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CHEMICAL SAFETY

TRAINING SCIENTISTS TO MINIMIZE RISK

2020

Joshua C. Grubbs | Aamer Ikram | Sohail A. Qureshi

Pakistan Biological Safety Association

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Methods

This manual was written in response to the expressed need for further guidance on chemical safety among those working in the life sciences in Pakistan. Increased awareness of biological safety and its importance prompted our partners to consider other areas for improved safety and they identified chemical safety as a major interest. Biologists use chemicals every day but might not have the required knowledge on how to safely manage chemicals in the context of their work.

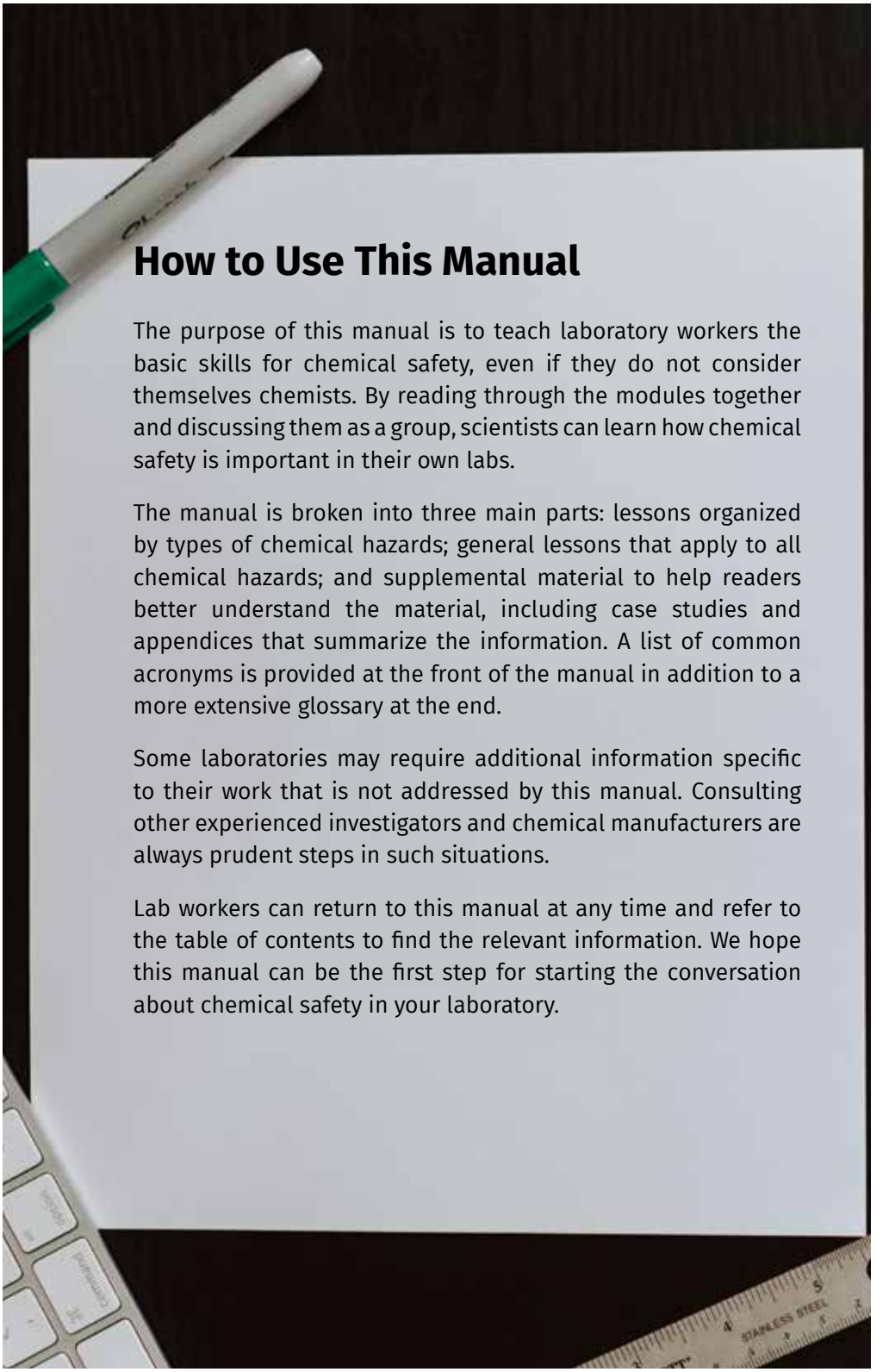
The first step in developing the manual was a thorough literature search of existing documents on chemical safety. Web of Science, PubMed, the United Nations website, and university websites were all searched for the terms “chemical safety,” “chemical hazards,” “chemical hygiene,” and other related terms. The aim was to locate existing guidelines and distill the essential safety measures they presented into a shorter document that incorporated practice questions and training material relevant for those working in the life sciences. There are many excellent resources for chemical safety, but they are primarily written as reference materials rather than didactic tools and they do not focus on chemical safety for those working in the life sciences. My past experience in undergraduate chemistry labs prompted me to also research universities’ chemical safety protocols, as these tend to present the information in an accessible manner for students.

The material for this manual primarily draws on two major reports published by the United Nations: The Globally Harmonized System of Classification and Labelling of Chemicals and Recommendations on the transport of dangerous goods: model

regulations. These two documents outline the international standards for chemical hazards and offer guidance on the appropriate precautions by hazard class. The first several chapters of this manual present the information in a similar progression as found in these documents for two reasons: (1) grouping chemicals into groups by hazard allows scientists to recognize patterns for safe usage for materials even if they are not familiar with them; and (2) following the international guidelines facilitates communication between scientists.

After presenting the chemical classes, the remainder of the manual includes material on topics that are common themes throughout each of the earlier modules, such as safe storage. Many of these modules present information from Chemical Laboratory Safety and Security: A Guide to Developing Standard Operating Procedures published by the National Academies of Sciences, Engineering, and Medicine with added questions for training purposes.

Finally, the sample case studies at the end tie together the earlier modules and are all based on real incidents in which improved safety could have avoided injury or damage. All case studies are original and are inspired by reported incidents as cited or my personal experiences. Appendices A and B are original and were developed ad hoc for this manual. Appendix C was adapted from templates in Chemical Laboratory Safety and Security: A Guide to Developing Standard Operating Procedures as cited in the body of the manual. All images were taken from Wikimedia Commons and licensed for general public use under Creative Commons.



How to Use This Manual

The purpose of this manual is to teach laboratory workers the basic skills for chemical safety, even if they do not consider themselves chemists. By reading through the modules together and discussing them as a group, scientists can learn how chemical safety is important in their own labs.

The manual is broken into three main parts: lessons organized by types of chemical hazards; general lessons that apply to all chemical hazards; and supplemental material to help readers better understand the material, including case studies and appendices that summarize the information. A list of common acronyms is provided at the front of the manual in addition to a more extensive glossary at the end.

Some laboratories may require additional information specific to their work that is not addressed by this manual. Consulting other experienced investigators and chemical manufacturers are always prudent steps in such situations.

Lab workers can return to this manual at any time and refer to the table of contents to find the relevant information. We hope this manual can be the first step for starting the conversation about chemical safety in your laboratory.

Acronyms

GHS – Globally Harmonized System

HEPA – High Efficiency Particulate Air (filter)

LD50 – Lethal Dose for 50%; dose of a chemical at which half of exposed organisms will die

PAPR – Powered Air-Purifying Respirator

PPE – Personal Protective Equipment

SAR – Supplied Air Respirator

SCBA – Self Contained Breathing Apparatus

SDS – Safety Data Sheet

SOP – Standard Operating Procedure

TDG – Transport of Dangerous Goods

UN – United Nations; this organization developed the Recommendations on the Transport of Dangerous Goods and the International Programme on Chemical Safety

1 Why is Chemical Safety Important?

Safety comes in many different forms. Biological safety, fire safety, and occupational safety are a few types that may come to mind. As a worker in a laboratory, there are specific types of safety that are especially important. Chemical safety is one of these. Scientists work with chemicals every day, even if they do not consider themselves chemists. Basic protocols rely on the use of chemicals to investigate biological phenomena. Chemicals are used to disinfect surfaces and kill pathogens. Everywhere you look, chemicals are an essential part of science.

Knowing how to properly store and handle chemicals can significantly reduce your risk. There will always be some risks, but by learning about them you can make better decisions that maximize your personal safety. Making chemical safety an integral part of your lab will not only keep you safe, but will also protect your coworkers from chemical accidents and exposures.

Note the labels on the storage cabinets below the lab bench. The flame indicates flammable chemicals, whereas the other cabinet is for bases. The third, unlabeled cabinet is for non-hazardous chemicals Proper storage and segregation of chemicals are critical for a safe work environment.

2 Types of Chemicals

2.1 Flammables

Flammable compounds are one of the clearest examples of why lab safety is necessary. Laboratory fires can destroy physical property and years of work, but more importantly, they can be fatal. In order to maintain a safe lab environment, we first need to understand how to identify flammable compounds.

Pre-Lesson Exercise

1. What flammable chemicals are present in your lab?
2. What can cause a flammable chemical to catch fire?
3. How does your lab store flammable chemicals? How do you think they should be stored?
4. How would you respond to a fire in your lab? Would your response be the same regardless of the chemical?

Identifying Flammable Chemicals

There are two critical ways of identifying flammable compounds:

1. Understanding warning labels
2. Knowing the general chemistry of combustion so you can identify classes of flammable compounds on your own

Warning Labels

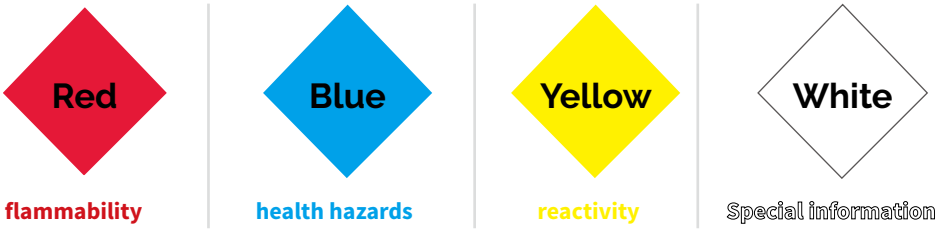
Warning labels are the language of the chemical world – if you are fluent in reading these, you will be able to understand and communicate risk with your fellow scientists. We will review all the warning labels and pictures later, but let's start with flammable compounds.

Have you seen these labels before? Where have you seen them, in or out of the laboratory?

This is the **most common label** on bottles and **S**afety **D**ata **S**heets (SDS). It is part of the **G**lobally Harmonized System (GHS) for chemical labelling.[1]

This label is used for shipping, though you still may see it in the lab. It is part of the United Nations (UN) Model Recommendations on the Transport of Dangerous Goods (TDG).[2]

One more type of label gives additional flammability information: the hazard diamond. This label is not part of the Globally Harmonized System (GHS), like the first label, but is still commonly used and important to understand. The higher the number in the red square on a scale of 0 to 4, the more flammable the compound. We will talk about the other colours later, so just focus on the part relevant to flammability.



Discuss these questions before moving on

Practice with Hazard Diamonds

1. Which colour do you think corresponds with flammability hazard?
2. Do you think higher or lower numbers indicate greater risk?
3. Where else could you look for more information on the compound's flammability?

[1]United Nations, et al. (2005). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). New York: United Nations.
[2]United Nations. Committee of Experts on the Transport of Dangerous Goods. (2015). Recommendations on the transport of dangerous goods: model regulations (19th rev. ed.). New York: United Nations.

The **red** box tells us how flammable the chemical is.

Higher numbers correspond with *greater* flammability.

We can *always* check the safety data sheet (SDS) from the manufacturer for additional details

Flammable Classes of Chemicals

Even without the warning label, knowing which classes of chemicals are flammable can help you identify risks and prepare accordingly. The earlier example of ethanol is a good place to start. Most scientists are aware that ethanol is flammable. However, all alcohols are flammable, not just ethanol. This means any compound ending in -ol, such a s methanol, isopropyl alcohol, and cyclohexanol, are all flammable.

Try to think of more examples before moving onto the next section

We can break down flammable chemicals into a handful of large groups. These categories are NOT extensive, but cover most of the flammable compounds you are likely to encounter.

Alcohols

(ethanol, isopropyl alcohol, cyclohexanol, etc.)

Ethers

(diethyl ether, tetrahydrofuran, ethylene oxide, etc.)

Organic Solvents

(hexane, acetone, acetonitrile, etc.)

Alkali Hydrides

(sodium hydride, lithium aluminum hydride, etc.)

Organometallics

(butyllithium, diethylzinc, etc.)

Alcohols are often used in many types of labs as a solvent or disinfectant. Ethers, metal hydrides, and organometallic compounds, however, are more likely to be found in organic chemistry labs. Organic solvents – especially hydrocarbon chains – are commonly used in labs, much like alcohols.

These groups will help you remember what classes of chemicals require special caution to prevent fires. If you see a type of alcohol or a chemical with the word "hydride" in its name, take a minute and double-check that you have taken all the precautions for working with a flammable chemical.

Self-Quiz: Looking at the names of these chemicals, try to identify if they are potentially flammable using your understanding of chemical classes. Remember, you should always check the labels and SDS and not only rely on chemical class, because there are always exceptions.

Potassium hydride, water, naphthalene, pentane, magnesium chloride, acetylene, butanol, ammonium nitrate, cobalt (II) fluoride, sodium dodecyl sulfate	
Flammable	Non-Flammable

Ignition Sources

Some chemicals spontaneously ignite when exposed to air (pyrophoric chemicals), but most require an energy source to start the reaction. Flames, electrical sparks, and static electricity can each provide the necessary activation energy to produce a combustion reaction. Common ignition sources include:

1. Bunsen burners
2. Electrical equipment
3. Gas-fired heating devices
4. Hot plates and stirring devices
5. Mechanically produced sparks (e.g. grinding)
6. Heat produced from chemical reaction

Researchers should always remove potential ignition sources whenever working with flammable chemicals. Laboratory management should also ensure that electrical equipment is nonsparking and not constructed with open switches or relays that could cause a fire.

Vapour and Flashbacks

The mixture of air and chemical vapour from a flammable liquid catch fire in the presence of an ignition source. Chemical vapours are often heavier than air and may settle near the floor and on the surface of the lab bench, all the while leaving a trail of vapour back to the container. Therefore, scientists must be conscious of ignition sources beyond their immediate workspace, since vapours can travel considerable distances from the container.

Flashbacks occur when the stream of vapour emanating from a container ignites and draws the fire back towards the container. The liquid then rapidly mixes with atmospheric oxygen and sustains an even greater fire. Flashbacks are particularly dangerous because they happen quickly and unexpectedly.

Combustible Dusts

Suspensions of certain solid chemicals in the air can also pose a fire hazard. Easily oxidized particles, including magnesium, zinc, or carbon powder, can combust in the presence of an ignition source and an oxidant (e.g. atmospheric oxygen). This is because of the large surface area of the particles, which provide the oxidant with more interfaces for combustion reactions.

What specific precautions would you take to avoid laboratory fires, using what you know about ignit on sources, vapour, flashbacks, and combustible dusts?

Storage

Lab workers should take special precautions when storing flammable chemicals to ensure a safe working environment. Containers with flammable chemicals should be stored in an approved cabinet and placed away from heat (keep within 18 – 27 °C) and direct light. Ventilated cabinets are NOT necessary unless required by local regulations.

You should separate flammable compounds from oxidizers and corrosive chemicals. Oxidizers are especially dangerous when combined with flammable compounds because they intensify the combustion reaction.

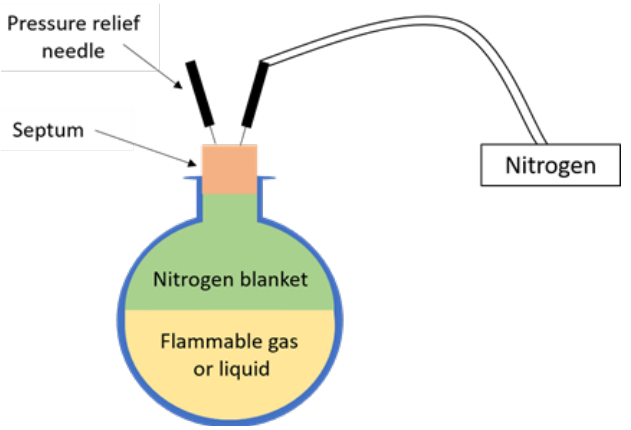
You should keep chemicals in their original containers. If chemicals need to be transferred to a different container, check the SDS for approved container materials and volumes.

Certain flammable compounds must be stored in an approved, explosion-proof refrigerator. These refrigerators are designed without exposed electrical interfaces that could ignite a fire. Only store flammable chemicals in an approved refrigerator when directly indicated on the Safety Data Sheet (SDS) for the chemical.

All fires require oxidizers, so how can a fire occur if a container with oxidizing chemicals is not present?

Handling

- Flammable compounds require attentive handling to reduce the risk of fire. The handling precautions slightly vary depending on the physical and chemical properties of the compound.
- Flammable liquids should NOT be handled in containers with large openings (e.g. large mouthed flasks) where the vapour can easily escape and come into contact with ignition sources. Transfer liquids in small volumes in accordance with SOP.
- Avoid static discharge by grounding containers when possible. Grounding can be achieved by touching the container to a ground wire connected to the earth. If grounding is not possible, work slowly to allow static charge to be dispersed. Consider using an inert gas blanket on top of flammable liquids to avoid contact with atmospheric oxygen.
- When working with flammable gases, vessels should be evacuated or purged with inert gas such as nitrogen for at least three cycles prior to the introduction of the flammable gas. Similar to the role of inert gas blankets, this step prevents the mixing of flammable gases and atmospheric oxygen. Specialized cabinets filled with an inert gas can also be used for handling flammable solids, including water-reactive alkali metals and metal hydrides.



This figure shows how you can fill the headspace of a container with an inert gas to prevent reactions with atmospheric oxygen. This is called a gas blanket. Using the same set up, you can also evacuate a container (replace all air with an inert gas) prior to introducing a flammable chemical.

Firefighting Measures

Preventing fires in the first place is critical. However, even if all precautions have been taken, flammable chemicals can still ignite and cause a fire. It is your responsibility to quickly respond to laboratory fires to protect yourself and your colleagues. This may mean extinguishing the fire yourself, if you are trained, or immediately evacuating and calling for help depending on the magnitude of the fire. In either case, first pull the nearest fire alarm to alert colleagues and emergency services.

Before continuing, make a list of the different methods for extinguishing a fire. How many can you think of?

Personal Measures

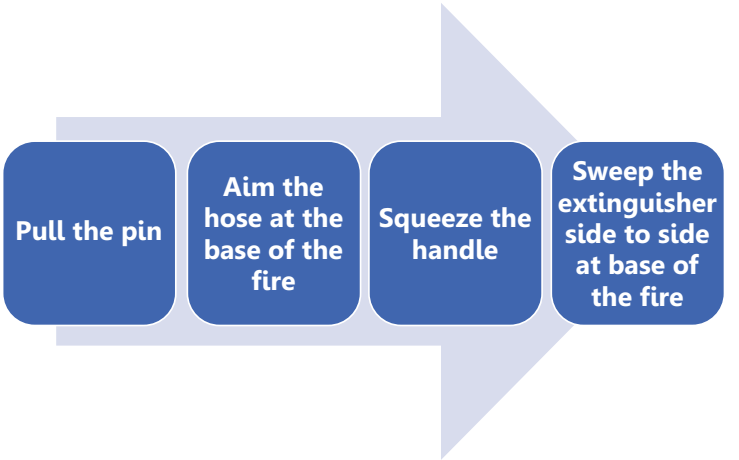
Lab workers should wear a flame-resistant lab coat when handling flammable chemicals. In the event of a person's clothes catching fire, he or she should immediately use the nearest safety shower to extinguish the flames on him or herself. Fire blankets are less effective and should only be used if a shower is not available.

