CHEMICAL SAFETY AND ETHICAL HANDLING OF CHEMICALS

Chemicals are at the heart of chemistry. These chemicals can be in the form of elements, compounds, mixtures, solutions, emulsions etc. They are used in bulk amounts in the various industries involved in manufacture or production of industries. They are also used in huge amounts in different types of research labs involving research scholars or any research scientist. Besides that, they are also used as an essential part of the practical curriculum in schools, colleges, universities and other training facilities to train and educate the students. Chemical safety has many associated scientific and technical components. Some chemicals either in their pure form or their generated byproducts may be toxic, carcinogenic, explosive etc. Improver handling of such chemicals can sometimes turn disastrous causing mishaps. Hence before entering a chemical laboratory, all the users (including teachers and students or guides and trainees) must ensure that they know the basics of **CHEMICAL SAFETY AND ETHICAL HANDLING OF CHEMICALS**. This is utmost essential not only for the individual handling chemicals but also for the safety of those around.

Chemical safety refers to all the practices, policies and procedures that have been designed to minimize the hazard caused by toxic or hazardous chemicals. This includes the risks of exposure to persons handling the chemicals, to the surrounding environment, and to the communities and ecosystems within that environment. According to the global health body, around two million people died due to exposure to hazardous chemicals in 2019, compared to 1.56 million in 2016.

One must always remember that

Chemical Safety = Knowledge + Common sense + Caution

Below is the list of some important acronyms often encountered in connection with chemical safety and handling of chemicals (Table 1):

Table 1: Some important acronyms connected with chemical safety and handling of chemicals

Serial Number	Acronym	Full Form
1)	**ACB**	Air Circuit Breaker
2)	**AED**	Automated External Defibrillator
3)	**AEP**	Authorized Electrical Person
4)	**AFFF**	Aqueous Film Forming Foam

5)	**AGT**	Authorized Gas Tester
6)	**ALARP**	As Low As Reasonably Practical
7)	**APR**	Air Purifying Respirator
8)	**APW**	Air Pressurized Water
9)	**ASR**	Air Supplying Respirator
10)	**BBS**	Behaviour Based Safety
11)	**BCSP**	Board of Certified Safety Professionals
12)	**BHSS**	British Health and Safety Society
13)	**BLEVE**	Boiling liquid expanding vapor explosion
14)	**CAZ**	Control Access Zone
15)	**CFR**	Code of Federal Regulations
1)	**CNG**	Compressed Natural Gas
2)	**CNS**	Central Nervous System
3)	**CO2**	Carbon Dioxide
4)	**COSHH**	Control of Substance Hazardous to Heat
5)	**CPR**	Cardiopulmonary resuscitation
6)	**CPCB**	Central Pollution Control Board
7)	**CS**	Confined Space
8)	**dB**	Decibels
9)	**DC**	Direct Current
10)	**DCP**	Dry Chemical Powder
11)	**ECO**	Echo Control Officer
12)	**EHO**	Environment Health Officer
13)	**EHS**	Environment Health and Safety

14)	**EIWP**	Electrical Isolation Work Permit
15)	**ELCB**	Earth Leakage Circuit Breaker
16)	**EMS**	Emergency Management System
17)	**EP**	Excavation Permit
18)	**EPA**	Environmental Protection Agency
19)	**ERP**	Emergency Rescue Plan
20)	**FAC**	First Aid Case
21)	**FEE**	Fire Extinguisher Equipment
22)	**FPR**	Fall Protection Required
23)	**FPS**	Fall protection System
24)	**FSC**	Fire Safety Co-ordination
25)	**GFCI**	Ground Fault Circuit Indicator
26)	**GHS**	Globally Harmonized System
27)	**GK**	Gas Kit
28)	**HAZCOM**	Hazardous Communication
29)	**HAZPOWER**	Hazardous Waste Operability and Emergency Recovery
30)	**HIRA**	Hazard Identification and Risk Assessment
31)	**HML**	High Medium Low
32)	**HSE**	Health & Safety Executive
33)	**HWP**	Heigh Weight Proportional
34)	**IDLH**	Immediately Danger to Life and Health
35)	**IGC**	International General Certification
36)	**IOSH**	Institution of Occupational Safety and Health
37)	**ISO**	International Standard Organization

38)	**LC**	Lethal Concentration
39)	**LD**	Lethal Dose
40)	**LEL**	Lower Explosive Limit
41)	**LMRA**	Last Minute Risk Assessment
42)	**LNG**	Liquefied Natural Gas
43)	**LOAC**	Limitation of Excess Certificate
44)	**LOTO**	Lock Out and Tag Out
45)	**LOTOTO**	Lock-Out – Tag-Out – Try-Out
46)	**LPG**	Liquid Petroleum Gas
47)	**MSD**	Musculoskeletal Disorder
48)	**MSDS**	Material Safety Data Sheet
49)	**NBC**	National Building Code
50)	**NEBOSH**	National Examination Board in Occupational Safety and Health
51)	**NEPA**	National Environmental Policy Act
52)	**NIHL**	Noise induced hearing loss
53)	**NSC**	National Safety Council
54)	**OEL**	Occupational Exposure Limit
55)	**OH & SMS**	Occupational Health and Safety Management System
56)	**OHS**	Occupational Health Service
57)	**OHC**	Occupational Health Centre
58)	**OSHA**	Occupational Safety and Health Administration
59)	**PASS**	**P** – Pull the Pin **A** – Aim Base of the Fire **S** – Square the Trigger **S** – Swipe Side by Side
60)	**PEL**	Permissible Explosive Limit

61)	**PH**	Potential Hazard
62)	**PM**	Particulate Matter
63)	**POSR**	Pre-operation Safety Review
64)	**PPE**	Personal Protective Equipment
65)	**PPM**	Part Per Million
66)	**PSSR**	Plant Start-up Safety Review
67)	**RACE**	**R** – Rescue **A** – Alarm **C** – Confined **E** – Extinguished
68)	**RPE**	Respiratory Protective Equipment
69)	**RTK**	Right To Know
70)	**SCBA**	Self-Contained Breathing Apparatus
71)	**SCUBA**	Self-Contained Under Water Breathing the Apparatus
72)	**SDS**	Safety Data Sheet. (Formerly called Material Safety Data Sheet (**MSDS**))
73)	**SHE**	Safety Health and Environment
74)	**SLI**	Safe Load Indicator
75)	**SOPs**	Standard Operating Procedures
76)	**SSP**	State Safety Program
77)	**STA**	Safety Task Assignment
78)	**STEL**	Short Term Exposure Limit
79)	**STP**	Sewage Treatment Plant
80)	**SWL**	Safe Working Load
81)	**SWP**	Safety Work Permit
82)	**TLV**	Threshold Limit Value
83)	**TPI**	Third Party Inspection
84)	**TSTI**	Total Safety Task Instruction

85)	**UEL**	Upper Explosive Limit
86)	**UFL**	Upper Flammability Limit
87)	**VCE**	Vapour Cloud Explosion
88)	**VEWP**	Vehicle Entry Work Permit
89)	**WEEL**	Workplace Environmental Exposure Limit
90)	**WDO**	Waste Disposal Officer
91)	**WHMIS**	Workplace Hazard Materials Information System
92)	**WHO**	World Health Organisation
93)	**WMITAB**	Waste Management Industry Training Advisory Board

** Some other important acronyms not included in the above table will also be used during the course of this chapter.

Chemical Substances can be classified in different classes and categories. Some important classes include acids (inorganic acids and organic acids), alkali (bases), colors, dyes, and pigments, cyanides, detergents, dopants, fillers, food contaminants, gases (cryogenic gases, industrial gases), metals and metal compounds, oxidizers, pesticides, radioactive chemicals, solvents etc. Chemicals can also be classified based on their toxicity. These include chemical substances with irritation effects, chemical substances with corrosive effects, allergens, asphyxiants, carcinogens, endocrine disruptors, reproductive and developmental toxins, neurotoxic chemicals, chemical substances causing adverse effects to other organs etc. A brief description of each type is given in the table below (**Table 2**):

Table 2: Important classes of chemical compounds used in laboratory

Serial No.	**Chemical Class**	**Description**
1)	Chemical substances causing irritation effects	These are non-corrosive chemicals that cause reversible inflammatory effects on living tissue by chemical action at the site of contact. Examples include acids like sulphuric acid, nitric acid etc. and bases like sodium hydroxide, potassium hydroxide etc.
2)	Chemical substances with corrosive effects	These are chemicals that cause destruction of living tissue by chemical action at the site of contact. Corrosive chemicals can harm not only the skin and eyes but also respiratory tract and if ingestion occurs, they can harm the

		gastrointestinal tract as well. Examples of such chemicals include bromine, sulphuric acid, hydrogen peroxide, phosphorous pentoxide etc.
3)	Allergens	These chemicals result in an adverse reaction by the immune system. Anaphylactic shock is a severe immediate allergic reaction that can result in death if not treated at time. Some chemicals can also cause delayed allergic reactions. Examples of such chemicals include diazomethane, formaldehyde, benzylic and allylic halides etc.
4)	Asphyxiants	These chemicals interfere with the transport of an adequate supply of oxygen to the vital organs of the body. Examples of such chemicals include acetylene, carbon dioxide, argon, helium, ethane, methane, carbon monoxide, inorganic cyanides etc.
5)	Acids	These are corrosive chemicals used in different industries for cleaning, etching, plating, stripping, organic synthesis etc. They can cause serious burns and damage to the tissue.
6)	Organic acids	Examples of organic acids include oxalic acid, lactic acid, formic acid, citric acid, adipic acid, acetic acid etc.
7)	Inorganic acids	Examples of inorganic acids include hydrobromic acid, hydrochloric acid, hydrocyanic acid, hydrofluoric acid, nitric acid, phosphoric acid etc.
8)	Alkali (Bases)	These chemicals are used primarily for cleaning and souring. It has been a general assumption that alkalis are not hazardous, but like acids they are acutely hazardous in concentrated form. They have strong caustic or corrosive action. Examples of such chemicals include ammonia, ammonia persulphate, ammonium fluoride, calcium hydroxide, potassium hydroxide etc.

9)	Carcinogen	These are chemical substances that are capable of causing cancer. They are chronically toxic substances, that is they cause damage after repeated or long-duration exposure and their effects may become evident only after a long latency period. Examples of such chemicals include asbestos, nickel, cadmium, radon, vinyl chloride, benzidine, benzene etc.
10)	Cyanides	These chemicals are highly irritating and rapidly acting poisons. Cyanides are quickly absorbed through the skins and lungs and prevent the body tissues from taking up oxygen, causing sudden death by asphyxiation. Examples of these chemicals include calcium cyanide, copper cyanide, hydrogen cyanide, nickel cyanide, potassium cyanide, potassium ferrocyanide etc.
11)	Dopants	These are metal compounds in solid, liquid or gas form and are used to make chips. are the most hazardous group of chemicals in They are also sometimes referred as impurities. They electronic industry. Even small amounts of leak or rupture can result in a chemical hazard and fatal injury to surrounding communities. Examples of these chemicals include phosphine, arsine, boranes etc.
12)	Gases	These chemicals have relatively low density and viscosity and undergo relatively great expansion and contraction with changes in pressure and temperature. If inhaled, some of them can be fatal to living beings. Examples of such gases include carbon monoxide, fluorine, hydrogen cyanide, methane, nitrogen oxide etc.
13)	Cryogenic gases	The word cryogenic means ultra-cold and these gases are generally stored in liquid form under high pressure. A major leak of liquefied gas can rapidly fill a workroom displacing oxygen and causing sudden death by asphyxiation. Examples of cryogenic gases include argon,

		carbon dioxide, carbon monoxide, deuterium, helium, hydrogen, nitrogen, oxygen, ozone.
14)	Endocrine disruptor chemicals (EDCs)	Endocrine disruptors are also called endocrine modulators, environmental hormones and endocrine active compounds. The EDCs are known to interfere with the body's endocrine system and produce adverse developmental, reproductive, neurological and immune effects in humans and animals. Examples of EDCs include polychlorinated biphenyls, DDT, bisphenol etc.
15)	Reproductive and developmental toxins	These are chemicals that cause adverse health effects to reproductive and developmental cycles of animals and humans. The adverse effects are on various aspects of reproduction such as fertility, gestation, lactation and the growth and development of embryo or foetus. These effects can be postnatal functional deficiencies, lethality, malformations, retarded growth etc. Example of such a chemical is dibromo chloropropane
16)	Neurotoxic chemicals	These chemicals induce an adverse effect on the structure or function of the central and/or peripheral nervous system, which can be permanent or reversible. Such chemicals may cause slurred speech and staggered gait. Example of some common neurotoxins are lead, ethanol (drinking ethanol), glutamate, nitric oxide, tetanus toxin, tetrodoxin etc.
17)	Greenhouse gases	These are gases that trap solar radiation and cause a rise in the temperature on earth. Examples of greenhouse gases include carbon dioxide, chlorofluorocarbons, methane, nitrous oxide etc.
18)	Inert gases	These are colourless, odourless and tasteless gas that are inert under ambient conditions. Examples of inert gases are Helium, Neon, Krypton, Xenon and Radon.

