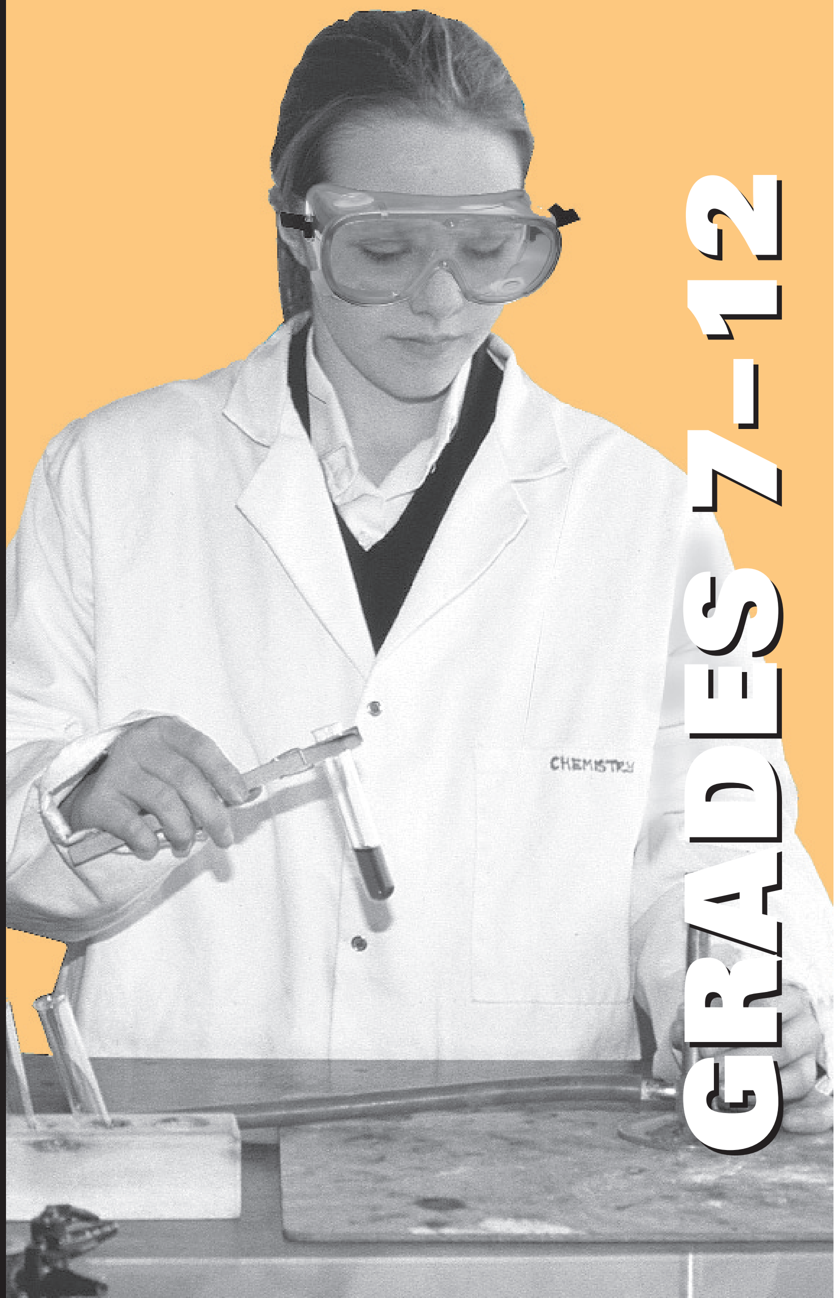
A Publication of the American Chemical Society and the ACS Board–Council Committee on Chemical Safety

Chemical Safety for Teachers and Their Supervisors



GRADES 7–12

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Grades 7–12

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Preface

Educators in grades 7–12 often have the privilege of introducing students to the chemical laboratory. Chemistry and chemicals have a central place in science, and safe chemical practices are the most basic and fundamental parts of any lesson. Having acquired good chemical safety habits early, students are better prepared when they move on to more advanced courses.

The ACS Committee on Chemical Safety is pleased to present this manual of guidelines and thanks the author, Dr. Jay Young. Dr. Young's experience and wisdom are appreciated by the Committee and are evident throughout the manual.

In addition to being available in print, this manual is available on the ACS Web site (www.acs.org) under the Committee on Chemical Safety. The Committee welcomes all comments. Please direct them to the Committee on Chemical Safety, American Chemical Society, 1155 Sixteenth Street, NW, Washington, DC 20036.

Henry C. Ramsey
Chair, ACS Committee on Chemical Safety
1998–2000

Disclaimer

This booklet contains information and guidelines that are believed to be reliable regarding the safe use and handling of chemicals in laboratories and student classrooms. The American Chemical Society (ACS), however, does not purport in this booklet, or in any other publication, to specify minimum safety or legal standards or to address all of the compliance requirements, risks, or safety problems associated with the handling of hazardous chemicals, their use, or the methods prescribed for using them in laboratories or classrooms. This booklet is intended to serve only as a beginning point for information and should not be construed as containing all the necessary compliance, safety, or warning information, nor should it be construed as representing the policy of ACS.

No warranty, guarantee, or representation is made by ACS as to the accuracy or sufficiency of the information and guidelines contained herein, and ACS assumes no liability or responsibility in connection therewith. It is the responsibility of the users of this booklet to consult and comply with pertinent local, state, and federal laws, regulations, and standards with respect to the handling of chemicals. Users of this booklet should consult with the school's legal counsel or other professional advisers about the applicable laws, safety issues, and compliance issues for storing chemicals and the methods for using the chemicals in school classrooms and laboratories.

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Introduction

All chemicals are hazardous, but they all can be used safely if we know how to control their hazardous characteristics while we use them. The suppliers of chemicals used in our schools are aware of and fulfill their responsibilities to inform their customers of the hazardous characteristics of the chemicals they provide.

Suppliers provide this information both by labels on the containers and by Material Safety Data Sheets (MSDSs) (provided separately). According to the U.S. Occupational Safety and Health Administration (OSHA) and, in some cases, corresponding state regulations,[1] it is the employer's responsibility to ensure that this important precautionary information is conveyed to teachers. Typically, a supervisor informs teachers on behalf of the principal.