Extinguishing Systems

Trained lab personnel should respond to small fires with portable extinguishers appropriate to the nature of the fire.

- Class A - Conventional water-based extinguishers: wood, paper, clothes
- Class B - Dry chemical or CO2 extinguishers: flammable liquids
- Class C - Dry chemical or CO2 extinguishers: electrical fires
- Class D - Dry powder extinguishers: reactive metals, organometallic compounds
- Regular sand in a plastic container can be used instead of dry chemical or dry powder extinguishers

Fires due to flammable liquids are extremely difficult to extinguish – remember to pull the nearest fire alarm and call for help before attempting to extinguish the fire. ONLY attempt to extinguish a fire if you have been trained by your institution and have the proper equipment to safely do so. If you are trained and the fire is small, you can follow the following steps to extinguish the fire, remembering the acronym "PASS."



What types of extinguishers would you use for the following chemicals?

tert-butyllithium, paper towels, paper towels soaked with hexane, sodium hydride, diethyl ether, elemental potassium		
Water-Based (Class A)	Dry Chemical (Class B or C)	Dry Powder (Class D)

Evacuation and Emergency Preparedness

Lab workers should thoroughly know the locations of all fire extinguishers in the lab and what types of fire they are used for, nearby fire-alarm pull stations, safety showers, and fire blankets.

Each lab should also have an emergency evacuation plan in place, including routes of escape and who to notify in the event of a lab fire.

If you are present for a fire larger than waste paper bin or not confident that you can safely extinguish it, immediately evacuate the lab and notify the fire department. Remember to always call for help first, regardless of whether you extinguish the fire or evacuate. Advise firefighters of the chemicals present in the lab and how the fire started so they can effectively address the situation.

When NOT to Attempt to Extinguish a Fire

- The fire is larger than a waste paper bin
- One extinguisher is not sufficient
- The fire is spreading from its origin
- The smoke is making it difficult to breathe
- You cannot fight the fire with your back to an exit
- The fire can block the only escape route You do not have adequate firefighting equipment

[Guidelines adapted from "Fire Protection and Prevention in Chemical Laboratories" by Sandia National Laboratories]

Compare the firefighting measures for these two compounds. Are the instructions different than you expected? What can you predict about the nature of the compound by the recommended extinguishing media?

Acetonitrile

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary

5.4 Further Information
Use water spray to cool unopened containers

Tert-butyllithium

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Dry powderDry powder Carbon dioxide (CO2)

Unsuitable extinguishing media
Water Carbon dioxide (CO2) Water

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further Information
No data avaiable

[Text from Sigma Aldrich: Acetonitrile (75-05-8) and Tetrahydrofuran (109-99-9 SDS)]

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United States Occupational Safety and Health Administration. Portable Fire Extinguishers - Fire Extinguisher Use.

2.2 Oxidizers

After learning about flammable compounds, you already know the basics of fire safety. Oxidizers require similar precautions because they can fuel fires started by flammable compounds. In this module we will learn about the chemistry of oxidizing compounds and how to handle them safely, especially in flammable environments.

Pre-Lesson Exercise

1. What is oxidation?
2. What oxidizing compounds are in your lab?
3. How do you think you should handle oxidizing compounds, given what you have learned about flammable compounds?

What are oxidizers?

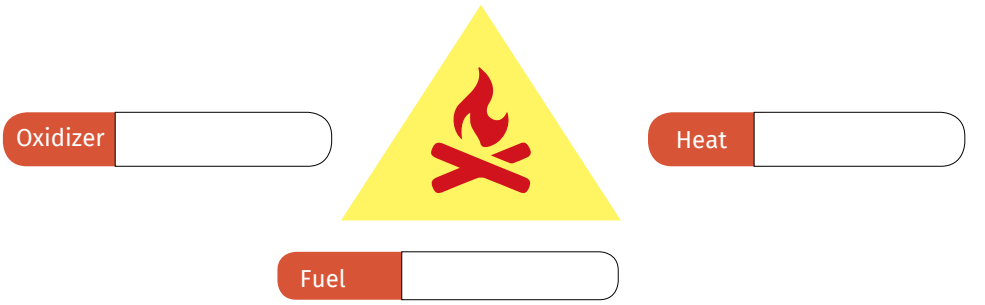
Oxidation and reduction reactions – informally known as redox reactions – involve electron transfers between atoms. An atom that loses electrons is oxidized, whereas an atom that gains electrons is reduced. Redox reactions always occur in pairs, since one atom needs to gain the electrons that another atom loses.

Oxidizers have particularly high electron affinities and can easily grab electrons from neighboring atoms, thus oxidizing them. This is important to consider when handling flammable compounds because combustion is a rapid redox reaction. The presence of oxidizing chemicals sustains the reaction by providing a readily available site for accepting electrons removed from the burning material.

You already learned about fuels (flammable compounds) and heat (energy and ignition sources) – the last critical piece is oxidizers. Atmospheric oxygen is the most common oxidizer, but chemicals in your lab can add to this part of the triangle. Fire safety experts illustrate the importance of oxidizers using the fire triangle.

Fires need each of the three components depicted to sustain themselves. Fire extinguishers often separate one of the components from the other two to stop the reaction and eliminate the fire.

Label the fire triangle with three materials you could find in your lab. Are they in proximity to each other?



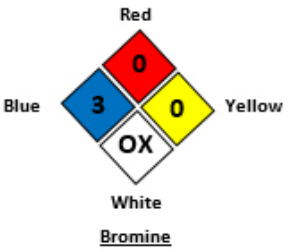
Identifying Oxidizers

Before moving on, we need to learn the warning labels for oxidizers. Keep in mind the labels you learned from the last module while looking at these.

The pictogram on the left is the common Globally Harmonized System (GHS) label for oxidizers. Chemical bottles and SDS will have this label. On the right we see the label used for labeling of oxidizers during transport, following the United Nations (UN) Recommendations on the Transport of Dangerous Goods (TDG). The 5.1 at the bottom refers to the TDG hazard category. Despite the different colours, the two labels are easily identified by the characteristic symbol of flames surrounding a circle. The circle represents the letter O for oxygen because oxidizers increase the oxygen available for combustion.

Compare the pictograms for flammable and oxidizers. What do you notice?

The pictogram for oxidizing compounds communicates a key message – it is not the same as a flammable compound, but is still a fire hazard, as depicted by the flames. We can also take a look at the hazard diamond for bromine to understand this distinction.



Bromine

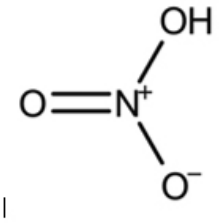
Remember that the red number corresponds with flammability and the white box is for special information. "OX" means oxidizer here.

Note that the flammability is 0, but the compound is still a strong oxidizer and can ignite fires.

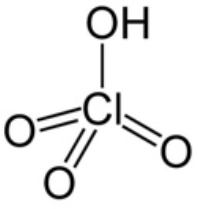
How can bromine have a score of 0 for flammability , but still be a fire hazard?

Oxidizing Classes of Chemicals

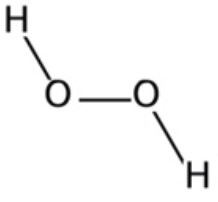
In contrast to flammable compounds, identifying classes of oxidizers requires more thinking. The best way to recognize oxidizers is to understand their chemistry, in addition to remembering a few common oxidizers present in most labs. Nitric acid, perchloric acid, and hydrogen peroxide are three oxidizing chemicals you should commit to memory. Always keep these chemicals away from gas flames. In addition to the helpful reminders below, remember to always check the SDS for all chemicals you use.



Nitric Acid



Perchloric acid



Hydrogen peroxide

What similarities do you notice about these compounds?

Oxygen

Compressed oxygen gas is a common, yet dangerous, material found across many labs. Oxygen is a strong oxidizing agent because it readily accepts electrons to achieve a stable configuration.

Halogens

Like oxygen, halogens readily accept electrons to achieve a stable configuration. These can be in gaseous (e.g. chlorine) or liquid (e.g. bromine) form.

Salts

Many salts are not oxidizers, but many oxidizers are salts. Thus, you cannot assume that a compound is an oxidizer because it is a salt. Salts with oxygen-rich anions, like nitrates or chromates, are often oxidizers. Some examples of oxidizing salts are ammoniun nitrate and potassium dichromate. Check the SDS.

Inorganic Peroxides

The bond between adjacent oxygen atoms readily reacts as an oxidizer. Hydrogen peroxide is a notable example. Other inorganic peroxides include sodium peroxide and potassium persulfate. Note that organic peroxides are also flammable compounds themselves and thus stored separately from other oxidizers.

Storage

Oxidizers should be stored in a chemical cabinet or shelf, separate from other chemical classes, especially flammable compounds. The combination of flammables and oxidizers creates a dangerous environment that can catch fire.

Oxidizers should also be separated from reducing agents (e.g. alkali metals – Li, Na, K, Rb, Cs, Fr), most acids, and organic peroxides. Combinations of these chemicals tend to be reactive and extremely unsafe.

Be careful to not contaminate stock solutions of oxidizers with any of the incompatible classes of chemicals mentioned above. Containers of oxidizers could become explosive if contaminated with metals, acids, or organic material.

If oxidizers are also fire hazards like flammable compounds, why is it important to distinguish between them?

What are chemical cabinets?

Chemical cabinets are storage spaces designed to contain reactive chemicals, separating them from the rest of the lab. They are often located under fume hoods and may be connected to the hood's ventilation system. Specific cabinets are approved for storing flammables. Many labs also use these cabinets for acids and oxidizers, placing different chemical classes on separate shelves within the cabinets. Note that the cabinets do not have to be ventilated if there is sufficient ventilation in the lab.

Many times, chemicals can be stored on shelves instead of using a chemical cabinet. Non-volatile, non-reactive chemicals that do NOT fall under the hazard classifications discussed can be stored on shelves. Shelves should be well constructed and coated with an epoxy paint to prevent corrosion. They should also have a lip to prevent containers from falling off the shelf.

Chemical cabinets can be standalone structures or built into fume hoods.

Handling & Firefighting Measures

- Laboratory workers should take similar precautions to those described in the module for flammable compounds. Prudent use of Personal Protective Equipment (PPE) and following SOP are always critical to safely handling chemicals, regardless of their class.
- Similarly, the firefighting measures follow the previous module's instructions. The choice of extinguishing system depends on the type of fuel.

Test your memory. Match the fire extinguisher with the chemical fire described.

Fire Extinguisher	Chemicals
Class A – Water-based	Hydrogen peroxide + zinc
Class B – Dry chemical	Ammonium nitrate + diethyl ether
Class D – Dry powder	Bromine + cardboard

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2.3 Corrosives

Corrosive chemicals encompass a range of compounds, but all of them share one aspect in common – they can destroy body tissues and other materials with which they come into contact. Acids are often the first to come to mind, but bases and other select compounds are also corrosive. Health considerations merit extra attention, as corrosive compounds can also cause respiratory and eye irritation in addition to chemical burns.

Pre-Lesson Exercise

10 mins

1. What corrosive chemicals are present in your lab?
2. How do you store corrosive chemicals in your lab?
3. Which protocols do you know that require a corrosive?

Identifying Corrosives

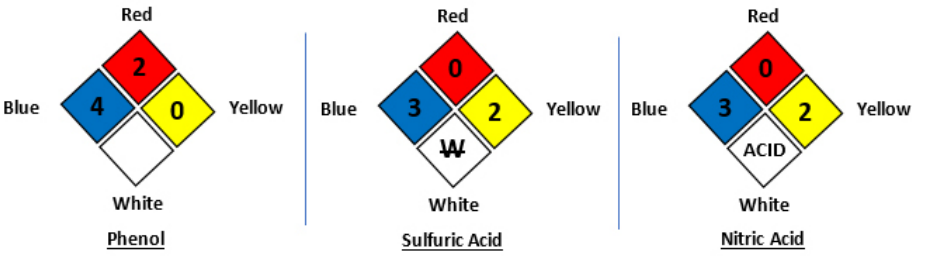
The pictogram on the left is the common GHS label for corrosives, as found on chemical bottles and SDS. Similarly, the pictogram on the right is used to label corrosives in transport.

What message do you interpret from the warning labels?

The GHS pictograms and warning labels are the best way to quickly confirm a chemical's corrosive nature, short of checking the SDS. The hazard diamonds are less informative on this class of chemicals because of inconsistencies in labelling conventions.

For corrosive compounds, the white square will sometimes read "COR" or "ACID" if the chemical is an acid. However, this information is often omitted and the diamond will merely contain a blank white square. Look at the examples below and consider what you learn from the hazard diamond as compared to the SDS.

Each of these chemicals are corrosive. Would you be able to determine that just by looking at the hazard diamond? Why or why not?



What are the benefits of the hazard diamond? What are some limitations?

Benefits:

Limitations:

Corrosive Classes of Chemicals

You should consider all **acids and bases** you encounter to potentially be corrosive materials. You can use the name of the compound to guide you, most often with acids. For example, even if you have never used oxalic acid before, you could predict that it might be corrosive because its name ends in "acid." Other acids, however, are not as easy to identity and require familiarity with warning labels and experience in the lab to know they are corrosive. Take phenol, for example: you might remember that this is an alcohol because it ends in "-ol" and know that it is probably flammable, but this chemical is also extremely corrosive.

There are a few shortcuts to identifying common **bases**, but remember to always look for this information in the SDS before working with a new chemical. Compounds ending in "hydroxide" are bases and should be handled with care. Likewise, metal hydrides in solution (e.g. lithium hydride) are corrosive bases.

Certain **oxidizers** are also corrosive. Bromine is not an acid or base, but its ability to rapidly oxidize makes it a corrosive compound. Sometimes acids are also oxidizers, such as nitric acid. We will discuss overlapping chemical classes later in this module.

Bromine: note the red gas in the container. Bromine is volatile and exists in an equilibrium with corrosive gas.

Overlapping Hazard Classifications

Many corrosives can also be flammable, water reactive (i.e. they violently react with water and generate heat), and oxidizers. In these cases, you will see multiple GHS pictograms on the label and SDS for the compound. Acids often fall into multiple classifications and are subcategorized as such:

- Inorganic oxidizing acids: corrosive and oxidizer (e.g. nitric acid, perchloric acid)
- Inorganic non-oxidizing acids (also called mineral acids): corrosive (e.g. hydrochloric acid)
- Organic acids: corrosive and flammable (e.g. acetic acid)

Storage

Acids and bases should be separated into different compartments to avoid unintended reactions. They can be stored in the same cabinet if there is a dividing wall between shelves.
Inorganic oxidizing acids should be stored separately from organic acids, as well as flammable compounds. All acids should be kept away from chemicals that could generate toxic gas and water reactive metals.
Store stock solutions of corrosive compounds in their original packaging, most often polyethylene containers.
Avoid metal containers since they will more easily erode.
Secondary containment measures, such as placing chemical bottles in a plastic bin or tray, are highly recommended. If the bottle leaks, the secondary container will prevent it from spilling out.
Store corrosives below eye level to avoid splashes to the eyes when moving the container onto and off the shelf.

Normally chemicals are stored together by class. Why can we not store all corrosive materials in the same location?

Handling

- Refer to the **S**tandard **O**perating **P**rocedure (SOP) provided by your laboratory or the manufacturer whenever handling corrosive chemicals. Wear tight-fitting goggles and gloves at all times. You may choose to wear another set of disposable gloves on top of your first pair for added protection. You should always wear close-toed shoes in the lab, but this especially important when there are corrosives around. If you are handling large volumes of corrosive substances, wear a rubber apron and face shield in addition to regular PPE.

- Pay attention to the **concentration** of the corrosive chemical you are using. Inadvertently using **higher concentrations** from stock solutions **could result in violent reactions**. When diluting corrosives, remember to always add the chemical to water, rather than adding water to the vessel with the corrosive. Adding water to the concentrated corrosive can cause the solution to quickly heat and splash out of the container. The saying **"Always add acid"** can help you remember the correct manner for making dilutions.

- Use **fume hoods** as directed by SOP. Many corrosives are volatile and can generate gas when they react with other chemicals. If you are using a vacuum line connected to a vessel containing a corrosive reaction mixture, use a cold trap to prevent the escape of corrosive fumes into the vacuum line.

- Use **reagent bottles** to minimize potential spills.

- **Do NOT handle containers of corrosives if you notice crystallization, discolouration, or powder deposits** around the container cap. These signs could indicate contamination resulting in explosive solutions, especially for containers of oxidizing acids.

- Make sure that your lab has s**pill response kits with neutralizers and absorbents** available in the case of a corrosive chemical spill. If your lab handles hydrofluoric acid, keep calcium gluconate on hand for first aid and refer to the SOP for safe handling.

Preparing a Spill Response Kit

There are two options for responding to a spill: neutralization and absorption. Both can be used together – e.g. neutralizing a spill and then recovering with absorbent pads. However, the neutralization step depends on the type of spill.

- Acid: neutralize with sodium bicarbonate ($NaHCO_3$)
- Base: neutralize with citric acid ($C_6H_8O_7$)
- Keep absorbent pads on hand for both types of spills

Significant risks are associated with cleaning up spills. Make sure to fully read the protocols for responding to chemical spills in the chemical emergencies module.

Nitric acid (HNO3) is an oxidizer and a corrosive – how would you store and handle this chemical? Is there any additional information you would need to make this decision?

Firefighting Measures

The choice of extinguisher will depend on the fuel source. In the case of metal fires, use Class D dry powder extinguishers. If an inorganic oxidizing acid causes an organic acid to catch fire, use Class B dry chemical extinguisher. Make sure to go back to the module on flammables and review the types of extinguishers if you have trouble remembering these. Always call for help in the event of a fire, and only attempt to extinguish a fire if you are trained and feel reasonably safe to do so. If not, quickly alert your colleagues, evacuate, and call for the fire department immediately.

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2.4 Compressed Gases

Compressed gases are different from some of the other hazards we discussed. Aside from their potential chemical hazards, compressed gases are also physical hazards due to the high pressure of the container. Proper maintenance and usage of compressed gas cylinders can reduce risk and improved lab safety for everyone.

Pre-Lesson Exercise

10 mins

1. What compressed gases are in your lab?
2. What are other hazards you can think of besides the chemical properties of the gas?
3. How are storage considerations different for compressed gases than other chemicals we have discussed so far?

Identifying Compressed Gases

Compressed gases are easily identifiable even without a label. The large metal cylinders are about 1.5 metres high and rest on the floor, unlike the small plastic bottles in a cabinet. However, compressed gases often have multiple labels depending on the chemical nature of the gas, and therefore you must be familiar with ALL labels in order to safely handle compressed gases.

The GHS label gives the most basic information and informs us that the container holds compressed gas. This label is often found in combination with another GHS label to describe other hazards (e.g. flammability).

This label identifies a flammable compressed gas. Note the pictogram is the same as the one for the GHS flammables label, but it is smaller and placed on an orange background. The “2” at the bottom indicates the container is categorized under TDG Hazard Class 2.

Examples: hydrogen, butane, acetylene, vinyl chloride

The green transport label corresponds with non-flammable, non-toxic compressed gases. The pictogram is the same as the one for the GHS compressed gas label.

Examples: helium, argon, nitrogen, carbon dioxide

This tranport label signifies a toxic gas. The pictogram is the same as the one for the GHS toxic label.

Examples: chlorine, hydrogen sulfide, anhydrous ammonia

There are separate labels for compressed gases in the United States that you may encounter, but they are essentially the same except for additional text.