19)	Fillers	Fillers are powders or tiny fibres added to resins to give bulk, strength and form. Examples of fillers are asbestos and chromates. They can cause cancer.
20)	Metals and metal compounds	Metals are good conductors of electricity and are widely used in electronics. They can occur in many forms such as bulk solids, powders and liquid solutions suspended in gas forms and are emitted as a fume when heated and as dust when drilled, sawn or fixed. They can be very harmful if swallowed or inhaled even in small amounts. Example of metals include antimony, arsenic, aluminium, barium, boron, calcium, chromium, cobalt, copper, nickel, selenium etc.
21)	Oxidizers	These are highly reactive chemicals that can be used to clear or render a metal surface free from corrosion. Some oxidizers have strong corrosive action and most of oxidizers are highly flammable which necessitates special handling and storage arrangements. Examples of oxidizers include silver nitrate, potassium iodide, oxygen, ozone, chlorine, chromic acid, hydrogen peroxide etc.
22)	Pesticides	These are chemicals that are used to control pests of different kinds. Some of them are non-toxic while others may seriously injure or even kill humans. Examples of pesticides include acaricide, aphicides, fumigants, fungicides, herbicides, insecticides, larvicides, miticides, repellents, rodenticides etc. Several pesticides are known to be carcinogenic; others cause irritation to the skin, eyes and mucous membranes. The organophosphate and carbamate pesticides affect the central nervous system.
23)	Resins (curing agents, plastics etc.)	Resins are of different types such as plastics, epoxies, glues, adhesives, paints, waxes, synthetic rubber etc. Different types of resins can have different health effects. For example, polymers may contain ingredients that can

		cause allergy, birth defects and cancer. Resins are also capable of producing a wide variety of highly toxic vapours and gases when heated or burned.
24)	Solvents	Solvents are liquid substances that fulfil several functions during a chemical reaction. For example, one of the important purpose of solvents is to dissolve the reactants and reagents and facilitate collisions to assist in product formation. The aromatic compounds and the chlorinated hydrocarbons are the most dangerous groups of solvents since many of them are known to cause cancer and other fatal disease. Prolonged exposure to solvents like acetone, alcohols, benzene, methylene chloride, toluene etc can cause acute and chronic health disease.

SAFE WORKING PROCEDURE AND PROTECTIVE EQUIPMENT

It is highly imperative that any person working in a chemical laboratory is aware of all the basic safe working procedures and personal protective equipment (PPE). The first thing that one should take care of is the PPE. It protects the user against any physical harm or hazards that are possible to happen at the workplace environment. The importance of PPE can be understood from the well-known proverb that “Prevention is better than cure”. PPE prepares the user for any health and safety risk and gives one extra protection in the event of an accident.

Personal Safety and Protective Equipment

The following are the important personal safety points to be taken care of before starting work in a chemical laboratory.

- A full sleeved, buttoned-up, knee length apron/lab coat is the first essential as PPE. Big front pockets in the apron are an added advantage.
- Always wear an appropriate protective eyewear/safety glass in the laboratory. If one is working with non-hazardous chemicals then the normal glasses of daily use also serve the cause but with hazardous materials additional precaution has to be taken.
- Appropriate hand gloves must be worn before handling any chemicals.
- Closed toe-shoes are also necessary to be worn in the laboratory.

- It is essential to wear full pants in the laboratory and shorts, skirts, quarter length clothing etc. are not permitted.
- Persons with long hairs should strictly tie their hair back to avoid accidents.
- Extra precautions are to be taken in the laboratory if one is wearing a dupatta or a saree type clothing.

** Many school and college going students have to use dupatta as a part of their uniform in India. In such circumstances, it is advisable to tie both ends of dupatta at the back in form of a knot. This can prevent several mis happenings.

The items shown in the figure below fall into the important personal protective equipment, that are essential for personal safety as well as the safety of fellow lab-mates (Figure 1).

Figure1: Most important Personal Protective Equipment (PPE)

Safe Working Procedure

Basic safety rules should be strictly adhered to while working in a laboratory. Some important safe working methods that one student or anyone working in a chemical laboratory should be aware of are given below.

- Before starting to work make sure that necessary PPE is worn.
- Long hair and any sort of loose clothing should be properly handled to prevent entanglement or potential capture.
- Use of contact lenses in chemical laboratories should be avoided especially around hazardous chemicals even if protective eyewear is being used.
- Safety glasses should be used not only during setting up reactions but also in area where chemicals are stored. There is always a risk of splashes or particulates entering the eye. Perforated shoes or sandals can be hazardous if there is a chemical spillage. Closed toe shoes offer the best solution.
- Use of jewelry items while working in labs should be avoided as this can pose multiple safety hazards.

- Clothing made of synthetic fibers should not be worn while working with flammable liquids or when a fire hazard is present as these materials tend to melt and stick to exposed skin.

- Everyone working in the lab must be aware of the locations of safety showers, eye wash stations, fire extinguishers and their handling. Most institutes often conduct mock safety drill of emergency situations. Students must learn handling of emergency equipment during such drills.

- Everyone in the laboratory must be well aware of the emergency exit routes.

- Appropriate care must be taken to avoid contact of chemicals with skin and eyes and all sorts of chemical exposures must be minimized.

- All sorts of hazardous materials, hazardous equipment or related hazards must be accompanied by proper warning signs.

- Distracting or startling those working in laboratory should be completely avoided

- Avoid distracting or startling persons working in the laboratory.

- Care must be taken while combining reagents and appropriate order must be maintained. For example, acid should be added to water and not the reverse as it leads to a highly exothermic reaction. Similarly solid should not be added to hot liquids.

- Chemical hygiene at work place is equally important as safety. For example, all containers should be properly labeled and unlabeled chemicals should not be used. Chemical containers should not be left open under any case and one should not try to sniff chemicals.

- Consuming food in or any sort of beverage in laboratory should be strictly prohibited and exposed areas of skin should be properly washed before leaving the laboratory or before consumption of any food. Proper hand washing is also essential simply after setting up a reaction.

- Do not use mouth suction for pipetting or starting a siphon.

- Before starting a work, determine the potential hazards and appropriate safety precautions.

- If an unknown chemical is produced in the laboratory, the material should be considered hazardous.

- Chemicals or waste should not be poured down into drains. All sink traps (including cup sink traps and floor drains) filled with water should be cleaned by running water down the drain at least monthly.

- All reactions should be carried out in fume hood (especially those involving hazardous materials) to avoid hazards and fume hoods should not be used for evaporating solvents or disposal of volatile solvents.

- Under no circumstances should a student work alone in the laboratory. In fact, sitting alone in the chemical laboratory should also be prohibited. However, if there is a separate sitting space away from the main laboratory, that can be permitted.

- All those working in the labs should have access to the chemical inventory of the lab, safety data sheets associated with the chemicals being used and relevant standard operating procedures. But access to areas such as stockrooms or specialized laboratories should be permitted only to trained personnel.

- There should be a regular check of the equipment to avoid wear or deterioration and proper records related to the equipment such as manufacturer's requirements, records of certification, maintenance or repairs should be maintained.

- Waste disposal should be given especial emphasis such as segregation of different types of waste, proper disposal of hazardous waste, proper disposal of solvents, recycling chemicals, if possible, from waste etc.

- Use of mobile phone or similar electronic gadgets in the active portion of laboratories or while performing experiments should be prohibited.

- Appropriate care must be taken for proper storage of lab-coats, used hand gloves etc. and avoid taking them to areas that can lead to contamination. For example, one should not wear hand-gloves while using computer otherwise it can lead to contaminations leading to potential hazard not only for the user but also those around.

PROTECTIVE APPAREL, EMERGENCY PROCEDURE AND FIRST AID

Protective Apparel

The Personal Protective Equipment or the protective apparel are the first minimum basics that anyone working in chemical laboratory should wear. These include full-sleeve buttoned knee length apron, safety glasses and closed toe shoes. Besides that, while working with any specific hazardous materials corresponding safety precaution should be taken. The protective characteristics of any protective clothing should be matched to the hazard. In case of presence of multiple hazards, multiple layers of protective clothing may be used. PPEs that reduce permeability or aprons that can be disposed after single use can be useful in case of working with toxics.

The commonly used laboratory coats are made of materials such as cotton, polyester, cotton-polyester blends, polyolefin etc. It is imperative to select appropriate clothing material depending on the possible hazard. Though cotton aprons are the most widely used, care must be taken as they can rapidly react with acids. While working with corrosive liquids, plastic or rubber aprons can be savior but turn inappropriate if there is risk of fire or in presence of flammable or explosive materials. Plastic aprons can also accumulate static electricity. Most of the synthetic fibers are flammable and can turn to be very dangerous and increase the severity of burns if working with flammable materials or while working near open flame. When working with flammable materials or pyrophoric, it is advisable to use lab coats made up of flame-resistant, non-permeable materials. If one is working with carcinogenic or potentially toxic chemicals, use of disposable garments is advisable. One must also take adequate care to remove such apparels after the work is done before moving out of laboratory and dispose the garments as hazardous waste.

High heels, perforated shoes, open-toe and open-heel shoes, sandals or clogs, should not be worn in laboratories. Shoes should have stable soles that provide traction in slippery or wet environments to reduce the chance of falling. Socks should cover the ankles so as to protect against chemical splashes. It is also advisable to wash reusable laboratory apparels separately from the daily common use laundry.

However, despite the precautions adopted, the possibility of non-existence of an emergency situation cannot be guaranteed. Regular laboratory inspection and equipment maintenance is beneficial to prevent laboratory accidents. There can be different sorts of emergency situation that can arise such as medical emergency, fire emergency, chemical emergency etc. Once the emergency occurs, it is essential to know what to do. One must ensure personal safety at first and the extent of response during an emergency is dependent on the seriousness of the accidents. The most important emergency situations are discussed under different heads but before that the there are some guidelines to be followed during an emergency

- During any sort of emergency keep yourself safe and calm.
- The emergency must be immediately reported to the local emergency responders or a safety department.
- All those in the nearby vicinity should be immediately informed of the emergency situations. Emergency alarms can be of great assistance during such situations.

First Aid Kit

** All types of labs must be equipped with a well maintained first-aid box.

A first aid kit is a box, bag or pack that holds supplies used to treat minor injuries including cuts, scrapes, burns, bruises and sprains etc. Basic medicines for illness like normal cold and flu or commonly prescribed pain killer or related medicines can also be included in the first-aid kit. The name itself indicates its importance and refers to the first or immediate or primary assistance given to someone in emergent need. It can be easily recognized as it always carries a big plus sign on it.

A first aid box may contain the following essential items: essential medicines, antiseptic lotions or creams, roller bandages, ace bandages (no creams, ointments), sterilized cotton, dettol, scissor, safety pins, tweezers, eye-wash, skin rash cream etc.