The teachers inform their students what to do and what to avoid when they prepare and perform experiments that involve chemicals and when they clean up afterward.

Everyone is responsible: students, teachers, supervisors, and higher administrators. All must work together to ensure that teachers and students use and handle chemicals with appropriate care and precaution. It is the intent of this handbook to assist all those responsible, particularly supervisors and teachers, in fulfilling these responsibilities.

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[1]See *Code of Federal Regulations*, Title 29, Part 1910, Sections 1200 and 1450, or corresponding state regulations.

To School System Supervisors: How To Use This Handbook

The theme of this handbook is prevention of accidents. Preventing accidents with chemicals involves two requirements: Knowledge and the Habit of Safety.

Knowledge entails in turn understanding the particular hazardous characteristics of a chemical that will be used. Is it flammable? Is it toxic? Knowledge also means knowing what to do and what to avoid when a chemical is flammable or corrosive. Moreover, knowledge includes knowing what to do in case no precautions or inadequate precautions were taken and an accident occurs. For example, how to use a fire extinguisher or what to do if a corrosive chemical is splashed on the skin. To gain this necessary information before using these chemicals, ask the chemical hygiene officer for your school system[2] and other local resource persons for their help, read the labels, study the MSDSs; use all these sources for necessary information.

It is the responsibility of supervisors or their representatives to ensure that teachers have the necessary knowledge, and teachers have the same responsibility to their students. Supervisors and teachers should use behavioral objectives when imparting the requisite knowledge and when evaluating the results of such instruction.

Unfortunately, behavioral objectives are not well suited for the evaluation of the habit of safety. Clearly, it is *not enough* for a teacher or student to know, for example, that only a very small quantity of a chemical with hazardous reactive characteristics should be used in an experiment. It is also necessary that they in fact apply that restriction in their use of reactive chemicals because they have the habit of doing their work in a safe manner. See Part 4 for further comments on this topic.

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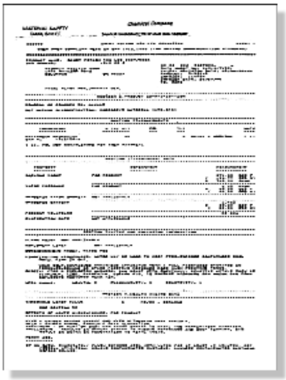
[2]Required by *Code of Federal Regulations*, Title 29, Part 1910, Section 1450, or corresponding state regulations.

1 Safety in the Use and Handling of Hazardous Chemicals



In this part, we will consider the hazards, precautions, and emergency procedures pertinent to the safe use and handling of chemicals. There are two categories to bear in mind: chemical hazards and physical hazards. But first, we need to briefly discuss labels and MSDSs.

Labels and Material Safety Data Sheets

Precautionary labels for chemicals typically present information in four parts, usually in the order described here.

First is a Signal Word: “Danger”, “Warning”, or “Caution”. Only one of the three should be used on a label. “Danger” is the strongest of the three and is used when the contents present a potential for serious foreseeable harm. “Caution” is restricted to chemicals that are foreseeably the least potentially harmful. “Warning” is for chemicals intermediate in their potential to cause foreseeable harm.

One or more Statements of Hazard follow the Signal Word. These are succinct descriptions of the major foreseeable way or ways in which the chemical could cause harm. Examples include “Flammable”, “Harmful if Inhaled”, “Causes Severe Burns”, “Poison” (with or without a skull and crossbones graphic), and “May Cause Irritation”. Chemicals that exhibit two or more hazards are labeled with a corresponding number of Statements of Hazard.

Next on the label are one or more Precautionary Measures, as appropriate. These are brief descriptions of actions to be undertaken or avoided and which, if heeded, will prevent the corresponding hazard(s) that are described by the Statements of Hazard from causing harm. Examples include “Keep Away from Heat, Sparks, and Flame”, “Use with Adequate Ventilation”, “Do Not Get in Eyes”, and “Avoid Breathing Dust”.

Usually, but not always, First Aid or other information will appear on a label below, or off to the side of, the Precautionary Measures. Typical First Aid information includes instructions such as how to induce vomiting or to *not* induce vomiting, if that is the case. Advice to wash off the skin or flush the eyes if the victim has been exposed to a corrosive chemical, how to extinguish a fire involving a chemical, and what to do if an excessive amount has been inhaled are also included.

Typically, MSDSs contain similar information, but in more detail, and frequently in a different order from that used for labels. Usually, MSDSs are not written for the layperson; they require interpretation by persons familiar with the technical terms used. Often, an over-emphasis is placed on the toxic characteristics of the subject chemical. There may also be vague or insufficient information regarding other hazards that the subject chemical presents. MSDSs vary widely in quality and reliability. Generally speaking, MSDSs from well-known, established suppliers of laboratory chemicals are likely to be better and more reliable than MSDSs from other sources. Often, a comparison of MSDSs for the same chemical from a variety of suppliers will suggest a source of MSDSs that is likely to be the most authoritative. Chemists and others who have an interest in the local school community can be resource persons to help supervisors and teachers understand the language and evaluate the content of an MSDS. The use of these resource persons is strongly encouraged.

Chemical Hazards

The hazards presented by any chemical depend upon the properties of that chemical. Each chemical is different from all others because it has properties that are different. So, it follows that each chemical presents different hazards. But to use a chemical properly, first we must know the hazards of that chemical; second, we must know and apply the appropriate precautionary measures that will reduce the probability of harm from those hazards; and third, we must know and be prepared to carry out the necessary emergency measures (should our precautions fail) that will minimize the harm, just in case.

It would seem that these requirements are formidable. How can I know that much about each of the many chemicals my students and I will use in the lab—to say nothing of teaching all this to the students?

Fortunately, there is a practical answer: classification. Chemicals present only four classes of chemical hazards:

- Flammability
- Corrosivity
- Toxicity
- Reactivity

The following sections describe each of these hazards separately. Keep in mind that any single chemical may simultaneously present more than one hazard. A few chemicals also possess physical hazards, which are discussed later. But before attending to these hazards, there is one all-important precautionary measure that requires first-place mention in any discussion of chemical hazards: eye protection.

