FUNDAMENTALS OF LABORATORY SAFETY

PHYSICAL HAZARDS IN THE ACADEMIC LABORATORY

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PREFACE

Fundamentals of Laboratory Safety: Physical Hazards in the Academic Laboratory contains the information most often needed by laboratory workers. It is designed to be the first-choice reference for those who require information on the general hazards in an academic laboratory. Intended for use in universities, colleges, high schools, and middle schools, the book is also suitable for individuals handling laboratory equipment and hazardous chemicals in engineering, research and development, clinical, quality control, and food science laboratories. In general, the book is an attempt to promote and improve safety in the laboratory.

Besides identifying and providing advice on how to eliminate the hazards commonly encountered in science labs, engineering labs, and even school technical shops (e.g., welding, woodworking, and metalworking), the chapters contained here discuss the general concepts of laboratory safety, safety inspections, rules of proper laboratory behavior, glassware hazards, electrical hazards, equipment hazards, biological hazards, compressed gas and cryogenic materials hazards, radiation hazards, noise hazards, laboratory ventilation, protective and emergency equipment, spills and fires, and first aid. The appendices offer information on toxicity and fire hazard rating scales, National Fire Protection (NFPA) labels, Department of Transportation (DOT) warning labels, a list of carcinogens and other hazardous laboratory substances, and the addresses and telephone numbers for NIOSH, OSHA, and EPA offices around the country.

This book and a companion volume, *Academic Laboratory Chemical Hazards Guidebook,* allow the laboratory worker (students, technicians, instructors, and scientists alike) to quickly find information on specific laboratory hazards and their management by use of the extensive table of contents and index. Both books are beneficial to workers not only in an academic science laboratory (both physical and biological), but also those in the engineering lab and even a machine shop. All these areas involve the use of hazardous materials and equipment. The goal has been to provide a volume that is more likely to contain the required information than any other single source. If the needed information is not in this book or its companion title, I have tried to direct the reader to the next best reference. I would like to thank Gene Falken for providing the spark to begin this project.

William J. Mahn

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CONTENTS

1 GENERAL CONCEPTS OF LABORATORY SAFETY

LABORATORY SAFETY PROBLEM

Safety in the laboratory requires the same kind of continuing attention and effort common to research, teaching, and analytical techniques. The use of new or different techniques, chemicals, and equipment requires careful study, instruction, and supervision. It also may require consultation with individuals having special knowledge or experience.

It should not be assumed that students, technical staff, or support personnel have adequate knowledge about laboratory safety. The information explosion makes it difficult to keep up to date on the possible consequences of exposures to laboratory chemicals and the precautions needed to control the hazards of laboratory operations. Academic training or past job experience may not have exposed one to the hazards of many of the new techniques and materials coming into use in every discipline, and we know that safety is not given adequate time or emphasis in an academic curriculum.

Too little time in laboratory courses is devoted to teaching the general principles of safety. A survey of chemistry and chemical engineering professors indicates that few include toxicology in their courses. Most believe that instruction on that subject should begin in high school and continue through college and graduate school. Generally, students are expected to acquire toxicological knowledge on their own. However, even if we began teaching students about chemical hazards we would still have a problem with those that have been trained already.

The central problems in any effort to provide general safety, chemical hazard, and toxicity information to those who need it in a laboratory setting seem to be the absence of an organized, functioning, and available repository for such information, and a general disinclination on the part of many to report hazards and toxicity information.

TYPES OF LABORATORY HAZARDS

In the laboratory, there are many sources of potential hazards. There are "routine" dangers: broken glass, knives and cutting tools, foreign bodies in the eye, falls, back injuries or hernias from improper lifting, and electrical shock. Also present are the unique hazards of corrosive, flammable, and toxic chemicals, radioactive substances, and runaway chemical reactions.

The major hazards in the laboratory arise from the following sources:

- Dangerous equipment
- Toxic chemicals
- Flammable reagents
- Explosive materials
- Radioactive substances
- Compressed gases
- Cryogenic gases

Laboratory equipment can cause burns, electrical shock, cuts, fires, and explosions.

Other health hazards arise from the toxic materials used routinely in an analytical laboratory. Toxic substances may exhibit acute or immediate toxicity, examples being cyanides, hydrogen sulfide, arsenic compounds, and iodine. Toxic materials may also exhibit chronic or long-term toxicity, examples being mercury, formaldehyde, and chromium (VI) compounds.