Material Safety Data Sheet

A Material Safety Data Sheet (MSDS) is a document containing information on the potential hazards associated with a chemical besides the information on how to work safely with a chemical. The hazards aforementioned may be health hazard or fire hazard or reactivity hazard or environmental hazard. MSDS is an essential starting point for the development of a complete health and safety program. The label on the material contains very limited information but a MSDS gives every necessary information connected to a chemical. It contains information on the use, storage, handling and emergency procedures related to the hazards of the material. It is generally the supplier or manufacturer of the material who prepare the MSDS. It tells what are the hazards associated with a particular chemical/material, safe usage of the chemical, what to expect if recommendations are not followed, steps to be adopted in case of any sort of accident, recognizing the symptoms of over-exposure and how to handle such critical situations. MSDS is the first thing that students must be informed about before entering a chemical laboratory besides the PPE.

Emergency protocol due to chemical spill

- **Chemical spill on surroundings**

  - In case of chemical spillage in surroundings, inform everyone in the nearby vicinity of the spillage and if necessary, evacuate the location and areas surrounding the skill.
  - After identification of the spilled chemical, immediately refer to the chemical's safety data sheet (SDS) to assess the hazard and the action to be taken in accordance with SDS.
  - In case of minor spills, take care that bodily exposure to spilled chemicals should be avoided and inhalation of vapours should be completely avoided. In case the spilled chemical is flammable, turn of the nearby heat or ignition source. Depending on the nature of spilled chemicals take appropriate action to contain the spill area. For example, if the spilled chemical is acid or base it has to be carefully neutralized using appropriate neutralizers after consulting the MSDS. Finally, all the residues should be collected and placed in suitable container.
  - In case of major spill, inform everyone around of the spill and evacuate the area immediately. Seek immediate help from the emergency personnel and help them in identifying the areas. In case the spilled chemical is flammable and if situation permits, shut down any source of heat source around the spilled chemicals. But this should be done only after quick assessment of the situation.

- **Chemical spill on body**

In case chemical spillage on body has taken place then follow the following protocols

- Try removing the spilled chemicals on the body under water or a safety shower and if chemical has been spilled on the clothing, remove the clothing.
- In case the chemical spill splashed into eyes, wash the eyes immediately with water for at least 15 minutes (Avoid use of contact lenses in chemical lab).
- If spillage of a strong acid has occurred on the body, try to remove the clothing if spilled with acid and rinse the effected areas with clean water.
- All sorts of contaminated clothing should be removed to avoid further exposure to chemicals.
- Alert people in the nearby vicinity of the spill and seek emergency help depending on the extent of hazard.

Emergency protocol during fire accident

There can be several causes of a fire or explosion in a lab such as overheating, leakage or spillage of flammable chemicals, electric sparks, gases being exposed to heat or open flame etc. One must be extra cautious in use of flammable or explosive materials. In case an emergency situation arises, the following protocols may be adopted.

- In case an individual's clothes are on fire, do not run as the fire will be accelerated. Lay on the ground with hands covering the face and roll around. This can put off the fire and if situation permits use safety shower to put off the fire.

- If there is a laboratory fire or explosion, take care of personal safety first and then immediately call/inform the emergency personnel.

- In case of a fire, all the nearby people should be informed immediately to evacuate the building. Fire alarms can be of great assistance in such situation.

- Always use staircase or emergency exit in case of a fire accident and avoid using elevators.

- If situation permits, shut down the electric power before evacuating the building.

- In case there is heavy smoke all around, cover mouth and nose using a wet towel to prevent inhalation of smoke.

- Small fire accidents can be handled by using the common fire extinguishers available around in laboratories. But one must be proficient in their use.

- At the end always keep in mind that one has to give priority to personal safety first and then help others if possible. Also be aware of a second fire or explosion.

Medical emergency protocol

- If the emergency situation is minor then initiate first aid and after that report the incident to the concerned.
- If the emergency is major, first of all maintain calm. Then initiate lifesaving measures if required and only if one known how to do so. Do not move the person unless there is danger of further harm and the person should be kept warm. Also call immediately for emergency response.

LABORATORY VENTILATION

A chemical laboratory involves use of different types of chemicals including solids, liquids and even gases. Besides that, several chemicals are generated as by-products of reactions. Laboratory ventilation provides everyone working in the lab besides those around a safe, comfortable and breathable environment. The risk of being exposed to hazardous chemicals every now and then is also reduced. However, setting up a proper laboratory ventilation involves careful planning, designing, maintenance of air supply and lot of mechanical equipment. This all means that a huge cost is involved in creation of a proper laboratory ventilation. There are two types of laboratory ventilation that is generally used by research labs or commercial facilities and they are natural ventilation and mechanical ventilation.

Natural ventilation depends on several factors like climate, building design and human behavior. Most importantly it depends on the speed and direction of wind and pressure of wind on any given day. Though environmentally friendly as well as an inexpensive process, natural ventilation can leave the workplace vulnerable to certain conditions.

Mechanical ventilation systems circulate fresh air using ducts and fans (fume hoods, Figure 2), rather than relying on airflow through small holes or cracks in walls, roof or windows.

**In most of the teaching labs in schools and colleges and even some universities, the provision of mechanical ventilation is not available. In such cases due care must be taken to always keep the exhaust fans on and use of hazardous materials must be done in presence of teachers.

Some important points connected to a proper mechanical laboratory ventilation are discussed below.

- There should be a mechanically generated and conditioned supply and exhaust air in all the laboratory spaces. The exhaust air should be completely towards outside and should not get back into the building under any circumstances. Air can be recirculated back only on the condition that the air was previously exhausted from a clean room and before circulating it back it should be filtered through high-efficiency particulate (HEPA) filter and that it should not contain any volatile hazardous material.

- Sufficient exhaust air shall be provided to assure the removal of hazardous airborne materials. Any sort of hazardous reactions should compulsorily be accomplished in fume hood or designated places. In a laboratory, fume hoods should operate continuously and may not be controlled by switches.

- The laboratory exhaust systems should be designed in such a manner that there is at least 25% excess capacity in case need for expansion might arise in future.

- Excessive generation of noise in laboratory ventilation systems should be avoided. Fan location and noise treatment shall provide for sound pressure level (SPL) in conformance with local ambient noise criteria. Despite the fact that fume hoods can generate lot of noise, a good laboratory design allows for easy verbal communication.

- There should be sufficient airflow velocity in each duct so that settlement of liquid or condensable solids on the walls of the ducts can be prevented. This velocity has to be sufficiently high to entrain solids which means that the system might become noisy.

- Fume hoods that are used for teaching purpose are generally used for designated hours and their continuous operation can lead to unnecessary energy wastage. To prevent this, exhaust from hoods for teaching labs should be routed to different blowers than those of research labs.

- Under normal working conditions, no windows should be kept open in labs that have continuous running fume hood facility. This can disrupt fume hood containment and also destroy the negative pressure containment that should be available in the laboratories.

- The laboratory shall be designed in such a way that fume hoods are not located near the exits of the labs. Reactions that are carried out in fume hoods can result in a fire, explosion or chemical release and if fume hood is located near the exit, there will be blockage of safe way out.

- Hoods should be labeled to clearly indicate the ventilation system of the fan to which they are connected.

- Flexible local exhaust devices (e.g., “snorkels” or “elephant trunks”) shall be designed to adequately control exposures to hazardous chemicals. They turn very useful as severely hazardous exhausts may result from gas chromatographs, vacuum pumps etc.

Figure 2: Fume hood in a chemical laboratory

Mechanical laboratory ventilations are further of two types.

- **Positive pressure mechanical ventilation:** This is suited in warm and humid climates where infiltration may need to be minimized to reduce condensation. Here the room is in positive pressure and room air is to be leaked out.
- **Negative pressure mechanical ventilation:** This is suited in cold climates where exfiltration must be prevented to minimize condensation. Here the room is in negative pressure and air is to be sucked in from outside.

SAFE STORAGE AND USE OF HAZARDOUS CHEMICALS

Before going into the details of safe storage and use of hazardous chemicals, it is essential that students know what are the different types of chemicals and the possible potential hazards.

The Hazard Communication Standard (HCS) and its internationalized version referred as Globally Harmonized System of Classification and Labelling of Chemicals (GHS) requires pictograms on labels to alert the users of chemical hazards to which they may be exposed. Each pictogram consists of a symbol on a white background framed with a red border and represents a distinct hazard (s). The best part of these pictograms is that even a layman without any prior knowledge of chemistry or someone who does not have educational background can also get a basic idea of the associated hazard from the pictogram. There are 9 most important pictograms. They are shown below along with the associated hazards in tabular form. (**Table 3)**, The pictograms have been collected from unece.org).

Table 3: Hazard Communication Standard/Globally Harmonized System of Classification and Labelling of Chemicals Pictograms

Pictogram	Pictogram	Associated Hazard (s)	General Meaning

Symbol	**Name**	**with examples of chemicals belonging to particular class**	
	Health Hazard	• Carcinogen • Mutagenicity • Reproductive • Toxicity • Respiratory • Sensitizer • Target Organ Toxicity • Aspiration Toxicity For example: Turpentine, petrol and some types of oils	These chemicals cause serious health problems. Some problems show up immediately, but some may show up much later.
	Flame	• Flammables • Pyrophorics • Self-Heating • Emits Flammable Gas • Self-Reactive • Organic Peroxides For example: Acetone, Methanol, generally most solvents	These chemicals burn or can release gases that burn.
	Exclamation Mark	• Irritant (skin and eye) • Skin Sensitizer • Acute Toxicity (harmful) • Narcotic effects • Respiratory Tract Irritant • Hazardous to Ozone Layer (Non-Mandatory) For example: Paraformaldehyde solution, hydrogen peroxide.	These chemicals cause health problems. Usually less toxic than chemicals labelled with the Health Hazard or Skull and Cross-bone pictograms. This pictogram is also used for chemicals that can destroy ozone layer.

	Gas Cylinder	• Gases Under Pressure For example: liquid nitrogen, liquid oxygen, liquid helium etc.	Gases and liquids under pressure can explode. This pictogram is used for both pressurized gases and liquefied gases such as liquid nitrogen
	Corrosion	• Skin Corrosion/Burns • Eye Damage • Corrosive to Metals For example: Strong acid and bases (like nitric acid and sodium hydroxide), calcium oxide, anhydrous zinc chloride.	These chemicals cause permanent damage to skin or eyes. These chemicals destroy metals.
	Exploding Bomb	• Explosives • Self-Reactive • Organic Peroxides For example: azidoazide azide, trinitro toluene, chromyl chloride, and nitroglycerin	These chemicals explode.
	Flame Over Cirlce	• Oxidizers For example: Sulfur dioxide, most halogens, potassium permanganate, nitric acid etc.	These chemicals give off oxygen and can make a fire spread
	Environment	• Aquatic Toxicity For example: Lead, mercury, cadmium, formaldehyde etc.	These chemicals are dangerous if they get into rivers, lakes or oceans
	Skull and Cross-bone	• Acute Toxicity (fatal or toxic) For example: Manganese heptoxide, some pesticides, paint thinners etc.	These chemicals are poisons that quickly cause sickness or death. A toxin may attack one or more parts of the body such as the liver, kidneys, nerves, lungs, skin, eyes or bone.

Besides these pictograms there is also Hazardous Material Diamond, which is a hazard communication system used to help emergency personnel or any user of chemicals quickly identify the risks posed by hazardous materials. Its use is defined by National Fire Protection Association's Standard 704, titled "NFPA 704: Standard System for the Identification of the Hazards of Materials for Emergency Response. The other names for this diamond include Fire Diamond, the NFPA Diamond, and the Safety Square. The diamond is divided into four squares of colors: Blue, Red, Yellow, and White (Figure 3). The red square describes flammability hazards, the leftmost square that is blue in color describes health hazards, the rightmost square is yellow and describe reactivity hazards. The bottom white square uses letter codes as "special notice". Blue, red and yellow diamonds have number 0-4 written on each. Higher the number, higher is the particular type of hazard.