Eye Protection

Always, when hazardous chemicals are used or handled, when glassware is used or handled, when flames are involved, all persons present, whether or not they are doing the handling or using, must wear eye protection.

Ordinary spectacles do not provide protection from chemical splashes; even spectacles with so-called hardened lenses do not provide this kind of protection. Similarly, contact lenses alone are not considered to offer sufficient protection when used without safety goggles. *Only safety goggles* (also known as chemical splash goggles) as described below and marked with the code “Z87” provide the kind of protection that is needed. The Z87 code refers to a voluntary standard promulgated by the American National Standards Institute called ANSI Z87. This standard describes several different kinds of eye and face protection, all of which can be purchased from suppliers and bear the Z87 code marking.

For example, a type of eye protection that is often and incorrectly worn as protection in a chemical environment is the type usually called "safety glasses". These are similar in appearance to ordinary spectacles and could be used in a chemical environment only if it were certain that the only hazard would be from flying fragments, not splashing liquids. In the ANSI standard, these are classified as types A, B, C, and D; the latter three have side-shields that offer partial protection against flying fragments approaching from the side. Type A only protects against a direct frontal flying fragment. None of the four, not A, B, C, or D, offer sufficient protection against splashes of liquids. All four, however, if they conform to the ANSI standard, are marked Z87.

There are two types of "safety goggles", types G and H, with no ventilation and with indirect ventilation, respectively. Only these two types are suitable for eye protection where chemicals are used and handled. Both types G and H are equipped with flexible edging so that they fit against the skin and thus protect from both flying fragments and flying splashes of liquid from all directions. Make sure that the type G or H safety goggles you and your students use are marked "Z87".

Flammability

The first chemical hazard to be discussed is flammability. Although one chemical may indeed be more flammable, say, than another,[3] the precautions and emergency treatment depend principally upon flammability itself, not the degree of flammability.

A flammable chemical (obviously) will burn. Other terms that convey the same hazard potential information include "extremely flammable" and "combustible". Keep in mind that the vapors of flammables, if ignited when mixed with air in suitable proportions (ranging from 1% to more than 50% [by volume] in some cases) can explode. Flammable solids sublime; hence, their vapors are just as hazardous as the vapors from a flammable liquid. For example, glacial acetic acid (solid or liquid, depending on the temperature) is a flammable chemical as defined here. Keep in mind also that the vapors of most flammables are denser than air and can travel 10, 20, or 30 feet, or even further. The traveling vapors mix with air as they move. Consequently, a source of ignition can be several tens of feet away from the flammable liquid and still cause a fire or explosion by igniting the vapor trail that has traveled from the flammable liquid to the ignition source.

[3]The degree of flammability of liquids or solids is numerically expressed by "flash point" (also, and more accurately, called "lower flash point"). The smaller the flash point number (expressed in degrees Fahrenheit or Celsius) the greater the degree of flammability. For example, the flash point of unleaded 87 octane gasoline is –40 ºF, compared with the less flammable kerosene, which has a flash point of +63 ºF.

Precautionary measures include the enforced absence of ignition sources, such as lighted burners, hot plates, other hot surfaces (a lighted incandescent light bulb), and sources of sparks (electrical sparks, static charge sparks, and friction sparks). Keep containers closed when not actually in use. Ensure that the air movement in the laboratory is sufficient to keep the concentration of the flammable vapor in the air well below 1%. Minimize the quantities available—usually 100 mL is more than ample for lab use. If more is necessary, provide it in separate containers, 100 mL maximum in each container. Store flammables in an approved flammable liquid storage cabinet, preferably in safety cans. Use fabric, not plastic, tape to tape glass vessels (test tubes, flasks, beakers) beforehand if they are to contain flammable gases or vapors. Otherwise, when handled by students or used by teachers in demonstrations of an exploding gas or vapor, there can be flying glass shards from the ignition of the air–gas mixture. Even with the necessary taping, conduct such demonstrations only behind a sturdy shield that will confine flying fragments.

Ask your local fire department to review your procurement, receiving, storing, handling, dispensing, use, and disposal of flammables and to make recommendations for improving safety.

Make certain in advance that the safety shower is working and that students know how to use it. Ensure beforehand that fully charged fire extinguishers are available that you (not the students) know how to operate, that there has been a recent, successful fire drill, that the fire alarm system is operating, that all persons know what the fire alarm bell sounds like, and what to do when it sounds. Students should be taught the "stop, drop, and roll" technique to be used if their clothes catch on fire elsewhere and in the laboratory taught to walk calmly to and use the safety shower to extinguish clothes that are on fire. A drill to practice these exercises is recommended.[4]

Corrosivity

A corrosive chemical either destroys living tissue or causes permanent change in such tissue through chemical action. (A chemical that corrodes iron, for example, wet salt [sodium chloride], is not corrosive under this definition—which pertains to chemical safety. Sulfuric acid will corrode iron but is also a corrosive in this safety context.) Corrosives can destroy both skin and tissues underneath the skin; corrosives destroy eyes, the respiratory system, and any other living tissue. Corrosive effects include impaired sight or permanent blindness, severe disfigurement, permanent severe breathing difficulties, even death.

Usual precautionary measures include preventing contact with skin, eyes, and the respiratory tract. Wear both safety goggles and a face shield. The face shield should be a full-face shield, large enough, and curved, to protect the whole face, neck, and ears; it, too, should bear the Z87 code mark.

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[4]The use of fire blankets for clothing fires is no longer recommended. Some contemporary clothing textiles melt as well as burn, and wrapping a fire blamket around the body serves to impress hot, molten polymer into the flesh; consequently, the healing of body burns is impaired.

