

به نام خدا



دانشگاه صنعتی شریف

دانشکده فیزیک

آزمایشگاه فیزیک پیشرفته

(موضوع: ایمنی در آزمایشگاه)

در این نوشتار مبحث ایمنی در موارد زیر بحث و بررسی خواهد شد:

۱. نکات عمومی و کلی
۲. ایمنی کار با وسایل الکتریکی
۳. ایمنی کار با انواع تابش ها
۴. ایمنی کار با مواد شیمیایی
  - اسیدها
  - گازها
  - مایعات سرمازا

## **Safety Precautions in the Advanced Physics Laboratory**

A laboratory should not be a dangerous place. Usually only a small amount of effort is needed to make your time in the lab as safe as the time you spend at home. Common laboratory hazards include electrical shock and fire, wet chemicals and their vapors, dry chemicals, power tools, lasers, compressed gases, vacuum, radioactivity, exposed belts and pulleys, electromagnetic radiation, and cryogenic liquids.

In this section we cover general safety precautions, electrical and radiation safety. You might be exposed to other hazards depending on the experiment you work. If you feel you are exposed to a hazard that you do not fully understand, stop what you are doing and ask your instructor. It is required that you READ THIS ENTIRE HANDOUT before doing any of the Advanced Physics lab work.

### **A) GENERAL PRECAUTIONS**

1. Never work with any hazard that you do not understand.
2. Never bring food or drinks into a laboratory.
3. Never work in a laboratory alone. This can sometimes be a very frustrating constraint.
4. Keep your work area neat and uncluttered.
5. Keep all electrical cables off of floors and away from traffic.
6. Know where fire extinguishers and exits are located.
7. In case of any emergency, call 115, and notify an instructor if possible.
8. Place all sensitive electronic equipment safely on your table or within your bag under your table so that expensive damage can be avoided.
9. Do not modify or damage the laboratory equipment in any way unless the modification is directed by the instructor. This does not include the changing of a lab setup as prescribed by the procedures in the carrying out of measurements.
10. Do not force any of the equipment. If an excessive amount of force is necessary then tell your instructor.
11. In case the fire alarm sounds, please exit the building by the nearest safe exit. Do Not Use The Elevators. If the fire is in the room leave everything behind. If the fire is not in the room and immediate danger is not apparent, then quickly and quietly pack your bag and exit the room or just leave the stuff behind. The instructor will lock the doors on the way out to ensure security.
12. In the case of any other emergency, follow the instructions of the laboratory instructor and all safety personal that may have responded to the scene.

### **B) ELECTRICAL SAFETY**

Electrical equipment and circuits are a major hazard in the lab. You must read this entire section during the first week of the lab.

It is the current that passes through your body that is dangerous. The voltage required to produce a dangerous current depends, by Ohm's law, on your body resistance. The damage it does to you depends on the current path through your body. The danger is much greater for a current that enters one hand, passes through your body, and exits by the other hand, than for a current that passes between two fingers of the same hand. Therefore, keep one hand behind your back if you ever work on a hazardous electrical system.

Shock is relatively more severe as the current rises. At values as low as 20 mA, breathing becomes labored, finally ceasing completely at about 75 mA. As the current approaches 100 mA, ventricular fibrillation of the heart occurs an uncoordinated twitching of the walls of the heart's ventricles. Above 200 mA, the muscular contractions are so severe that the heart is forcibly clamped during the shock. This clamping protects the heart from going into ventricular fibrillation, and the victim's chances for survival are better. Immediate first aid is crucial, so call 115 immediately if you suspect someone has been shocked.

The internal resistance of your body (right hand to left hand, or hand to leg) is typically 500  $\Omega$ . In series with this is the surface resistance of your skin, which varies from 1000  $\Omega$  when moist to over 100 k $\Omega$  when dry. Thus a voltage as low as 50 V can potentially produce a hazardous current if your hands are wet.

Never work with electrical equipment if your hands or clothing are wet. Dry yourself thoroughly before you start work. Note that when you are hot the perspiration on your hands increases the hazard.

Be sure the power is off before touching a helpless person.

## **The Fatal Current**

Strange as it may seem, most fatal electric shocks happen to people who should know better. Here are some electro-medical facts that should make you think twice before taking that last chance.

### **IT'S THE CURRENT THAT KILLS**

Offhand it would seem that a shock of 10,000 V would be more deadly than 100 V. But this is not so! Individuals have been electrocuted by appliances using ordinary house currents of 220 V and by electrical apparatus in industry using as little as 42 V direct currents. The real measure of shock's intensity lies in the amount of current (amperes) forced through the body, and not the voltage. Any electrical device used on a house wiring circuit can, under certain conditions, transmit a fatal current.

While any amount of current over 10 mA is capable of producing painful to severe shock, currents between 100 and 200 mA are lethal.

Currents above 200 mA, while producing severe burns and unconsciousness, do not usually cause death if the victim is given immediate attention. Resuscitation, consisting of artificial respiration, will usually revive the victim.

From a practical viewpoint, after a person is knocked out by an electrical shock it is impossible to tell how much current passed through the vital organs of their body. Artificial respiration must be applied immediately if breathing has stopped.

## DANGER -- LOW VOLTAGE!

It is common knowledge that victims of high-voltage shock usually respond to artificial respiration more readily than the victims of low-voltage shock. The reason may be the merciful clamping of the heart, owing to the high current densities associated with high voltages. However, lest these details be misinterpreted, the only reasonable conclusion that can be drawn is that 75 V are just as lethal as 750 V.

The actual resistance of the body varies depending upon the points of contact and the skin condition (moist or dry). Between the ears, for example, the internal resistance (less than skin resistance) is only 100  $\Omega$ , while from hand to foot it is closer to 500  $\Omega$ . The skin resistance may vary from 1000  $\Omega$  for wet skin to over 500,000  $\Omega$  for dry skin.