United States compressed gas labels

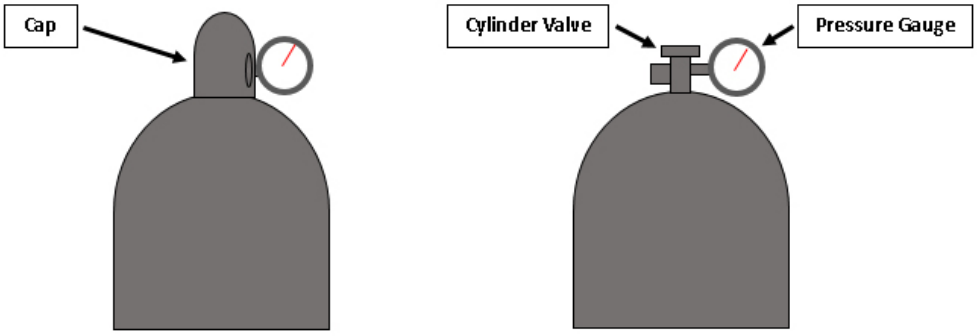
Storage

The storage requirements for compressed gases address their chemical and physical hazards. In addition to separating incompatible chemical groups (e.g. acids and bases, flammables, and oxidizers), there are several steps required to ensure the high-pressure containers do not explode.

Before continuing, take a moment to answer these questions:

What is right with this picture? What do you notice that should be changed?

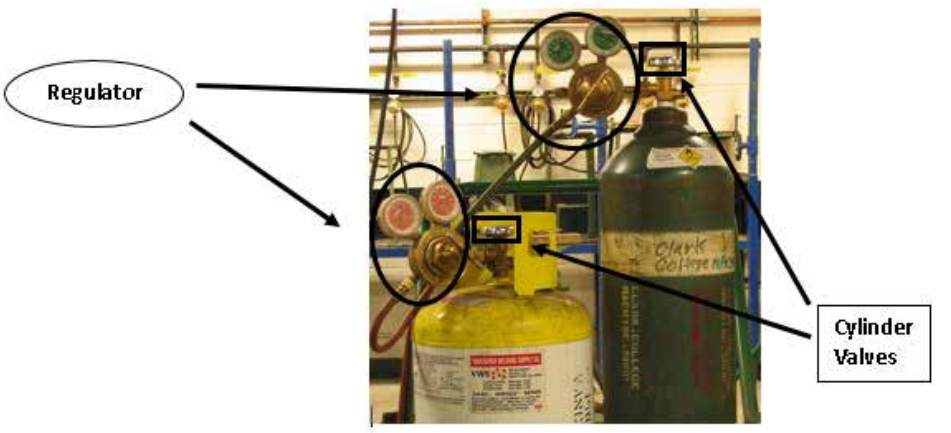
Store compressed gas cylinders upright in a well ventilated, designated area.
Store compressed gas cylinders away from heat and flames. High temperatures can cause the gas to rapidly expand and rupture the high-pressure cylinder, resulting in an explosion.
Secure gas cylinders to the wall or lab bench with at least one non-flammable restraint one-third of the way down from the top of the container. An additional restraint placed one-third of the way up from the bottom is also recommended.
Separate compressed gases in the same manner as you would for incompatible chemical groups. For instance, do NOT store oxidizing gases in the same space as flammable gases.
Keep cylinder caps ON until the gas cylinder is secured to the wall or lab bench. Only remove the cylinder caps when in use and reattach cylinder caps before placing cylinders back into storage.
Do NOT store full and empty cylinders in the same location. Clearly mark empty cylinders so that lab workers do not confuse filled and empty containers.
Do NOT empty cylinders to less than 25 psi. This could result in air mixing with residual gas in the container. The resulting gas would be contaminated and possibly explosive.



Lower temperatures cause gases to contract, decreasing the risk of an explosion. However, it is UNSAFE to store compressed gases in a walk-in refrigerator (unless explicitly instructed in the SDS). Why?

Handling

- Gas cylinders are heavy, and their improper transport can result in personal injury. Always use a handcart with a strap or chain to securely move gas cylinders and avoid back injury. If you need to lift a cylinder, bend your knees and keep your back straight. Do NOT attempt to carry the cylinder on your shoulder or bend your back to pick the cylinder up.
- Use oxygen-monitoring equipment if working with inert gases in a confined space. Some gases, such as argon or nitrogen, have no smell and can displace oxygen and cause asphyxiation.
- NEVER release gas from a cylinder without using a regulator. These devices allow you to safely dispense gas in a controlled manner.
- If you notice a leak, do NOT attempt to repair it yourself. Move the cylinder to a ventilated area if you can safely do so and contact the fire department.
- Use the regulator to adjust output, NOT the cylinder valve.

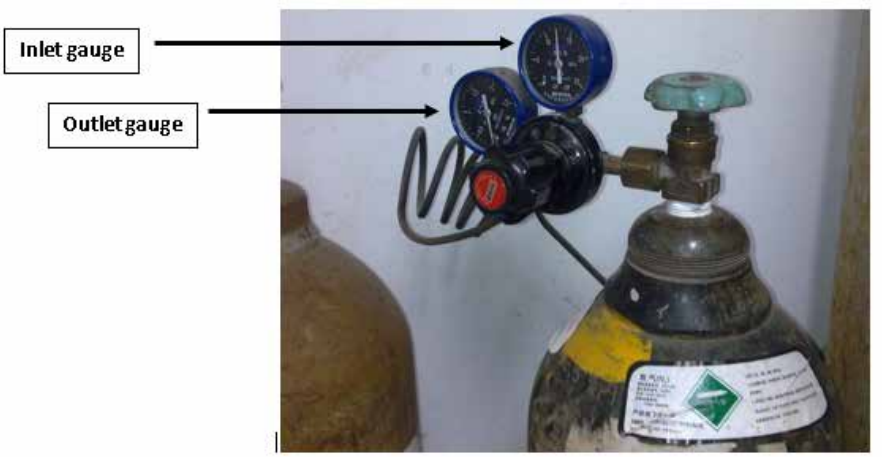


How to Use a Regulator

These steps describe the basics of how to use a regulator. Different cylinders require slightly different regulators (e.g. different diametres, thread styles), but the general protocols are the same. Check with the manufacturer to ensure that the regulator style and gas cylinder are compatible. Always thoroughly read the SOP provided by the manufacturer to ensure proper installation.

- Check the regulator for damage. If there is any debris in the threads, clean them out before continuing. Damage or debris will prevent a complete seal between the regulator and cylinder.

- Set the regulator pressure to zero and completely close the outlet valve, turning the handle clockwise.
- Attach the CLOSED regulator to the compressed gas cylinder, turning in the clockwise direction. If the regulator feels loose or does not fit, do NOT force the regulator to fit the cylinder. You are using the wrong regulator. Check the manufacturer's materials for the proper type of regulator.
- Tighten the connection with a wrench, turning in the clockwise direction.
- Slowly open the cylinder valve by turning it counter-clockwise. If the inlet pressure gauge on the regulator is lower than expected for the cylinder, there is probably a leak at the cylinder-regulator connection. Check for leaks (regardless of inlet pressure) by applying a dilute soap solution to the connection and looking for bubbles.
- If there is a leak, close the cylinder valve completely, tighten the connection, and recheck for leaks.
- After confirming there are no leaks, stand to the side of the cylinder so that the outlet is facing AWAY from you and open the cylinder valve one-eighth of a turn. The gauge should read the full pressure of the cylinder.
- Turn the regulator's adjusting knob to set the outlet pressure.
- Ensure that the outlet line is connected its associated equipment. Open the outlet valve.



A regulator attached to a compressed gas cylinder

Shutting Off Gas Cylinders

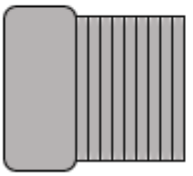
1. Completely close the cylinder valve by turning clockwise. This is sufficient for temporarily turning off the gas flow if you plan on resuming work within half an hour.
2. If you want to turn the gas flow off for longer, also set the regulator pressure to zero. If your set-up includes an outlet valve at the end of the tubing past the regulator, open the valve to allow excess gas to leave the line (purging) and then close.
3. For long-term storage, remove the regulator and reinstall the cylinder cap.

The steps to turning gas flow on and off are simple, but they must be done in the correct order to be safe. What do you think would happen if these steps were completed out of order?

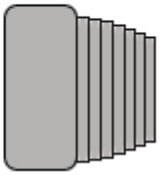
Piping and Assembly

- Only use tubing approved for high-pressure use. Most approved tubing is constructed with metal instead of plastic. Regularly inspect lines for corrosion and replace them as necessary.
- Bond and ground all equipment and cylinders and containing flammable gases. This can be achieved by clamping metal wires to connect adjacent cylinders, in addition to connecting at least one cylinder to a grounding source. Underground metal water pipes or metal sections of the building frame are appropriate grounding sources.
- Do NOT use oil or lubricant for fitting connections on oxygen tubing. This is a fire hazard.

Parallel fitting



Tapered fitting



- Do NOT use copper pipes for acetylene.
- Do NOT use iron pipes for chlorine.
- Use Teflon® ONLY for tapered pipe fittings. Most regulators and cylinders do NOT require Teflon®. Check with the manufacturer to confirm.

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2.5 Cryogens

Like compressed gases, cryogens are both physical and chemical hazards. Common cryogens like liquid nitrogen and dry ice are not reactive, but they can destroy tissue due to rapid freezing. Other cryogens can also be toxic or flammable. Furthermore, these chemicals can create unsafe environments because of their rapid evaporation and formation of gas. Using the proper PPE and setting up a safe workspace can minimize the risks associated with cryogens.

Pre-Lesson Exercise

1. What procedures have you done that require the use of cryogens?
2. What cryogens are in your lab?
3. Where do you store cryogens? Do you store all cryogens in the same manner?

Identifying Cryogens

Cryogens do NOT have their own GHS pictogram and require closer attention to identify them. Instead, the hazard statement on the SDS will alert you about a chemical's cryogenic properties. For instance, the SDS for liquid nitrogen reads "Warning - contains refrigerated gas; may cause cryogenic burns or injury."

The tanks of liquid nitrogen will have the GHS, TDG, or US hazard pictogram on the outside of the container. The three labels are often used interchangeably and sometimes in combination with one another.

The type of container is another great way to quickly identify cryogens. Instead of cylinders, cryogens are kept in insulated tanks to keep them cool. Dry ice, which is a solid, is not stored in tanks, but rather insulated coolers.

Storage

Cryogens are stored in liquid or solid form, but can rapidly convert to gas because of their low boiling points. The storage space for cryogens, therefore, should be well ventilated to prevent the displacement of oxygen as cryogens rapidly evaporate.
Special care should be taken to separate flammable cryogens, such as liquid hydrogen and methane, from heat sources and oxidizers. Liquid oxygen is an oxidizing cryogen and should similarly be segregated from flammables and heat.
Dry ice should be stored in insulated containers that open from the top. Tops should be loose-fitting to allow vapour to easily escape when the container is opened. Storage space should have adequate ventilation close to floor level where containers are placed, since carbon dioxide is denser than air.

How are cryogens similar to compressed gases? What storage recommendations do they share?

Handling

- Only use approved containers with pressure relief mechanisms to handle cryogens. These containers are double-wall vacuum insulated to keep the cryogen at a low temperature. Increases in temperature can cause cryogens to rapidly expand and explode.
- Do NOT handle cryogens in enclosed spaces where they can quickly displace oxygen as they enter the gaseous phase.
- ALWAYS use the appropriate PPE: full protective eyewear or face shields and cryogenic gloves.
- Boiling and splashing occur whenever transferring cryogens from their storage tanks into smaller containers. Pour cryogens slowly to reduce boiling and splashing.
- Use wooden or rubber insulated tongs to manipulate materials in cryogenic liquid baths.
- Do NOT fill containers to more than 80% of capacity. Cryogens can rapidly expand and cause pressure to build up, possibly resulting in an explosion.
- Some cryogens like liquid nitrogen and liquid helium can liquefy oxygen from the air and create a fire hazard. Keep cryogens away from heat and ignition sources.
- Avoid contact with vapour from evaporating cryogens, which can also damage tissue.

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2.6 Explosive and Peroxide-Forming Chemicals

Explosive materials are among the most hazardous chemicals you may encounter in the lab. The energy released in an explosion can cause fatal burns and physical injury to bystanders. Some chemicals are not explosive themselves, but can become explosive when contaminated. Learning how to properly handle these chemicals can reduce the risk of an explosion in the lab.

Pre-Lesson Exercise

10 mins

1. Do you know of any potentially explosive materials in your lab?
2. What situations can initiate an explosion?
3. Compare explosives with flammables. How are they similar? How are they different?

Identifying Explosive and Peroxide-Forming Chemicals

The label on the left is the GHS pictogram label for explosive materials. On the right is the TDG label for their transport. Both labeling schemes share the same pictogram of an exploding circle. The TDG label includes the number 1 at the bottom, corresponding with TDG Hazard Class 2 for explosives.

Just like we could identify classes of chemicals that are flammable, we can also use chemical groups to decide if a compound is likely to be explosive. The chemical properties of these compounds cause them to be more reactive and unstable, which means they can quickly release an incredible amount of energy. The chemical energy stored in the bonds between atoms is converted to work (rapid expansion) and heat, both of which are responsible for massive destruction.

These groups of chemicals are potentially explosive because of their electron configurations and the large energy difference between reactants and products. However, the stability of compounds varies within these groups depending on the chemical bonds present. For example, potassium perchlorate is not explosive,

but ammonium perchlorate is extremely explosive. This is why you ALWAYS need to consult the SDS before working with unfamiliar chemicals. Remember, these are general guidelines and can help you quickly identify potential hazards, but you are responsible for informing yourself of all possible risks on the SDS.

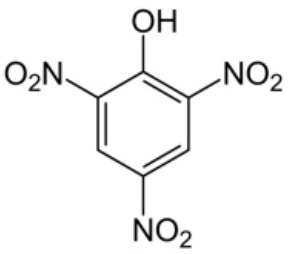
Explosive Materials

Nitrogen-Oxygen Compounds	**Oxides and Peroxides**	**Nitrogen-rich Chemicals**
Perchlorates	**Acetylenic Chemicals**	**Contaminated Chemicals**

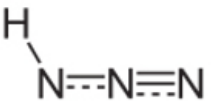
- Nitrogen-Oxygen Compounds: Compounds containing “nitro” or “nitrate” in their name can often be explosive. The stability of the gaseous products and the oxidizing ability of the oxygen make these chemicals particularly reactive.
  Examples: dry picric acid, ethylidene dinitrate

- Oxides and Peroxides: Weak oxygen bonds in some oxides and peroxides facilitate quick reactions. Peroxides are especially reactive and can form shock-sensitive crystal structures that unexpectedly detonate.
  Examples: benzoyl peroxide, bis (1-chloroethylthallium chloride) oxide

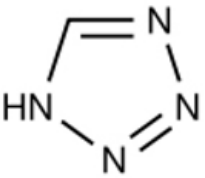
- Nitrogen-rich Chemicals: Like nitrogen-oxygen compounds, chemicals rich in nitrogen tend to contain a large amount of energy because of their stable products (N2). These include azides, aziridines, and other compounds with the “-az” root in their names.
  Examples: 1-bromoaziridine, hydrogen azide, tetrazole



Picric Acid



Hydrogen azide



Tetrazole

- Perchlorates: Some perchlorate salts are rapid oxidizers and can cause an explosion through an uncontrolled redox reaction. These are usually crystalline solids and they can explode when subjected to mechanical forces, like grinding.
  Examples: ammonium perchlorate, ethyl perchlorate, hexyl perchlorate

- Acetylenic Chemicals: Acetylene and related compounds are unstable and can explosively decompose.
  Examples: n-chloro-3-aminopropyne, propiolic acid, 3-propynethiol

- Peroxide-Forming Chemicals: A range of organic compounds can form peroxides by reacting with air whenever the container is opened. These chemicals are not explosive themselves, but rather precursors to explosive compounds. Commercially prepared organic solvents often have stabilizers added to prevent peroxide formation, but they still require periodic testing for peroxides.
  Examples: chloroprene, isopropyl ether, tetrafluoroethylene

- Contaminated Chemicals: Some chemicals are not explosive on their own, but can form explosive mixtures when contaminated. Like air can contaminate ethers and form explosive peroxides, other chemicals can be introduced to solutions of alkyl nitrates to form an explosive mixture.
  Examples: sodium amide exposed to moisture, alkyl nitrates contaminated with nitrogen oxides

Explosive mixtures are often formed in poorly labeled waste containers. If multiple people are using the same fume hood and they dispose of excess chemicals in the same container, they can create explosive mixtures.

In one notable incident, lab workers placed used polyacrylamide gels, hydrogen peroxide, and 2-ethoxyethanol (an ether) in the same waste container. After the container had been left for weeks, it exploded and moved a cinderblock wall located 9 metres away from the blast.

Labeling waste containers is just as important as labeling chemicals used in reactions to avoid similar incidents.

There are many types of potentially explosive chemicals and it can be difficult to remember them all. What patterns do you notice about types of explosive chemicals that can help you remember them? Where can you always check for information on explosion hazards?

Organic Peroxides

Organic peroxides are a subset of particularly hazardous explosive chemicals. They are explosive AND flammable, and thus require extra caution. Organic peroxides even have their own TDG label for transport. However, chemicals in the lab will often only have the explosive and flammable pictograms rather than the combined label shown below.

You should also remember that some organic compounds can become organic peroxides over time after reacting with atmospheric oxygen. Even though they are not organic peroxides when purchased and NOT necessarily labeled as explosion hazards, they require regular testing for peroxide-formation. Testing guidelines are included in the next section on safe storage of explosives and potentially explosive materials.

Peroxide-Formers

Many organic compounds can form peroxides when exposed to light and air. Ethers are the most hazardous, but there are other groups of chemicals than can also form explosive peroxides. These usually have weak C-H bonds that allow oxygen in the air to integrate itself into the chemical structure, forming a peroxide.

Ethers	Secondary alcohols
Aldehydes and Ketones	Ureas, amides, and lactams

Like always, these groupings are only general guidelines and DO NOT include all possible peroxide formers. Check the SDS to definitively identify peroxide-forming chemicals.

Storage

Storage recommendations vary depending on the nature of the explosive material. Higher risk materials require greater precautions. Peroxide-formers are not stored in the same manner as explosive nitrate salts, for example. Make sure you understand the differences and why storage guidelines are NOT the same for all explosive materials.

This module presents explosives materials and potentially explosive materials (i.e. peroxide-formers). What is the difference and why is this distinction important?

Explosive Materials

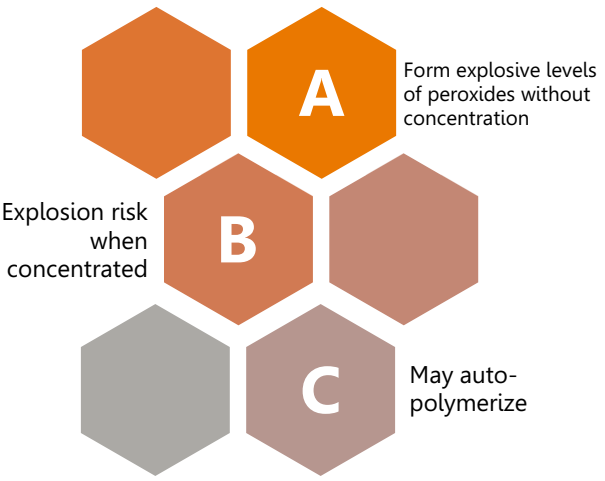
Make a list of all explosive chemicals in the lab inventory.
Store explosives in an approved explosive magazine. Ensure this space is well labeled so other lab workers do not disturb the chemicals.
Store explosives away from possible ignition sources, like heat, light, and sparks.
Liquid organic peroxides should be stored at the lowest possible temperature without freezing. Freezing can cause the formation of explosive crystals.

Even soft mechanical grinding can cause enough friction to cause an explosion. A graduate student working with nickel hydrazine perchlorate attempted to break up clumps with a pestle and mortar, resulting in a large explosion and the loss of three fingers.