Wear gloves made of a material known to be impervious to the corrosive being handled. Be sure the gloves are free of corrosive contaminant on the inside before wearing. If it is likely that bare arms will be splashed, wear sleeve gauntlets made of the same material as the gloves. Use a lab apron, made of a material known to be impervious, large enough, and sufficiently full-tailored to protect the clothing. The apron should be tied so as to protect the lower neck/upper chest and be long enough to protect the calf of the leg. Never wear shoes with open toes, or with woven leather strips, or other gaps over the toes, or with cloth-covered toes in the laboratory.

- Always store corrosives *below* eye level.
- After handling corrosive chemicals, always wash thoroughly using plenty of water.

Promptly flush splashes of corrosives off the skin with copious flowing water for at least 15 minutes. If splashed on clothing, the clothing must be removed while under a safety shower. Do not remove the clothing and then get under the shower. While under the shower, remove all clothing, including shoes, socks, wristwatch and strap, and other jewelry[5] if they are splashed with corrosives (this is no time for modesty). Stay under the shower for at least 15 minutes while someone else calls a doctor. (It helps if the water is tepid, not cold.) Make certain in advance that the safety shower is working and that students know how to use it.

A splash of a corrosive chemical in the eye is a very serious matter. Get the victim to an eyewash fountain within 30 seconds maximum, preferably even sooner. The eyewash fountain must be capable of delivering a gentle but copious flow of fresh water (preferably tepid) for at least 15 minutes to both eyes. (Most portable eyewash devices cannot meet this requirement.) Ensure in advance that safety showers and eyewash fountains are working and that students know how to use them.

While the victim is flushing the eyes for at least 15 minutes, someone else should call the doctor for further instructions. (Is the doctor's phone number already posted by the telephone?) The victim should hold both eyelids open with thumb and forefinger and roll the eyeballs up, down, left and right, continuously, so as to work the flushing water around to the back of the eyeball and wash any chemical away from the optic nerve. If the chemical destroys a portion of the optic nerve, permanent blindness ensues. If instead the chemical destroys a portion of the front of the eye, the prognosis is less pessimistic.

In all cases of contact with corrosives, take the victim to a physician for further evaluation and treatment.

Irritants are chemicals similar to corrosives except that they do not destroy tissue by chemical action. Irritants cause inflammation, itching, and so on. The effects are usually reversible but may or may not be severe or long lasting; victims should be referred to a physician.

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[5]Some authorities recommend that no jewelry, not even wristwatches, be worn in a laboratory environment.

Finally, some chemicals are sensitizers. The first exposure does not usually cause any notable symptoms. The second, or perhaps the third or fourth or more, exposure does cause symptoms because the victim has been sensitized by prior exposure(s). Poison ivy is an example of this kind of effect; some victims can be exposed several dozens of times before that next, and then often quite serious, exposure incident.

From the above discussion, it would seem that the use of corrosive chemicals in grades 7–12 should be severely limited or perhaps not used at all. Corrosive chemicals are potentially seriously harmful. There is no need for their use in pre-high school laboratory work. At that level, purchase and use diluted solutions of the strong acids and bases.[6] Other corrosives such as elemental bromine are not needed at all.

On the other hand, high school students can use corrosives if the precautions described above are followed. After all, as adults in training, older students can profit from supervised instruction in matters that would be inappropriate for less mature students.

Toxicity

Broadly speaking, there are two different toxic effects, chronic and acute. A chronic toxic effect is noted only after repeated exposures or after a single, long exposure. Commonly known chronic toxic effects include cancer and reproductive malfunctions. Acute toxic effects occur promptly upon exposure, or within a short time—a few hours at most. Methyl and ethyl alcohol are examples. Both exhibit the same acute toxic effect: inebriation. Ethyl alcohol exhibits a chronic effect: cirrhosis of the liver.

Methyl alcohol exhibits two additional acute toxic effects: blindness and death. To understand this, consider the "dose–response" phenomenon, a characteristic of all toxins, both acute and chronic: the greater the dose, the more severe the response to the toxin. Thus, *a very small* amount of methyl alcohol inebriates, a bit more causes blindness, yet a bit more is fatal. All toxic substances share this characteristic; exposure to a larger amount of the toxin is worse than exposure to a smaller amount; an exposure of longer duration has a greater toxic effect than exposure of a shorter duration.

One precautionary measure for toxins is now obvious: Minimize the exposure. Use the smallest amount of a toxin that is suitable for the purposes of an experiment. Minimize the time an experimenter will work with a toxin. Work with toxins only in a fume hood that is known to be operating properly.

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[6]For example, even dilute sodium hydroxide solutions are corrosive. Thus, 1 molar (about 4%) solutions can totally *destroy* epidermal and underlying tissue if not promptly washed off the skin; remove contaminated clothing while washing off the skin. If diluted solutions cannot be purchased, follow the precautions described in the MSDS when diluting a corrosive solution.

Toxic chemicals can enter the body in five different ways, called “routes of exposure”. The first route of exposure to be discussed is inhalation.

1. **Inhalation**. It is commonly thought that if you cannot smell a toxin, then you are not being exposed unduly. This is true for some odoriferous toxins and false for others; there is no way to tell which is which. It is especially incorrect to think that the more offensive the odor, the more toxic the substance. The safe procedure is to keep the concentration of the toxic vapor well below the “threshold limit value” (TLV). Not all toxins have been assigned a TLV value. TLVs for toxic chemicals, if a value has been assigned, are given in the MSDSs for those chemicals.

   Note that TLV values pertain to fully grown adults. Younger persons may be more susceptible to toxic exposure than fully grown adults. Therefore, in laboratory work for students in grades 7–12, it is particularly important to ensure that vapor and dust concentrations of toxics are maintained well below established TLV values. Fortunately, there are many chemicals useful for laboratory work in grades 7–12 for which this need not be a concern, because their TLV values are sufficiently high so that their expected air concentrations are well below their TLV values.

   Under certain circumstances, your employer is required to measure the concentrations of toxins in the air you breathe and to provide you, the teacher–employee, both with the results of the measurement and with consultation by a physician or other health practitioner, all at no expense to you.[7] No similar requirements have been promulgated for the protection of students or other nonemployees.