Flammable materials in the laboratory include many organic solvents such as methyl ethyl ketone and acetone. Many materials are explosive under the right conditions; acetylene, ethyl ether, and hydrogen are examples.

Radioactive substances are often found in analytical laboratories where they are used as sources for detectors. An example is the tritium source in electron capture gas chromatographs and x-ray absorption detectors. Radioactive tracers are very convenient in following extractions and other processes.

Compressed gases are extensively used in an analytical laboratory in conjunction with chromatographic equipment, various fields of spectrophotometry (especially atomic absorption), polarographic techniques, and other analytical methods. Cryogenic gases are also employed in superconducting experiments and some specialized analytical applications such as nuclear magnetic resonance spectroscopy.

All of the aforementioned items are required for a laboratory to perform its functions. Their hazards cannot be eliminated, only controlled and minimized.

Health and Safety Hazard Rating Scales

The health and safety hazard system described here is similar to and compatible with the hazard identification system of the National Fire Prevention Association (NFPA) in its *Hazardous Chemical Data Manual*. The system is also described in the National Institute of Occupational Safety and Health (NIOSH) manual, *Manual of Safety and Health Hazards in the School Science Laboratory*. The rating scale for both health and safety hazards uses numerals from zero to four. A rating of zero (0) for an experiment indicates relatively little hazard involved, whereas a rating of four (4) indicates a serious hazard that is potentially lethal. Health ratings are based on the toxicity or pathogenicity of materials, chemicals, and organisms; safety ratings are based on the flammability and reactivity of chemicals and materials, the nature of procedures, and the kind and nature of glassware, equipment, instruments, and small tools involved. Experiments receive overall ratings after consideration of the quantity of materials used, their mode of dispensing, and the matrix (conditions and methods of use) in which the hazardous materials exist. The following criteria are used to determine the ratings:

Toxicity of chemicals

NFPA health hazard criteria

Flammability of materials used in the experiments

NFPA reactivity of materials

Pathogenicity of biological organisms

Electrical hazard potential

Hazards from small tools and cutting instruments

Procedures involved in the experiments

Hazards in manipulating laboratory instruments and glassware

Health Ratings Based on Toxicity. When possible, a quantitative basis for the index ratings is used. Occupational Safety and Health Administration (OSHA) time-weighted average exposure data and, when available, rat oral LD_{50} or LC_{50} data are used in compiling the ratings. When this information is not available, judgment is based on other pertinent toxicological information. The bases of the health ratings are described in Table 1–1.

In all microbiology experiments, the presence of pathogens is assumed. The hazard level is assigned based on the nature of the pathogenic effects of the organism.

Safety Ratings Based on Physical Hazards. For safety ratings, a quantitative basis is more difficult to use. If the experiment uses materials rated by NFPA, then that code is used as a basis. Again, the quantity, conditions, and sample matrix are considered in arriving at a rating number, and a zero (0) to four (4) scale is used for materials, procedures, equipment, and experiments.

A rating of 4 is assigned if very dangerous materials such as those rated NFPA Code 4 are used or if very dangerous equipment is used. Effectively, this includes substances with flashpoints below 23°C, (73°F) and boiling points under 38°C (100°F); materials that form explosive mixtures with air; equipment readily capable of fatal electrical shock; equipment with exposed high-voltage circuits; and power cutting tools that are unguarded.

A rating of 3 is assigned to experiments involving materials with flashpoints between 23°C (73°F) and 38°C (100°F); materials capable of explosion but requiring a strong initiating source or needing to be heated; and equipment capable of shock, burning, and cutting with severe results.

A rating of 2 is assigned to experiments using materials that must be heated above ambient temperature before they can ignite [e.g., liquids with a flashpoint of

TABLE 1–1. Health Hazard Rating Scale

Health Hazard Rating	LD_{50}	LC_{50}
4	<50 mg/kg or carcinogen	<100 ppm
3	50–500 mg/kg	100–1000 ppm
2	500–5000 mg/kg	1000–10,000 ppm
1	>5 g/kg	>10,000 ppm

Source: Manual of Safety and Health Hazards in the School Science Laboratory, NIOSH, Cincinnati, Ohio, 1980, p. 2.

38°C (100°F) or over, but not exceeding 93°C (200°F)]; reagents that can react violently but not detonate; and power tools that are insulated and cannot cut.

A rating of 1 is assigned when experiments involve materials that must be preheated before ignition can occur. Examples include materials that must be heated to 816°C (1500°F) for 5 min before ignition can occur and liquids with flashpoints above 93°C (200°F); materials that, although usually stable, can become unstable at elevated temperature; and hand tools capable of puncturing or cutting.