Peroxide-Formers (Potentially Explosive Materials)

Some chemicals can form peroxides after exposure to air. Store in airtight containers and in an inert environment when possible.
Do NOT store peroxide-formers in the refrigerator. This recommendation is different than the guidelines for organic peroxides.
Record the opening date and required discard date on the container. Consult the SDS for how long the chemical can safely be stored.
Test peroxide-formers for the presence of peroxides before the expiry date. Many chemical companies sell dipsticks that can detect peroxides. Record the test results directly on the container. Dispose of any chemicals with peroxide concentrations above 100 ppm (check manufacturer guidelines for testing kits).
NEVER test containers of peroxide-formers of unknown age. Expired peroxide-forming chemicals can contain shock-sensitive peroxide crystals in the cap which detonate upon opening.
Do NOT touch a container that has an oily layer or crystal formation near the cap. These indicate the presence of explosive peroxides. Contact your institution's safety operations. Regularly inspect peroxide-formers for these signs of peroxides.
If you find Class B or C peroxide-formers past their discard date, cautiously discard in accordance with your institution's procedures. NEVER touch Class A peroxide-formers past their discard date. Immediately call for safety operations personnel.
Ethers should be stored in opaque containers under an inert gas blanket or above a reducing agent to reduce formation of peroxides.

The figures below explain the different classes of peroxidizable chemicals. The testing and disposal schedule depends on the class of peroxide-formers. Class A lists the most hazardous peroxide-formers, which need to be tested most frequently (every 3 months). Classes B and C only require testing every 6 months.



Note that "concentration" refers to rotary evaporation and distillation, or other purification techniques.

Peroxide-Former Classes: Examples		
Class A	Class B	Class C
Tetrafluoroethylene	Benzyl alcohol	Acrylic acid
Isopropyl ether	Cyclohexene	Acrylonitrile
Vinylidene chloride	THF	Vinyl chloride

Shelf Life for Peroxide-forming Chemicals	
Chemical	Test by or Dispose After
Unopened container from manufacturer	18 months
Class A	3 months
Class B	6 months
Class C	6 months

Handling

- PPE is extremely important when handling explosive materials. Wear a full face shield, thick leather gloves, and a lab coat.
- Conduct all work in a fume hood with the sash lowered. Use a blast shield or protective barrier in addition to the sash for extra protection.
- Heat, friction, static electricity, and large pressure differences can cause detonation. Avoid these whenever handling explosive materials.
- Use polyethylene containers instead of glass ones to avoid the formation of sparks when opening and closing the container.
- Do NOT use metal spatulas or stir bars when handling peroxides. Metal contamination can lead to explosive decomposition.
- Do NOT handle materials near open flames or heat.
- Rotary evaporation and distillation of peroxide-formers are high explosion risks because they concentrate explosive chemicals. ALWAYS test peroxide-formers before performing either of these procedures.
- Use as small an amount as possible when working with explosive or potentially explosive materials. If using liquid peroxides, do NOT return used peroxide to the container as this could result in contamination.
- Do NOT use peroxides with volatile solvents if the solution is at a temperature which might vapourise the solvent and concentrate the peroxides.
- Clean up liquid peroxide spills using vermiculite (clay). Small volumes (≤ 25 g) can be disposed of by diluting with water to a concentration of 2% or less and transferring to a polyethylene container with an aqueous reducing agent. Larger volumes require expert removal to minimise the risk of explosion.

Which ignition sources are similar between those for flammables and explosives? Which are different?

Review: Sort the following chemicals into explosives, peroxide-formers, and neither.

Diethyl ether, sodium azide, nitrogen gas, 2-hexanol, diacetylene, acetal, ethyl perchlorate, cobalt (II) fluoride		
Explosive	Peroxide-Former	Neither

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2.7 Toxic Chemicals

Exposure to toxic chemicals can cause severe injury or death. Unlike many of the other chemicals presented so far, toxic materials are dangerous because of their chemical reactions inside the body. For instance, flammables and explosives are uncontrolled reactions that occur outside of the body, whereas toxic chemicals disrupt the intracellular metabolism of an exposed individual.

Pre-Lesson Exercise

10 mins

1. What toxic chemicals are in your lab?
2. Many chemicals in the lab can be fatal. What is different about toxic materials compared to flammables, for instance?
3. Almost any chemical can be toxic in the right amount. Why are toxic chemicals treated with extra caution?

What are Toxic Chemicals?

Chemicals are defined as toxic by their lethal dose for fifty percent of an exposed population (LD50). That is, half of the organisms exposed to the LD50 dose of a toxic chemical will die. Lower LD50 values for a toxic chemical correspond with greater hazard because less of the chemical is needed for a fatal dose.

The units for LD50 are milligrams of chemical per kilogram of body weight. Note that this is a relative unit, so the same amount of a chemical would be more dangerous to a person that weighs significantly less. On the other hand, LC50 is measured in parts per million (ppm) and describes the toxic concentration of a gas, vapour, or dust in the air.

Note that LD50 is for oral or dermal exposures and LC50 is for inhalation

The mechanisms of action are different for each chemical, but they all negatively affect vital bodily functions. Cyanide, for example, interferes with the electron transport chain in the mitochondria, whereas phenol interrupts ion flows for nervous system function.

This team is practicing how to respond to arsenic exposures.

Toxic chemicals are divided into five different hazard categories depending on how lethal they are. Category 1 includes the most lethal chemicals, whereas Category 5 lists chemicals that are low acute toxicity hazards but may be dangerous to vulnerable populations. Chemicals can be assigned to different categories based on route of exposure. For example, acrylamide is a category 3 toxin orally, but category 4 toxin by inhalation. The categories are important to keep in mind, as the labels are different depending on the hazard level of the toxic compound.

Example category assignments by oral toxicity			
Category 1	Sodium cyanide	Category 4	Formic acid
Category 2	Hexane	Category 5	Trypan blue
Category 3	Acrylamide		

Identifying Toxic Chemicals

Toxic chemicals have two potential GHS labels depending on their hazard level: the skull and crossbones and the exclamation mark. The skull and crossbones pictogram identifies the greatest toxicity hazards, including chemicals from Categories 1, 2, and 3. The exclamation mark corresponds with less toxic compounds in Category 4.

Chemicals classified under Category 5 are not labeled with either pictogram.

Toxic chemicals have two possible labels depending on hazard level. How can you remember which one indicates more hazardous chemicals?

This chart summarizes the parameters used to decide which label applies to a toxic chemical. Notice the numbers under the skull and crossbones pictogram are much smaller, indicating a lower dose can be fatal.

Route of Exposure		
Oral	LD50 ≤ 300 mg/kg	300 mg/kg ≤ LD50 ≤ 2000 mg/kg
Dermal	LD50 ≤ 1000 mg/kg	1000 mg/kg ≤ LD50 ≤ 2000 mg/kg
Inhalation	LC50 ≤ 2500 ppm	2500 ppm ≤ LC50 ≤ 20000 ppm

We will discuss the exclamation point more in the next module where we present chemical hazards to health. This pictogram can be confusing because it is used in conjunction with other hazard labels that may not be toxic but are still harmful.

The TDG labels for transport are only used for chemicals assigned the skull and crossbones pictogram (i.e. Categories 1-3). They include the same symbol on a white background with the number 6 at the bottom, indicating UN Hazard Class 6 for toxic materials.

Storage

Store toxics separate from other hazardous chemical classes, especially flammables and oxidizers. Fires among toxic materials can create dangerous fumes.
Keep toxics in a well-ventilated area to avoid the accumulation of toxic vapours. Store away from heat and light.
Ensure that containers are tightly sealed to avoid accidental exposures.
Do NOT store in a fume hood unless it is a toxic gas for which the SOP specifically requires fume hood storage. Fume hoods are intended for routine use when handling small amounts of chemicals and using them for storage could expose workers using the workspace.

Why do you think the LD50 values are different depending on the route of exposure? What does it mean that the LD50 value is smaller for oral exposures than dermal exposures when classifying toxic materials?

Handling

- Designate a specific area in your lab for handling toxic chemicals. Always handle toxic chemicals that are volatile or produce dust in a fume hood.
- Communicate with all lab workers when and where work with toxic chemicals will be conducted. Consider posting signs to alert people to the hazardous work.
- Minimise the number of people in the room when working with highly toxic chemicals.
- Know all signs and symptoms of exposure to the chemical.
- Check the SDS for specific PPE guidelines. If the chemical can be absorbed through the skin, you should wear clothing and gloves that cover all skin, in addition to a respirator. See the module on PPE for additional guidance.
- Wash hands and forearms immediately after working with toxic materials. Leave contaminated PPE, such as gloves, in the space reserved for handling toxic materials.
- You should NEVER eat, drink, or apply cosmetics in the lab, but these actions are especially dangerous when working with toxic materials.

The main routes of exposure are inhalation and contact with the skin. However, lab workers can still ingest toxic chemicals. How does this happen?

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2.8 Health Hazards

Chemical health hazards and toxic materials are both similar in that they facilitate dangerous chemical reactions inside the body. However, we distinguish between these two hazard classes in order to emphasize the acute nature of toxic substances. Toxic substances can quickly cause death, whereas chemical health hazards generally cause chronic issues. However, chemical health hazards can still be fatal and require extreme caution. In this module we will discuss the various types of chemical health hazards and best practices for working with them in the lab.

Pre-Lesson Exercise

10 mins

1. What chemical health hazards exist in your lab?
2. What health effects can chemicals cause besides death?
3. What is the difference between chemical health hazards and toxic chemicals?

Identifying Health Hazards in the Lab

The GHS pictogram for health hazards depicts the silhouette of an individual with a star-shaped white space in the middle. This should be clearly marked on the SDS and container label for the chemical. There is no corresponding TDG label for transport of health hazards. Even though there are multiple types of health hazards, the same pictogram is used for all of them. Therefore, it is important to fully read the SDS to understand the specific health hazard associated with the chemical in use.

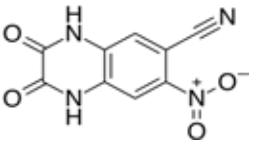
The different types of health hazards fall into six general categories: respiratory sensitizers; germ cell mutagens; carcinogens; reproductive toxins; target organ toxins; and aspiration hazards.

Respiratory Sensitizers cause hypersensitivity of the airways after inhalation. The response is immune system mediated and causes asthma symptoms.

Germ Cell Mutagens cause an increase in the frequency of mutations in germ cells that will be passed onto progeny. That is, they produce heritable mutations.

Carcinogens induce cancer or increase its incidence. Germ cell mutagens are sometimes carcinogenic.

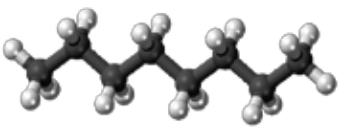
Reproductive Toxins adversely affect sexual function, fertility, and the development of offspring. They can cause fetal death, structural abnormalities of the fetus, altered growth, or functional deficiencies in the developing child.



Target Organ Toxins damage specific organ system structures or functions. Neurotoxins, for example, target the nervous system.

CNQX – a neurotoxin

Aspiration Hazards are liquids that can cause damage to the airways when breathed in as a mist. Pulmonary injury and chemical pneumonia are possible outcomes. Many hydrocarbons and chlorinated hydrocarbons fall under this category.



Octane – an aspiration hazard

Think about what you learned in the last module regarding routes of exposure. How could you be exposed to the health hazards discussed here? How could prevent exposure?

Comparison of Sensitizers and Irritants

These two terms are sometimes used interchangeably but mean two different things. Sensitizers are chemicals that cause a heightened immune response after previous exposure. Irritants, on the other hand, are noncorrosive substances that cause reversible inflammation. Irritants do NOT lower the threshold of exposure for causing an allergic reaction like sensitizers do. However, both cause inflammation. Sensitizers are often considered to be more hazardous than irritants because they cause long-term immunological changes in exposed tissues.

Irritants will often be labeled with the GHS exclamation point pictogram, whereas sensitizers are labeled using the GHS health hazard pictogram. Remember, the exclamation point can also be used to designate low-level toxicity, so you need to always check the details in the SDS to confirm which hazard it represents.

Examples of Sensitizers and Irritants in the Lab	
Sensitizers	Irritants
Formaldehyde	Iodine
Phenol	Benzoyl chloride
Acetic anhydride	Cyclohexane
Cobalt	Sulfur dioxide

Read through Section 2 of the SDS for octane and discuss the hazards you identify.

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Skin irritation (Category 2), H315
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram 

Signal word Danger

Hazard statement(s)
H225 Highly flammable liquid and vapour
H304 May be fatal if swallowed and enters airways.
H315 Causes skin irritation.
H336 May cause drowsiness or dizziness.
H410 Very toxic to aquatic life with long lasting effects
.
Precautionary statement(s)
P210 Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233 Keep container tightly closed.

11.1 Information on toxicological effects

Acute toxicity
LC50 Inhalation - Rat - 4 h - 118,000 mg/m3

Dermal: No data available

No data available

Skin corrosion/irritation
No data available

Serious eye damage/eye irritation
No data available

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Reproductive toxicity
No data available

No data available

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
The substance or mixture is known to cause human aspiration toxicity hazards or has to be regarded as if it causes a human aspiration toxicity hazard.

Additional Information
RTECS: RG8400000

burning sensation, Cough, wheezing, laryngitis, Shortness of breath, Headache, Nausea, Vomiting, Central nervous system depression, narcosis

Does this section add any more information on the health hazards associated with octane?

Storage & Handling

The recommendations for storage and handling of chemical health hazards are identical to those for toxic chemicals. Ensuring that health hazards are stored in a designated area, kept in sealed containers, and appropriately labeled all decrease risk of harm. Likewise, following established SOP and handling health hazards in a fume hood with the appropriate PPE can keep workers safe.

Additionally, there are a few key points to emphasize for health hazards:

- Workers should be familiar with all the symptoms of exposure to hazardous chemicals in the lab
- Lab management should consider exposure monitoring for frequently used health hazards (air sampling, biomonitoring, etc. – these are ways labs can monitor health by checking air samples in the work area or blood samples from lab workers to detect exposure)
- ALWAYS check the SDS and consult with experts regarding the specific health hazards of a chemical, since the pictogram alone does not provide detailed information

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2.9 Environmental Hazards

Chemicals in the lab are often not only hazardous to humans, but also other organisms in the environment. The release of Environmental Hazards can result in the death of many plants and animals, disrupting food chains and the natural balance of the ecosystem. Aquatic life forms are especially vulnerable, as runoff from labs and industry can easily introduce hazardous chemicals to the waterways. Learning how to manage and dispose of environmental hazards can minimize the impact your lab has on its environment.

Pre-Lesson Exercise

10 mins

1. What environmental hazards does your lab handle?
2. Make a short list of the organisms you think could be affected by the chemicals in your lab.
3. What other hazard classes do you think might overlap with environmental hazards (e.g. flammables, oxidizers, corrosives, etc.)?

Identifying Environmental Hazards in the Lab

The GHS label for environmental hazards depicts a tree without leaves and a fish inside a red diamond. The two symbols are a reminder that plants and animals both experience negative effects because of chemical exposures. The TDG label for the transport of environmental hazards is identical to the GHS label, the only difference being its black and white border.

Some examples of environmental hazards include: tetrachloroethylene, bromobenzene, and diphenyl ethe

Storage & Handling

Chemicals should be stored according to their hazard classes as previously described. For example, a chemical that is toxic and an environmental hazard should be stored in accordance with the guidelines for toxic chemicals.

Disposal

Environmental Hazards cannot be disposed of by pouring down the drain. Most labs use commercial waste management services for removing and destroying hazardous waste. See the next module on the chemical life cycle for more information on proper disposal.

Waste poured down the drain can flow into local waterways and harm the environment.

Module References

United Nations, et al. (2005). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). New York, United Nations.

3 The Chemical Life Cycle

How you use chemicals in the lab is only one part of the story. The processes before and after are just as important for workplace safety. In this module we will discuss the best practices for managing your lab's chemicals from procurement all the way to disposal. Knowing what chemicals you need, what chemicals you have, and how to safely dispose of chemicals are all essential to maintaining a safe workspace and creating the conditions for a healthy environment.

What is the Chemical Life cycle?

The idea of a life cycle means that we need to think about where chemicals come from and where they go. Their hazards are important to consider every step of the way, rather than only when you are opening a container to conduct an experiment. We divide the chemical life cycle into four segments and will discuss each in greater detail.

Procurement

Chemical safety starts before chemicals even enter the lab. There are several questions to consider before purchasing chemicals:

1. Does the lab have an inventory of chemicals?
2. How much of each chemical is needed for an experiment?
3. Does another collaborating lab have the chemicals you need in stock?
4. Is the lab equipped to address the hazards of the chemicals to be purchased?
5. Is there a designated space for accepting shipments of chemical products?

The first three questions address a similar concern: reducing waste. If a lab does not know what chemicals it already has, it is imprudent to purchase chemicals it might already have in stock. Buying more chemicals would only add to the mismanaged stock of chemicals, creating more waste and opportunities for the release of hazardous substances. Similarly, purchasing a much larger volume of chemicals than necessary is wasteful and introduces more chemicals that will eventually need to be properly disposed.

Instead, purchase smaller volumes of chemicals and design experiments to use as small an amount of chemicals as possible to generate less waste for disposal. Keeping the entire life cycle in mind from the beginning helps you make better choices that maximize efficiency and safety throughout your time in the lab.

One of the hallmarks of science is replicability. How can you reduce waste while maintaining high standards by repeating trials multiple times?

The last two questions indicate the importance of being prepared to receive new chemicals. If you plan to purchase a toxic compound, for example, you will need to make sure your fume hood is properly working, your respirator is fitted, and your colleagues are cautioned about the nature of your work. These steps need to take place before the chemical is ordered. Your lab must also have an established, central area for receiving packages.

In what circumstances should you refuse to accept a package?

Part of responsible procurement is to know the signs of unsafe packages. You should refuse to accept packages without clear labels identifying their contents. Furthermore, if you notice signs of breakage, such as hearing rattling inside the box or seeing wet spots from a leak, you should not accept the package or only open it inside a fume hood.

Storage

By now you should already know the main principles for the storage of hazardous chemicals. Each class has its own precautions, but they share many general themes that are worth repeating here.

- All chemical containers must be clearly labeled, preferably in their original packaging
- Chemicals should be separated by hazard class – e.g. do NOT store flammables with oxidizers
- Do NOT store chemicals on the floor, under work benches, or near passages and exit routes
- Do NOT store chemicals in fume hoods unless specifically directed to do so in the SDS
- Store heavier containers on lower shelves – this is important for keeping the shelving balanced, especially in the case of seismic activity
- Do NOT store chemicals on top of cabinets or shelves above 1.5 metres – these can easily be knocked over when reaching for a container
- Peroxide-forming materials must be regularly tested for peroxides (see "Working with Explosive and Peroxide-Forming Chemicals")

Handling

Two acronyms summarize the most important directions to remember when handling hazardous chemicals: PPE and SOP. Using the appropriate Personal Protective Equipment (PPE) can protect you from chemical exposures during an experiment. Following the Standard Operating Procedures (SOP) can ensure that you handle chemicals using the safest techniques and equipment

This scientist is wearing the appropriate PPE for working with samples containing influenza virions. She is also following the SOP by transferring the sample using approved glassware, sample containers, and a fume hood to conduct her work.

The next two modules in this manual go into further detail on the topics of PPE and SOP.

Disposal

Chemicals present at the end of an experiment require still careful handling. In fact, chemical waste can contain multiple hazard classes at the same time depending on the chemicals used. You can take steps to decrease risk by managing your waste collection and disposal practices.