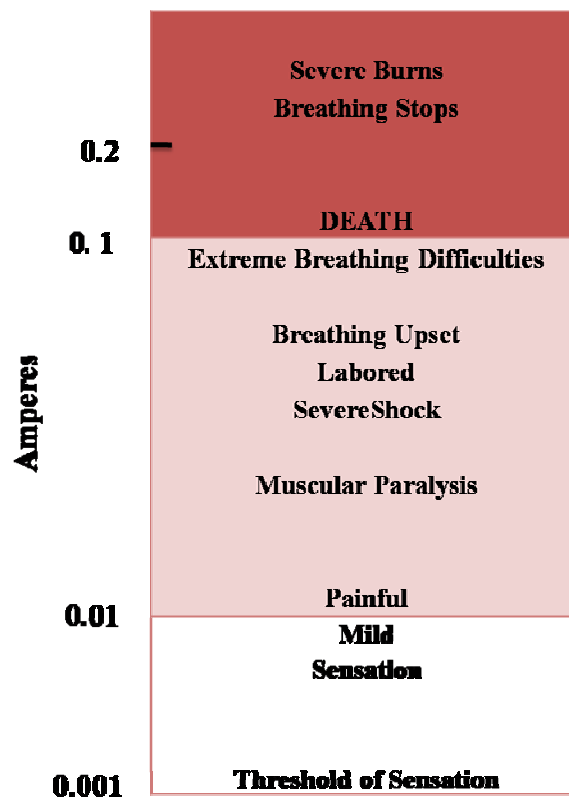
Don't touch the electrical connections with the moist hand.

When working around potentially hazardous electrical equipment, move slowly. Make sure your feet are firmly placed for good balance. Don't lunge after falling tools. Kill all power, and ground all high-voltage points before touching wiring. Make sure that power cannot be accidentally restored. Do not work on ungrounded equipment.

Don't examine live equipment when mentally or physically fatigued. Keep one hand in your pocket while investigating live electrical equipment.

Above all, do not touch electrical equipment while standing on metal floors, damp concrete or other well grounded surfaces. Do not handle electrical equipment while wearing damp clothing (particularly wet shoes) or while skin surfaces are damp.

Do not work alone! Remember, the more you know about electrical equipment, the more heedless you're apt to become. Don't take unnecessary risks.



## Physiological Effects of Electrical Currents

In the last there are some advices in work with high voltages;

1. Inspect wiring of equipment before each use. Replace damaged or frayed electrical cords immediately.
2. Use safe work practices every time electrical equipment is used.
3. Know the location and how to operate shut-off switches and/or circuit breaker panels. Use these devices to shut off equipment in the event of a fire or electrocution.
4. Limit the use of extension cords. Use only for temporary operations and then only for short periods of time. In all other cases, request installation of a new electrical outlet.
5. Multi-plug adapters must have circuit breakers or fuses.
6. Place exposed electrical conductors (such as those sometimes used with electrophoresis devices) behind shields.
7. Minimize the potential for water or chemical spills on or near electrical equipment.

## C) Radiation Safety

In one division we can divide the radiation in two types such as;

**Particulate Radiation:** Sub-atomic particles with mass and charge. Alpha, Beta, Protons, electrons, neutrons are the examples of this type.

**EM Radiation:** Electromagnetic waves with no mass and charge for example X-rays, gamma rays.

Radiation also can be divided into two broad categories - ionizing radiation and non-ionizing radiation. Ionizing radiation is the particular type of radiation emitted by radioactive substances. It differs from non-ionizing radiation in that it is very energetic and has the capacity to ionize matter when it interacts with it.

### Biological Effects of Radiation

The biological effects of radiation are principally due to the ionization it produces. Even a small amount of ionization can seriously disrupt the function of sensitive living cells or even kill them. Three different units are used to measure these effects: the roentgen, the rad, and the rem. The roentgen (R) is defined as the amount of radiation that produces  $3.3 \times 10^{-10}$ C of electric charge (either positive ions or electrons) in  $1 \text{ cm}^3$  of dry air at standard conditions. It is a measure of exposure to radiation. The roentgen has been largely replaced by the rad (radiation absorbed dose), a measure of the energy absorbed, which is defined as the amount of radiation that deposits  $10^{-2} \text{ J/kg}$  of energy in any material. The SI unit, joules per kilogram, is called a gray (Gy). Thus

$$1 \text{ rad} = 10^{-2} \text{ Gy}$$

Since 1 R is equivalent to the deposit of about  $8.7 \times 10^{-3} \text{ J/kg}$  of energy, the rad and the roentgen are of roughly equal magnitude. The amount of biological damage depends not only on the energy absorbed, which is equivalent to the number of ion pairs formed, but also on the spacing of the ion pairs. If the ion pairs are closely spaced, as in the ionization caused by  $\alpha$  particles, the biological effects are increased. The unit rem (roentgen equivalent in man) is the dose that has the same biological effect as 1 rad of  $\beta$  or  $\gamma$  radiation. One rem of any kind of radiation has about the same biological effect on a person:

$$\text{Dose in rem} = \text{RBE} \times \text{dose in rad}$$

Where RBE is the relative biological effectiveness factor. Table 1 gives approximate values of the RBE factors for different types of radiation.

