge. Only small quantities should be

transferred to glass containers. If transferring from a metal container to glass, the metal container should be grounded.

Chemical Disposal

The Environmental Protection Agency (EPA) classifies wastes by their reaction characteristics. A summary of the major classifications and some general treatment guidelines are listed below. Specific information may be found in the book, *Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards* (National Academies Press, 2011), as well as other reference materials.

Ignitability: These substances generally include flammable solvents and certain solids. Flammable solvents must never be poured down the drain. They should be collected for disposal in approved flammable solvent containers. In some cases it may be feasible to recover and reuse solvents by distillation. Such solvent recovery must include appropriate safety precautions and attention to potentially dangerous contamination such as that due to peroxide formation.

Corrosivity: This classification includes common acids and bases. They must be collected in waste containers that will not ultimately corrode and leak, such as plastic containers. It often may be appropriate to neutralize waste acids with waste bases and where allowed by local regulations, dispose of the neutral materials via the sanitary sewer system. Again, the nature of the neutralized material must be considered to ensure that it does not involve an environmental hazard such as chromium salts from chromic acid neutralization.

Reactivity: These substances include reactive metals such as sodium and various water reactive reagents. Compounds such as cyanides or sulfides are included in this class if they can readily evolve toxic gases such as hydrogen cyanide. Their collection for disposal must be carried out with particular care. When present in small quantities, it is advisable to deactivate reactive metals by careful reaction with appropriate alcohols and to deactivate certain oxygen or sulfur containing compounds through oxidation. Specific procedures should be consulted.

Toxicity: Although the EPA has specific procedures for determining toxicity, all chemicals may be toxic in certain concentrations. Appropriate procedures should be established in each laboratory for collection and disposal of these materials.

The handling of reaction byproducts, surplus and waste chemicals, and contaminated materials is an important part of laboratory safety procedures. Each laboratory worker is responsible for ensuring that wastes are handled in a manner that minimizes personal hazard and recognizes the potential for environmental contamination.

Most instructional laboratories will have clear procedures for students to follow in order to minimize the generation of waste materials. Typically reaction byproducts and surplus chemicals will be neutralized or deactivated as part of the experimental procedure. Waste materials must be handled in specific ways as designated by federal and local regulations. University guidelines for waste disposal can be found in Chapter 7 of the Cornell University Chemical Hygiene Plan (available at <http://people.ccmr.cornell.edu/~cober/complete.chemical.hygiene.plan.2000.pdf>).

Some general guidelines are:

- 1) Dispose of waste materials promptly. When disposing of chemicals one basic principle applies: Keep each different class of chemical in a separate clearly labeled disposal container.
- 2) Never put chemicals into a sink or down the drain unless they are deactivated or neutralized and they are allowed by local regulation in the sanitary sewer system. [See Chemical Hygiene Plan for list of chemicals that can be safely disposed of in the sanitary sewer.]
- 3) Put ordinary waste paper in a wastepaper basket separate from the 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. It must be treated as a chemical waste.
- 4) Broken glass belongs in its own marked waste container. Broken thermometers may contain mercury in the fragments and these belong in their own special sealed "broken thermometer" container.
- 5) Peroxides, because of their reactivity, and the unpredictable nature of their formation in laboratory chemicals, have attracted considerable attention. The disposal of large quantities (25 g or more) of peroxides requires expert assistance. Consider each case individually for handling and disposal.

A complete list of compounds considered safe for drain disposal can be found in Chapter 7 of the Cornell University Chemical Hygiene Plan (available at <http://people.ccmr.cornell.edu/~cober/complete.chemical.hygiene.plan.2000.pdf>).

Disposal techniques for chemicals not found in this list must be disposed of using techniques approved of by Cornell Environmental Health and Safety. When possible, hazardous chemicals can be neutralized and then disposed. When chemicals are produced that cannot be disposed of using the sanitary sewer, techniques to decrease the volume of the waste should be considered.

References

Safety in Academic Chemistry Laboratories. A publication of the American Chemical Society Committee on Chemical Safety. Fifth edition. 1990

Cornell University Chemical Hygiene Plan: Guide to Chemical Safety for Laboratory Workers. A publication of the Office of Environmental Health, 2000. (<http://people.ccmr.cornell.edu/~cober/complete.chemical.hygiene.plan.2000.pdf>)

OSHA Laboratory Standard

One of the best books to get started with regulatory compliance is a publication from the American Chemical Society entitled, "Laboratory Waste Management. A Guidebook."

Pre-Laboratory Questions

- 1) Why are contact lenses hazardous in the laboratory?
- 2) What is the minimum information needed on the label for each chemical? When are Right-To-Know labels required?
- 3) Why is it important to label a bottle even if it only contains distilled water?
- 4) Find an SDS for sodium nitrate.
 - a) Who created the SDS?
 - b) What is the solubility of sodium nitrate in water?
 - c) Is sodium nitrate carcinogenic?
 - d) What is the LD50 oral rat?
 - e) How much sodium nitrate would you have to ingest to give a 50% chance of death (estimate from available LD50 data).
 - f) How much of a 1 M solution would you have to ingest to give a 50% chance of death?
 - g) Are there any chronic effects of exposure to sodium nitrate?
- 5) You are in the laboratory preparing chemical solutions for an experiment and it is lunchtime. You decide to go to CTB to eat. What must you do before leaving the laboratory?