The preceding discussion has emphasized inhalation. The other four routes are:

2. **Injection**, for example, by a cut from contaminated, broken glassware or sharp knife.
3. **Absorption through intact skin**, for example, phenol splashed on the skin—which can be fatal if not promptly flushed off.
4. **Ingestion**, for example, swallowing a toxic solution.
5. **Via other body orifices**, such as the ear canal and the eyeball socket. Our eyes are a bit loose in their sockets. Vapors, mists, and fine dusts can enter the body via this route.

In addition to minimizing the exposure by using the least amount necessary for the shortest possible period of time, precautionary measures for toxins include **barriers**, **cleanliness**, and **avoidance**. Thus, one avoidance precaution is, simply, good ventilation throughout the laboratory as well as the use of fume hoods. Wearing impervious gloves is an example of a barrier precaution.

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[7]These circumstances are described in Federal OSHA regulations, 29 CFR 1910. 1200 (the “Hazard Communication” regulation) and 29 CFR 1910. 1450 (the “Occupational Exposure to Hazardous Chemicals in Laboratories” regulation), or in corresponding state regulations, usually available from your county library.

Cleanliness includes good housekeeping practices, such as minimizing dust from solid toxins, mist from liquid toxins, prompt spill cleanup, and probably most important of all, **thorough washing** of hands and arms and scrubbing under fingernails as a habitual practice before leaving the laboratory.

Further precautions involve your awareness of the most likely symptoms of toxic overexposure: headache, nausea, and dizziness. Whenever you experience any of these three while you or someone else nearby is working with a toxic chemical, get to fresh air immediately and do not return until the symptom has disappeared. If on your return the symptom recurs, leave immediately and call a physician; it is likely that you have been overexposed.

However, the absence of these or other symptoms does not necessarily indicate no exposure. In advance, read the MSDSs for the chemicals you and your students will be handling. Consult with a local physician in advance, advising him or her of the toxic chemicals used in the lab and ensure that the physician will be prepared in advance to treat victims of toxic exposures. For each toxic chemical, after reading the MSDS:

1. Evaluate the toxic risk posed to your students in their use, with precautions, of the chemical;
2. Evaluate the educational benefit to be gained if the chemical is used, with precautions, by your students; and
3. Based on the balance between risk and benefit, decide whether or not to use the chemical. (See the discussion on risks and benefits in Part 2.)

And, if you decide to use a particular chemical, be sure that you know

- whether or not, in case of ingestion, vomiting should or should not be induced,
- the symptoms of exposure to that chemical, and
- if applicable, the recommended procedure in case of unconsciousness.

Reactivity

Next, reactive hazards. Container labels do not always describe the fact that a chemical is self-reactive, for example, that it will spontaneously explode, or that if mechanically disturbed it could explode. Nor do labels always state that a chemical, if mixed with certain other chemicals, will react rapidly and release a large amount of energy. For reactivity information, refer to the MSDS for a chemical; if applicable, that information should be described in the MSDS.

Precautionary measures for self-reactive chemicals include, of course, not providing students with any such chemicals. These include picric acid, wet or dry (when dry—as it may become in students' use—picric acid can detonate when mechanically disturbed). Peroxide formers are similarly hazardous. They include metallic potassium, diethyl ether, and other ethers such as dioxane and tetrahydrofuran; their peroxides are explosively unstable when mechanically disturbed.

The other reactive hazard is reactive incompatibility. Even dilute acid is reactively incompatible with dilute base. Other combinations include oxidizing agents and reducing agents—chlorates and powdered metal, to cite one example. There are other kinds of incompatible pairs. For this, the MSDS is the usual information source.

Precautionary measures include providing reactively incompatible pairs to students only when that provision is deliberately determined by the teacher—and even then providing very small quantities, and only under direct supervision. Precautionary measures also, and emphatically, include proper storage practices. Incompatible pairs are kept separate from each other in the storage area. Above all else, never store chemicals in alphabetical order by name. Alphabetical storage leads inevitably to adjacent positions for several pairs of incompatibles.[8] Chemicals that are incompatible with common fire-fighting media—water, carbon dioxide—should be stored under conditions that minimize the possibility of reactions should it be necessary to fight a fire in the storage area. Refer to the MSDS for information on this incompatibility.

Some of the commercial suppliers of laboratory chemicals for schools have incorporated the use of color-coded labels with different colors, or alternating stripes of color, or both, on the label to indicate the manner of storage. Each different color or stripe code signifies a separate storage space; only chemicals with the same color or the same stripe coding are compatible with each other and therefore may be stored with other similarly coded chemicals. When this storage protocol is followed, incompatible chemicals are well separated from each other. Unfortunately, different laboratory chemical suppliers use differing color codes. When storing chemicals from different suppliers, be aware that a chemical coded with a green stripe, say, from supplier X may or may not be compatible with a green stripe-coded chemical from supplier Q. Consult both suppliers' MSDSs for clarification.

Physical Hazards

We come now to our last hazard category, physical hazards. Some physical hazards are associated with chemicals, some with objects, and some with people. A physical hazard that once was quite common among teachers of chemistry was their tendency to accept donations of chemicals from well-meaning donors. An example of a physical hazard that is associated with some chemicals is slipperiness. Concentrated sulfuric acid is very slippery. It is reported to be impossible to remain standing in the middle of a spill of this acid.

Radiation from radioactive species is a physical hazard. Dry ice can cause freeze burns and is another example of a chemical with a physical hazard. Various nonchemical physical hazards include loose clothing (sleeves, blouses, neck ties), loose long hair, bulky jewelry, horseplay, hot surfaces, and unattended but still-lit Bunsen burners. Readers can supply their own additional examples. For all of these, the precautionary measures are obvious.

[8]The reference manual in the catalog from Flinn Scientific, Inc., Batavia, IL 60510 (www.flinnsci.com), contains useful chemical storage information.

2 Teaching Safety to Our Students and Other Safety Considerations

Part 1 describes chemical hazards, precautionary measures, and the handling of emergencies. Here, we discuss the most important topic: our students.