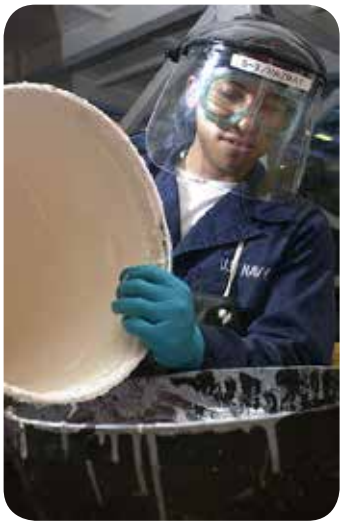
Waste Containers:

Do NOT mix chemical and biological waste – collect these in separate containers and treat biological waste according to your institution's protocols

- Collect waste in compatible containers over the course of your experiment – polyethylene bottles often work well and do not corrode, but check the SDS for all chemicals used first
- Waste includes solutions used in an experiment, pipette tips used to dispense chemicals, and any products generated in an experiment
- Treat materials used to clean up chemical spills (e.g. absorbent pads, sand, etc.) as hazardous waste
- Do NOT mix incompatible waste in the same container – for example, do NOT use the same container for organic solvents (flammables) and oxidizers
- Label each waste container with: a list of all chemicals inside, the date it was first used, the date it was filled, and the name of the person using the container
- Do NOT overfill waste containers – cap the container and write the date on the label as soon as the waste approaches the top of the container
- Close the waste container when you are not actively adding waste
- All waste containers should have secondary containment – consider placing waste containers in a polyethylene tub to prevent spills when adding waste

Disposal is the most variable step because it depends on the specific chemicals used in an experiment and the institution's resources and policies on waste management. Regardless of the chemicals used, always consult with management and your institution's guidelines before planning an experiment to plan how to safely dispose of waste.

- Many laboratories have contracts for chemical waste disposal with commercial vendors – check with your institution to verify if you have access to such services
- Municipal waste management systems often have special divisions for hazardous waste – consult your institution and municipality for further information
- Incineration is the best option for safe disposal of hazardous waste – if your institution has an incinerator on site, consult their policy for incinerator usage
- Acids and bases can usually be neutralized and flushed down the drain with excess water – check local and national regulations for waste water before pouring anything down the drain, including neutralized acids and bases
- Specific waste products can be treated in the lab according to established SOP on a case-by-case basis – check with management to determine if this is an acceptable option



A worker pours chemical waste into a container for pick up. Notice that he is wearing gloves, safety goggles, and a face shield.

Module References

Duke Occupational & Environmental Safety Office. Chemical Hygiene. Retrieved June 5. 2018, 2018, from https://www.safety.duke.edu/laboratory-safety/chemical-hygiene

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

4 Personal Protective Equipment (PPE)

Wearing the appropriate Personal Protective Equipment (PPE) can be the difference between severe injury and a minor inconvenience in the lab. Protect yourself by wearing the correct PPE and understanding when and how to use it.

Clockwise from top left: powered air-purifying respirator (PAPR); nitrile glove; lab coat; safety glasses; face shield

Dressing for Lab

Dressing safely for lab begins before you even don your PPE. Wearing trousers that cover the legs and close-toed shoes are the most important steps you can take to prevent injuries in lab. Your clothes add an additional barrier between your skin and chemicals splashes, preventing irritation and chemical burns. For this same reason you should also wear long sleeved clothing to protect your arms.

Individuals with long hair should pull their hair back and secure it using an elastic band or hairpiece. This prevents the hair from coming into contact with chemicals or catching fire when leaning over the lab bench.

Individuals with contact lenses should take greater precautions with eye wear to prevent dust and fumes from becoming trapped against the eye. Contact lens users should use full eye protection and avoid wearing their contact lenses when possible. In case of chemical splashes to the eye, they should immediately use the eye wash station before removing their contact lenses. Workers should clearly communicate if they use contact lenses to management, so they can notify first responders in case of a medical emergency.

How do you dress for lab? Do you dress differently depending on the work you will be doing in lab?

Gloves

Gloves are the classic PPE all lab workers have used at some point. They prevent accidental exposure to the skin by providing a barrier between your hands and the chemicals you are manipulating. In order to be as effective as possible, though, you need to choose the appropriate type of glove and ensure you remove them properly. Otherwise, incompatible glove materials can allow chemicals to pass through and improper removal can leave chemical traces on your hands.

Materials

Most labs use nitrile gloves, but there are other options to consider depending on the nature of the work. Butyl, neoprene, and Viton™ are a few of the other commonly used glove materials you may encounter in the lab. Knowing which gloves to choose is important in order to avoid wearing gloves that are permeable to the chemicals you are using.

Use these general principles and the table below to guide your decision on which gloves to use. Check the SDS and SOP for additional guidance on selecting gloves.

- Latex gloves work well for biological agents, but offer poor protection from many chemicals, including strong acids/bases and many organic solvents; some users experience an allergic reaction to latex
- Nitrile gloves are extremely common and offer adequate protection against

oils, weak acids/bases, and halogenated hydrocarbons for an economic price, but may not suit your lab's needs

- Butyl gloves protect against many different corrosive chemicals (strong acids/bases), but are less suitable for aliphatic compounds (i.e. chemicals composed of long carbon chains), aromatic compounds, and halogenated solvents
- Butyl gloves protect against ketones and esters, whereas many other high-quality gloves do NOT protect against these chemicals
- Neoprene is a resistant, synthetic material that protects the wearer from aliphatic solvents, organic acids (which are usually weaker), and bases
- Viton™ is a synthetic polymer made by DuPont that protects against many different hazardous chemicals, but is expensive

What type of gloves should I wear?

Chemical Group	Glove Material					
	Latex	Nitrile	Neoprene	PVC	Butyl	Viton™
Water miscible substances, weak acids/bases	✓	✓	✓	✓	✓	✓
Oils		✓				
Chlorinated hydrocarbons		✓				✓
Aromatic solvents						✓
Aliphatic solvents		✓	✓			✓
Strong acids					✓	
Strong bases			✓		✓	
Polychlorinated biphenyls (PCB)						✓

Ansell has a detailed matrix of compatible glove materials for many more chemicals available online: https://www.ansellpro.com/download/Ansell_8thEditionChemicalResistanceGuide.pdf

Finally, remember to use heat resistant and cryogenic gloves for extremely hot and cold work, respectively. These physical hazards are also dangerous and require proper PPE for safe handling.

Does your lab have more than one type of gloves? Which gloves have you used before?

Using Gloves

- Immediately remove and change your gloves if you notice a tear or contamination – frequently inspect gloves for contamination
- Change gloves periodically, especially when working with corrosive chemicals that might permeate the gloves
- Wear two pairs of gloves at the same time for work with extremely hazardous chemicals – you can even mix different types of gloves to protect against mixed hazards (e.g. cleaning broken glassware that held a corrosive liquid)
- Remove your gloves before touching shared surfaces away from your lab bench or fume hood (e.g. door knobs, light switches, shared equipment, break rooms, office supplies)
- Do NOT wear gloves outside of the laboratory to avoid exposing unprotected individuals
- Treat used gloves as hazardous waste and do NOT remove from the immediate area – e.g. dispose of used gloves in a waste container inside the fume hood

<u>Remember</u>: Gloves only protect the user and do NOT prevent contamination of the workplace environment




Removing Gloves

Even if you wear impermeable gloves, failing to properly remove them can still expose you to dangerous chemicals. Remove the gloves in such a manner that your skin does not touch the outside material. Follow these steps to safely remove your gloves:

1. Pinch one glove near the wrist.
2. Pull the glove off using your middle finger, pulling the glove from the outside.
3. Hold the discarded glove in the still gloved hand.
4. Stick an ungloved finger on the inside of the gloved hand and peel the glove off.
5. Discard the used gloves and wash hands with soap and water.

Eye Wear

Protective eye wear comes in different shapes and sizes, and thus offers various levels of protection for all kinds of work. Safety glasses are the most basic PPE for eye protection and offer minimal protection from chemical splashes. On the other hand, safety goggles create a sealed barrier around the eyes and prevent splashes from reaching the eyes even if they land above or below the screen. Safety goggles are thus superior to safety glasses for full splash protection

Safety glasses (left) and safety goggles (right) – which offer greater protection?

Face shields also protect the eyes but have the same weakness as safety glasses because they do not create a sealed barrier. However, face shields are useful for protecting the rest of the face from airborne matter. The best practice is to use face shields in conjunction with safety glasses or goggles when there is a high risk of chemical splashes.

Safety goggles offer significantly greater protection than safety glasses. When do you think safety glasses are appropriate to wear?

Lab Coats

Lab coats offer another layer of protection in addition to the clothes you are wearing. You should wear a lab coat whenever you are handling liquids in order to protect against splashes. Lab coats are especially important to wear whenever heating liquids, as they can unexpectedly splatter. Regular cotton lab coats are acceptable for general use, but not when handling flammables. Scientists working with flammable materials should wear a flame-resistant lab coat made of polyaramid material. Those working with large volumes of liquids, for instance, a worker acid-washing glassware, should wear a rubber apron on top of their lab coat for additional protection.

Lab coats should NOT be worn outside of the laboratory to avoid the spread of contamination. Laundering should be provided onsite or through a commercial service, and NOT done in workers' households.

Respirators

Respirators protect the user from inhalation and aspiration hazards when handling volatile chemicals. They offer greater protection than a surgical mask, since they create a sealed barrier between the wearer and the environment, preventing the entry of vapour that could otherwise be inhaled. There is a wide selection of respirators, from which your lab can select according to its needs.

Chemical cartridge respirators
• Cartridges absorb specific hazardous chemicals • NOT for use in low oxygen settings or emergency response
Organic vapour respirators
• Cartridges absorb volatile organic chemicals • NOT for use in low oxygen settings or emergency response
Dust, fumes, and mist respirators
• Often disposable masks worn over the mouth and noise to filter out particulate matter • NOT suitable for protection against gases

Supplied air respirators (SAR)
• Deliver fresh air, using positive pressure to keep contaminated air out • Suitable for use in low oxygen environments
Powered air-purifying respirators (PAPR)
• Same principle as SARs, but air is filtered from environment and forced through mask instead of coming from a lab air line • Does not require cylinders or positive pressure airlines
Self-contained breathing apparatus (SCBA)
• Air supplied from cylinder carried on the user's back • Only respirator approved for emergency response

Each of these classes of respirators can be worn with full face or half face headpieces depending on the level of protection needed.

The two pictures to the left illustrate full face and half face cartridge respirators. Both offer the same respiratory protection, but the full face respirator also protects the eyes from chemical exposures

Full face (left) and half face (right) respirators

Clearance Requirement

- All individuals must be medically cleared before using a respirator
- Fitting and training must occur before using a respirator
- Fitting and training must be repeated at least once a year

Using Respirators in the Lab

- For chemical cartridge respirators, choose the cartridge that protects against the specific chemicals you will be exposed to; make sure to read the label for acceptable concentrations and schedule for replacement
- Do NOT share respirators, with the exception of PAPRs which can be used by different individuals
- Glasses can be worn with half face respirators if they do not interfere with the seal of the facepiece; eyepiece inserts purchased from the manufacturer may

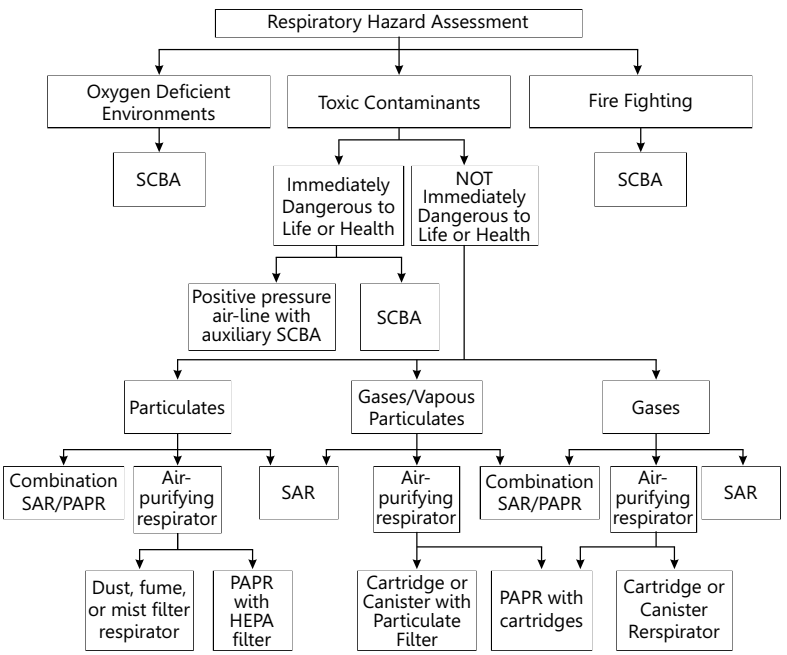
be necessary in place of regular spectacles for full facepieces; contact lenses are acceptable with half and full facepieces

Some respirators use cartridges like the one in this picture to filter out specific chemical exposures.

- Labs should post reminders on how to properly use respirators in relevant areas
- Respirators should be inspected annually – however, SCBAs require more frequent, monthly inspections and cleaning after each use
- Workers using respirators must be retrained on how to properly fit and use the equipment at least once a year

Choosing a Respirator

The tree on the following page shows the full set of options for respirators you can use depending on the type of risk. You may notice that the final hazards at the bottom of the tree branch out into many different options. This is because there are multiple acceptable respirators that can be used for those risks. For instance, if you are working with particulate matter, you could use combination SAR/PAPR, dust/fume respirators, HEPA filter respirators, or regular SAR. The final decision on which one is most appropriate lies with you and lab management.



[Adapted from Appendix B of NIH Respiratory Protection Program]

PAPR or SAR are necessary for individuals with facial hair – cartridge respirators or fitted masks (e.g. N-95) cannot create an airtight seal when facial hair (e.g. beards or mustaches) is present

Types of Dust, Fume, and Mist Filter Respirators

There are several types of disposable respirators for dust, fumes, and mists. Unlike the other types of respirators, these only protect workers from particulate matter and aerosols. They are useful when working with powders or during protocols that may generate dust that could be breathed in.

One of the most common filtering facepieces is the N-95. However, workers have several other options depending on the risk of their work environments.

Each one of these respirators has a letter and a number to describe its level of protection.

- N – **N**ot oil resistant
- R – Oil **R**esistant
- P – Oil **P**roof

The N-95 respirator (pictured here) is a disposable respirator that filters out particulate matter – it requires proper fitting to work effectively

The R-series and P-series are similar in that they both resist oil aerosols, but the P-series can be reused in the presence of oil whereas R-series respirators need to be replaced after a work shift.

The number after the letter tells the user what percentage of particles are filtered out. For instance, an N-95 respirator does not protect against oils and filters out 95% of particulate matter 0.3 microns in diameter and larger. The next two certified levels of protection are 99 and 100 for 99% and 99.7% filter capacity, respectively.

Thus, there are nine different options for filter respirators: N-95, N-97, N-100, R-95, R-97, R-100, P-95, P-97, and P-100. Lab workers should decide on which respirator is appropriate depending on the chemicals they encounter (e.g. oil-based) and the frequency of their use. For examples, labs that frequently use protocols that may involve aerosolization of oils should consider P-series respirators. All filter respirators need to be properly fitted to ensure proper function.

Module References

Safety. (1996). NIOSH Guide to the Selection and Use of Particulate Respirators. Retrieved from Washington, DC: https://www.cdc.gov/niosh/docs/96-101/default.html

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

NIH Office of Research Services. (2015). Respiratory Protection Program: National Institutes of Health

Occupational Safety and Health Administration. (2004). Personal Protective Equipment. Washington, DC.

UK Health and Safety Executive. Selecting Protective Gloves for Work with Chemicals.

5 Standard Operating Procedures (SOP)

Standard Operating Procedures (SOP) are established protocols that outline how to minimize safety risks when handling chemical processes and procedures. They outline the safety precautions for specific experiments and provide researchers with a safety plan before starting their work in the lab. Lab workers and management must work together to develop SOP or modify existing ones for all work conducted in the lab. Many institutions already have their own collection of SOP that can be taken and adjusted for many kinds of lab work.

Moderate Risk vs. High Risk SOP

Lab personnel need to consider the level of risk when preparing SOP. Moderate and low risk activities both require certain details, but more hazardous procedures require additional information to account for all safety measures. Determining what is "moderate risk" and what is "high risk" is subjective and requires experience, so lab workers should always consult with lab managers and senior staff when developing SOP.

Risk	Control Measures	Example
Low Risk	Lab standards are sufficient	Serial dilution of standard solution
Moderate Risk	Risk reduction where possible	Acid-base neutralization
High Risk	Substantial measures need to reduce risk	Use of pyrophorics, explosives, large volumes of flammable liquids, procedures with high failure rate

Developing an SOP

Consult your lab manager and institution for existing SOP your lab can modify. If there is no SOP, the National Academies of Sciences, Engineering, and Medicine have developed templates you can reference when writing your own. Remember, SOP should be clear and detailed, but not too complicated so that workers with limited experience can successfully follow them.

Please consult the publication, Chemical Laboratory Safety and Security – A Guide to Developing Standard Operating Procedures, for examples: https://doi.org/10.17226/21918

Adapted SOP templates from the National Academies of Science, Engineering, and Medicine are available in Appendix C at the end of this manual.

Module References

National Academies of Sciences, Engineering, Medicine. (2016). Chemical Laboratory Safety and Security: A Guide to Developing Standard Operating Procedures. Washington, DC: The National Academies Press.

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

6 Proper Use of Laboratory Equipment

Knowing how to properly use lab equipment is a crucial part of safely handling chemicals. If you understand the chemical hazard classes and their specific risks, you can thoughtfully operate equipment in such a way that prevents accidents and exposure. Some skills are based on "common sense" – for example, moving flammable chemicals far away from hotplates. Combined with the concrete skills of how to operate equipment, you can minimize risk and create a safe work environment in your lab.

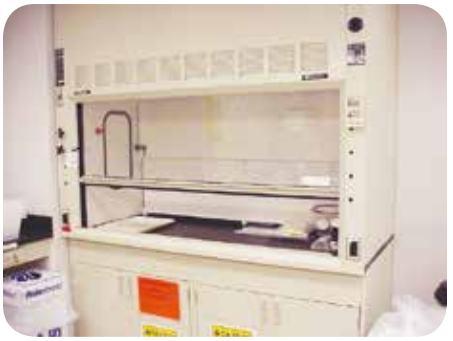
Pre-Lesson Exercise

1. What equipment do you regularly use in the lab?
2. How does the hazard class of the chemical affect the precautions you take when using certain equipment?
3. What should you do if you are unfamiliar with how to use a piece of equipment in lab?

Fume Hoods

Fume hoods allow lab workers to work with volatile chemicals and powders without releasing contaminants into the workspace. Make sure you know these best practices to take full advantage of your fume hood's protection.

Keep all materials at least 6 inches away from opening but do NOT place chemicals or equipment directly against the back
Keep the vertical sash below the mark indicated for safe operation – if you raise the sash too high, the ventilation system will not be able to prevent all fumes from escaping
Do NOT use fume hoods for storage of chemicals or equipment.
Keep the vertical sash closed when not actively using the fume hood
Raise equipment in the fume hood on blocks to improve airflow when possible



Keep your fume hood clean!

Clean fume hoods
=
Safe fume hoods

Hot Plates

Hot plates are a significant fire hazard in the lab and require careful use. Flammable chemicals are the cause of most concern, but hot plates can also start fires or cause other injuries even without flammables present. Electrical fires from cords in contact with the heated surface, or boiling over and splattering of liquids both are cause for concern.