**Table 1** Approximate RBE factors

| Type of radiation                               | RBE factor |
|---|------------|
| <b>Photons &lt; 4 MeV</b>                       | 1          |
| <b>Photons &gt; 4 MeV</b>                       | 0.7        |
| <b><math>\beta</math> particles &lt; 30 keV</b> | 1.7        |
| <b><math>\beta</math> particles &gt; 30 keV</b> | 1          |
| <b>Slow neutrons</b>                            | 4 or 5     |
| <b>Fast neutrons</b>                            | 10         |
| <b>Protons</b>                                  | 10         |
| <b><math>\alpha</math> particles</b>            | 10         |
| <b>Heavy ions</b>                               | 20         |

**Table 2** Radiation and dose units

|                        | Customary unit       |                  | SI unit                 |                  |   |
|------------------------|----------------------|------------------|-------------------------|------------------|---|
| Quantity               | Name                 | Symbol           | Name                    | Symbol           | Conversion  |
| <b>Energy</b>          | <i>electron volt</i> | <i>eV</i>        | <i>joule</i>            | <i>J</i>         | $1 \text{ MeV} = 1.602 \times 10^{-13} \text{ J}$   |
| <b>Exposure</b>        | <i>Roentgen</i>      | <i>R</i>         | <i>coulomb/kilogram</i> | <i>C/kg</i>      | $1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg}$  |
| <b>Absorbed dose</b>   | <i>Rad</i>           | <i>rad or rd</i> | <i>gray</i>             | <i>Gy = J/kg</i> | $1 \text{ rad} = 10^{-2} \text{ J/kg} = 10^{-2} \text{ Gy}$                               |
| <b>Dose equivalent</b> | <i>Rem</i>           | <i>Rem</i>       | <i>sievert</i>          | <i>Sv</i>        | $1 \text{ rem} = 10^{-2} \text{ Sv}$  |
| <b>Activity</b>        | <i>Curie</i>         | <i>Ci</i>        | <i>becquerel</i>        | <i>Bq = 1/s</i>  | $1 \text{ Ci} = 3.7 \times 10^{10} \text{ decays/s}$<br>$= 3.7 \times 10^{10} \text{ Bq}$ |

The SI unit for dose equivalent is the sievert (Sv), which is defined as the product of the gray and the RBE:

$$1 \text{ Sv} = 1 \text{ Gy} \times \text{RBE} = 100 \text{ rem}$$

Table 2 compares the various radiation units we have discussed.

Our knowledge of the effects of large radiation doses comes mainly from the studies of victims of atomic bomb explosions. Doses under 25 rem over the entire body seem to have no immediate effects. Doses of 50 to 100 rem damage the blood forming tissues, and those of 500 rem usually lead to the death in a short time of 50 percent of those exposed. Exposures over 700 rem are invariably fatal. The long-term effects of sub lethal doses acquired over a period of time are more difficult to measure. The chances of dying of cancer are doubled by a dose somewhere between 100 and 500 rem. Not much is known about the effects of very low level doses. It is possible that there is some threshold dose below which the damage done is repaired so that there is no resulting increase in the chance of cancer. But it is also possible that there is no threshold and that the cancer-causing effects of radiation are proportional to the cumulative dose even at low levels. This is the subject of active current research.

**Table 3** Average radiation dose received by a member of the U.S. population

| Radiation source                           | dose (mSv/y)             |
|--|--------------------------|
| <b>Cosmic rays</b>                         | <i>0.27 (527 mrem/y)</i> |
| <b>Internal radioactive nuclides</b>       | <i>0.39</i>              |
| <b>Consumer products</b>                   | <i>0.10</i>              |
| <b>Ground</b>                              | <i>0.28</i>              |
| <b>Radon</b>                               | <i>2.0</i>               |
| <b>Diagnostic x rays, nuclear medicine</b> | <i>0.53</i>              |
| <b>Global fallout</b>                      | <i>0.01</i>              |
| <b>Nuclear power</b>                       | <i>0.01</i>              |

Some typical human radiation exposures are listed in Table 3. The internal dose listed in this table is from radioactive nuclei, such as  $^{14}\text{C}$ ,  $^{40}\text{K}$ , and uranium and its decay products, inside our bodies. Most of the radioactive fallout due to nuclear weapons testing is  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ , both of which have half-lives of about 30 y. If there is no further testing, this source of radiation will eventually become negligible. We are shielded from most cosmic radiation by the atmosphere. The dose we now receive is about 40 mrem/y at sea level; it increases by about 1 mrem/y for every 30 m of altitude.

One of the decay products of the  $^{238}\text{U}$  decay chain is  $^{222}\text{Rn}$ , which decays by an emission with a half-life of 3.82 days. This decay is followed by other  $\alpha$  and  $\beta$  decays that result in  $^{210}\text{Pb}$ , which has a half-life of 22.3 y. Since radon is an inert gas, it diffuses through materials without interacting with them chemically. It is recognized as a health hazard because it seeps into buildings from the ground, where it accumulates, and enters the lungs during respiration. Should it decay while in the lungs, the energy deposited by its  $\alpha$  particle and those of its decay products in the sensitive lung tissue can cause significant damage and can result in lung cancer? This constitutes the largest component of human exposure to natural sources of radioactivity.

The largest source of artificial exposure to radiation is currently medical diagnostic x rays. The dose received varies enormously, depending on the type of machine used, the sensitivity of the film, and so forth. For a chest x ray, some mobile units give doses of 1000 millirems, and the average dose is around 200 millirems. If the best procedures are used, however, the dose from a chest x ray can be limited to 6 millirems.

Because of our lack of knowledge about the risks of radiation, we should clearly limit our exposure to it as much as possible. Table 4 lists some of the dose limits recommended by the National Council on Radiation Protection and Measurement.