Risks versus Benefits

We have already alluded to our theme: Help students participate in chemical safety. As we know, any human activity carries with it some risk of harm. If we are prudent, we minimize the probability of harm by taking appropriate precautions. Often without being fully aware of it, we also make a risk benefit decision: I will take a bath because the benefits of bathing outweigh the risk of slipping, falling, and breaking my neck in the bathtub.

As teachers, it is our responsibility to weigh the risks and benefits inherent in lab work. We cannot pass off a portion of our responsibility by involving students in our decisions. We must instruct our students in the process of evaluating risks and benefits, and we can ask for their creativity by seeking their contributions on minimizing risks.

The technique to obtain student involvement is obvious. To have a safe lab, it is necessary to inform the students of the hazards and precautions involved in the assigned lab work. Involve students in a discussion of these matters. Encourage their participation. Guide their discussion toward the correct conclusions for safe work. They will be better able to learn how to work safely and develop their individual sense of responsibility and good habits for the safe handling and use of chemicals. And they just might have some ideas about how to balance risks and benefits that are better than my ideas and yours.

Accident/Incident Records

If an accident/incident happens, no matter how minor, it can be used to improve your lab safety, again via student participation.

Some teachers prefer to use a predesigned format for accident/incident reporting. For example, they suggest that by keeping records over the years one can pinpoint particular causes of accidents and that it is easy to collect such statistics from a standard format. Then, if we discover that over the years, 61.5% of students have had big lumps on their left elbows, we can discern the cause. That sharp left turn everyone must make just inside the door when entering the lab has caused many students to hit their left elbow on the protruding bulletin board that has been there for a long time.

There are other good ways to improve safety: Ask the students involved. Every accident report, whether in a formatted style or a freely constructed essay, should require, in the student's own words, a short sentence or paragraph on the topic: "How I could have prevented this accident." Note the individual emphasis, how *I*, not someone else, could have prevented the occurrence.

Insidious Hazards

Some hazards are not obvious; some even appear to be safety measures. Portable eyewash bottles are an example. At first thought they seem to be a good idea; they are inexpensive, immediately available, and provide water ready and at hand to flush the eyes. In fact, they are hazardous. To be effective, the eyes must be flushed for at least 15 minutes with a copious flow of water. An eyewash bottle cannot meet these requirements. If both eyes have been exposed, the victim using a portable eyewash bottle must decide which eye to flush. The water in the bottle is unlikely to be sterile, especially if the bottle has not been recently resterilized and refilled with boiling hot distilled water.

Providing correctly plumbed eyewash fountains that conform to the ANSI standard Z358.1, "American National Standard for Emergency Eyewash and Shower Equipment", eliminates this insidious hazard.

Another example: Some teachers provide chemicals to their students in containers they and their assistants prepare locally. This is a good safety practice in that the amounts made available to students will be less than the amount in the original container or because the hazardous chemical has been diluted to a lower concentration. This is a poor safety practice in that teachers usually do not copy the hazard and precautionary information from the original label onto the label they prepare for the students' containers. It is, after all, tedious to copy that much information on the label the students will see. The result is, of course, that although the teacher may indeed know the hazards and precautions, the students will not.

The solution is obvious. Undertake the admittedly tedious task of copying hazard and precautionary information from the original label onto the label for the locally prepared bottle. Always make sure that all chemicals used by your students are labeled with all the hazards and precautions given on the label provided by your supplier.

You may wish to assign this copying task to your students who will then learn more than otherwise about the hazards and precautions pertinent to the chemicals they will be using in their laboratory work. Students who are facile with computers might enjoy the challenge of copying label information into a label using a format that they have designed.

Critically examine your laboratory environment. See if you can identify any insidious hazards. Alternatively, if you decide to involve your students in safety inspections, as suggested below, perhaps it would be useful to ask them to look for any insidious hazards.

Safety Inspections

Some inspectors seem to act as though a safety inspection is a visit by an outsider (who may or may not be qualified), the product of which is a list of infractions that must, in the opinion of the inspector, be corrected even if that would consume the entire budget for the next three years.

A proper safety inspection is different. It is a walk-around, eyeball evaluation of practices and procedures related to safety. But it is based on a prior, agreed-on set of specific practices and procedures.

Hence, before one can have a safety inspection, there must be a set of safety rules—some broad, some quite detailed. Usually, it is desirable that both inspector and inspectee have discussed the set of rules beforehand—and perhaps consequently modified a few items. Usually, it is desirable for the inspectee to have reasonable advance notice of the inspector's visit. Ordinarily, after the inspection, the report draft is discussed privately with the inspectee before the final draft is prepared for the inspector's superiors. Above all, the purpose of an inspection should be constructive.

To summarize, a safety inspection addresses a single question: Are safety rules being followed? Instead of calling in an outside safety inspector, organize a few students into a safety committee whose task is to conduct a safety inspection this month. Next month, a different group of students will comprise the committee, and so on for the following months.

Encourage the student safety committee to select a few rules from the set of laboratory safety rules you probably announced on the first lab day. Then, if the students can devise good, stated reasons for doing so, suggest that the committee modify one or more of the rules. Or, suggest that they delete or add a few rules on their own. Of course, they would justify their suggested changes in writing. Then, conduct a safety inspection in accordance with the students' changes. A written report based on the committee findings is always appropriate, followed by a class critique of the committee's findings and your commitment to ensure that the identified shortcomings are corrected.

3 Preparing Your Own Safety Checklist

No treatment of chemical safety is complete without a list of things to mark off as accomplished or to be accomplished. No such list is ever complete, without need of further revision and improvement. But to the point, a list prepared by another person is almost without value. Each responsible person should prepare his or her own list, while of course seeking the comments and suggestions of others who are judged to be competent.

Here is a list to get you started on preparing your own safety checklist. It has been adapted, with permission, from the U.S. Consumer Products Safety Commission's fine 1984 publication on lab safety, *School Science Laboratories: A Guide to Some Hazardous Substances*, now out of print. It is offered here as a useful safety tool for those who might wish to use it as a resource when they prepare their own (perhaps not quite as lengthy) list.