A rating of 0 is assigned when there is little possibility of injury from the equipment or procedures involved. Materials used in these experiments will not burn and are not violently reactive with water or fire exposure. No dangerous equipment is used.

A summary of the scale is contained in Table 1–2. Table 1–3 gives examples of health and safety ratings for some instructional chemistry lab experiments.

Chemical Hazards

Laboratories that use chemicals have diverse goals: research, product and process development, routine analysis or education. The use and distribution of chemicals must be consistent with the goals of the laboratory. Teaching laboratories and research laboratories have different goals and, therefore, different operating conditions from other types of labs. Although the work done in teaching laboratories can usually be designed to use chemical substances that have well-known properties, work in research laboratories frequently involves chemical substances that have completely unknown properties. Teaching laboratories often involve large numbers of relatively inexperienced students, whereas research laboratories usually involve a small number of experienced investigators assisted by technicians.

Chemical hazards may be divided into six categories: flammability, instability, reactivity, corrosivity, toxicity, and radioactivity.

The risk associated with the possession and use of each specific substance is dependent on the following:

1. The knowledge and commitment to safe laboratory practices of all who handle it.

TABLE 1–3. Hazards Index for Example Instructional Chemistry Experiments

Class of Experiments	Health/Safety
Acids and bases	2/1
Chemical families	3/2
Chemical and physical change	2/2
Conductivity and ionization	2/1
Crystals	0/0
Density measurements	0/0
Equilibrium	1/1
Gas laws	4/1
Heat of reaction	2/3
Measurement	1/0
Organic chemistry	2/3
Oxidation and reduction	2/1
Qualitative analysis	0/1
Radiation chemistry	0/0
Scientific processes and procedures	0/1
Stoichiometry	2/2
Reaction rates	0/0
Solubility	2/1
Thermal chemical measurements	2/2

Source: Manual of Safety and Health Hazards in the School Science Laboratory, NIOSH, Cincinnati, Ohio, 1980, p. 5.

TABLE 1–2. Hazards Rating Scale

Scale	Health	Safety
4	Brief exposure could result in death.	Serious accident 80–100% probable. Death or serious injury very likely to result from the accident.
3	Prolonged exposure could result in death. Brief exposure could result in serious injury.	Accident 60–80% probable. Death or serious injury likely to result from the accident.
2	Prolonged exposure could result in serious injury. Brief exposure could result in mild injury.	Accident 40–60% probable. Injury may result from the accident.
1	Prolonged exposure could result in irritation or a mild injury.	Accident 20–40% probable. Slight injury may result from the accident.
0	Prolonged exposure should not result in irritation or injury.	Accident 0–20% probable. No injury should result from the accident.

Source: Manual of Safety and Health Hazards in the School Science Laboratory, NIOSH, Cincinnati, Ohio, 1980, p. 6.

2. Its physical, chemical, and biological properties.
3. The quantity received and the manner in which it is stored and distributed.
4. The manner in which it is used.
5. The manner of disposal of the substance and its derivatives.
6. The length of time it is on the premises.
7. The number of persons who work in the area and have open access to the substance.

The decision to procure a specific quantity of a specific chemical is a commitment to handle it responsibly from receipt to ultimate disposal. Each operation in which it is handled and each period between operations present opportunities for misadventure.

Have on hand and maintain up-to-date toxicological and chemical hazard data for all chemicals to be used in the laboratory, if such information is available. This information should be readily accessible to all concerned; for example, emergency personnel, safety officers, and firefighters.

The processes involved in the procurement, use, and disposal of chemicals are summarized in *Academic Laboratory Chemical Hazards Guidebook*, Chaps. 3–5. The safety coordinator and representative group must monitor these processes and make provisions for the orderly disposal of the material should circumstances such as spills or accumulation of unusable or hazardous material dictate such action.

The undeniable hazard of handling a variety of chemicals and legal requirements provide good and sufficient reasons for laboratories to bring their operations into compliance with current practice.

Handling Chemicals in the Laboratory. Chemicals occur in almost limitless (and ever-increasing) varieties. For this reason, general precautions for handling almost all chemicals are needed, rather than specific guidelines for each chemical. Otherwise, laboratory work will be needlessly handicapped, practically and economically, by attempts to adhere to a labyrinth of separate guidelines or, more likely, the laboratory worker will simply ignore the entire complex set of guidelines and, consequently, be exposed to excessive hazard.