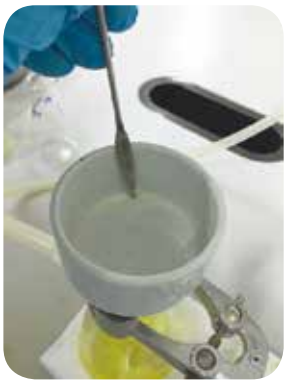
Clean your workspace and remove all flammable items (e.g. organic solvents, ethanol squirt bottles, paper towels)
Ensure none of the electrical wiring of the hot plate comes into contact with the heated surface
Always clamp down glassware to a ring stand while heating – this is important to prevent containers from falling over when boiling
Use magnetic stir bars or boiling stones to ensure even heating and avoid splattering
NEVER leave an active hot plate unattended
Provide secondary containment when heating flammable chemicals – you can do this by creating a water bath on the hot plate and immersing the container of flammable liquid
Do NOT use plastic materials on hot plate – always use approved glassware and check for cracks before heating

This scientist is performing a vacuum filtration. Note that the flask is clamped to a ring stand not visible in this picture.

Vacuum Line

Working under a vacuum is a common technique when purifying product or separating mixtures. The vacuum creates a physical hazard for lab workers, as glassware can break under stress and injure individuals nearby. Vacuums also frequently require cold traps, and thus introduce cryogen-related hazards for workers. Following these recommendations can help minimize your risk when working with a vacuum.

Only use glassware approved for work under vacuum – inspect for cracks and chips before use
Always clamp down glassware to a ring stand when under vacuum
Consider wrapping glassware under vacuum with tape to prevent flying glass in case of implosion
Use a cold trap or other trapping device to prevent contamination of the vacuum system
Enclose the cold trap with a rigid container in case of implosion
Use crushed ice and isopropanol for the cold trap – only use liquid nitrogen when necessary and do NOT open during operation of the vacuum
Treat the pump oil as hazardous waste when using a vacuum for systems with hazardous chemicals
Ensure that stand-alone vacuum exhaust is vented outside of the lab



This scientist is performing a vacuum filtration. Note that the flask is clamped to a ring stand not visible in this picture.

Module References

ETA Safety. (2015). Hot Plate Safety in Lab Areas: Lawrence Berkeley National Laboratory.

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

UC Berkeley Office of Environment, Health & Safety. Vacuum System Hazards and Precautions.

7 Safety Data Sheets (SDS)

Throughout this manual, each module has repeated a key message – always check the safety data sheet (SDS). Chemical manufacturers are required to provide an SDS for every chemical they distribute, providing lab workers with the necessary information to stay safe. However, it is easy to get lost in all the information if you are not familiar with how to read an SDS. In this module we will discuss how to use this essential document and recognize its strengths and limitations.

Pre-Lesson Exercise

1. Where can you find SDS for chemicals in your lab?
2. What can you learn from the SDS that is not on the container label?
3. What would you do if you thought the SDS for a chemical might not be accurate?

SDS Sections

Safety data sheets (SDS) are divided into sixteen sections, covering material from the chemical's reactivity to firefighting measures. Knowing how an SDS is formatted can help you quickly find the information you need. However, you should read the entire document the first time you use a chemical, even if you are interested in a particular hazard, because there may be other risks of which you are unaware. These documents can be confusing and have many unfamiliar terms, but as long as you know the basics, you will be able to extract the relevant information for your work. Refer to the appendix at the end of this module for guidance on some of the acronyms commonly used in SDS. If you think there is a mistake in the SDS, contact the manufacturer for more information.

Section 1 – Identification

Each manufacturer formats the SDS sections differently, but there is specific information they will always contain. For instance, section 1 will always include the Chemical Abstracts Services (CAS) number used for identifying the chemical, in addition to contact information for the manufacturer. This section will also often include common names and uses of the chemical.

1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name	:	Acetonitrile
Product Number	:	271004
Brand	:	Sigma-Aldrich
Index-No.		608-001-00-3
CAS-No.	:	75-05-8

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses	:	Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company	:	Sigma-Aldrich 3050 Spruce Street SAINT LOUIS MO 63103 USA
Telephone	:	+1 800-325-5832
Fax	:	+1 800-325-5052

1.4 Emergency telephone number

Emergency Phone #	:	+1-703-527-3887 (CHEMTREC)

Section 2 – Hazards Identification

This section reviews the different hazard classes as discussed in the beginning of the manual. If a chemical is flammable, explosive, or otherwise hazardous, the hazards identification section will explain those risks. Look for the GHS pictograms here.

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Acute toxicity, Oral (Category 4), H302
Acute toxicity, Inhalation (Category 4), H332
Acute toxicity, Dermal (Category 4), H312
Eye irritation (Category 2A), H319

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word: Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H302 + H312 + H332	Harmful if swallowed, in contact with skin or if inhaled.
H319	Causes serious eye irritation.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.

The exclamation mark pictogram has multiple meanings. How can the SDS hazard statements help interpret the GHS pictogram?

Section 3 – Composition/Information on Ingredients

This part of the SDS is essentially a more detailed version of Section 1. If the compound contains a mixture of different chemicals, such as stabilizers added to ethers, their identities would all be listed under this section. The SDS also lists the concentration of the chemical here.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1 Substances

Synonyms	:	Methyl cyanide ACN
Formula	:	C_2H_3N
Molecular weight	:	41.05 g/mol
CAS-No.	:	75-05-8
EC-No.	:	200-835-2
Index-No.	:	208-001-00-3
Registration number	:	01-2119471307-38-XXXX

Hazardous components

Component	Classification	Concentration
Acetonitrile		
	Flam. Liq. 2; Acute Tox. 4; Eye Irrit. 2A; H225, H302 + H312 + H332, H319	90 -100

For the full text of the H-Statements mentioned in this Section, see Section 16.

Other manufacturers list the synonyms under Section 1.
Make sure to look in both places if you are unsure of a chemical's identity.

Section 4 – First Aid Measures

The appropriate first aid response depends on the type of exposure. Ingestion, contact, and inhalation each can cause different biological responses and thus require specific actions in case of exposure.

4. First-aid measures

General Advice	Immediate medical attention is required Show this safety data sheet to the doctor in attendance.
Eye Contact	Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes immediate medical attention is required.
Skin Contact	Wash off immediately with plenty of water for at least 15minutes. Immediate medical attention is required.
Inhalation	Move to fresh air. If breathing is irregular or stopped, administer artificial respiration. Do not use mouth-to-mouth method if victim ingested or inhaled the substance; give artificial respiration with the aid of a pocket mask equipped with a one-way valve or other proper respiratory medical device. Immediate medical attention is required.
Ingestion	Do not induce vomiting. Call a physician or Poison Control Center immediately.
Most important symptoms and effects	Breathing difficulties, Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting: Metabolism may release cyanide, which may result in headache, dizziness, weakness, collapse, unconsciousness, and possible death: Inhalation of high vapor concentrations may cause symptoms like headache, dizzines, tiredness, nausea and vomiting
Notes to Physician	Treat symptomatically

Notice that the format is slightly different for this SDS section taken from another manufactuer. The section number and title are the same, but the subsections are bolded and not numbered. The information is the still the same.

Section 5 – Firefighting Measures

Section 5 presents the different kinds of fire extinguishers discussed back in the first module on flammables. Depending on the nature of the chemical, conventional water sprays might not be effective. In such a case, alternative extinguishing systems are recommended here.

Look at the excerpts from two manufacturers' SDS information on firefighting. Think of any differences or incomplete information you may notice.

Manufacturer #1: Thermo Fisher Scientific

5. Fire-fighting measures

Suitable Extinguishing Media	Water spray. CO_2, dry chemical, dry sand, alcohol-resistant foam. Cool closed containers exposed to fire with water spray.
Unsuitable Extinguishing Media	Water may be ineffective, Do not use a solid water stream as it as it may scatter and spread fire
Flash Point	12.8 °C / 55 °F
Method -	No information available
Autoignition Temperature	528 °C / 977 °F
Explosion Limits	
Upper	16 vol %
Lower	3 vol %
Oxidizing Properties	Not oxidising
Sensitivity to Mechanical Impact	No information available
Sensitivity to Static Discharge	No information available
Soecific Hazards Arising from the Chemical	

Flammable. Vapors may form explosive mixtures with air. Vapors may travel to source of ignition and flash back. Containers may explode when heated. Vapors may form explosive mixtures with air.

Hazardous Combustion Products
Hydrogen cyanide (hydrocyanic acid) Nitrogen oxides (NOx) Carbon monoxide (CO) Carbon dioxide (CO2)
Protective Equipment and Precautions for Firefighters
As in any fire, wear self-contained breathing apparatus pressure-demand, MSHA NIOSH (approved or equivalent) and full protective gear. Thermal decomposition can lead to release of irritating gases and vapors

NFPA

Health	Flammability	Instability	Physical hazards
2	3	0	N/A

Manufacturer #2: Sigma Aldrich

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture
No data available

5.3 Advice for firefighters
Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information
Use water spray to cool unopened containers.

The first SDS included the information from the hazard diamond but presented them just as numbers without a visual. Did you notice this?

What information is missing from the second SDS?

Which SDS is more useful? Why?

Section 6 – Accidental Relsease Measures

This section describes the appropriate response for cleaning up chemical spills. Sometimes spills can simply be cleaned by soaking up with absorbant material, but in special cases it must first be neutralized. If the chemical is explosive or flammable, care must be taken to avoid contact with ignition sources.

6. Accidental release measures

Personal Precautions	Remove all sources of ignition. Take precautionary measures against static discharges. Evacuate personnel to safe areas. Keep people away from and upwind of spill/leak. Ensure adequate ventilation. Use personal protective equipment.
Environmental Precautions	Should not be released into the environment. See Section 12 for additional ecological information.
Methods for Containment and Clean Up	Remove all sources of ignition. Take precautionary measures against static discharges. Provide adequate ventilation. Use spark-proof tools and explosion-proof equipment. Soak up with inert absorbent material. Keep in suitable, closed containers for disposal. Prevent product from entering drains.

How would you clean up a spill of acetonitrile according to the directions above?

Section 7 – Handling and Storage

You should already feel comfortable with the basic storage recommendations by hazard class, but Section 7 of the SDS neatly outlines these for review. The SDS will also include information on incompatible chemical storage groups in this section. Note that the text here recommends wearing PPE, but does not give any further details. The next section will elaborate on the type of PPE.

7. Handling and storage

Handling	Wear personal protective equipment. Ensure adequate ventilation. Keep away from open flames, hot surfaces and sources of ignition. Take precautionary measures against static discharges. Do not get in eyes, on skin, or on clothing. Do not breathe vapors or spray mist. Use spark-proof tools and explosion-proof equipment. Use only non-sparking tools. To avoid ignition of vapors by static electricity discharge, all metal parts of the equipment must be grounded
Storage	Keep container tightly closed in a dry and well-ventilated place. Keep away from heat and sources of ignition. Flammables area.

Section 8 – Exposure Controls / Personal Protection

There are two components to this section: workplace limits on exposure and recommended PPE. The former is important for monitoring workplace health, but does not otherwise offer any advice on best practices for chemical safety.

However, the second part of Section 8, Personal Protection, is extremely relevant to your work in lab. Using the proper PPE can be the difference between injury and health and should always be a part of every SOP in your lab.

Read through the sections from two different manufacturers below and compare the information they provide regarding the use of PPE.

These workers are using N-95 face masks and face shields to protect themselves.

Manufacturer #1: Thermo Fisher Scientific

Personal Protective Equipment

Eye/face Protection	Wear appropriate protective eyeglasses or chemical safety goggles as described by OSHA's eye and face protection regulations in 29 CFR 1910.133 or European Standard EN166.
Skin and body protection	Wear appropriate protective gloves and clothing to prevent skin exposure.
Respiratory Protection	Follow the OSHA respirator regulations found in 29 CFR 1910.134 or European Standard EN 149. Use a NIOSH/MSHA or European Standard EN 149 approved respirator if exposure limits are exceeded or if irritation or other symptoms are experienced.
Hygiene Measures	When using, do not eat, drink or smoke. Provide regular cleaning of equipment, work area and clothing.

Manufacturer #2: Sigma Aldrich

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection

Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection

Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested: Butoject® (KCL 897 / Aldrich Z677647, Size M)

Splash contact
Material: butyl-rubber
Minimum layer thickness: 0.3 mm
Break through time: 480 min
Material tested: Butoject® (KCL 897 / Aldrich Z677647, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300,
e-mail sales@k En374
If used in solution, or mixed with other substances, and under conditions which differ from supplier of the CE approved gloves. This recommendation is advisory only and must be e industrial hygienist and safety officer familiar with the specific situation of anticipated use should not be construed as offering an approval for any specific use scenario
.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing. protective equipment must be selected according to the concentration and amount of the at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face res purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to If the respirator is the sole means of protection, use a full-face supplied air respirator. Use components tested and approved under appropriate government standards such as NIOS

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains.

Which manufacturer provides more detailed recommendations for PPE? Go back to the exercise for Section 5 – was this the same manufacturer that provided more information there? Compare the benefits and drawbacks of each manufacturer's SDS so far.

Section 9 – Physical and Chemical Properties

The "Physical and Chemical Properties" section lists the most pertinent descriptive details about the chemical in question. Its state, phase change temperatures, and pH are all included among other points, such as vapour pressure and solubility. These data are most helpful when you think about them in the context of your experiment. For instance, if you plan on heating a solution to 100 °C, it is important to know if the boiling point of the chemical is above or below this temperature. Or if the vapour density is greater than one, you should remember to keep ignition sources away from the floor where dense, flammable vapours may collect.

9. Physical and chemical properties	
Physical State	Liquid
Appearance	Colorless
Odor	aromatic
Odor Threshold	170 ppm
pH	No information available
Melting Point/Range	-46 °C / -50.8 °F
Boiling Point/Range	81 - 82 °C / 177.8 - 179.6 °F @ 760 mmHg
Flash Point	12.8 °C / 55 °F
Evaporation Rate	5.79
Flammability (solid,gas)	Not applicable
Flammability or explosive limits	
Upper	16 vol %
Lower	3 vol %
Vapor Pressure	97 mbar @ 20 °C
Vapor Density	1.42
Specific Gravity	0.781
Solubility	miscible
Partition coefficient: n-octanol/water	No data available
Autoignition Temperature	525 °C / 977 °F
Decomposition Temperature	No information available
Viscosity	0.36 CP at 20°C
Molecular Formula	C2 H3N
Molecular Weight	41.05

Do you recognize all the properties listed above? Can you make an educated guess what they mean? Which properties do you think are most important to consider for the experiments you conduct?

Physical and Chemical Properties - Definitions	
Appearance	Phase (solid, liquid, gas) and colour
Odor	Describes the odor of the compound
Odor Threshold	Lowest concentration of the odor where it can be detected by smell
Melting/Freezing Point	Temperature at which compound freezes and melts
Initial Boling Point and Range	Temperature(s) at which compound boils; impurities can cause the compound to boil over a small range of temperatures; lower values correspond with greater volatility
Flashpoint	Lowest temperature at which vapour can ignite; lower flashpoints signal more dangerous compounds
Evaporation Rate	Relative rate of evaporation compared to that of butyl acetate; greater value indicates higher volatility
Flammability	Describes risk of chemical catching fire; note that this section is often labeled as “Not Available” for many known flammable chemicals – check Sections 5 and 7 for more complete information
Upper/Lower Flammability or Explosive Limits	These values describe the airborne concentrations between which the chemical can ignite; a wider range means that the chemical can catch fire more readily
Vapour Pressure	Partial pressure of chemical vapour; greater vapour pressure corresponds with greater volatilty
Vapour Density	Density of the vapour relative to air; values greater than 1 indicate heavy vapours that will sink towards the ground
Relative Density	Density of liquid relative to water
Solubility	Solubility in water; this may be a number or a phrase (e.g. miscible, soluble)
Partition Coefficient	Logarithmic ratio of the solubilities of the chemical in octanol and water, respectively; greater values indicate greater hydrophobicity
Auto-ignition Temperature	Temperature at which chemical ignites without the presence of an ignition source
Decomposition Temperature	Temperature at which chemical begins to decompose into products in the absence of other reagents
Viscosity	Value for a fluid’s resistance to flow; “thickness” of a fluid

Revisit the questions above after reading through this table. Are your answers still the same?

Section 10 – Stability and Reactivity

Section 10 is one of the most important sections because of its information on incompatible hazard groups. The first part of this manual constantly reinforces the principle of compatible storage because this builds a solid foundation for understanding chemical reactions that can create unsafe environments.

Elemental sodium violently reacts with water

The section offers further considerations that cover the safe handling of chemicals and appropriate conditions for their use. Outside of designated conditions, chemicals can decompose and yield other dangerous materials that require additional precautions.

Acetonitrile is a flammable compound. Think of which groups would be incompatible with acetonitrile and check your answers against the SDS section below.

10. STABILITY AND REACTIVITY

10.1 **Reactivity**
No data available

10.2 **Chemical stability**
Stable under recommended storage conditions.

10.3 **Possibility of hazardous reactions**
Vapours may form explosive mixture with air.

10.4 **Conditions to avoid**
Heat, flames and sparks. Extremes of temperature and direct sunlight.

10.5 **Incompatible materials**
acids, Bases, Oxidizing agents, Reducing agents, Alkali metals

10.6 **Hazardous decomposition products**
Other decomposition products - No data available
Hazardous decomposition products formed under fire conditions. - Carbon oxides, Nitrogen oxides (Nox)

Section 11 – Toxicological Information

The basic health effects will be outlined in Section 11, "Toxicological Information." These include acute toxicity and chronic health impacts as well as likely routes of exposure. This section will also explain the symptoms of exposure. Everyone working with toxic chemicals is responsible for knowing the symptoms of exposure. Finally, SDS include numerical data on toxicity estimates (e.g. LD50) from animal testing.

11. Toxicological Information

Acute Toxicity

Product Information
Component Information

Component	LD50 Oral	Ld50 Dermal	LC50 Inhalation
Acetonitrile	**ATE = 617 mg/kg** 450-787 mg/kg (Rat) 2460 mg/kg (Rat)	> 2000 mg/kg (Rabbit)	**ATE = 3587 ppm** 7551 ppm (Rat) 8h

Toxicologically Synergistic Products — No information available

Delayed and immediate effects as well as chronic effects from short and long-term exposure

Irritation — Irritating to eyes

Sensitization — No information available

Carcinogenicity — The table below indicates whether each agency has listed any ingredient as a carcinogen.

Component	CAS-NO	TARC	NTP	ACGIH	OSHA	Mexico
Acetonitrile	75-05-8	Not listed	Not listed	Not listed	Not listed	Not listed

Mutagenic Effects — No information available

Reproductive Effects — No information available.

Developmental Effects — No information available.

Teratogenicity — No information available.

STOT - single exposure — None known
STOT - repeated exposure — None known

Aspiration hazard — No information available

Symptoms / effects, both acute and delayed — Symptoms of overexposure may be headache, dizziness, tiredness, nausea and vomiting: Metabolism may release cyanide, which may result in headache, dizziness, weakness, collapse, unconsciousness, and possible death: Inhalation of high vapor concentrations may cause symptoms like headache, dizziness, tiredness, nausea and vomiting

Endocrine Disruptor Information — No information available

Other Adverse Effects — The toxicological properties have not been fully investigated.

Look at the LD50 data for acetonitrile. Which is more dangerous, oral or dermal exposure?

The phrase "No information available" is frequently used. What does that mean in the context of health effects, like cancer?

Section 12 – Ecological Information

The ecological information in Section 12 is closely linked to the following section on accidental release. This section describes toxic effects on the environment, degradability, bioaccumulative potential, soil mobility, and other adverse effects. Scientists using chemicals for fieldwork outside of the laboratory should be most concerned regarding this information.

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Pimephales promelas (fathead minnow) - 1,640.00 mg/l - 96 h
	NOEC - Oryzias latipes - 102 mg/l - 21 d
Toxicity to daphnia and other aquatic invertebrates	Ec50 - Daphnia magna (Water flea) - 3,600 mg/ - 48 h (OECD Test Guideline 202)
	NOEC - Daphnia magna (Water flea) - 160 mg/l - 21 d

12.2 Persistence and degradability

Biodegradability — Result: 84 % - Readily biodegradable. (OECD Test Guideline 301C)

12.3 Bioaccumulative potential

No bioaccumulation is to be expected (log Pow <= 4).