**Table 4** Recommended dose limits

|   | Maximum permissible dose equivalent for occupational exposure |
|---|---|
| <b>Combined whole-body occupational exposure</b>    | <i>5 rems in any one year</i>                                 |
| <b>Prospective annual limit</b>                     |   |
| <b>Retrospective annual limit</b>                   | <i>10–15 rems in any one year</i>                             |
| <b>Long-term accumulation to age <i>N</i> years</b> | <i>(<i>N</i> - 18) × 5 rems</i>                               |
| <b>Skin</b>   | <i>15 rems in any one year</i>                                |
| <b>Hands</b>  | <i>75 rems in any one year (25 per quarter)</i>               |
| <b>Forearms</b>                                     | <i>30 rems in any one year (10 per quarter)</i>               |
| <b>Other organs, tissues, and organ systems</b>     | <i>15 rems in any one year</i>                                |
| <b>Fertile women (with respect to fetus)</b>        | <i>(5 per quarter)</i>  |
| <b>Dose limits for nonoccupationally exposed</b>    | <i>0.5 rem in gestation period</i>                            |
| <b>Population average</b>                           | <i>0.17 rem in any one year</i>                               |
| <b>An individual in the population</b>              | <i>0.5 rem in any one year</i>                                |
| <b>Students</b>                                     | <i>0.1 rem in any one year</i>                                |

## Ultraviolet Light

In the advanced physics lab students commonly work with the Uv sources. In this section we want to discuss about the ultraviolet light and its damages on the human health.

Ultraviolet light (UV) is non-ionizing radiation in the 180 to 400-nanometer wavelength region of the electromagnetic spectrum. The ultraviolet spectrum is commonly divided into the following three regions:

**Table 5** division of Uv zone

| Region     | Region Length | WaveLength |
|------------|---------------|------------|
| <b>UVA</b> | Black Light   | 315-400    |
| <b>UVB</b> | Erythemat     | 280-314    |
| <b>UVC</b> | Germicidal    | 180-280    |

Exposure to ultraviolet radiation is typically limited to the UVA region resulting from exposure to direct sunlight. The Earth’s atmosphere shields us from the more harmful UVC and greater than 99% of UVB radiation. However, some equipment can generate concentrated UV radiation in all the spectral regions that, if used without the appropriate shielding and personal protective equipment, can cause injury with only a few seconds of exposure.

## HAZARDS ASSOCIATED WITH EXPOSURE TO ULTRAVIOLET LIGHT

An unfortunate property of UV radiation is that there are no immediate warning symptoms to indicate overexposure. Symptoms of overexposure including varying degrees of erythema (sunburn) or photokeratitis (welder's flash) typically appear hours after exposure has occurred.

**Skin Injury** - UV radiation can initiate a photochemical reaction called erythema within exposed skin. This "sunburn" can be quite severe and can occur as a result of only a few seconds

exposure. Effects are exaggerated for skin photosensitized by agents such as coal tar products, certain foods (e.g., celery root), certain medications and photoallergens. Chronic skin exposure to UV radiation has been linked to premature skin aging, wrinkles and skin cancer.

**Eye Injury** – UV radiation exposure can injure the cornea, the outer protective coating of the eye. Photokeratitis is a painful inflammation of the eye caused by UV radiation-induced lesions on the cornea. Symptoms include a sensation of sand in the eye that may last up to two days. Chronic exposures to acute high-energy UV radiation can lead to the formation of cataracts.

### SPECIAL WORK PRACTICES

Never allow the skin or eyes to be exposed to UV radiation sources. The UV radiation generated by laboratory equipment can exceed recommended exposure limits and cause injury with exposures as brief as three seconds in duration.

## D) Safety in Work with Chemicals

Chemical agents are classified into various hazards classifications in accordance with their physiological properties and their health hazards. Addressing the risks posed by a chemical as indicated by its classification is key to its safe use.

Each class of chemical agent has a pictorial symbol and in some cases a letter indicating its hazard group. These symbols will be found on the labels of chemical containers.



Explosive



Oxidizing



Flammable



Toxic



harmful



Corrosive

Each of these materials has specific conditions to storage and handling.

### **Corrosive Chemicals—Procedures for Safe Handling and Storage**

Corrosives (liquids, solids, and gases) are chemicals that cause visible destruction of or irreversible alterations in, living tissue by chemical action at the site of contact. Corrosive effects can occur not only to the skin and eyes, but also to the respiratory tract through inhalation and to the gastrointestinal tract through ingestion. Corrosive liquids have a high potential to cause external injury to the body, while corrosive gases are readily absorbed into the body through skin contact and inhalation. Corrosive solids and their dusts can damage tissue by dissolving rapidly in moisture on the skin or within the respiratory tract when inhaled. In order to minimize these potential hazards, precautionary procedures must be observed when handling corrosives.

#### **Handling**

- Safety goggles, protective gloves, and a laboratory coat should always be worn when working with corrosive chemicals. A face shield, rubber apron, and rubber booties may also be appropriate depending on the work performed.
- Appropriate protective gloves which are resistant to permeation or penetration from corrosive chemicals should be selected and tested for the absence of pin holes prior to use.
- Eyewashes and safety showers should be readily available in areas where corrosive chemicals are used and stored. In the event of skin and eye contact with a corrosive chemical, the affected area should be immediately flushed with water for 15 minutes. Contaminated clothing should be removed and medical attention sought.
- Corrosive chemicals should be handled in a fume hood to ensure that any possible hazardous or noxious fumes generated are adequately vented.
- When mixing concentrated acids with water, add the acid slowly to the water. Allow the acid to run down the side of a container and mix slowly to avoid violent reactions and splattering. Never add water to acid.
- Appropriate spill material should be available in areas where corrosive chemicals are used and stored.

- Protective carriers should be used when transporting corrosive chemicals.

## **Storage**

- Containers and equipment used for storage and processing of corrosive material should be corrosion resistant.
- Corrosive chemicals should be stored below eye level, preferably near the floor to minimize the danger of their falling from cabinets or shelves.
- Acids and caustics (i.e., bases) should be stored separately from each other. Secondary containers can be used to help with separation within a corrosive cabinet.
- Inorganic acids should be separated from organic acids and flammable/combustible material (inorganic acids are particularly reactive with flammable/combustible material).
- Acids should be segregated from active metals (e.g., sodium, potassium, and magnesium) and from chemicals that can generate toxic gases (e.g., sodium cyanide and iron sulfide).