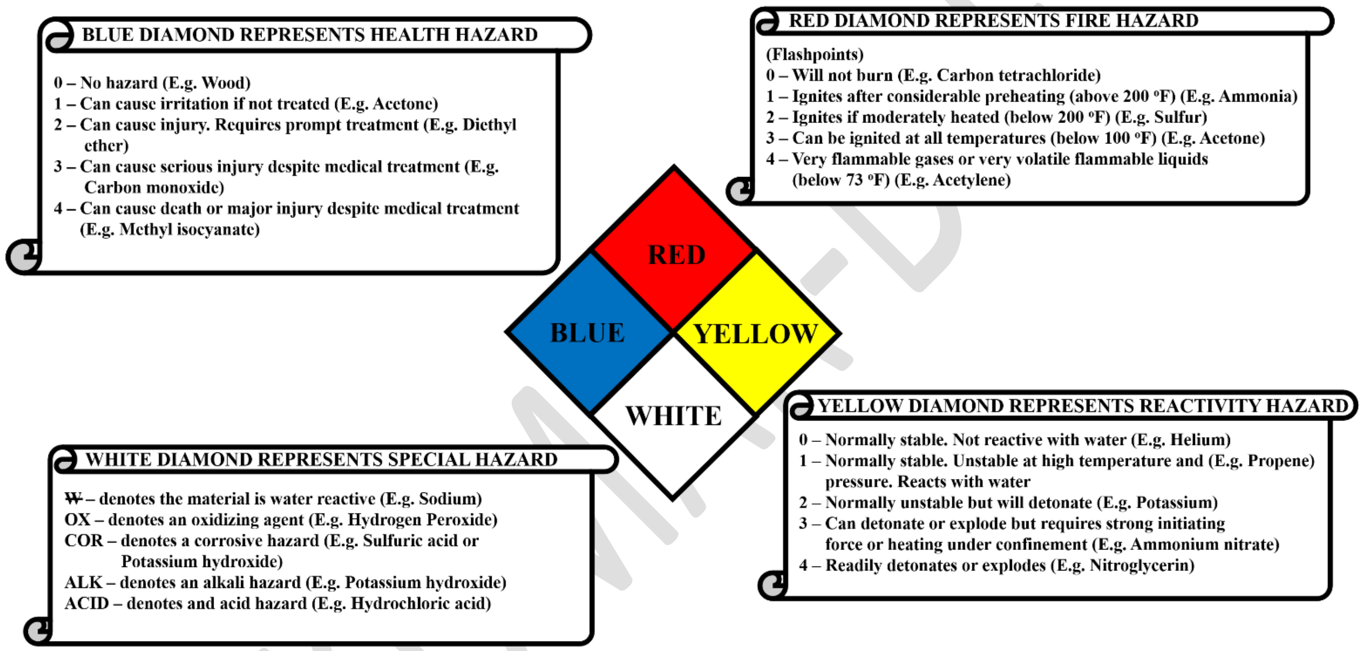

Figure 3: Hazardous Material Diamond by National Fire Protection Association

The first and foremost thing that everyone must essentially follow before touching the bottle or container of a chemical is to refer to their MSDS. The people working in the laboratory should be trained about preparation of a proper laboratory inventory for the chemicals. There are some general guidelines that everyone must follow to reduce the risks associated with the handling and storage of material within the laboratory.

- Whenever a new container of a chemical is opened, the day, month and year should be immediately noted on the bottle with a permanent-marker or a non-erasable pen. This is highly essential for chemicals that have the potential to form peroxides but it should be a standard practice to be adopted by the workers irrespective of the nature of the chemicals.
- The common working place should not be the storehouse of chemical. Only those chemicals which are used actively or frequently used should be kept in nearby vicinity. Storage of chemicals on the lab-bench, fume hoods and other work areas must be minimized. Besides that, the laboratory doors should be kept close all times when fume

hoods are working.

- Students or any one working in the laboratory should not use chemicals or equipment if they have not been trained for the same.
- The chemical storage guidelines for some important class of chemicals that have specific chemical hazards will be discussed one by one in coming section.
- Glass chemical containers should never be directly stored on the floor (without secondary containment) or window ledges.
- All chemical storage area should be well lit and ventilated and kept away from exits, heats etc., besides that chemical storage shelves must be securely fastened to the walls and have suitable protection at the door corners to prevent them from falling in the event of earthquake.
- Storage of chemicals above shoulder height should be avoided, especially for liquid chemicals, acids, corrosives etc.
- Secondary containments such as polyethylene or stainless-steel trays, secondary containers for storage of hazardous chemicals etc. can be very helpful.
- Never store any food item in the laboratory refrigerator meant for chemicals, not even packaged food items or cold drinks etc.
- It is always advisable to use first-in, first-out (use oldest chemical first) system. This ensures prevention of degradation of older chemicals.

Guidelines for storage and use of acids

- Large bottles of acids should always be stored on low shelves or in cabinets marked for corrosive chemicals or on trays in acid cabinets.
- Oxidizing acids should be segregated from organic acids, flammable and combustible materials.
- Acids should be kept segregated from bases and other active metals like sodium, potassium, magnesium and other similar incompatible materials.
- While transporting acids always make use of bottle carriers or a cart. Lifting big acid bottles in hand should be strictly prohibited. And if the need to lift the bottle arises due to some emergency, one hand should be placed at the bottom of the bottle and the other at the top of the bottle.
- In case of event of acid spill, spill control pillows or appropriate acid neutralizers must be used. Bases should not be used to neutralize acid spill.

Guidelines for storage and use of bases

- Bottles of liquid bases should be stored on trays in a cabinet marked as bases or corrosives. However solid bases like sodium hydroxide, potassium hydroxide, sodium carbonate etc. can be stored in normal cabinet for chemical storage. But the bottles should be airtight.

- Bases must be kept segregated from acids and other incompatible materials.
- Inorganic hydroxide solutions should be stored in polyethylene containers.
- In case of a base spillage, use spill control pillows or caustic neutralizers. Acids should not be used for neutralization of base spills.

Guidelines for storage and use of flammables

- Flammable liquids or chemicals should be stored only in specially equipped flammable-safe refrigerator or flammable cabinet.
- All flammable materials should be kept at a safe distance from sources of ignition.
- Commonly used organic solvents are flammable and they should not be stored in the vicinity of working area. There should be a separate dedicated area for storage of solvents away from any source that can create a fire hazard. Especial care should be taken for containers of low boiling solvents like dichloromethane, diethyl ether, chloroform, hexane and petroleum ether.
- Before using flammable materials, the user must make sure that fire extinguishing and spill control equipment are readily available if emergency situation arises.
- One must have knowledge of appropriate fire extinguisher to be used for different class of flammable materials.

Guidelines for storage and use of oxidizers

- Oxidizers should be stored in a cool and dry area.
- They should be stored away from flammable and combustible materials such as paper, wood etc.

Guidelines for storage and use of peroxide forming chemicals

- The user must never forget to mention the date, month and year on the bottle of peroxide forming chemicals when it is newly opened.
- Such chemicals must always be stored in a dark, cool and dry area.
- There are indicator strips that can be used to check the formation of peroxides in a particular chemical. Such strips must be used whenever necessary, especially if the date of manufacture of the chemical is too old.
- Peroxide forming chemicals must be disposed of on or before expiration date of one year after opening, whichever is earlier.

Guidelines for storage and use of compressed gases

- Cylinders of compressed gases must always be stored in secure and upright position.
- Such cylinders must always be kept in a chained.

- As most of the times, cylinders do not have appropriate labels it is a safe practice to indicate their status such as Full or In Use or Empty.
- If a cylinder of a compressed gas is not being used, the valve cap should be replaced.
- Cylinders must be transported using a cylinder cart and not be transported by rolling around or lifting up.

PROCEDURE FOR WORKING WITH SUBSTANCES THAT POSE HAZARDS

Any person working in the chemical laboratory should essentially wear proper PPE, follow all important SOP's, always practice good housekeeping and receive appropriate training for handling hazardous chemicals. The following are some specific guidelines that one should follow when working with substances that may pose hazards.

- If a substitute for the hazardous chemical to be used is available, one should always use the less hazardous material and thus decrease the risk of exposure. This would obviously be possible if the less hazardous material does not result in a drastic decrease of yield.

- Any hazardous substance should be ordered only after prior consultation with not only those in-charge of handling chemicals but also the personal investigator/guide/supervisor.

- Whenever the use of potentially hazardous material is involved in any reaction, it is better to plan the experiment in advance, layout of apparatus and chemical and waste containers that are necessary. Besides that, such reactions should under no circumstances be done if one is alone.

- Ensure that all the appropriate personal protective equipment is worn. The gloves must be discarded in appropriate manner immediately after use.

- For reactions involving hazardous materials, it's advisable to use minimum quantities of chemicals to perform the experiment. It is also advisable to add the buffer directly to the main reaction vessel and then making dilutions appropriately. This would decrease the risk of hazard.

- It is better to use premade solutions of hazardous powdered substances if available. However, if solutions are not available, then powder must be weighed in fume hoods. In case the particles of the powdered substance are too light and might pose an even more serious hazard due to the air flow of fume hood, then one must take care to use a dust mask when weighing the chemical. A wetted paper towel must also be kept in the nearby vicinity to facilitate cleanup.

- For the purpose of the safety of the co-workers, one can request the co-workers to vacate the nearby area only during the time when such hazardous materials are weighed outside the lab but presence of coworkers in all other cases is essential. Cleaning up the working surfaces to decontaminate it of the hazardous material is also a good practice.

- Use of secondary containment such as larger trays makes things very easier and simpler to conduct experiment in and for storage of particularly hazardous substances.

- Hazardous materials must be stored in separate containers or cabinets and should have clear stickers/labels mentioning the nature of associated hazard such as Carcinogens, Reproductive Toxins, Neurotoxic etc.

- Frequent washing of hands even though hand-gloves are used is highly essential and is an integral part of personal hygiene.

- If situation demands use vacuum for cleaning of hazardous substances, one must ensure to make use of only High Efficiency Particulate Air (HEPA) filters recommended for best capture and protection. However, after the clean-up process, the vacuum bag and its contents must be disposed appropriately as hazardous waste.

- As a responsible researcher, it is advisable that the user indicates all the potential hazards and the safety precautions to be taken in the final publication or project report if prepared.

- Any reaction or hazardous material should be kept at least 6 inches (15 cm) behind the plane of sash. The user should never put their head inside the fume hood to check an experiment. The plane of sash is the barrier between contaminated and uncontaminated air. If the sash of the fume hood opens in vertical position due care must be taken that it is kept at its lowest position to maintain a safe working environment. Besides that, for a healthy and safe working environment, fume hoods should always be kept clean and clear and should not be cluttered with usable. If there is any chemical spill or any sort of waste materials after setting up of reaction, everything should be properly disposed.

- When working with hazardous substances, try to avoid eye injury and hence use safety glasses, avoid ingestion of hazardous chemicals and thus do not eat anything in lab or no activity that can lead to ingestion of hazardous chemicals should be done, avoid inhalation of hazardous chemicals by making use of fume hood and mask, avoid injection of hazardous materials while using syringe and finally minimize skin contact as much as possible.

PROCEDURE FOR WORKING WITH SUBSTANCES THAT POSE FLAMMABLE AND EXPLOSIVE HAZARDS

Before getting into the procedure for working with substances that pose flammable and explosive hazards, one needs to be well acquainted with terms connected to flammable materials. Flammable materials are defined as those that ignite or catch flame immediately when they come in contact with fire or high temperature in the air.

Types of flammable materials

Flammable materials can be solid, liquids and gases.

A flammable solid is a solid which is readily combustible or which may cause or contribute to fire through friction. There are three classes of flammable solids:

- Desensitized explosives which need to be kept wetted with sufficient water or alcohol or plasticizer to suppress explosive nature.
- Materials that are thermally unstable and can undergo a strongly exothermic decomposition even without the participation of oxygen. Such materials are termed as self-reactive materials.
- Readily combustible solids such as solids which may cause a fire through friction, pyrophoric materials etc.