12.4 Mobility in soil

Not expected to adsorb on soil.

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

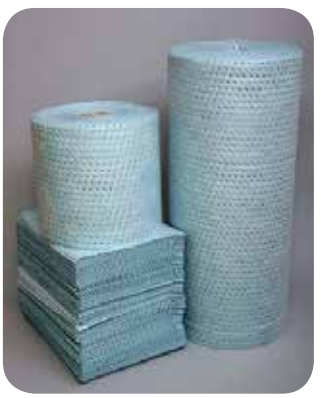
12.6 Other adverse effects

Avoid release to the environment.

Stability in water — Remarks: Hydrolyses slowly.

Section 13 – Disposal Considerations

Even if chemicals are handled properly, failing to safely dispose of any waste generated in lab creates a hazard for lab personnel and staff responsible for removing waste. Section 13 summarizes the major guidelines for appropriately disposing of chemical waste. Solutions left over after an experiment, old containers, contaminated packaging, and materials used for cleaning up spills all fall under this category.



Manufacturer #1: Thermo Fisher Scientific

13. Disposal considerations

Waste Disposal Methods Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. Chemical waste generators must also consult local, regional, and national hazardous waste regulations to ensure complete and accurate classification.

Component	RCRA-P Series Wastes	RCRA-U Series Wastes
Acetonitrile - 75-05-8	U003	-

Manufacturer #2: Sigma Aldrich

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

Not all manufacturers create detailed SDS for their chemicals. Compare the Section 13 excerpts from two different manufacturers' SDS and decide which is more helpful.

Section 14 – Transport Information

The most relevant part of this section describes labeling for transport. Transport labels should reinforce the messages of the GHS hazard labels in Section 2. However, only the hazard class number is often included and requires knowledge of the UN Transport of Dangerous Goods recommendations. This this section will also discuss precautions for transport within or around the lab if appliable.

Section 15 – Regulatory Information

Section 15 contains technical details regarding the regulations governing the chemical's use and distribution. Safety, health, and environmental regulations may be established for the material. These are important, but not directly relevant to lab workers.

Section 16 – Other Information

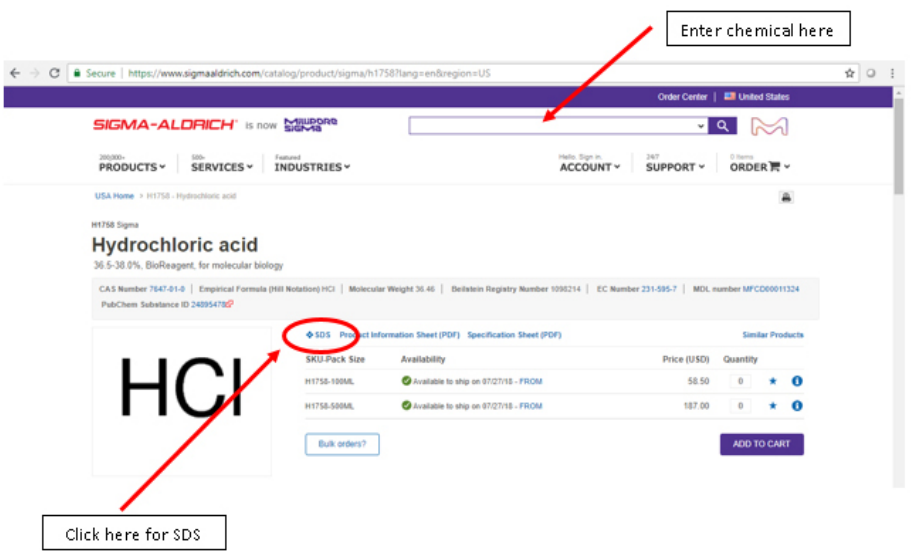
The final section of the SDS usually reviews some of the technical details regarding the document's preparation. Some manufacturers also use this section as an appendix and place additional information here, such as hazard diamond parameters, if not previously included.

Best Practices for Using SDS in the Lab

- Keep printed copies of the SDS for all chemicals in the lab for easy reference
- Look up additional information for chemicals when the SDS frequently reports "No data available," especially in Section 9
- Consult other manufacturers' SDS or check websites such as PubChem (https://pubchem.ncbi.nlm.nih.gov/) if you notice errors in an SDS – some documents are compiled from databases and have incorrect information
- Remember to check the concentration listed on the SDS – hazards for the same chemical can differ by concentration (e.g. low concentrations of hydrochloric acid are less likely to cause chemical burns than highly concentrated hydrochloric acid)

Where to Find SDS

There are several websites where you can access SDS for chemicals in your lab. The best option is to go directly to the manufacturer's website and download the SDS from the product's page. If the specific manufacturer that sold the chemical does not have a website or SDS data, you can go to other manufacturers like Sigma Aldrich or Thermo Fisher Scientific and use their SDS.



Other websites have information on chemical hazards that extremely helpful as well, even though they are not SDS. PubChem, NIOSH, and the European Chemicals Agency provide excellent safety information and are useful tools for scientists in general.

- https://www.sigmaaldrich.com/united-states.html
- https://www.fishersci.com/us/en/brands/I8T3NQD9/fisher-chemical.html
- https://pubchem.ncbi.nlm.nih.gov/
- https://www.cdc.gov/niosh/npg/
- https://echa.europa.eu/information-on-chemicals/

Common Terms and Acronyms in SDS

- ATE – Acute Toxicity Estimate
- Breakthrough time – time required for a chemical to penetrate a material; greater breakthrough times indicate safer gloves
- CAS – Chemical Abstracts Services; unique identification number for chemicals
- EC50 – Half maximal effect concentration; concentration at which organisms experience half of the maximum observed dose-response
- EC-No. – European Community number; another identification number for chemicals
- HCS – Hazard Communication Standard; set of labelling standards set by the Occupational Safety and Health Administration
- HNOC – Hazard Not Otherwise Classified; this means that a chemical may be hazardous, but does not meet the full criteria for any hazard classifications under a given standard
- H-statement – hazard statement; these are listed in Section 2 of the SDS and describe the hazards illustrated by the pictograms
- NFPA – National Fire Protection Association; this organization is responsible for assigning values for chemicals' hazard diamonds
- NIOSH – National Institute of Occupational Safety and Health; authority for workplace safety in the United States
- NOEC – No Observed Effect Concentration; concentration at and below which there are no observed effects from exposure to a chemical
- OECD – Organization for Economic Cooperation and Development; this organization develops standard protocols for evaluating various parameters listed in SDS
- OSHA – Occupational Safety and Health Administration; another authority for workplace safety in the United States
- PBT – Persistent, Bioaccumulative, and Toxic; describes environmental toxicity
- STOT – Specific Target Organ Toxicity; describes the biological effects of a chemical on specific human organ systems
- vPvB – Very Persistent and Very Bioaccumulative; describes environmental toxicity

Module References

Comer, J., & Tam, K. (2007). Lipophilicity Profiles: Theory and Measurement Pharmacokinetic Optimization in Drug Research.

Daintith, J. (2008). A Dictionary of Chemistry (6th ed.). Oxford: Oxford University Press.

Hofmann, H. E. (1932). Evaporation Rates of Organic Liquids. Industrial & Engineering Chemistry, 24(2), 135-140. doi: 10.1021/ie50266a004

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Sigmann, S. (2018). Chemical safety education for the 21st century — Fostering safety information competency in chemists. Journal of Chemical Health and Safety, 25(3), 17-29. doi: https://doi.org/10.1016/j.jchas.2017.11.002

Thermo Fisher Scientific. (2018). Acetonitrile (75-05-8). Fair Lawn, NJ.

United Nations, et al. (2005). Globally Harmonized System of Classification and Labelling of Chemicals (GHS). New York, United Nations.

8 Workforce Expectations

Safety is everyone's responsibility. However, there are different expectations and guidelines depending on your role in the lab. For example, the lab manager has different responsibilities than a lab technician, but both are crucial to maintaining a safe work environment.

Before continuing, take a few minutes to think about what responsibilities the lab workforce has for ensuring safety.

What responsibilities do workers have to maintain a safe work environment?

Expectations for lab personnel:

- Personnel are trained and competent; they should have the experience, knowledge, and skills to do their work safely
- Communicate needs to management
- Keep a clean workspace
- Do NOT work alone – if there is an incident and no one is present, your colleagues cannot call for help or assist you
- Do NOT conduct unauthorized experiments
- Wear appropriate PPE and follow SOP
- Ensure that colleagues follow SOP
- Read the SDS for chemicals before beginning an experiment
- Notify others of your work and any associated hazards

- Know the location and proper use of all safety equipment – this includes fire extinguishers, safety showers, eyewash station, first-aid kit, spill clean-up kit, telephone
- Be aware of your surroundings
- Report all incidents and near misses (injury, spill, etc.)
- Properly dispose of waste
- Consult supervisor if unsure of how to conduct any responsibilities in the lab

Module References

Duke Occupational & Environmental Safety Office. Chemical Hygiene. Retrieved June 5. 2018, 2018, from https://www.safety.duke.edu/laboratory-safety/chemical-hygiene

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

9 Management Expectations

If lab workers are responsible for day-to-day safety in the lab, then lab management is responsible for ensuring the conditions for lab workers to safely do their jobs. For example, lab workers need to know the locations and proper use of fire extinguishers, but management is responsible for making sure the lab has fire extinguishers in the first place. In other words, the management holds the ultimate responsibility for maintaining a safe environment.

The implications of a safe environment go beyond just stocking lab safety supplies, however. Lab management needs to build the infrastructure for safety monitoring and promote a culture in which lab workers are empowered to express their needs and concerns.

What responsibilities should management have for promoting workplace safety? What would you do differently if you managed a lab?

Expectations for lab management:

- Clearly establish roles and responsibilities within the lab
- Continuously teach safety skills and best practices for lab work – this is important for new workers as well as those with prior experience
- Develop and modify appropriate SOP for procedures in the lab
- Encourage all staff to consult management for SOP when working with unfamiliar chemicals
- Periodically inspect labs for safety requirements and share the results during lab meetings
- Require all accidents, incidents, and near misses to be reported – understanding their causes is important for avoiding similar events in the future
- Encourage lab workers to come to management with any concerns about safety – **be humble and listen to their needs.**

10 Chemical Emergencies

Even if you follow all the proper safety precautions to minimize risk in the lab, accidents can still happen. It is critical to plan for the unexpected and train all lab workers how to respond in case of emergency. Labs need to have a clear, written policy that outlines how to respond to emergencies and who to contact. With the proper preparation and training, you can protect yourself and your colleagues in the lab.

Pre-Lesson Exercise

10 mins

1. What potential emergencies could occur in your lab?
2. What safety equipment does your lab have? Where is it stored?
3. Who should you notify if there is an emergency?

Safety Equipment

Each lab should be equipped with basic safety equipment in addition to any specialized equipment for specific risks to the lab.

- Safety shower
- Eyewash station
- First-aid kit
- Fire extinguisher
- Fire blanket
- Spill cleanup kit
- Self-contained breathing apparatus (SCBA) if applicable
- Calcium gluconate (if your lab uses hydrofluoric acid [HF])

All lab workers need to know the locations of showers and eyewash stations in the lab. Both need to be tested at least every three to six months to ensure they are working properly. If your lab keeps a SCBA on hand, it must be tested monthly.

In the case of chemical splashes in the eyes, flush eyes for fifteen minutes. Use your fingers to hold the eyelids back so the stream of water completely washes your eyes.

For splashes to the body, stand under the safety shower and pull the handle to inundate yourself with water. Remove contaminated clothing and continue to rinse. Keeping on contaminated clothing can exposure your skin to sustained contact with the chemical and worsen irritation or burns.

Use the safety shower or fire blanket if your clothes or hair catch fire. Safety showers are preferred, but fire blankets are acceptable if there is not a shower immediately nearby.

Emergency Procedures

1. ALWAYS call for help first
2. Evaluate the situation – is it safe to respond? Are you at risk if you intervene? Do you need to take immediate action to avoid loss of life?
3. Alert nearby colleagues of the situation – someone must notify lab management
4. Respond – use the necessary emergency equipment
5. Do NOT move injured people unless they are in immediate danger
6. Turn off any equipment if you can do so without placing yourself in danger
7. Tell first responders exactly what happened and what chemicals are present – give them a copy of the SDS

A hazardous materials response team trains for an emergency.

Spills and Cleanup

Deciding how to respond to a chemical spill depends on the hazard class of the chemical and the volume spilled. For instance, neutralization is preferable for acids and bases, whereas simple absorption works for organic solvents. However, larger spills require specialized teams and equipment for safe cleanup. When working with toxics, even small spills may be extremely dangerous and require a hazardous materials team response. As you can see, spills become complicated quickly because each spill is different. The following guidelines are NOT definitive but will help familiarize you with the various techniques for cleaning up. Always consult the SDS and use your discretion when responding to chemical spills.

General Tips

- Call for help and notify lab management before attempting to respond to a chemical spill
- Always wear appropriate PPE when cleaning up, including goggles, gloves, and respirators or shoe covers if necessary
- Work from the outside in, cleaning up spills from the edges first
- For liquid spills, only attempt to clean up when the volume is 4 litres or less – otherwise, call a hazardous materials team for assistance
- Treat all waste generated from cleanup as hazardous material with the same properties as the chemical spilled

Neutralization

- Use sodium sulfate or powdered citric acid to neutralize bases
- Use sodium bicarbonate to neutralize acids
- Neutralize the spilled liquid SLOWLY – the resulting reaction can generate heat and splattering
- Continually check the pH of the spill by holding test strips above the liquid – the goal is to reach a pH of 7 before absorbing the liquid
- Use absorbent pads or sand to absorb the neutralized liquid

Absorption

- Neutralized acids and other liquid spills can be absorbed using absorbent pads or sand

- For flammables, immediately absorb spilled liquid and place in sealed containers – if spill is large (e.g. greater than 1 litre), immediately evacuate

Communication

- Lab management should have a written policy on emergency procedures and ensure that all lab workers are thoroughly trained on how to respond to emergencies
- Each lab should know their specific evacuation route and where to go if they need to evacuate
- There should be a clear policy outlined for reporting emergencies
- The policy should have the contact information for informing management of emergencies

Module References

National Research Council (2011). Prudent Practices in the Laboratory: Handling and Management of Chemical Hazards, Updated Version. Washington, DC, The National Academies Press.

Sandia National Laboratories. Laboratory Emergency Planning, Response, and Management: Chemical Security Program.

11 Chemical Security

Everything up until now has been about chemical safety. Chemical security is another concern but has the similar goal of protecting human health. Security combines different technical and administrative controls to prevent, detect, and delay intentional, malevolent incidents. Like chemical safety, security is everyone's responsibility and requires a collective effort. Making chemical security a central part of your lab's planning can help create a safe and secure space for your work.

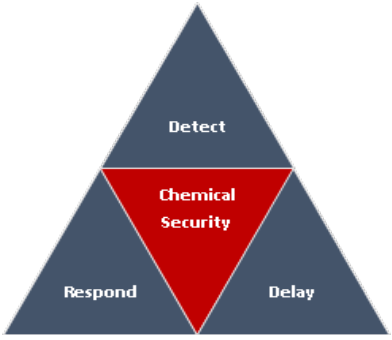
Pre-Lesson Exercise

1. What does security mean to you?
2. How might different labs have different security needs?
3. How can you promote safety and security at the same time?

Principles of Security

Labs need to first identify potential security concerns before they can design a system and plan for managing security-related risks. There are many possible risks, some of which include:

- Theft of materials for economic gain
- Theft or diversion of materials for developing weapons
- Unauthorized research for personal gain
- Intentional release of hazardous materials or other sabotage
- Release of sensitive data



Security systems should have three primary goals: to detect, delay, and respond to concerns.

- Detection of security breaches can allow the lab to respond and prevent an incident (e.g. ID badge access control, CCTV, entry checkpoints)
- Multiple layers of access control delay intrusion and theft (e.g. fences, walls, locked doors)
- Responding to ongoing incidents can prevent further damage (e.g. guards, police, staff)

Keeping a Chemical Inventory

Maintaining an accurate inventory of all the chemicals in your lab is an effective way of promoting both safety and security. Knowing what chemicals you have and how much you have can help minimize the creation of hazardous waste when excess inventory expires. Additionally, a robust inventory can detect diversion of chemicals to theft or unauthorized research.

A worker takes inventory of the chemicals in his lab's stockroom Dual-Use Chemicals

Dual-use chemicals

Dual-use chemicals are agents that can be used for intentionally causing harm or developing weapons in addition to their approved research purposes. Lab management should take significant precautions above and beyond normal protocols for securing dual-use chemicals. Keeping inventory and access records is essential for dual-use chemicals.

- Limit the number of workers who have access to dual-use chemicals
- Maintain inventory and access records for dual-use chemicals
- Implement a log-in/log-out system for access to areas with dual-use chemicals
- Develop a formal policy prohibiting unauthorized research using lab facilities or materials

Behavioural Cues

In addition to physical controls (e.g. locked doors, CCTV monitoring, electronic access control, ID badges, etc.) and recordkeeping, looking out for irregular behaviours can detect security concerns.

Try to think of examples of irregular behaviours that may indicate a security concern before continuing to the list below.

- Frequently works after hours
- Works alone
- Conceals work or quickly puts materials away when others enter the lab
- Disregards safety and following procedures
- Does not ask for permission or inform supervisor of changes in protocol
- Attempts to order chemicals without following protocol
- Brings materials home
- Attempts to circumvent security systems – e.g. walks into restricted areas without permission
- Takes pictures of security systems
- Looks through waste containers and dumpsters

Communicate with your lab manager if you notice colleagues displaying any of these behaviours. These behaviours are not concrete evidence of wrongdoing, but rather indicate areas of concern for management to investigate. Moreover, the likelihood of a security concern increases with the frequency of the various behaviours listed above. For example, a scientist working late might not raise concerns, but a scientist that works late, does not follow protocols, and tries to access restricted areas should certainly initiate action. Simple measures, such as adding locks to labs and cabinets as well as conducting background checks on all personnel can help promote a secure work environment.

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12 Safety Culture

Safety culture is at the heart of every chemical safety programme. It is the glue that holds together the careful planning and training which laboratories provide. But what is it? Safety culture encompasses the workplace attitudes and practices that support a safe environment through communication and accountability. Without it, the other investments in safety cannot be fully effective. That is, workers need to internalize the value of safety and feel comfortable expressing their safety concerns, or they will not be able to prevent unnecessary workplace accidents.

The three main components of safety culture are: accountability; clear expectations; and communication. Together, these elements promote an environment where workers are equipped to work safely and empowered to speak up when they see something that is not safe.

Accountability

- Labs must be transparent in reporting accidents, incidents, and near misses – they can only learn from their mistakes if they acknowledge them and share the lessons with each othe
- Management needs to consistently enforce safety guidelines at all levels
- Labs should engage in frequent self-evaluation to monitor workplace safety
- Colleagues need to gently correct each other if they observe unsafe behavior

Clear Expectations

- Lab management needs to make roles and responsibilities clear from the beginning
- Management needs to agree on safety guidelines – for example, if the lab manager says something is acceptable, but the safety officer disagrees, workers are unsure how to proceed
- Leaders need to be consistent and practice the guidelines they teach – for example, lab managers should always use appropriate PPE and set a good example for lab workers
- Management must train and equip workforce members for lab safety – without training on institutional safety guidelines, workers will not know how to conduct themselves and respond to accidents in accordance with institutional policies

Communication

- Leadership should encourage lab workers to speak up if they see something that is not safe. Lab managers can do this by including safety on the agenda for every lab meeting and periodically checking in with individual workers.
- Workers should not feel afraid to communicate their concerns – if they do not feel comfortable speaking with their supervisor, they should privately speak with management at their institution.