## ***Hydrofluoric Acid***

Hydrogen Fluoride (HF) is a corrosive, liquid or gas with a pungent, irritating odor that is extremely hazardous at any concentration. Both liquid and vapor can cause severe burns and complete heart failure. Specialized medical treatment is required for exposures to even very dilute HF. The most common concentrations of HF:

- **49% Hydrofluoric acid** (Aqueous HF): a non-fuming strength, but hazardous, corrosive acid (pH 3.4)
- **70% Hydrofluoric acid**: a highly hazardous, fuming, corrosive acid.
- **Anhydrous Hydrogen Fluoride** (AHF): a clear, colorless, corrosive fuming liquid with an extremely acrid odor that forms dense white vapor clouds when released.

Anhydrous HF is one of the strongest acids known. It reacts with most organic and inorganic substances. It forms fluorides with metals and hydrofluoric acid with water.

### **Fatal Exposures**

The most serious consequences of exposure to HF are hypocalcemia and hypomagnesemia, the lowering of serum calcium and magnesium, respectively, which can result in complete heart failure. HF binds with calcium whenever contact occurs with skin or other body tissues. Although flushing is effective in removing surface acid, it doesn't affect the fluoride ions that may have already penetrated. Binding of calcium can bring about cell death in a short time since it is necessary for cell life. If exposure occurs over a large area of skin surface, a great amount of calcium may be inactivated, so that inadequate amounts of  $\text{Ca}^{2+}$  are available for body functions. Nerve endings are irritated by increased levels of potassium entering the extracellular spaces to compensate for the reduced levels of calcium. Cell destruction and bone demineralization may progress for several days.

**WORKING WITH HF IS PERMITTED ONLY WHEN THE ANTIDOTE, CALCIUM GLUCONATE GEL, IS ON HAND.**

Short term exposure in low concentrations will cause irritation of the eyes, nose, upper and lower respiratory tract. This results in tearing, sore throat, cough, chest tightness, and wheezing. **Inhalation** of higher concentrations (>10-15 ppm) can result in serious damage to the lungs, and fatal pulmonary edema after a delay of several hours. Even a brief exposure (5 min) to 50 to 250 ppm may be fatal. **Ingestion** of high doses of fluorides will cause convulsions and cardiac arrhythmias. Severe burning and/or perforation of the digestive system may lead to death. **Skin contact** will cause irritation and severe skin and deep tissue burns. The burns may appear hours after contact, even when no pain is felt at the time of contact. A solution of 50% concentration will cause immediate excruciatingly painful, deep-seated burns and tissue destruction that are slow to heal. Weaker solutions (25-50%) may take a few minutes to be noticed, while dilute solutions (<20%) do not usually become apparent until several hours after exposure. Vapors can dissolve in the moisture on the surface of the eyes and cause irritation. Splashing into the eyes may cause severe and irreversible damage with possible corneal scarring.

### ***Chronic Exposure***

Chronic health effects can occur at a delayed time after exposure and can last for months or years. **Ingestion** of fluoride through drinking, including drinking water, may cause dental fluorosis or mottling (staining or pitting of teeth). At low levels, fluoride provides the benefits of dental cavity prevention and treatment of osteoporosis. At higher intakes, skeletal fluorosis (i.e., an accumulation of fluoride in the skeletal tissues associated with pathological bone formation) has been noted. At high concentrations, adverse pulmonary effects, kidney damage, thyroid injury, anemia, hypersensitivity, and dermatological reactions may occur. **Inhalation** of hydrogen fluoride may cause irritation and congestion of the nose, throat, and bronchi at low levels, increased bone density among workers, and damage to liver, kidneys, and lungs. Repeated inhalation may cause bronchitis with cough, phlegm, and/or shortness of breath.

### **Protection from HF Exposure**

The best way to reduce HF exposure is to substitute a less toxic chemical. However, if working with HF is the only alternative, take the following steps to protect yourself:

- When appropriate, pump from closed stock or reagent bottles.
- Wear lab coat over long pants and closed toe shoes.
- Protect eyes and face with goggles and face shield.



- Work in a properly functioning fume hood, at least 6" from the edge, with sash drawn to colored dot designating optimum performance.
- Wear an acid resistant apron when pouring from stock bottles or cleaning up a spill.
- Double glove: wear at least **two pairs** of 3.5mm nitrile rubber gloves when working with small quantities. Replace them when they are contaminated with HF. In working with larger quantities or immersing hands in HF, wear outer gloves with a higher breakthrough time. Selection should be based on potential exposure.

### Flammable and Combustible Liquids—Procedures for Safe Handling and Storage

Chemicals which exist, at ambient temperatures, in a liquid form with sufficient vapor pressure to ignite in the presence of an ignition source are called flammable or combustible liquids (note that the flammable/combustible liquid itself does not burn; it is the vapor from the liquid that burns). "**Flammables**" generate sufficient vapor at temperatures below 100 °F (37.8 °C), whereas "**Combustibles**" generate sufficient vapor at temperatures at or above 100 °F. Invisible vapor trails from these liquids can reach remote ignition sources causing flashback fires. In addition, these liquids become increasingly hazardous at elevated temperatures due to more rapid vaporization. For these reasons, precautionary measures must be observed when handling and storing flammables and combustibles.

#### Classification

Table 5

| Classification                     | Flash Point <sup>1</sup>        | Boiling Point      |
|------------------------------------|---------------------------------|--------------------|
| <b>Class IA Flammable Liquid</b>   | <73 °F (22.8 °C)                | < 100 °F (37.8 °C) |
| <b>Class IB Flammable Liquid</b>   | <73 °F                          | >/= 100 °F         |
| <b>Class IC Flammable Liquid</b>   | >/= 73 °F and <100 °F           | -----              |
| <b>Class II Combustible Liquid</b> | >/= 100 °F and < 140 °F (60 °C) | -----              |
| <b>Class IIIA Combustible</b>      | >/= 140 °F and < 200 °F (93 °C) | -----              |

<sup>1</sup> The minimum temperature at which a liquid gives off vapor in sufficient concentration to form an ignitable mixture in air near the surface of a liquid.