Flammable gases are defined as any material which is a gas at 20 ˚C (68 ˚F) or less and 101.3 kPa (14.7 psi) of pressure which is ignitable at 101.2 kPa (14.7 psi) when in a mixture of 13 percent or less by volume with air or has a flammable range at 101.3 kPa (14.7 psi) with air of at least 12 percent regardless of the lower limit.

Flammable and combustible liquids are those that can burn easily. Their classification is based on their flashpoints.

Flammable and combustible liquids are liquids that can burn. They are classified, or grouped, as either flammable or combustible by their flashpoints. Flashpoint is defined as the lowest temperature at which vapors above a volatile combustible substance ignite in air when exposed to flame or it can be defined as the temperature at which a particular organic compound gives off sufficient vapor to ignite in air. The different classes of flammable and combustible liquids are given below (**Table 4**):

Table 4: Different classes of flammable and combustible liquid:

Class	Boiling Point ˚C	Flash Point ˚C	Examples

	(˚F)	(˚F)	
1A flammable liquid	<37.8 (100)	<22.8 (73)	Ethyl ether, pentane
1B flammable liquid	≥37.8 (100)	<22.8 (73)	Acetone, ethyl alcohol
1C flammable liquid	-	≥22.8 (73) and <37.8 (100)	Butanol, isoamyl acetate
2 combustible liquid	-	≥37.8 (100) and <60 (140)	Formalin, cyclohexanone
3A combustible liquid	-	≥60 (140) and <93.3 (200)	Phenol, dichlorobenzene
3B combustible liquid	-	≥93.3 (200)	Ethylene glycol, mineral oil

Auto-ignition temperature

The temperature at which a material self-ignites without any obvious source of ignition, such as a spark or flame is known as auto-ignition temperature or ignition temperature of that compound. The autoignition temperature for most common flammable or combustible liquids are in the range of 300 ˚C (572 ˚F) to 550 ˚C (1022 ˚F). But it can be also a very low value such as for ethyl ether whose autoignition temperature is 160 ˚C (356 ˚F).

Fire or explosion hazard from flammable and combustible liquids

Flammable liquids are capable of giving off enough vapor at normal room temperature to form mixtures that can burn with air. Combustible liquids too at temperatures above their flashpoint can release enough vapor to form burnable mixtures with air. Hence both these types of liquids are potential fire hazard causing liquids. As both the types of liquids burn very fast, they give off a lot of heat and often clouds of thick, black, toxic smoke. The major problem associated with flammable and combustible liquids is that their vapors are usually invisible which means they are hard to detect unless some special instruments are employed for the purpose.

As most of such liquids flow very fast, it means that they can easily spread on the floor or workbench even if there is a small spillage. And in case there is a fire mishap, such liquids can quickly spread the fire under the doors, down stairs, or even into neighboring buildings. Besides that, materials like wood, cardboard, clothes etc. absorb liquids and this means that hazardous vapors can still be released into the atmosphere even when the spilled liquid has been cleaned up. Flammable and combustible liquids can pose several other hazards to body depending on the specific material and route of exposure to body. Several of such liquids have also corrosive nature.

Danger of flashback

Open containers of flammable and combustible liquid release vapors into the air. These vapors are heavier than air which implies that inadequate ventilation can cause these vapors to settle and collect in low areas like sewers, sumps, basements etc. Besides that, vapors spread much faster than liquids and if these vapors come in contact with an ignition source, the fire produced can flash back or travel back to the liquid. This is known as danger of flashback and this can lead to unfortunate hazards.

Some general guidelines for safe working with flammable materials:

- The correct use of personal protective equipment and correct apparel is the first thing that one must always follow.
- Always make use of fume hood when transferring or heating flammable liquids.
- Containers of flammable materials must be handled very carefully. In case of liquid solvent bottles, never lift them with single hand and it is advisable to make use of bottle transporting cans available for the purpose. If flammable material is solid and comes in a glass bottle, it is advisable to use a temporary bigger plastic container while moving the chemical for reaction purpose. Glass bottles can easily break down but plastic containers won't.
- All flammable gases must be handled in fume hood.
- Whenever flammable materials are being used make sure that there is no open flame in the nearby vicinity.
- It is imperative to control all possible sources of ignition and heat in the laboratory such as ovens and electric motors in all those areas where flammable vapors can be present.
- Make use of only that electrical equipment for setting up a reaction which are labelled as explosion proof.
- Always ground the metal container when there is a need to transfer flammable liquids.
- Flammable solids must be handled gently and slowly (away from source of air) to minimize generation of hazardous dust.
- Solvent distillation chambers or set ups should never be left unattended.
- Before using any flammable material (solid, liquid or gas) one has to be sure of the presence of the proper extinguishing media in the nearby vicinity and under no condition should anyone work alone in a chemical laboratory.
- In case of handling compressed gases, the regular of the cylinder should be properly checked. Also, the regular and cylinder valves must be free from any sort of grease, oil, dirt and solvent as this can lead to an explosion. The storage temperature of compressed gases should not exceed 52 ˚C (125 ˚F).
- Before introducing a flammable gas in a reaction vessel, the vessel should be purged well by evacuation or with an inert gas. This process should be repeated at least three times.

PROCEDURES FOR WORKING WITH GASES AT PRESSURES ABOVE OR BELOW ATMOSPHERIC PRESSURE

Gas cylinders find wide application in chemical industries, research labs, pharmaceutical industries etc. Examples of such gases include normal air, ammonia, carbon dioxide, chlorine, helium, hydrogen, nitrogen, oxygen, argon etc. Gas cylinders may be colored either with one or more colors depending on the gas filled in it. The upper curved part of the cylinder is known as shoulder while the lower part is known as body (Figure 4). As most of the gas cylinders do not have any written information about their contents, to avoid the confusion process of color codes were introduced. This serves both safety purpose and prevents mix-ups handling. However, the color codes may vary from country to country. It is always advisable that one refers to the standard guidelines of the country one is working at. The color codes which are most commonly followed for cylinder are given in the table below (**Table 5**). However, one should note that the color of the gas cylinder has nothing to do with the color of the gas filled into it and it indicates the hazard associated with the gas.

Poisonous and corrosive gas cylinders have yellow color, flammable gas cylinders have red color, oxidizing gas cylinders are light blue in color and inert gas cylinders are bright green.

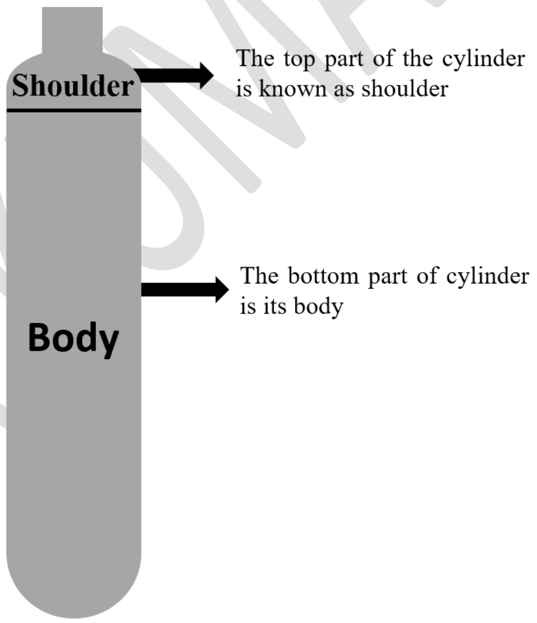

Figure 4: Gas cylinders used in chemical laboratory

Table 5: Color codes of common gas cylinders used in laboratory

Serial No.	Gas cylinder	Colour	
		Shoulder	Body
1)	Air	Grey	Grey
2)	Ammonia	Red	Yellow and black
3)	Carbon dioxide	Silver	Black
4)	Chlorine	Yellow	Yellow
5)	Helium	Brown	Brown
6)	Hydrogen	Red	Red
7)	Nitrogen	Black	Grey
8)	Oxygen	White	Black

The GHS pictogram with a cylinder refers to gases. Based on the hazard associated, gases can be categorized into different types as shown below (**Table 6**):

Table 6: Classes of gases based on hazards

Hazard class and category	Associated Hazard
Gases under pressure -Compressed gas	Contains gas under pressure, may explode if heated
Gases under pressure - Liquefied gas	Contains gas under pressure, may explode if heated
Gases under pressure - Refrigerated liquefied gas	Contains refrigerated gas, may cause cryogenic burns or injury
Gases under pressure – Dissolved Gas	Contains gas under pressure, may explode if heated

In case of accidental release of gases under pressure, very hazardous fire or health emergency can arise as this would mean very fast spread of the gas molecules. Gas cylinders can also be felt to be missile like as it can rocket or spin out of control with great force capable of causing serious damages and injury. Liquefied gases can cause cryogenic burns or frostbites. Hence in all cases adopting safe procedures while working with gases is very important. The procedure for safe handling of different sort of gases is discussed below.

Handling compressed gases

- The first most essential thing while working with compressed gases is to wear an appropriate personal protective equipment and safety glasses with side shields must be used.
- On receiving the cylinder from suppliers clearly label it mentioning its content to avoid confusion later on. Also be aware of the colour code of the cylinders followed at the place you are working.
- In case a cylinder or cylinder valve is found to be damaged prior to use, do not try to repair it yourself as it can be very risky. It must be immediately taken out of use and returned to the supplier to assess the damaged part and further repair.
- Always secure the cylinders above their middle line and only soldered link chains or belts with buckles are acceptable.
- If cylinders are to be moved from one place to other, do not roll the cylinder. Make use of handcarts for moving both empty and filled cylinders and before moving chain them to the cart properly. Three wheeled or four wheeled carts are best suited for this purpose.
- All cylinders in use must compulsorily have a pressure controlling device that also shows the reading of the pressure. This helps in maintaining a controlled flow of gas from cylinder.
- There should be only one valve on each cylinder which must be used to stop the gas flow when required. To prevent fire hazards, these valves must never be lubricated using grease, oils, etc. Only PTFE Teflon's must be used to tighten the fittings if required.
- Whenever a new cylinder is connected, tighten the regulators and valves using a proper size wrench and occasionally check to confirm that there is no leakage of gas.
- The location of cylinders must be at a safe distance from any source of heat or where they become part of an electrical circuit.
- Cylinders must not be exposed to temperatures above 50 ˚C (122 ˚F). Some rupture devices on cylinders will release at about 65 ˚C (149 ˚F). Some small cylinders, such are not fitted with rupture devices and may explode if exposed to high temperatures.
- Take all precautions to avoid rapid release of gas because it will cause an unsecured gas hose to whip dangerously. This may also result in the buildup of a static charge that can ignite the flammable gas.
- Before connecting the regulator, make sure that everything is alright and no homemade adapters etc. shall be used.
- When the gas in the cylinder is about to finish, always note that it should not be completely emptied and leave a slight pressure to keep contaminants out.

- Never ever make an attempt to transfer gas from one compressed cylinder to another. This can be only done by the manufacturer or supplier.
- Besides all the above-mentioned precautions for handling, storage of compressed gas cylinders must also be done with utmost care. If the cylinder is not in use, keep the main valve closed. All sorts of dissolved gas cylinders must be maintained in upright position. The location of cylinders must also be checked properly to avoid any heavy object that can strike or fall on the.
- Cylinders must not be stored in damp areas or near salt, corrosive chemicals, chemical vapors, heat, or direct sunlight. Cylinders stored outside must be protected from the weather. Corrosive gas cylinders must be returned for disposal every two years.