Under the proper conditions, most chemicals can be hazardous. This book and *Academic Laboratory Chemical Hazards Guidebook* recommends chemical handling procedures that are aimed at minimizing all chemical hazards in the laboratory. In addition, special precautions for working with substances known to be flammable, explosive, or unusually toxic are described.

It is imperative that the work occurring in teaching and experimental research laboratories be differentiated from that in pilot plants and industrial manufacturing. Research in academic and industrial laboratories is carried out on a small scale and, hence, generally involves low levels of exposure of laboratory workers to chemicals. This is particularly true when the laboratory worker makes proper use of the hoods, protective apparel, and other safety devices that should be present in a well-equipped laboratory. Furthermore, in contrast to the typical industrial plant, where workers may be exposed to a limited number of substances over very long periods, the laboratory worker is exposed to a large variety of substances at low levels for brief periods of time. Finally, the professional expertise, common sense, judgment, and safety awareness of the worker performing chemical operations in the laboratory most often put him or her in the best position to judge necessary safety precautions. The problem is that all too often, that judgment is not made responsibly.

Careful attention must be paid to the appropriateness of the experimental work conducted in relation to the adequacy of the physical facilities available and the personnel involved. Once these points are established, it is the role of the safety coordinator and representative group to assist in the development of adequate guidelines for operations. For example, the ventilation facilities in a given laboratory may preclude certain kinds of work or the use of certain materials.

A continuing appraisal of safety facilities (hoods, incinerators, etc.) should be made, and modernization should be instituted whenever such facilities are judged inadequate for the work planned.

Disposal of Waste Substances. Some laboratories currently dispose of waste substances by pouring them down the drain or by placing them in drums to be buried in a landfill by an outside contractor. Such indiscriminate disposal is unacceptable and is being curtailed by a combination of local, state, and federal regulations. It is important that an institutional safety plan provide for the regular disposal of waste chemicals. Waste from individual laboratories should be removed at intervals of not more than 1 week to a central waste disposal storage area and then removed from that area at regular intervals. The most practical alternative for removal of combustible materials is to construct or contract for access to an incinerator that is capable of incinerating chemical and biological waste materials in an environmentally acceptable manner. The institutional plan for this type of disposal must include consideration of what materials can be incinerated, how they are to be collected and stored, and their mode of transport to the incinerator. See *Academic Laboratory Chemical Hazards Guidebook*, Chap. 5 for information on chemical disposal.

GENERAL RECOMMENDATIONS FOR SAFE PRACTICES IN LABORATORIES

It is impossible to design a set of rules that will cover all possible hazards and occurrences. Some general guidelines are given below that experience has shown to be useful for avoiding accidents or reducing injuries in the laboratory.

The most important rule is that everyone involved in laboratory operations, from a person at the highest administrative level to the individual worker, must be safety-minded. Safety awareness will become a habit on the part of everyone only if the issue of safety is discussed repeatedly and only if senior and responsible staff evince a sincere and continuing interest and are perceived as such by all their associates. The individual, however, must accept responsibility for carrying out his or her own work in accordance with good safety practices and should be prepared in advance for possible accidents by knowing what emergency aids are available and how they are to be used.

The supervisor of the laboratory has overall safety responsibility and should provide for regular formal safety and housekeeping inspections (at least quarterly for universities and other organizations that have frequent personnel changes and semiannually for other laboratories), in addition to continual informal inspections. Laboratory supervisors are responsible for ensuring that (1) workers know safety rules and follow them, (2) adequate emergency equipment in proper working order is available, (3) training in the use of emergency equipment has been provided, (4) information on special or unusual hazards in nonroutine work has been distributed to laboratory workers, and (5) an appropriate safety orientation has been given to individuals when they are first assigned to a laboratory space. The laboratory worker should develop good personal safety habits: (1) eye protection should be worn at all times, (2) exposure to chemicals should be kept to a minimum, and (3) smoking and eating should be avoided in areas where chemicals are present.

Advance planning is one of the best ways to avoid serious incidents. Before performing any chemical operation, the laboratory worker should consider the possibility of certain accidents or occurrences and be prepared to take proper emergency actions.

Overfamiliarity with a particular laboratory operation may result in a worker's overlooking or underrating its hazards. This attitude can lead to a false sense of security, which frequently results in carelessness. Every laboratory worker has a basic responsibility to himself or herself and colleagues to plan and execute laboratory operations in a safe manner.