## Handling

- Appropriate personal protective equipment (gloves, lab coat, and safety goggles) should be worn when working with flammable/combustible liquids.
- Flammable/combustible liquids should never be heated using open flames. Preferred heat sources include steam baths, water baths, oil baths, hot air baths, and heating mantels.
- Ignition sources should be eliminated in areas where flammable vapors may be present.
- Flammable/combustible liquids should only be dispensed under a fume hood. Ventilation is one of the most effective ways to prevent the formation and concentration of flammable vapors.
- When pouring from containers of 1 gallon (3.8 liters) or greater capacity, make sure both containers involved are electrically interconnected by bonding to each other and to a ground. The friction of flowing liquid may be sufficient to generate static electricity, which in turn may discharge, causing a spark and ignition.
- Flammable/combustible liquids in containers larger than 1 gallon (3.8 liters) should be transferred to smaller containers that can be easily manipulated by one person.
- Appropriate fire extinguishers should be available in areas where flammables are used.

## Storage

- Flammable/combustible liquid in quantities exceeding a total of 10 gallons (38 liters) within a laboratory should be stored in approved flammable storage cabinets or safety cans.
- Flammable/combustible liquid stored outside of flammable storage cabinets in the laboratory should be kept to the minimum necessary for the work being done.
- Containers larger than 5 gallons (19 liters) shall not be stored in the laboratory.
- Flammable/combustible liquid stored in glass containers shall not exceed 1 gallon (3.8 liters).
- Flammable storage cabinets and safety cans should not be altered or modified unless specified by Indiana's Fire Prevention Code/National Fire Protection Agency guidelines.
- Flammable/combustible liquids should only be stored in explosion-proof or laboratory-safe refrigeration equipment.
- Flammable/combustible liquid containers filled or empty should not be stored in hallways or obstructing exits.
- Waste flammable/combustible liquids should be stored in safety cans.
- Flammables and combustibles should not be stored near oxidizers, corrosives, combustible material, or near heat sources. Make sure all chemicals stored near flammable and combustibles are compatible.

## Oxidizing Agents—Procedures for Safe Handling and Storage

Oxidizing agents are chemicals that bring about an oxidation reaction. The oxidizing agent may

- 1) provide oxygen to the substance being oxidized (in which case the agent has to be oxygen or contain oxygen) or
- 2) Receive electrons being transferred from the substance undergoing oxidation (chlorine is a good oxidizing agent for electron-transfer purposes, even though it does not contain oxygen).

The intensity of the oxidation reaction depends on the oxidizing-reducing potential of the material involved. Fire or explosion is possible when strong oxidizing agents come into contact with easily oxidizable compounds, such as metals, metal hydrides or organics. Because oxidizing agents possess varying degrees of instability, they can be explosively unpredictable.

### Examples of Oxidizing Agents

Table 6

|                 |   |
|-----------------|---|
| <b>Gases:</b>   | fluorine, chlorine, ozone, nitrous oxide, oxygen  |
| <b>Liquids:</b> | hydrogen peroxide, nitric acid, perchloric acid, bromine, sulfuric acid   |
| <b>Solids:</b>  | nitrites, nitrates, perchlorates, peroxides, chromates, dichromates, picrates, permanganates, hypochlorites, bromates, iodates, chlorites, chlorates, persulfates |

### Handling

- Appropriate personal protective equipment (safety goggles, gloves, lab coat, etc.) should be worn when working with oxidizers.
- If a reaction is potentially explosive, or if the reaction is unknown, use a fume hood (with the sash down as a protective barrier), safety shield, or other methods for isolating the material or the process.
- Oxidizers can react violently when in contact with incompatible materials. For this reason, know the reactivity of the material involved in an experimental process. Assure that no extraneous material is in the area where it can become involved in a reaction.
- The quantity of oxidizer used should be the minimum necessary for the procedure. Do not leave excessive amounts of an oxidizer in the vicinity of the process.
- Perchloric acid must not be used in a regular chemical fume hood. A specially designed Perchloric Acid Fume Hood must be utilized for this purpose.

### Storage

- Oxidizers should be stored in a cool, dry place.
- Oxidizers should be segregated from organic material, flammables, combustibles and strong reducing agents such as zinc, alkaline metals, and formic acid.

- Oxidizing acids such as perchloric acid and nitric acid should be stored separately in compatible secondary containers away from other acids.

## Reactive Chemicals—Procedures for Safe Handling and Storage

Reactives are substances that have the potential to vigorously polymerize, decompose, condense, or become self-reactive due to shock, pressure, temperature, light, or contact with another material. All reactive hazards involve the release of energy in a quantity or at a rate too great to be dissipated by the immediate environment of the reaction system, so that destructive effects occur. Reactive chemicals include: 1) **explosives**, 2) **organic peroxides**, 3) **water-reactives** and 4) **pyrophorics**. Effective control is essential to minimize the occurrence of reactive chemical hazards.

**1) Explosives** - cause sudden, almost instantaneous release of pressure, gas, and heat when subjected to sudden adverse conditions. Heat, light, mechanical shock, detonation, and certain catalysts can initiate explosive reactions. Compounds containing the functional groups azide, acetylide, diazo, nitroso, haloamine, peroxide, and ozonide are sensitive to shock and heat and can explode violently.