Safety culture does not develop on its own overnight. It requires institutional commitment and workforce participation. Take a few minutes to read the quote below and discuss how you can promote safety culture in your lab.

"Every individual accepts responsibility for safe mission performance. Individuals demonstrate a questioning attitude by challenging assumptions, investigating anomalies, and considering potential adverse consequences of planned actions. All employees are mindful of work conditions that may impact safety, and assist each other in preventing unsafe acts or behaviors."

- Integrated Safety Management System Manual (DOE M 450.4-1)

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13 Case Studies

Flammable Compounds

In December 2008, a 23-year old Pakistani student at University of California Los Angeles was performing an experiment and suffered a fatal accident. Sheri – the student – was transferring large volumes of tert-butyllithium when the liquid exploded and covered her body with burns. She was wearing gloves, but did not have a flame-resistant lab coat on and no supervisor was present even though she did not have extensive experience in lab. The likely cause of the accident was improper technique: Sheri was pipetting too much liquid and used a short, plastic syringe. Sheri had wanted to scale-up an earlier reaction so that she could obtain more product in one experiment. During the explosion, a nearby flask of hexane was ignited and increased the intensity of the fire. Another technician ran over and tried to wrap his lab coat around her to stop the fire but was unsuccessful in extinguishing the flames. Even though she performed the experiment in a fume hood, the blast still caused significant burns across her entire body, eventually leading to organ failure and death.

1. What is tert-butyllithium?
2. If you are asked to work with a chemical with which you are not familiar, what might you to do?
3. Where could Sheri or her advisor have obtained more information on necessary safety precautions for tert-butyllithium?
4. What safety measures did Sheri take? What measures did she not?
5. What changes could have improved the safety of the experiment?
6. How could better communication have prevented this accident?
7. Shock Sensitive Compounds

Javed needed diethyl ether for his experiment, but did not have any in his lab. He asked another lab if he could use their supply and was directed to their storeroom. Javed noticed small crystals formed at the bottom of the old container, but did not think it mattered, since he would only be pipetting a small amount of the liquid from the top. However, when he set the container on his lab bench, the shock sensitive peroxide crystals violently reacted and shattered the glass container, resulting in cuts to his hands and face. He was not working under a fume hood, but he was fortunately wearing his safety goggles, so his eyes were not injured during the

explosion. He went to the safety shower and rinsed himself off for 15 minutes while his colleague called for medical attention.

1. What could have prevented this accident?
2. What did Javed do right in this scenario? What did he do wrong?
3. What implications does this scenario have for the lab's management? For the technician?
4. How could improved training have changed the scenario?

Corrosive Compounds

Dr. Baqai was performing a digestion on a set of samples so that he could run them using mass spectrometry. The procedure required him to pipette highly concentrated sulfuric acid into each sample container. After working for hours, he became tired and pipetted the acid without paying attention and accidently released some of the liquid onto his hand. Dr. Baqai was wearing two pairs of nitrile gloves, so he removed the outer glove and continued to work. After a while his left hand felt warm and he realized that some of the acid had traveled through the second glove and began to burn him. He quickly removed the glove and rinsed his hand for 15 minutes.

1. How do repetitive actions pose a risk in the laboratory setting?
2. Does the choice of glove material matter here? What other options did Dr. Baqai have? What would be safer and why?
3. What did Dr. Baqai do right? What did he do wrong?

Toxic Compounds

A scientist (Mina) studying arsenic in contaminated groundwater was using the element in some assays for a study. The arsenic standard which Mina had purchased was powder form, requiring her to weigh out and dilute the arsenic in water. Her colleague was using the fume hood with the balance which was normally used in that laboratory for measuring toxic powders, so Mina decided to weigh her samples using the balance directly on the open lab bench across the room. When transferring the arsenic to a weigh boat, some of the powder became airborne and Mina breathed it in. She only breathed in a little and did not feel ill, so she wiped down her bench and did not report the incident.

1. How could Mina have avoided the danger of handling powdered chemicals in the first place?
2. What precautions should be taken when measuring chemicals in powder form?
3. How could improved communication have changed this scenario?

Cryogenic Compounds

A biologist was preparing tissue samples to be shipped and decided to flash freeze them using liquid nitrogen to preserve them for safe transport. Since liquid nitrogen is extremely cold, he did not expect any danger of combustion. However, the liquid nitrogen was cool enough to liquefy atmospheric oxygen and became highly flammable. The oxygen-enriched liquid caught flame and the biologist promptly extinguished it using a fire extinguisher. He was not wearing any PPE.

1. What PPE should the biologist have been wearing?
2. Do cryogens have other safety risks in addition to flammability? If so, what are they?
3. Which type of fire extinguisher should the biologist have used?
4. What considerations should be taken for storing cryogens given their specific risks?

Broken Glass and Sharps

Soha was preparing a solution using a volumetric pipette and extremely focused on measuring the proper volume of liquid. As she bent down to read the volume inside the pipette, the pressure of her hand pushing the pipette against the bottom of the container caused it shatter in her hand. Soha's finger was cut and she began to bleed profusely, while the lab bench was covered with shards of glass.

1. What separate safety issues arose as a result of this incident?
2. What steps should Soha have taken immediately following the incident?
3. How would waste products be disposed of in such a situation?
4. How should lab workers prioritize safety response efforts when there are multiple concerns?

Explosive Compounds

Abdul had been studying high energy materials in his lab for weeks, but he was not able to obtain the results he wanted. Instead of working with the chemicals in small quantities, he decided to scale up the reaction to be more efficient and ensure homogeneity of the sample for testing. He had completed the reaction to make 50 mg many times before, so he thought making 10 g of the material would be alright, even though he did not consult his supervisor. One day he scaled up to 5 g and

another researcher warned him that he should not do that, but Abdul ignored her. The next time he came into lab, Abdul proceeded to synthesize 10 g of material. After finishing the reaction, he noticed small, slightly darker clumps in the product. He squirted hexane into the dish and attempted to gently grind the clumps. He removed his goggles before giving the powder one last grind when the vessel exploded in his hands. The friction caused an explosion that resulted in the loss of three fingers and severe burns across his body. Abdul did not work in a fume hood or use a blast shield.

1. Chemical incidents are usually the result of a series of failures. What mistakes did Abdul make? What was the first one?
2. Abdul ignored his colleague's advice. Why do researchers ignore feedback? How might the lab's culture have facilitated his interaction?
3. What could Abdul have done differently at the end instead of grinding up the clumps?

Personal Safety

Adnan is always responsive to incoming emails and always checks his phone for notifications throughout the day. Sometimes he even checks for messages in between steps of an experiment while he waits for his samples to run. Adnan often pulls his phone out of his pocket and checks his email without removing his gloves, but he only does so when he is not working with dangerous chemicals or bacteria.

1. What potential safety issues can you identify in this situation?
2. When should you wear your gloves? When should you remove them?
3. How should contaminated gloves be disposed of properly?

Appendix A – Pictogram Review Sheet

Hazard	Globally Harmonised System (GHS) Pictogram	UN Transport of Dangerous Goods (TDG) Pictogram	Other Common Pictograms (US Included)
Flammable			
Oxidizer			
Corrosive			
Compressed Gas			
Explosive			

Hazard	Globally Harmonised System (GHS) Pictogram	UN Transport of Dangerous Goods (TDG) Pictogram	Other Common Pictograms (US Included)
Health Hazard			
Environmental Hazard			

Appendix B – Common Chemicals in Life Science Laboratories

	Flammable	Oxidizer	Corrosive	Compressed Gas	Cryogens	Explosive or Peroxide-Forming	Toxic	Irritant or Sensitizer	Health Effects
General Use and Disinfectants									
Ethanol [CH3CH2OH]	✓							✓	
Ethylene oxide [C2H4O]	✓			✓			✓	✓	✓
Hydrogen peroxide [H2O2]		✓	✓					✓	
Liquid nitrogen [N2]				✓	✓				
Sodium hypochlorite [NaOCl]			✓					✓	
Electrophoresis									
2-mercaptoethanol [HOCH2CH2SH]			✓				✓	✓	✓
Acrylamide [CH2=CHC(O) NH2]							✓	✓	✓
Ammonium persulfate [(NH4)2S2O8]		✓						✓	✓
Dithiothreitol (DTT) [C4H10O2S2]								✓	
Ethidium bromide [C21H20BrN3]							✓		✓
Formamide [HCONH2]									✓
Hydrochloric acid [HCl]			✓					✓	
N,N'-Methylenebis(acrylamide) [C7H10N2O2]								✓	✓

	Flammable	Oxidizer	Corrosive	Compressed Gas	Cryogens	Explosive or Peroxide-Forming	Toxic	Irritant or Sensitizer	Health Effects
Sodium dodecyl sulfate (SDS) [CH3(CH2)11SO4Na]	✓		✓					✓	
	✓		✓				✓		
Liquid Chromatography									
Acetonitrile [CH3CN]	✓							✓	
Methanol [CH3OH]	✓						✓		✓
Formic acid [HCOOH]	✓		✓				✓		
Imidazole [C3N2H4]			✓					✓	✓
Organic Chemistry									
Cyclohexane [C6H12]	✓							✓	✓
Diethyl ether [(C2H5)2O]	✓					✓		✓	
Hexane [C6H14]	✓							✓	✓
Nitric acid [HNO3]		✓	✓						
Pentane [C5H12]	✓							✓	✓
Tetrahydrofuran (THF) [(CH2)4O]	✓					✓		✓	✓

Appendix C – Standard Operating Procedure (SOP) Templates

Moderate Risk SOP

1. Title and Description of Experiment or Process:
2. Preparer(s):
3. Location:
4. Authorized Personnel for Procedure (with contact information):
    a. Principal Investigator/Supervisor:
    b. Student/Technician/Operator:
    c. Others to be Notified of Work (e.g. colleagues in shared lab space, safety personnel, department head, etc.):
5. Potential Hazards:
6. Describe all special requirements for specific items that require a greater level of safety
    a. Planned chemicals involved
    b. Personal protective equipment
    c. Engineering and environmental controls (e.g. fume hood, inert atmosphere, etc.)
    d. Operational ranges and conditions
    e. Special handling and storage requirements (e.g. glassware or techniques for transfers)
    f. Spill and accident procedure as needed
    g. Waste handling and disposal
7. Identify any training needs
    h. Specific training required
    i. Users requiring training
    j. Date completed
8. Verification and Review

By signing below, you acknowledge that you have read, understand, and approve the SOP.

a. PI name (please print)
b. Pl signature
c. *Safety staff name (please print)
d. *Safety staff signature
e. Current date
f. Date of SOP expiry (e.g., 1 year)

List of references (include SDS and personnel consulted):

*Note that safety staff can include a chemical safety officer, environmental health and safety officer, or the equivalent personnel at an institution

Moderate Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP? ☐ Yes ☐ No

If no, then list date of approval

Last reviewed by (please print)

If yes, then list and describe modifications

High Risk SOP Outline

1. Title and Description of Experiment or Process:
2. Preparer(s):
3. Location:
4. Authorized Personnel (with contact information)
    a. Principal Investigator/Supervisor:
    b. Student/Technician/Operator:
    c. Others to be Notified:
5. Identify any training needs
    f. Experimental techniques
    g. Specific training required
    h. Users requiring training
    i. Date completed

6. Detailed process description

Description:

List ranges for variables	Temperature:
	Pressure:
	Viscosity:
	Flammability:
	Other:
List operational ranges and conditions	
Materials to be used	Chemicals:
	Equipment:

Detailed Procedure

Column A: process steps; step-by-step procedures for the experiment; e.g. transfers, production of gases, transporting chemical between different labs, work up of waste, etc.

Column B: safety notes for mitigating risk for each step; e.g. fire extinguishing measures, cleaning work space, securing cylinders, inspecting equipment, etc.

	Column A: Process Steps	Column B: Safety Notes
1.0		
1.1		
1.2		
1.3		
2.0		
2.1		
...		

7. Engineering Controls

Engineering Controls	Check box if applicable	Description
Fume hood or glove box	?	
Special ventilation	?	
HEPA-filtered vacuum lines	?	
Non-reactive containers	?	
Pressure relief devices	?	
Temperature control	?	
Bench paper, pads, plastic-backed paper	?	
Special signage	?	
Safe sharp devices	?	
Other safety devices used:	?	

8. Personal Protective Equipment (PPE)

Personal Protective Equipment	Check box if applicable	Description
Gloves	☐	(Include material and if you are wearing double gloves, thicker gloves, etc.)
Lab coats	☐	
Suits	☐	
Aprons	☐	
Long pants	☐	
Close-toed shoes	☐	
Long sleeves	☐	
Safety glasses	☐	
Goggles	☐	
Face shields	☐	
Respirators	☐	(Include cartridge type and replacement schedule if applicable)
Hearing protection	☐	(Include level of protection needed)
Special equipment	☐	(e.g., blast shields, special enclosures, etc.)
Other PPE (e.g. blast shields, etc.):	☐	

9. Work Practice Controls

Controls	Description
Designated areas	
Procedures for requesting emergency assistance	
Emergency phone numbers	
Locations of fire alarms, fire extinguishers, fire blankets, eye washes, showers, etc.	
Emergency responders	
Workers on shifts	? Yes ? No
Training on all experimental techniques and experiments	? Yes ? No
Restricting access; locks	? Yes ? No
Housekeeping	? Yes ? No
Lockout/tagout procedure plan (i.e. plan for shutting down dangerous equipment)	? Yes ? No
After-hour procedures	? Yes ? No
Preventive maintenance	? Yes ? No

10. Monitoring

Monitoring	Description
Personnel exposure monitoring	
Leak checking	(e.g. gas detectors)
Gas release and spill monitoring	
Temperature and pressure	
Alarms	

11. Spill and Accident Procedures

	Description and Location
Secondary containment	
Spill kits	
Emergency shutdown procedures	
Process shutdown	
Persons to inform	

12. Waste Disposal Procedures (include segregation of by hazard class, used PPE, collection and transport procedures, documentation and regulations, etc.):

13. Storage (check all that apply)

- ☐ Ventilated enclosures
- ☐ Refrigeration
- ☐ Gas cabinet
- ☐ Compliance with regulations
- ☐ Expiry date
- ☐ Inventory
- ☐ Other: _____

14. Transport Procedures (e.g., secondary container for transport between labs or for secondary experimental apparatus):

15. Peer Review

Name (please print):
Signature:
Current date:
Notes:

Name (please print):
Signature:
Current date:
Notes:

16. Verification and Review

By signing below, you acknowledge that you have read, understand, and approve the SOP.

PI name (please print):
Pl signature:
Safety staff name (please print):
Safety staff signature:
Current date:
Date of SOP expiry (e.g., 1 year)

17. List of references (include SDS and personnel consulted):

High Risk Standard Operating Procedure Review and Modifications Log

Were modifications made to current SOP?	? Yes	? No
If no, then list date of approval		
Last reviewed by (please print)		
If yes, then list and describe modifications		

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Glossary

Acid – a chemical that causes the release of hydrogen ions in water; often corrosive; generates heat when reacted with bases

Alkali metals – elements in Group 1 of the Periodic Table (e.g. Li, Na, K); water reactive

Base – a chemical that causes the release of hydrogen ions in water; often corrosive; generates heat when reacted with acids

Carcinogen – known to or suspected of causing cancer

CAS number – Chemical Abstracts Service number; a unique identifier assigned to each chemical

Cold trap – a U-shaped tube placed between a reaction vessel and vacuum line; the tubing is immersed in coolant to cause vapours to condense and not enter the vacuum system

Combustible – capable of catching fire at higher temperatures; flash point between 37.8 °C and 93.3 °C

Corrosive – destructive to surfaces and tissues

Cryogen – extremely cold substance with a low boiling point

Dual-use chemical – agent that can be used for intentionally causing harm or developing weapons in addition to their approved research purposes

Explosive – capable of reacting violently and rapidly expanding

Face shield – screen that shields the entire face from chemical splashes; does not protect against vapours

Flammable – capable of catching fire at regular working temperatures; flash point below 37.8 °C

Flashback – occurs when the stream of vapour emanating from a container ignites and draws the fire back towards the container

Flashpoint – Lowest temperature at which vapour can ignite

Fume hood – ventilated cabinet for safely handling chemicals that may generate dust or vapour; includes a glass barrier that can be moved up and down

Gas blanket – an inert gas used to displace atmospheric air in a closed system

Globally Harmonized System (GHS) – system for labelling and classification of chemicals developed by the United Nations; the hazard pictograms are assigned to chemicals according to these guidelines

Inert – nonreactive; nitrogen is often used as an inert gas to displace oxygen

Inorganic – not composed of carbon; opposite of organic

Irritant – noncorrosive substance that causes reversible inflammation

Lachrymator – causes the eyes to generate tears; eye irritant

Mass spectrometry – method of detecting and characterizing unknown chemicals by fragmentation pattern

Mutagen – agent that increases the frequency of mutations in populations of cells or organisms

N-95 – commonly used disposable respirator for particulate matter

Neurotoxin – agent that adversely effects the nervous system

Organic – composed of carbon; opposite of inorganic

Organic peroxide – a chemical with a carbon backbone and an O-O bond; flammable and explosive

Oxidizer – a chemical that accepts electrons during an oxidation-reduction reaction; oxidizers must be present for combustion to occur

PAPR – powered air-purifying respirator; device that forces filtered atmospheric air into the face piece; this is a better option for workers with facial hair because the positive-pressure keeps contaminants out even if the fit is not tight against the face

Peroxide – a chemical with an O-O bond; can be explosive

Personal Protective Equipment (PPE) – safety equipment that lab workers wear to minimize chemical exposures; e.g. gloves, goggles, apron, respirator, etc.

Pyrophoric – spontaneously ignites in the presence of oxygen and water

Reactive – describes a chemical that readily reacts with a low activation energy; e.g. alkali metals are reactive

Regulator – two-gauge valve used to set the output pressure of a compressed gas in a cylinder

Reproductive toxin – toxin that can adversely affect sexual function, fertility, and the development of offspring

Respirator – breathing device that protects the worker from inhaling dangerous gases, fumes, or particulate matter

Safety culture – workplace attitudes and practices that support a safe environment through communication and accountability

Safety Data Sheet (SDS) – document that explains the hazards and safety precautions for a chemical

Safety glasses – basic eye protection for small chemical splashes; do not protect against vapours

Safety goggles – goggles that form a tight seal around the eyes; offer the greatest level of eye protection

SAR – supplied air respirator; type of respirator in which blower or cylinder supplies

fresh air to the user, rather than relying on the lungs to draw new air in; powered air-purifying respirators (PAPR) are a type of SAR

SCBA – self-contained breathing apparatus; the only respirator approved for emergency responses

Sensitizer – chemical that causes a heightened immune response after previous exposure

Shock-sensitive – capable of exploding in response to mechanical forces (e.g. shaking, friction from opening container cap, etc.)

Solvent – liquid used to dissolve other chemicals; e.g. water, diethyl ether, tetrahydrofuran (THF)

Standard Operating Procedure (SOP) – an established protocol for how to safely use specific chemicals

Teratogen – toxin that can cause birth malformations

Toxic – describes any substance that adversely affects health; LD50 often used to quantify toxicity; see neurotoxin, reproductive toxin, and teratogen for specific types of toxic substances

Transport of Dangerous Goods (TDG) – United Nations conventions for the labelling and safety measures to be taken when transporting hazardous materials; these labels are slightly different than the GHS ones; shortened version of "United Nations Model Recommendations on the Transport of Dangerous Goods"

Volatile – readily produces vapour/fumes; has a high vapour pressure and low boiling point

Water reactive – combusts or produces flammable fumes due to contact with waterModule References.