Handling liquefied gases

Liquefied gas commonly used in laboratory include liquid nitrogen. Anyone handling or working with liquefied gases must be well aware of the possible potential hazards that can arise due to an accident. And hence proper precautions and expertise in handling such chemicals is necessary. For the first few times such gases must be handled with assistance of trained personnel or experienced seniors or teachers. Besides that, following things must be kept in mind

- Whenever working with liquefied gases, always wear cold insulating gloves and proper eye or face protection. This can be a face shield or safety glasses.
- Metal items such as watches, rings or any other sort of jewellery should be removed while working with such gases as they can freeze to exposed skin if splashed by a cold gas.
- While using such gases for reaction set up make use of cryogenic dewar flask. But one must ascertain that the dewar flasks are capable of withstanding extremely low temperatures

SAFE STORAGE AND DISPOSAL OF WASTE CHEMICAL

Chemical waste generated from any chemical laboratory requires a safe and proper disposal method. These wastes have the greatest potential to harm people or the environment and pose serious threats to environmental regulations. Many hazardous wastes are capable of creating immediate health hazard to anyone who comes in contact with them. It can be a chemical byproduct or a contaminated solid or anything in between. The first step in beginning towards the safe disposal of chemical waste is to have a basic knowledge of the different types of waste that are generated in a laboratory and keeping different types of waste segregated in appropriate containers. The following chemical waste classification guideline can be of assistance to get an idea (**Table 7**).

Chemical Waste Disposal Guideline

Table 7: Classification of chemical waste

Inncouous aqueous waste	Organic solvent	Red List	Solid Waste
• Acid (pH < 4) • Alkali (pH > 10) • Harmless soluble inorganic salts • Alcohol containing salt • Hypochlorite solution • Fine (TLC Grade) silica and alumina	• Chlorinated solvent: for example- DCM, Chloroform, chlorobenzene etc. • Non-chlorinated solvent: for example- THF, ethyl acetate, hexane, toluene, methanol etc.	• Compounds with transition metals • Biocides • Cyanides • Mineral oils and hydrocarbons • Poisonous organosilicon compounds • Metal phosphides • Phosphorous element • Fluorides and nitrites • Radioactive waste • Harmful organic compounds like carcinogenic, neurotoxic etc.	• Lightly contaminated: for example- gloves, empty vials, centrifuge tubes etc. • Broken glassware’s

Once the nature of waste has been identified, the following general guidelines should be followed for collection of wastes over a period of time.

- Designate a hazardous waste storage area which is near where the waste is generated and under the control of lab personnel.
- Select compatible containers for the waste such as chemical compatibility i.e., chemicals must not react with, weaken, or dissolve the container or lid. Acids or bases should never be stored in metal containers, hydrofluoric acid should not be stored in glass. Appropriately sized containers with secure caps and closures should be used.

Secondary containers can be very useful to capture spills and leaks from primary container.

- Every waste container should be properly labelled with a complete hazardous waste tag.
- Liquid waste containers should never be overfilled to allow for expansion and safe transportation. Besides that, solids waste never be mixed with liquid waste. Halogenated and non-halogenated solvent waste should not be mixed and organic solvents should not be mixed with toxic metal waste. Oils should also be stored in separate containers.
- Chemically contaminated solid waste should be packed differently for disposal such as lab trash, dry chemicals, and sharp and piercing objects.
- Disposal of empty containers should be done after assessing the material they are made of and what sort of hazardous material they contained.
- Unknown or unidentified chemical waste are to be disposed considering them as hazardous waste but it is always advisable to be cautious and not let such situation arise.

After proper separation of laboratory waste has been accomplished, the decision tree shown in Figure 5 can assist in identifying the options for the treatment and disposal of waste under different circumstances and prevailing conditions. However, even waste segregation or treatments or disposal by any other way must be done under trained personnel.

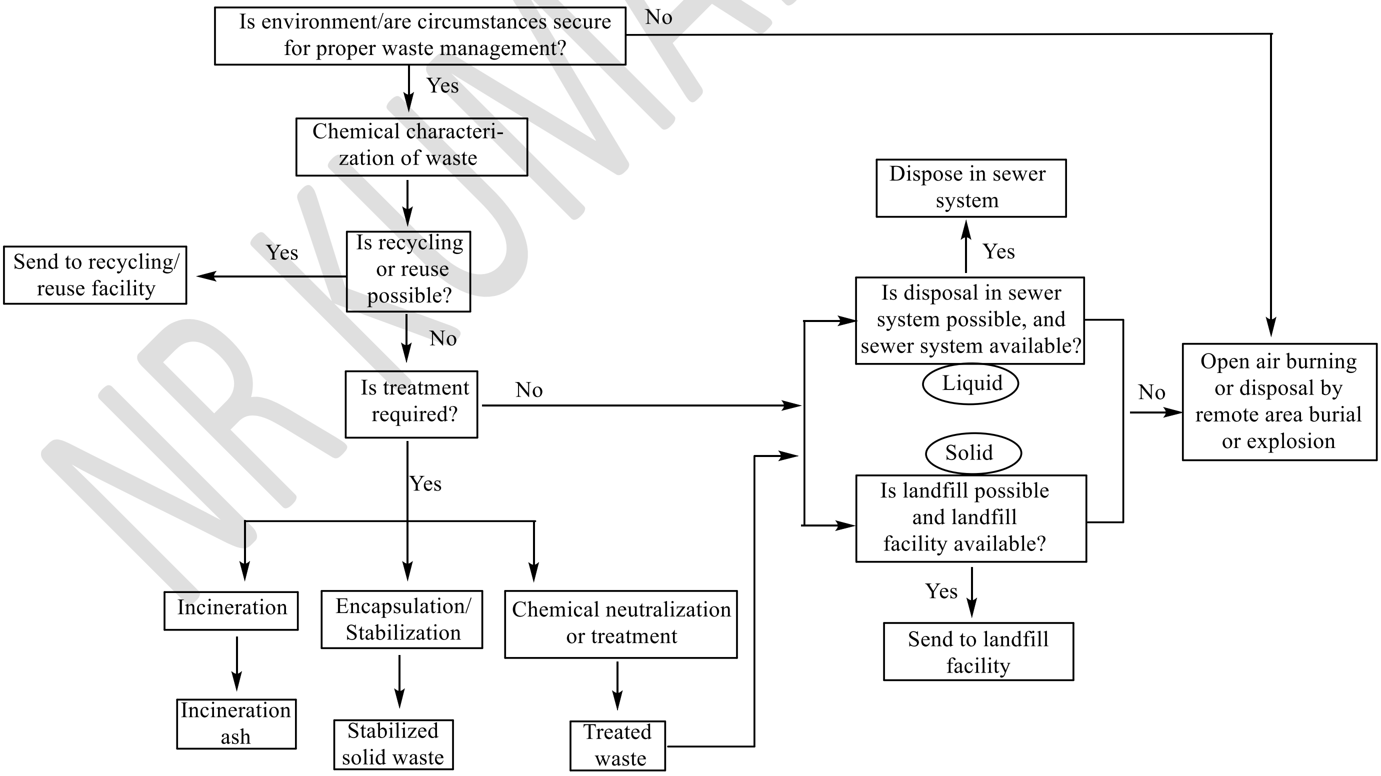

Figure 5: Flowchart to select a proper waste disposal method in a chemical laboratory

RECOVERY, RECYCLING AND REUSE OF LABORATORY CHEMICALS WASTE

Hazardous chemical waste generated from teaching laboratories or research laboratories or industries are a serious threat not only to human beings but also complete ecosystem. The best approach for the management of toxic and hazardous waste is the 3R's method that is reduce, reuse and recycling.

What is Hazardous Waste Recycling?

A hazardous secondary material is recycled if it is used or reused (e.g., as an ingredient in a process), reclaimed, or used in certain ways including used in a manner constituting disposal and burned for energy recovery.

** Used or residual waste-like materials are called secondary materials and are divided into the following five groups spent materials, by-products, sludges, commercial chemical products and scrap metal. A material is reclaimed if it is processed to recover a usable product or if it is regenerated (e.g., regeneration of spent solvents).

A material is used or reused if it is either employed as an ingredient in an industrial process to make a product (e.g., distillation bottoms from one process used as feedstock in another process) or if it is employed as an effective substitute for a commercial product (e.g., spent pickle liquor used as a sludge conditioner in wastewater treatment).

"Use constituting disposal" is recycling that involves the direct placement of wastes or products containing wastes (e.g., asphalt with petroleum-refining wastes as an ingredient) on the land. "Burning for energy recovery" is recycling that involves burning a hazardous waste for its fuel value (either directly or when it is used to produce a fuel).

Benefits of recycling of hazardous waste

The major benefits of hazardous waste recycling fall under two category that is environmental benefits and economic benefits:

Environmental benefits

- Interrelated environmental benefits of recycling waste are like reducing the consumption of raw materials, reducing pollution, reducing energy use and reducing the volume of waste that must be treated and disposed of.
- Newer raw materials mean involvement of several processes like extraction, refining, transportation and processing which can have severe impact on the environment. Recycling wastes will ensure less air, water and soil pollution that is inherently associated with above problems

- Recycling of hazardous waste means utilization of less energy for generation of raw materials, decrease in energy demand means less burning of fossil fuels and this means less emission of greenhouse gases and hence less pollution.
- Recycling waste means that the amount of hazardous waste sent for treatment and disposal will decrease. This means less need for hazardous waste landfills and incinerators, as well as a decrease in energy used for those systems, which leads to less pollution.

Economic benefits

- When hazardous wastes are recovered, production efficiency of companies are increased and costs are reduced.
- A business can also have a huge positive impact from the "green" image associated with the recycling of hazardous waste.

Resource Conservation and Recovery Act (RCRA)

The hierarchy of waste management priorities is shown below in Figure 6.

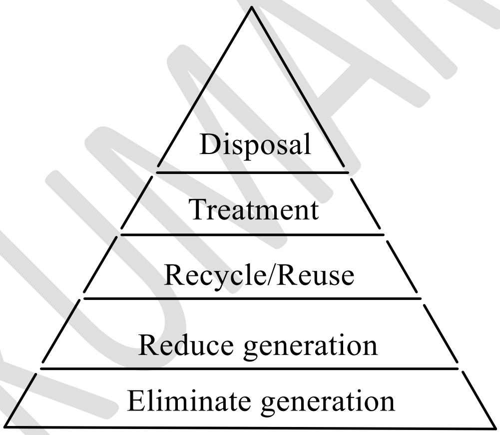

Figure 6: Hierarchy of waste management

The first priority in the list is to eliminate the use of hazardous substances by using alternative processes or raw materials that are not hazardous. The second priority should be reducing the generation of hazardous waste by employing alteration or modification in the manufacturing process. The third priority is the recycling of hazardous substances like solvents, acids etc. The final steps are the treatment and the disposal.

Whether a particular type of waste can be recycled or not is to be decided based on Resource Conservation and Recovery Act (RCRA) enacted in 1976 in United States. A determination about whether or not a waste is classified as a solid waste is the first important step in the Hazardous waste identification process. A material cannot be regulated as a hazardous waste unless it is first determined to be a solid waste. The generator is responsible for determining whether the recyclable secondary material is subject to reduced requirements or full regulation. Under the RCRA hazardous waste regulations, materials that are recycled may be:

- Not subject to RCRA hazardous waste regulation: Recycled materials that are not subject to RCRA hazardous waste regulation are

  - Recycled materials specifically excluded from the definition of solid waste: waste used as an ingredient, waste used as a product substitute, wastes returned to the production process.

  - Recycled materials that are solid wastes but not hazardous wastes: agricultural waste, spent chlorofluorocarbon refrigerants, used oil filters, used oil distillation bottoms.

  - Hazardous wastes that are not subject to hazardous waste regulation when recycled: industrial ethyl alcohol, scrap metal, waste-derived fuels from refining processes, unrefined waste-derived fuels and oils from petroleum refineries.

- Subject to alternative controls when recycled: universal waste, used oil, recyclable materials used in a manner constituting disposal, materials utilized for precious metal recovery, spent lead-acid batteries being reclaimed, hazardous waste burned in boilers and industrial furnaces etc.