- Appropriate personal protective equipment (face shield, safety goggles, leather outer gloves, chemical resistant gloves, lab coat, etc.) should be worn when working with explosives.
- Before working with explosives, understand their chemical properties, know the products of side reactions, the incompatibility of certain chemicals, and monitor environmental catalysts such as temperature changes.
- Containers should be dated upon receipt and when opened. Expired explosives should be discarded promptly.
- Explosives should be kept to the minimum necessary for the procedure.
- If there is a chance of explosion, use protective barriers (e.g., fume hood sash and safety shield) or other methods for isolating the material or process.
- Explosives should be stored in a cool, dry, and protected area. Segregate from other material that could create a serious risk to life or property should an accident occur.

**2) Organic Peroxides** - contain an -O-O- structure bonded to organic groups. These compounds can be considered as structural derivatives of hydrogen peroxide, H-O-O-H, in which one or both of the hydrogen atoms have been replaced by an organic group. Generally, organic peroxides are low-powered explosives that are sensitive to shock, sparks, and heat due to the weak -O-O- bond that can be cleaved easily. Some organic compounds such as ethers, tetrahydrofuran, and p-dioxane can react with oxygen from the air forming unstable peroxides. Peroxide formation can occur under normal storage conditions, when compounds become concentrated by evaporation, or when mixed with other compounds. These accumulated peroxides can violently explode when exposed to shock, friction, or heat.

- Appropriate personal protective equipment (safety goggles, gloves, lab coat, etc.) should be worn when working with organic peroxides or peroxide-forming compounds.
- Containers should be labeled with the receiving and opening dates. Unopened material should be discarded within 1 year and opened material should be discarded within 6 months.
- Containers should be airtight and stored in a cool, dry place away from direct sunlight. Segregate from incompatible chemicals.
- Peroxide formers, liquid peroxides, or solutions should not be refrigerated below the temperature at which the peroxide freezes or precipitates. Peroxides in these forms are extra sensitive to shock (never store diethyl ether in a refrigerator or freezer).
- Unused peroxides should never be returned to the stock container.
- Metal spatulas should not be used with peroxide formers. Only ceramic or plastic spatulas should be used. Contamination by metal can cause explosive decomposition.
- Friction, grinding, and all forms of impact, especially with solid organic peroxides should be avoided. Never use glass containers with screw cap lids or glass stoppers. Instead, use plastic bottles and sealers.
- Testing for the presence of peroxides should be performed periodically.
- Containers with obvious crystal formation around the lid or viscous liquid at the bottom of the container should NOT be opened or moved.

**3) Water-Reactives** - react with water or moisture in the air releasing heat or flammable, toxic gas. Examples include alkali metals, alkaline earth metals, carbides, hydrides, inorganic chlorides, nitrides, peroxides, and phosphides.

- Appropriate personal protective equipment (safety goggles, gloves, lab coat, etc.) should be worn when working with water-reactives.
- Water-reactives should be stored under mineral oil in a cool, dry place. Isolate from other chemicals.
- Water-reactives should not be stored near water, alcohols, and other compounds containing acidic OH.
- In case of fire, keep water away. Appropriate fire extinguishers should be available in areas where water-reactives are used (use a Type "D" fire extinguishing media to extinguish active metal fires).

**4) Pyrophorics** - ignite spontaneously in air below 130 ° F (54 ° C). Often the flame is invisible. Examples of pyrophoric materials include silane, silicon tetrachloride, white and yellow phosphorus, sodium, tetraethyl lead, potassium, nickel carbonyl, and cesium.

- Appropriate personal protective equipment (safety goggles, gloves, lab coat, etc.) should be worn when working with pyrophorics.
- Pyrophorics should be used and stored in inert environments.

- Appropriate fire extinguishers should be available in areas where pyrophorics are used.

## **Compressed Gases—Procedures for Safe Handling and Storage**

In general, a compressed gas is any material contained under pressure that is dissolved or liquefied by compression or refrigeration. Compressed gas cylinders should be handled as high-energy sources and therefore as potential explosives and projectiles. Prudent safety practices should be followed when handling compressed gases since they expose workers to both chemical and physical hazards.

### **Handling**

- Safety glasses with side shields (or safety goggles) and other appropriate personal protective equipment should be worn when working with compressed gases.
- Cylinders should be marked with a label that clearly identifies the contents.
- All cylinders should be checked for damage prior to use. Do not repair damaged cylinders or valves. Damaged or defective cylinders, valves, etc., should be taken out of use immediately and returned to the manufacturer/distributor for repair.
- All gas cylinders (full or empty) should be rigidly secured to a substantial structure at 2/3 height. Only two cylinders per restraint are allowed in the laboratory and only soldered link chains or belts with buckles are acceptable. Cylinder stands are also acceptable but not preferred.
- Hand carts shall be used when moving gas cylinders. Cylinders must be chained to the carts.
- All cylinders must be fitted with safety valve covers before they are moved.
- Only three-wheeled or four-wheeled carts should be used to move cylinders.
- A pressure-regulating device shall be used at all times to control the flow of gas from the cylinder.
- The main cylinder valve shall be the only means by which gas flow is to be shut off. The correct position for the main valve is all the way on or all the way off.
- Cylinder valves should never be lubricated, modified, forced, or tampered.
- After connecting a cylinder, check for leaks at connections. Periodically check for leaks while the cylinder is in use.
- Regulators and valves should be tightened firmly with the proper size wrench. Do not use adjustable wrenches or pliers because they may damage the nuts.
- Cylinders should not be placed near heat or where they can become part of an electrical circuit.
- Cylinders should 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 as lecture bottles, are not fitted with rupture devices and may explode if exposed to high temperatures.
- Rapid release of a compressed gas should be avoided because it will cause an unsecured gas hose to whip dangerously and also may build up enough static charge to ignite a flammable gas.