General Principles

Every laboratory worker should observe the following rules:

1. Know the safety rules and procedures that apply to the work being done. Determine the potential hazards (e.g., physical, chemical, biological) and appropriate safety precautions before beginning any new operation.
2. Know the location of and how to use the emergency equipment in your area, as well as how to obtain additional help in an emergency, and be familiar with emergency procedures.
3. Know the types of protective equipment available and use the proper type for each job.
4. Be alert to unsafe conditions and actions and call attention to them so that corrections can be made as soon as possible. Someone else's accident can be as dangerous to you as any you might have.
5. Avoid consuming food or beverages or smoking in areas where chemicals are being used or stored.
6. Avoid hazards to the environment by following accepted waste disposal procedures. Chemical reactions may require traps or scrubbing devices to prevent the escape of toxic substances.
7. Be certain all chemicals are correctly and clearly labeled. Post warning signs when unusual hazards, such as radiation, laser operations, flammable materials, biological hazards, or other special problems exist.
8. Remain out of the area of a fire or personal injury unless it is your responsibility to help meet the emergency. Curious bystanders interfere with rescue and emergency personnel and endanger themselves.
9. Avoid distracting or startling any other worker. Practical jokes or horseplay cannot be tolerated at any time.
10. Use equipment only for its designed purpose.
11. Position and clamp reaction apparatus thoughtfully in order to permit manipulation

without the need to move the apparatus until the entire reaction is completed. Combine reagents in appropriate order and avoid adding solids to hot liquids.

12. Think, act, and encourage safety until it becomes a habit.

Health and Hygiene

1. Wear appropriate eye protection at all times.
2. Use protective apparel, including face shields, gloves, and other special clothing or footwear as needed.
3. Confine long hair and loose clothing when in the laboratory.
4. Do not use mouth suction to pipet chemicals or to start a siphon; a pipet bulb or an aspirator should be used to provide vacuum.
5. Avoid exposure to gases, vapors, and aerosols. Use appropriate safety equipment whenever such exposure is likely.
6. Wash well before leaving the laboratory area. However, avoid the use of solvents for washing the skin. They remove the natural protective oils from the skin and can cause irritation and inflammation. In some cases, washing with a solvent might facilitate absorption of a toxic chemical.

Food Handling

Contamination of food, drink, and smoking materials is a potential route for exposure to toxic substances. Food should be stored, handled, and consumed in an area free of hazardous substances.

1. Well-defined areas should be established for the storage and consumption of food and beverages. No food should be stored or consumed outside of this area.
2. Areas where food is permitted should be prominently marked and a warning sign (e.g., EATING AREA—NO CHEMICALS) posted. No chemicals or chemical equipment should be allowed in such areas.
3. Consumption of food or beverages and smoking should not be permitted in areas where laboratory operations are being carried out.
4. Glassware or utensils that have been used for laboratory operations should never be used to prepare or consume food or beverages. Laboratory refrigerators, ice chests, cold rooms, and such should not be used for food storage; separate equipment should be available for that use and prominently labeled.

Housekeeping

There is a definite relationship between safety performance and orderliness in the laboratory. When housekeeping standards fall, safety performance inevitably deteriorates. The work area should be kept clean, and chemicals and equipment should be properly labeled and stored.

1. Work areas should be kept clean and free from obstructions. Cleanup should follow the completion of any operation or at the end of each day.
2. Wastes should be deposited in appropriate receptacles.
3. Spilled chemicals should be cleaned up immediately and disposed of properly. Disposal procedures should be established and all laboratory personnel informed of them; the effects of other laboratory accidents should also be cleaned up promptly.
4. Unlabeled containers and chemical wastes should be disposed of promptly, by appropriate procedures. Such materials, as well as chemicals that are no longer needed, should not accumulate in the laboratory.
5. Floors should be cleaned regularly; accumulated dust, chromatography adsorbents, and other assorted chemicals pose respiratory hazards.
6. Stairways and hallways should not be used as storage areas.
7. Access to exits, emergency equipment, controls, and such should never be blocked.
8. Equipment and chemicals should be stored properly; clutter should be kept to a minimum.

Equipment Maintenance

Good equipment maintenance is important for safe, efficient operations. Equipment should be inspected and maintained regularly. Servicing schedules will depend on both the possibilities and consequences of failure. Maintenance plans should include a procedure to ensure that a device out of service cannot be restarted.

Guarding for Safety. All mechanical equipment should be adequately furnished with guards that pre-