- Subject to full hazardous waste regulation

General guidelines for recycle, recovery and reuse of chemical waste inside a lab

- The solvents used in the synthesis of various products can be recovered and reused. All that is needed for this is either a distillation set up of a clean rota-vapor.
- In several chemical reactions lot of by-products are generated. These unwanted products form wastes if left un-recovered. These by-products might be of use in other reactions as raw materials and hence they can be recovered using suitable techniques such as condensation, distillation, absorption etc.
- Water used for cooling purpose, seal pot water, vacuum pump water etc. can be recycled and reused for other operations like neutralization, washing etc.
- Solvents from column chromatography can be easily recycled and reused. One must note that after recovery of the solvent treating it with anhydrous sodium sulphate to absorb the moisture present is a good practice.
- Solvents can also be recovered from work-up procedures, especially when reactions are carried on large scales.
- Re-circulating the same water within a unit operation several times before it becomes unfit.

- Acetone is generally used as a washing solvent for glass apparatus. This acetone must be recovered on weekly basis.

PROCEDURE FOR LABORATORY DISPOSAL OF EXPLOSIVES

Disposal of explosives refers to destruction or rendering them permanently explosively inert or in other words it refers to their safe and legal transfer to the competent authority in charge of rendering explosives inert. The method adopted for disposal or destruction of explosives or flammable and pyrophoric materials depend on the nature of the explosive and its hazards, and the type and position of disposal site. The five most commonly adopted methods for the disposal of explosives

- Functioning in the design mode
- Burning
- Detonation
- Dissolving or diluting by a solvent
- Chemical destruction (including bioremediation)

Given below are some important guidelines or procedure associated with the safe disposal of laboratory explosives:

- Proper arrangement should be made for storage of residue of reactive materials. Their containers should never be left open.
- Any unused or unwanted reactive materials must be transferred to an appropriate reaction flask and then must be destroyed by suitable technique such as hydrolysis and/or neutralization with sufficient cooling. The empty container must also be rinsed at least three times with an inert dry compatible solvent and the rinse must also be neutralized and hydrolyzed. Further, addition and removal of the rinse solvent from the container must be done under an inert atmosphere.
- Leave the triple rinsed container in the open fume hood or under ambient atmospheric conditions at a safe location for at least a week.
- The empty container, solvent rinses and water rinse should be disposed as hazardous waste and should not be mixed with incompatible waste streams.
- During setting up of a reaction till the disposal of hazardous waste, several items become contaminated in the entire process. This includes disposable gloves, wipers, bench papers etc. All these items contaminated with pyrophoric materials should be disposed as hazardous waste.
- The contaminated waste should not be left overnight in the open laboratory but must be properly contained to prevent fires.
- Dumping and burial are not suitable techniques for disposal of laboratory explosives as these techniques ultimately do not destroy the explosives to make them harmless.

- Adequate care must be taken to avoid accumulation of explosive waste in the lab and it should be disposed of as soon as possible.
- All those explosives that are more stable under diluted conditions should be diluted with an appropriate solvent in appropriate waste containers.
- Explosive wastes must be kept segregated from other types of waste.
- In case the container of an explosive or reactive chemical container is observed to be damaged, bulging, past-expiration, leaking or compromised in any way, maintain a safe distance from such containers and also prevent others from going to its vicinity. Besides that, this must be immediately brought to the notice of concerned authority.
- Avoid dumping of explosive wastes down a drain or avoid discarding explosives in regular trash containers.
- Containers containing low boiling organic solvent wastes should be kept in cool ventilated area. Commonly used solvents like dichloromethane, diethyl ether, chloroform, hexane etc. have very low boiling point and if outside conditions are hot, the vapors created inside the waste container can cause potential hazard.
- Chemical waste with potential peroxide forming ability should not be left untreated for long periods of time.

IDENTIFICATION, VERIFICATION AND SEGREGATION OF LABORATORY WASTE

Disposal of chemical waste or laboratory waste requires clear information about the properties of the waste. All the containers of chemical wastes must be clearly marked and their source must also be clearly defined on the container. In academic laboratories where student turnover is frequent, it becomes highly imperative that the materials used or generated be clearly identified.

Disposal of laboratory waste at waste treatment facilities require detailed description about the materials used or waste generated. This includes information like: physical description, water reactivity, water solubility, pH and neutralization information, ignitability (flammability), presence of oxidizer, presence of sulfides or cyanides, presence of halogens, presence of radioactive materials, presence of biohazardous materials and presence of toxic constituents etc. All these factors make proper identification and segregation of laboratory waste necessary. Besides that, identification and segregation of chemical waste is also necessary to avoid any sort of potential hazard to the environment or living beings that might arise due to improper management and ignorance of those involved.

It is the scientific and social responsibility of all the teachers, staff as well as students working in the laboratory to involve in proper waste segregation. Everyone working in a chemical lab besides those supervising the process should be trained about the proper identification and segregation of waste in designated waste containers that have proper labelling. It is always a best practice to follow the Recover, Recycle and Reuse policy, if possible, in compliance with the chemical waste handling guidelines. A brief idea on identification and segregation of waste has already been discussed before. However detailed insights based on the category of waste are provided below in **Table 8**.

Table 8: Identification and Segregation of laboratory waste

Waste category	Specific waste in the category	Recommendations
Liquid waste	• Organic halogenated solvents: solvents like dichloromethane, chloroform or any other chlorine or halogen containing solvent. • Organic non-halogenated solvents: solvents like ethyl acetate, hexanes, methanol, ethanol etc • Aqueous acid waste: aqueous waste with pH<7 like waste generated in titrations, reactions, work-up, chromatographic analysis etc. • Aqueous neutral/basic waste: aqueous waste with pH>7 like waste generated in titrations, reactions, work-up, chromatographic analysis etc.	• Always label the containers appropriately • Waste solvent drums should be stored in a cool, ventilated area • Concentrated acid and basic solutions should be diluted with water • Do not store concentrated acid and base waste in metal containers.
Solid waste	• Organic solid waste: hazardous solid organic compounds like polynuclear aromatic hydrocarbons, picric acid and several other solid compounds used in organic synthesis labs. • Inorganic solid waste: hazardous inorganic solid waste like transition metal	• Organic solid waste, inorganic solid waste, heavy metal waste, and other types of solid waste must be stored in different appropriately labelled containers. • Containers of solid waste containing normal waste PPE, tissue papers etc. can

	containing compounds • Solids used for purification purposes: silica, celite, alumina etc • Heavy metal waste: mercury, lead, tin, chromium, cadmium etc. • Other solid waste: contaminated PPE, chemical wipes, tissue papers, gloves etc.	be labelled as burnable non-hazardous solid waste • Containers of solid waste containing PPE, tissue paper etc that has been contaminated with hazardous chemicals are to be labelled as burnable hazardous solid waste.
Glassware waste	• Broken glassware: broken glassware like beakers, flasks, burettes, pipettes etc. • Glass containers: empty solvent bottles, reagent bottles etc.	• Broken glassware must be collected in appropriate rigid containers like plastic barrels with lid. • All empty glass bottles must be thoroughly cleaned (either by using solvent or water) before segregating it as glassware waste.

DISPOSAL OF CHEMICALS IN THE SANITARY SEWER SYSTEM

Some chemicals that are of significantly low toxicity, moderate pH, and those that are water soluble can be safely discarded in the sanitary sewer system. However, there are several criteria that are to be essentially met for safe disposal of selected chemicals in the sanitary sewer system such as low quantities, degradable nature etc.

When discharging waste to the sanitary sewer system, note the following

- Do not dispose anything in sanitary sewer system that is capable of leading to a storm sewer.
- Only sinks that do not have a history of clogging or overflowing should be used for disposal.
- The sink present inside the fume hood is best for such disposal.

- After the waste has been drained into the sewer, make sure to flush with at least 10-20fold excess water. This ensures the thorough rinsing of the sink, sink trap and dilution of the waste.
- The quantities being discharged should be limited to 100 grams of solute per laboratory per day.
- Always wear appropriate PPE before disposal of waste in sanitary sewer system.
- Any sort of biological material must be appropriately inactivated (either in an auto-clave or by bleach treatment) before being released into the sanitary sewer system.

Materials that may be disposed off through sanitary sewer system in limited quantities are

- Chemicals that are liquid and readily soluble in water (At least 3%).
- Materials that are biodegradable or amenable to treatment by the waste water treatment process.
- Aqueous solution of inorganic substances of low toxicity.
- Those liquids that have pH between 5 to 9.
- Biological compounds and cellular constituents like proteins, nucleic acids, carbohydrates, sugars, amino acids, surfactants and other metabolic intermediates.
- Soluble salt combinations of low toxicity ions and of less than 10% concentration. However, before discharging any such chemicals into the sanitary sewer, one must make sure that all other criteria such as pH, flammability, toxicity etc. limits are met.
- Aqueous solution of low molecular weight biodegradable organic chemicals like alcohols, aldehydes, ketones, amines, ethers, nitriles, esters, etc. However, before discharging any such chemicals into the sanitary sewer, one must make sure that all other criteria such as pH, flammability, toxicity etc. limits are met.

Wastes that are strictly prohibited from sewer disposal are

- Raw chemical waste: unused, pure or concentrated chemicals.
- Chlorinated hydrocarbon waste: chloromethanes, chloroethanes, chloroethylenes, chloropropanes, chlorobutanes, chlorinated paraffins, chlorinated pesticides nucleus-chlorinated aromatic hydrocarbons, side chain chlorinated aromatic hydrocarbons etc.
- Chlorofluorocarbon waste

- Brominated hydrocarbon waste: bromoform, bromomethane etc.

- Cyanide waste: includes cyanide, cyanate and thiocyanate compounds like potassium cyanide, copper cyanide etc.

- Corrosive waste: waste with pH lower than 5 and higher than 9.

- Solvent waste: example includes most organic solvents like acetone, benzene, n-butyl alcohol, ethyl ether, methanol, pyridine, toluene etc.

- Oil and grease wastes

- Ignitable wastes: liquid wastes with a flashpoint less than 60 °C, non-liquid wastes that are capable of causing fire through friction, reaction with moisture, or spontaneous chemical changes, ignitable compresses gases and oxidizers.

- Reactive wastes: wastes that are normally unstable and readily undergo violent change, react violently or form explosives with water, can generate toxic gases, vapors or fumes when mixed with water or exposed to extreme pH conditions, are capable of detonation or explosive reaction under specific conditions.

- Solid or viscous waste, nuisance waste, untreatable waste, hot liquid or vapor wastes etc.

INCINERATION OF HAZARDOUS CHEMICALS

Incineration is a method of treating waste which involves the combustion or high temperature burning of the waste substances found in waste materials. The solid mass of the original waste is reduced by around 80 to 85%, while the volume is reduced by between 95 to 96%. Incineration does not totally replace the process of landfilling; it significantly reduces the amount of waste to be disposed. Incineration is also sometimes referred as controlled-flame combustion or calcination. The process of incineration is conducted inside an incinerator which is a type of furnace designed for burning hazardous materials in a combustion chamber. Incineration capable of destroying varieties of hazardous materials such as solvents, polychlorinated biphenyls, pesticides etc. but it does not destroy hazardous metals like lead, chromium etc.

Three types of waste can be subjected to incineration treatment.

- Municipal waste: This is the solid portion of waste generated by households, commercial establishments, public and private institutions, government agencies and other sources.

- Hazardous waste: These are the waste materials that are potentially dangerous to human health or the environment. Such wastes are generated by manufacturers, service and wholesale-trade companies, universities, educational institutions, government facilities, chemical manufacturing industry and users etc.

- Medical waste: This waste comes from the health care facilities at different levels. Medical wastes can have infectious and toxic characteristics and proper disposal is a must.