- Appropriate regulators should be used on each gas cylinder. Threads and the configuration of valve outlets are different for each family of gases to avoid improper use. Adaptors and homemade modifications are prohibited.
- Cylinders should never be bled completely empty. Leave a slight pressure to keep contaminants out.

## **Storage**

- When not in use, cylinders should be stored with their main valve closed and the valve safety cap in place.
- Cylinders must be stored upright and not on their side. All cylinders should be secured.
- Cylinders awaiting use should be stored according to their hazard classes.
- Cylinders should not be located where objects may strike or fall on them.
- Cylinders should not be stored in damp areas or near salt, corrosive chemicals, chemical vapors, heat, or direct sunlight. Cylinders stored outside should be protected from the weather.

## **Special Precautions**

### Flammable Gases

- No more than two cylinders should be manifolded together; however several instruments or outlets are permitted for a single cylinder.
- Valves on flammable gas cylinders should be shut off when the laboratory is unattended and no experimental process is in progress.
- Flames involving a highly flammable gas should not be extinguished until the source of the gas has been safely shut off; otherwise it can reignite causing an explosion.

### Acetylene Gas Cylinders

- Acetylene cylinders must always be stored upright. They contain acetone, which can discharge instead of or along with acetylene. Do not use an acetylene cylinder that has been stored or handled in a nonupright position until it has remained in an upright position for at least 30 minutes.
- A flame arrestor must protect the outlet line of an acetylene cylinder.
- Compatible tubing should be used to transport gaseous acetylene. Some tubing like copper forms explosive acetylides.

### Lecture Bottles

- All lecture bottles should be marked with a label that clearly identifies the contents.

- Lecture bottles should be stored according to their hazard classes.
- Lecture bottles that contain toxic gases should be stored in a ventilated cabinet.
- Lecture bottles should be stored in a secure place to eliminate them from rolling or falling.
- Lecture bottles should not be stored near corrosives, heat, direct sunlight, or in damp areas.
- To avoid costly disposal fees, lecture bottles should only be purchased from suppliers that will accept returned bottles (full or empty). Contact the supplier before purchasing lecture bottles to ensure that they have a return policy.
- Lecture bottles should be dated upon initial use. It is advised that bottles be sent back to the supplier after one year to avoid accumulation of old bottles.

### **Cryogenic Liquids—Procedures for Safe Handling and Storage**

Cryogenic liquids are liquefied gases having boiling points of less than  $-73.3^{\circ}\text{C}$  ( $-100^{\circ}\text{F}$ ). The primary hazards of cryogenic liquids include both physical hazards such as fire, explosion, and pressure buildup and health hazards such as severe frostbite and asphyxiation. Potential fire or explosion hazards exist because cryogenic liquids are capable, under the right conditions, of condensing oxygen from the atmosphere. This oxygen-rich environment in combination with flammable/combustible materials, and an ignition source are particularly hazardous. Pressure is also a hazard because of the large volume expansion ratio from liquid to gas that a cryogen exhibits as it warms and the liquid evaporates. This expansion ratio also makes cryogenic liquids more prone to splash and therefore skin and eye contact is more likely to occur. Contact with living tissue can cause frostbite or thermal burns, and prolonged contact can cause blood clots that have very serious consequences. All laboratory personnel should follow prudent safety practices when handling and storing cryogenic liquids.

## Properties of Common Cryogenic Liquids

Table 7

| Gas      | Boiling Point ( °C) | Volume Expansion Ratio |
|----------|---------------------|------------------------|
| Helium   | -269                | 757-1                  |
| Hydrogen | -252.7              | 851-1                  |
| Nitrogen | -195.8              | 696-1                  |
| Fluorine | -187.0              | 888-1                  |
| Argon    | -185.7              | 847-1                  |
| Oxygen   | -183.0              | 860-1                  |
| Methane  | -161.4              | 578-1                  |

## Handling

- Appropriate personal protective equipment should be worn when handling cryogenic liquids. This includes special cryogen gloves, safety goggles, full-face shield, impervious apron or coat, long pants, and high topped shoes. Gloves should be impervious and sufficiently large to be readily removed should a cryogen be spilled. Watches, rings, and other jewelry should NOT be worn.
- Unprotected body parts should not come in contact with vessels or pipes that contain cryogenic liquids because extremely cold material may bond firmly to the skin and tear flesh if separation is attempted.
- Objects that are in contact with cryogenic liquid should be handled with tongs or proper gloves.
- All precautions should be taken to keep liquid oxygen from organic materials; spills on oxidizable surfaces can be hazardous.
- All equipment should be kept clean, especially when working with liquid or gaseous oxygen.
- Work areas should be well ventilated.
- Transfers or pouring of cryogenic liquid should be done very slowly to minimize boiling and splashing.
- Cryogenic liquids and dry ice used as refrigerant baths should be open to the atmosphere. They should never be in a closed system where they may develop uncontrolled or dangerously high pressure.
- Liquid hydrogen should not be transferred in an air atmosphere because oxygen from the air can condense in the liquid hydrogen presenting a possible explosion risk.

## Storage

- Cryogenic liquids should be handled and stored in containers that are designed for the pressure and temperature to which they may be subjected. The most common container for cryogenic liquids is a double-walled, evacuated container known as a dewar flask.

- Containers and systems containing cryogenic liquids should have pressure relief mechanisms.
- Cylinders and other pressure vessels such as dewar flasks used for the storage of cryogenic liquids should not be filled more than 80% of capacity, to protect against possible thermal expansion of the contents and bursting of the vessel by hydrostatic pressure. If the possibility exists that the temperature of the cylinder may increase to above 30 °C (86 °F), a lower percentage (i.e., 60 percent capacity) should be the limit.
- Dewar flasks should be shielded with tape or wire mesh to minimize flying glass and fragments should an implosion occur.
- Dewar flasks should be labeled with the full cryogenic liquid name and hazard warning information.