Work Habits

- Never work alone in a science laboratory or storage area.
- Never eat, drink, smoke, apply cosmetics, or chew gum or tobacco in a science laboratory or storage area. Do not store or consume food or beverages in a laboratory environment.
- Always keep containers of chemicals closed when not in use.
- Never pipet by mouth.
- After working in a science laboratory and after cleaning up spills, thoroughly wash hands and arms and clean under fingernails.
- Restrain loose clothing (e.g., sleeves, full-cut blouses, neckties) and long hair and remove dangling jewelry.
- Tape all Dewar flasks with fabric-based tape.
- Never leave heat sources unattended (e.g., gas burners, hot plates, heating mantles, sand baths).
- Do not store chemicals and/or apparatus on the lab bench.
- Keep lab shelves organized.
- Never place a chemical, not even water, near the edges of a lab bench or workspace.
- Use a fume hood that is known to be in operating condition when working with toxic, flammable, and/or volatile substances.
- Never put your head inside a fume hood.
- Never store anything in a fume hood.
- Obtain, read, and be sure you understand the MSDS for each chemical that is to be used before allowing students to begin an experiment.
- Analyze new lab procedures in advance to identify any hazardous aspects. Minimize and/or eliminate these hazardous components before proceeding.

- Analyze any student-designed lab procedures in advance to identify any hazardous aspects. Help the student authors to minimize and/or eliminate these hazardous aspects before proceeding.
- Analyze close calls and accidents to prevent repeat performances.
- Eliminate the causes of close calls and accidents.
- Provide protection for both the lab worker and others nearby.
- Identify which chemicals in your storeroom and laboratory may be properly disposed of down the sink drain and which may not be. If this information is not in the MSDS, ask your supplier, and keep a record of your request and the reply.
- Do not inadvertently mix chemicals in the sink drain; clear the first chemical from the drain by flushing, then introduce the next chemical (provided both are known to be harmless to the environment, of course).
- Always inform co-workers beforehand of your plans to carry out work with hazardous chemicals.
- Remember that the purpose of a safety inspection is to improve existing conditions, not to place blame or assign guilt.
- Familiarize lab occupants with the sound of the alarm bell or horn and explain what to do when it is heard.
- Carry out regular fire or other emergency drills; review the results and thereby improve the performance in the next drill.
- Preplan for fire emergencies: Frequently inform your local fire department of your current chemical inventory, including the locations of stored chemicals and the quantities on hand.
- Preplan for emergencies requiring evacuation: Identify devices that should be turned off, if possible, before leaving. Inform personnel of the designated escape route and an alternate route.
- Designate a meeting place for personnel that is a safe distance away.
- Nominate one person and an alternate to account for all who arrive at the designated meeting place. Identify as unique the only person who is qualified to authorize reentry into the building.
- Preplan for emergencies requiring first aid treatment: Responsible personnel should be both CPR-proficient and know in advance how to administer first aid for the variety of chemicals being used.
- Preplan for emergencies requiring first aid treatment follow-up: Selected physicians and/or hospital emergency rooms should be advised of the variety of chemicals being used and their personnel should be knowledgeable concerning appropriate follow-up treatment, including specific antidotes, if any.

Safety Wear

- Always wear only ANSI Z87-approved safety goggles, type G or H.
- When appropriate, wear only gloves made of a material known to resist penetration by the chemical being handled and that have been checked for pin holes, tears, or rips and the absence of interior contamination.
- Always wear a laboratory coat or apron.

- Wear footwear that protects the feet; do not wear open-toe shoes or shoes with cloth or woven uppers. Never be barefoot where chemicals are being used.

Facilities and Equipment

- Have separate, labeled containers for broken glass, for each different type of hazardous chemical waste, and for general trash.
- Keep the floor area around safety showers, eyewash fountains, and fire extinguishers free and clear of all obstructions.
- Never block any escape routes.
- Never, ever prop open a fire door.
- Never store materials on the floor or aisles of the lab or storage room.
- Provide safety guards for all moving belts and pulleys.
- Instruct lab personnel in the proper use of the eyewash fountain, emphasizing continuous movement of the eyeballs, and holding eyelids open with thumb and forefinger.
- If contamination is suspected, arrange for sampling the breathing air for measurement of possible contaminants.
- Regularly inspect emergency blankets, if they are present, for rips and holes, and keep good records of the inspections.
- Regularly check safety showers and eyewash fountains for proper rate of water flow, and keep records of inspections.
- Keep up-to-date emergency phone numbers posted next to the telephone.
- Place fire extinguishers near an escape route, not in a “dead end”.
- Regularly maintain fire extinguishers and keep records of that maintenance. Arrange with your local fire department for the training of teachers and administrators in the proper use of extinguishers.
- Regularly check fume hoods for proper air flow. Ensure that exhaust air from fume hood exhaust vents (usually on the building roof) is not drawn back into the intake for the general ventilation of the building.
- Secure all compressed gas cylinders at all times and transport them only while secured on a hand truck.
- Restrict the use and handling of compressed gas to persons who have received formal training in the safe use and handling of compressed gas cylinders and their contents.
- Install chemical storage shelves with lips, and never use stacked boxes in lieu of shelves.
- Only use an explosion-proof refrigerator for storage of laboratory chemicals.
- Have appropriate equipment and materials (refer to the MSDS) available in advance for spill control and cleanup; replace the materials when they become outdated.

Purchase, Use, and Disposal of Chemicals

- Inventory all chemicals on hand at least annually; keep the inventory list up-to-date as chemicals are consumed and replacement chemicals are received.
- If possible, limit the purchase of chemicals to quantities that will be consumed within one year and that are packaged in small containers suitable for direct use in the lab without transfer to other containers.
- Label all chemicals that are to be stored with date of receipt or preparation and have labels initialed by the person responsible.
- Generally, bottles of chemicals should not remain: 1. Unused on shelves in the lab for more than one week, 2. In the storeroom near the lab unused for more than one month, or 3. In the main stockroom unused for more than one year.
- After one week of nonuse, move those chemicals in the lab to either the storeroom or the main stockroom. After one month of nonuse, move chemicals from the storeroom to the main stockroom. And, properly dispose of any chemicals that remain in the stockroom for more than one year.
- Ensure that the disposal procedures for waste chemicals conform to environmental protection requirements.
- Do not purchase or store large quantities of flammable liquids. Ask local fire department officials to recommend the maximum quantities that may be kept on hand.
- Never open a chemical container until the label and MSDS have been read and completely understood.