Working of an incinerator

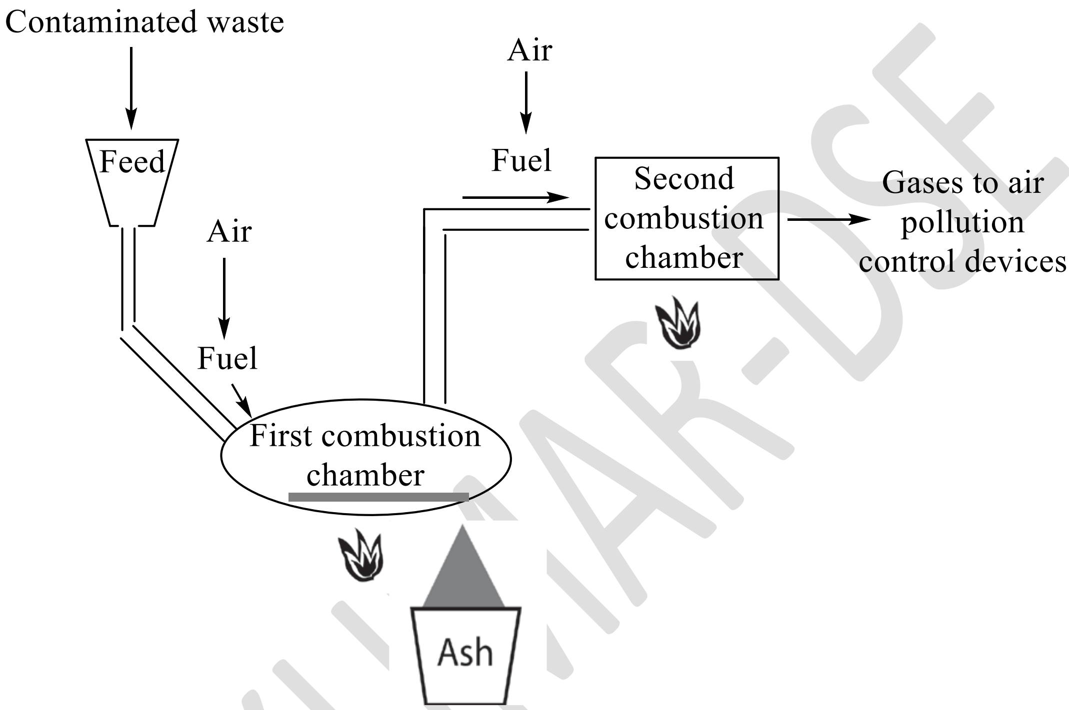

Figure 7: Working of a chemical waste incinerator

Hazardous materials are pumped or excavated into containers before incineration. If the particles are large, then grinding might be needed or removal of rock and debris, or removing excess water. The materials are then introduced to the first combustion chamber where they are subjected to extreme temperature conditions. Air or pure oxygen is supplied to the chamber to supply the oxygen needed for burning. The temperature in the combustion chamber may range from 800 ˚C to 1400 ˚C. The duration of heating depends on the type of material. Solid wastes must be heated for 30 to 90 minutes whereas liquid and gaseous waste may require a few seconds and further some time must be given to mixing of the materials. As the temperature rises and time progresses, the waste heats up, the contaminants volatilize and most of them are destroyed. Gases which are not destroyed in the first combustion chamber pass to the second combustion for further heating and destruction. These resulting gases further pass to air pollution control devices. In the air pollution control chambers, all sorts of particulate matter and acidic gases are removed. The working of a typical chemical waste incinerator is shown below in Figure 7.

Advantages of hazardous waste incineration are

- It leads to complete destruction of waste
- High temperature treatment leads to significant reduction of volume and mass and conversion of waste into ash.
- Incinerators have scrubbers for cleaning the polluted gases.
- Incinerators make use of high temperature filter candles for trapping of fine dust particles.
- In areas where landfill space is limited incineration facilities turn as a savior.
- Incineration becomes a hygienic practice when it comes to smells and pests released into the environment.
- Incineration is an alternative and reliable source of generated electricity for homes and industry.
- The ash produced in incineration process can be reused in the construction industry for road building.
- The reliance on fossil fuels for energy production is significantly reduced.

Some substances such as activated carbon, animal fats, some agrochemical etc. cannot be incinerated. Animal fats are highly flammable and uncontrollable which can create hazardous issues in the incineration plant whereas some agrochemicals are capable of releasing highly hazardous gases which can be detrimental to both environment and human health.

TRANSPORTATION OF HAZARDOUS CHEMICALS

Transportation of hazardous chemicals or hazardous waste means movement of hazardous substances by air, rail, water or road transport either to the place of their use (industries, research laboratories) or for treatment, storage and disposal purpose. Spill risk becomes significantly high during loading, transportation and unloading. This makes appropriate knowledge of everyone involved in transportation of hazardous chemicals extremely important. Besides the individual responsibilities of those involved in transportation of chemicals, some important considerations for every transporter or operator carrying the dangerous waste are:

- Every transport carrying hazardous goods shall show a distinct mark of the class label appropriate to the hazardous chemicals.

- Every package containing hazardous waste shall display distinct class labels appropriate to the hazardous chemicals.

- If package contain goods that denote more than one hazard, such packages shall display distinct labels to indicate the hazards.

- Every transport carrying hazardous goods shall be fitted with a techograph

** A techograph is an instrument used to record the lapse of running time of the motor vehicle, time speed maintained, acceleration and declaration etc. and a spark arrester.

Stages of transport of hazardous chemicals and responsibilities involved at each level

The four main stages of hazardous chemical transportation are: Authorization, Packaging, Labelling and Transportation.

- Authorization: Everyone engaged in the transportation of hazardous materials has to obtain authorization from the pollution control committee of the place. This involves processing, treatment, package, transportation, collection etc.

- Packaging: The containers to be used for transportation must be able to withstand normal handling and retain integrity for a minimum of six months. The packaging material shall not break open or become defective during transportation. It should be properly sealed to prevent leakages due to jerks and vibrations caused by uneven road surface. Packaging material should be such that no significant chemical or galvanic action among any of the material takes place.

- Labelling: Labelling of individual transport containers and also transport vehicles is to be done. All sort of hazard of the material should be mentioned. Labelling should also be done in vernacular language so that the common public is aware of the nature of the materials transported. Emergency contact phone numbers shall be prominently displayed such as the phone number of the concerned Regional Officer of the Pollution Control Board or Pollution Control Committee, fire station, police station and other agencies concerned.

- Transportation: This is a combined responsibility of the generator and all those involved in transportation (including the owner and driver and his assistance) to obtain necessary permission and ensure safe transport of the hazardous materials.

Responsibilities of the Hazardous material generator

- The generator of the hazardous chemicals shall ensure that chemicals are packaged in a manner suitable for safe handling, storage and transport. Labelling on packaging is readily visible and material used for packaging shall withstand physical conditions and climatic factors.

- The generator shall ensure that information regarding characteristics of chemicals particularly in terms of being corrosive, reactive, ignitable or toxic is provided on the label.

- Transport of hazardous chemicals shall be in accordance with the provisions of the rules made by the Central Government under the Motor Vehicles Act 1988.

- Both the generator and transporter must ensure that all the legal processes involved are strictly adhered to. This relates to all the forms and legal documents that they will need at different stages of transport.

Responsibilities of the Hazardous material transporter

- The transporter shall obtain permission from the concerned pollution board for transport of hazardous chemicals.

- The transport vehicle shall be designed suitably to handle and transport hazardous chemicals of various characteristics. Besides that, all the rules pertaining to transport of hazardous chemicals put forward by the central government of the state government must be followed.

- The chemicals should be transported in closed containers and must be delivered at designated points only.

- In case of a spillage, leakage or any other accident during transportation, the transporter must immediately inform the pollution board or local authority and occupier of the facility.

- The transporter shall train the driver with regard to the emergency response measures to be taken during the transportation of the waste. Educational qualification of the driver shall be minimum 10^{th} pass. Besides that, the driver shall have a valid driving license and a minimum of 5 years of experience in transporting the chemicals. The driver must also be appropriately trained to handle the emergency situation.

- Carrying of passengers should be strictly prohibited in transport vehicles.

- The transporter shall possess requisite copies of the certificate and should also obtain valid Pollution Under Control Certificate (PUCC) during the transportation of hazardous chemicals and it shall be displayed on the vehicle.

- Emergency contacts, phone numbers, Transport Emergency Card, hazardous material information in vernacular languages must be clearly displayed on the vehicle.

- Hazardous chemical or hazardous waste transport vehicle shall run only at a speed specified under Motor Vehicles Act in order to avoid any eventuality during transportation.

- The transport vehicle must be dedicated for transportation of hazardous materials only and shall not be used for other things. Besides that, each vehicle shall carry first-aid kit, spill control and fire extinguisher.

SOME DISASTROUS ACCIDENTS CAUSED BY CHEMICALS

Historical insights reveal the occurrence of several major disasters caused by chemicals either in industries or research lab that involve handling of chemicals. There are also reports of such accidents that have taken place in schools, colleges and universities. It is highly imperative that students are aware of such disasters and be more aware while working with hazardous chemicals. The list below gives details of some selected chemical accidents, to give the readers an insight that chemical safety and ethical handling of chemicals is important at all stages (**Table 9**). However, it is also possible that sometimes despite the care of users, misfortune incidents might happen.

Table 9: List of some recorded chemical disasters (both small scale and large scale)

Serial No.	**Year**	**Location**	**Chemicals that caused the accident and causalities**
1)	September 21, 1921	Oppau, Germany	Ammonium nitrate, more than 500 people died
2)	April 16, 1947	Texas City, Texas, USA	Ammonium nitrate, more than 576 people died and around 3500 injured
3)	March 23, 2005	Texas City, Texas, USA	Hydrocarbons, around 15 people were killed and 180 injured
4)	November 13, 2005	Jilin City, China	Nitrobenzene, benzene, nitric acid, around 5 people were killed and 70 injured
5)	November 3, 1984	Bhopal, India	Methyl isocyanate, around 2000 people died immediately, around 8000 died in later years
6)	June 1, 1974	Flixborough, UK	Cyclohexane, around 28 people were killed and 36 injured
7)	July 10, 1976	Sevesto, Italy	2,4,5-Trichlorophenol, 2,3,7,8-tetrachlorodibenzo-p-dioxin, around 3300 animals died in few days, around 450 people were found to suffer from skin lesions and chlorance
8)	September 21, 2001	Toulouse, France	Ammonium Nitrate, around 30 people died and 10,000 were injured
9)	November 26, 1986	Chernobyl, Ukraine	Nuclear and Radioactive materials, as an estimate less than 100 people died that can be attributed directly to the accident, around 20,000 fatalities, Varying estimates of increased mortalities over subsequent

			decades have been made.
10)	December 6, 1917	Halifax, Nova Scotia, Canada	War time explosives like Trinitrotoluene, Picric acid, benzol and guncotton, around 1600 people were killed instantly and 9000 were severely injured.
11)	July 6, 2013	Lac Megantic, Que	Oil containing tankers, around 47 people were killed
12)	October 23, 1898	Pasadena, Texas, US	Ethylene leak, around 23 people were killed and 314 were injured
13)	April 26, 1942	Benxi, China	Gas and coal dust explosion, around 1549 workers were killed
14)	January, 2010	Chemistry lab at Texas Tech University	Nickel Hydrazine Perchlorate, one student suffered burns and lost three fingers
15)	August, 1996	A scientist named Karen Wetterhahn at Dartmouth College, Hanover, US	Dimethylmercury, Due to the slow poisoning effect caused by the hazardous chemical, Karren Wetterhahn went into coma and finally died.
16)	December 30, 1058	Los Alamos National laboratory, Los Alamos, New Mexico, US	Severe Radiation Poisoning caused by Plutonium compounds; Chemical operator Cecil Kelley died within 35 hours of the accident.
17)	2013	Maharishi Dayanand Saraswati University, Rajasthan India	Sulphuric acid, three post-graduate students suffered burn injuries
18)	January, 2011	JSS PG Centre, Mysore	Fire due to highly combustible chemical, A teacher lost her life due to severe burns.
19)	December, 2018	IISc Bangalore	Explosion of hydrogen cylinder, one person died and three were injured