Substitutions

- When feasible, substitute less hazardous chemicals for chemicals with greater hazards.
- Reduce risks by diluting substances whenever possible instead of using concentrates.
- Use lesser quantities instead of greater quantities in experiments and demonstrations whenever possible.
- Use films, videotapes, computer displays, and other methods rather than experiments involving hazardous substances.

4 A Commentary on Safety

Whether we teach chemistry, biology, physics, general science, or other science courses, we have all heard about some other teacher's serious chemical accident. Sometimes, we are inclined to be content with the fact that it did not happen to us and sort of hopefully let it go at that.

On the other hand, to make that hope a little more secure for those who have not yet had a serious accident and to make it less likely that there will be another one for those who have experienced a serious accident, let us consider the four principles of chemical safety along with some of their corollaries and a few examples.

1. The manner of use of a chemical determines the probability that harm will or will not follow.

This first principle has a corollary:

Every chemical, without exception, is hazardous; that is, every chemical has the potential to cause harm.

For example, did you know that oxygen is poisonous if inhaled at a concentration a bit greater than its natural concentration in the air (about 21%)? Did you know that chromium and nickel compounds are suspected carcinogens? Did you know that glacial (concentrated) acetic acid, the major flavor component of vinegar, is both corrosive and flammable?

2. If it might happen, it will happen—eventually.

The corollary:

Only a probability of zero predicts that an event will never occur; *a low probability is a probability that is greater than zero*. A probability greater than zero, even if quite small, say 0.00000002, means that such an event is certain to happen—it just won't happen very often.

At one time or another, each of us has said, "I'll take a chance, it won't happen to me this one time." And, since we survived, it didn't happen; we beat the odds. It is easy to beat the odds when they are quite small. But remember that when we say to ourselves, "I'll take a chance and do it because it won't happen to me this one time (the probability of harm is very low)," we are really saying that the probability of harm is not zero. *Whenever the probability of an event is greater than zero, no matter how small, then it is **certain** that the event will occur at some time later, or perhaps sooner*. A personal example will suffice: When was the last time you did not buckle up when driving your car?

3. Each and every person is individually and personally responsible for the safe use of chemicals.

This corollary has the following four parts; teachers should heed all four and help their students do the same.

Use a chemical only if you have reviewed the label and MSDS; and therefore

- Know in advance the hazards presented by that chemical.
- Know in advance the precautions you must follow to minimize the probability of harm.
- Are able to take those precautions.
- Have prepared in advance and are able to carry out the necessary first aid and emergency measures in the event something goes wrong.

4. Before it ever happens, every accident predicts that it will happen.

This fourth principle is the most important; its corollary lies at the very heart of the practice of safety:

All accidents are predicted by one or more close calls that happen first. There are no exceptions to this corollary.

Pay attention to close calls; determine their causes. Eliminate the cause(s) of a close call, and you have stopped an accident. A few examples:

- When was the last time that you were driving your car and another driver honked his or her horn in response to the way you were driving? (According to accident statisticians, once in every 300 times a serious accident or injury is predicted as certain [95% confidence level].)
- In the middle of the lab period, a student says “Ouch!” because he or she inadvertently, but briefly, touched a piece of hot glass tubing. (For this kind of close call, accident statistics predict a probable skin burn approximately once every 30 occasions.)
- You see a student briefly remove his or her safety goggles to more conveniently read the meniscus level of liquid in a graduate cylinder. (This is another incident predicted to lead to injury 1 out of 300 times, with a probable [not certain] 95% confidence level.)
- Spilled water or other liquid on the lab bench is not cleaned up within a reasonable time. (This is a close call with a 1 in 30 approximate prediction probability of a serious accident.)

Definitions are in order here. A close call is a disruption of good order in which no person is injured and no property is seriously damaged. Examples include any of the above as well as a bottle that is out of place, a label that is partially defaced, a small fire that was quickly extinguished, or two students engaged in horseplay. Although there is no ensuing harm, a close call is never inconsequential. Always, it is instead a prophetic message, an announcement, a warning—

An accident is coming, sooner or later.

The way we defeat such a prophecy is to determine the cause or causes of the close call and take corrective steps **now**, so that at least one forthcoming accident is eliminated.

This handbook can be summarized: All accidents are preceded by at least one close call. To prevent accidents—

Be alert to close calls and eliminate their cause or causes.

References

The following publications are recommended to teachers who want to learn more about chemical use and safety.

A Model Chemical Hygiene Plan for High Schools; 1995; American Chemical Society, 1155 16th Street, NW, Washignton, DC 20036. Useful also for junior high schools.

Safety in the Elementary (K–6) Science Classroom; 1993; American Chemical Society Committee on Chemical Safety, 1155 16th Street, NW, Washington, DC 20036. Making the experimental environment safe for younger students; an eight-page summary.

Safety in Academic Chemistry Laboratories; 6th ed., rev. 1998; American Chemical Society Committee on Chemical Safety, 1155 16th Street, NW, Washington, DC 20036. For college and university laboratories; probably the best brief summary available. Single copies are free to teachers (at any level) on request.

Safety Audit/Inspection Manual; 2000; American Chemical Society Committee on Chemical Safety, 1155 16th Street, NW, Washington, DC 20036. Basic guidelines for conducting safety audits and inspections and for executing corrective actions revealed to be necessary by an audit or inspection.

Improving Safety in the Chemical Laboratory: A Practical Guide; 2nd ed.; Young, Jay A., Ed.; Wiley-Interscience: New York, 1991. A general and practical discussion.

Laboratory Waste Management: A Guidebook; Pine, Stanley H.; Phifer, R. W.; American Chemical Society Publications Department, 1155 16th Street, NW, Washington, DC 20036. A guide for the disposal of laboratory waste.

Acknowledgments

The principles and guidance set forth in this handbook have been adapted and updated from the recommendations in the following publications.

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