Laboratory Safety

Physics 128AL

UCSB Physics Instructional Lab Group

Summer 2025

- What is safety?
- Safety is an important consideration when designing an experiment that minimizes risks and potential harm, while still allowing for education, development, and innovation.
- The risk of an accident is always present and is unavoidable. However, even activities that have high levels of potential risk can be engaged in *safely*.
- How can we minimize risks so that they decrease to acceptable levels?
- We can do this by identifying sources of hazards and by assessing the risks of accidents inherent to these hazards, developing standard operating procedures and safe practices, and by ensuring that everyone follows them.

- Risk arises in some form in virtually all of life's activities.
- It is important not to ignore risk or be frightened by it.
- Systematic methods to assess and handle risk can be developed.
- Risk management process is divided into four stages:
  - identification,
  - evaluation,
  - development of engineering controls, and
  - implementation.

What are potential hazards in our lab?

Spend a minute to think alone or talk to neighbors about potential hazards.

- **Mechanical**
  falling objects, powerful permanent magnets, sharp objects, chipped glass, over-pressurized containers, etc.
- **Electrical**
  electric shock and electrocution, associated fire hazard, etc.
- **Lasers and UV light**
  eye and skin damage
- **Ionizing radiation**
  chemical damage to body tissues
- **Heat and cryogenic**
  burns, frostbites, etc.
- **Chemical**
  toxic substances (e.g. lead, copper sulfate), burns, fires, etc.

Factors establishing the severity of associated injury:

- Current **path** through your body:
  *current passing through your **heart** is most dangerous.*
- Current **magnitude** (voltage plays a role via Ohm's law):
  $\gtrsim 10\,mA$ *is dangerous;* $\gtrsim 100\,mA$ *is possibly lethal.*
- Current **frequency**: *DC's "let-go" threshold is higher than the AC's; however, heart follows AC, DC will stop it.*
- Skin resistance, and whether the voltage is sufficiently large to break the skin (which happens at around 500–600 V):
  ***kilo** ohms to a few **mega** ohms depending on the dryness of skin, contact area, etc. Can be as low as 100 ohms.*
- Duration of the shock or discharge.
- Other factors, such as the susceptibility of the heart in different phases of the cardiac cycle, etc.

	DC, mA	AC (RMS), mA	
		60 Hz	10 kHz
Slight sensation on hand	1	0.4	7
Perception threshold, median	5.2	1.1	12
Shock—*not painful and muscular control not lost*	9	1.8	17
Painful shock *let-go threshold, median*	76	16	75
Painful and severe shock *muscular control lost by 99 %*	90	23	94
Possible ventricular fibrillation *(after 3 sec shock)*	500	100	500

Table 1: Modified from *Dalziel, C.F. Deleterious effects of electric shock. Meeting of experts on electrical accidents and related matters. Geneva, Switzerland, 1961.*

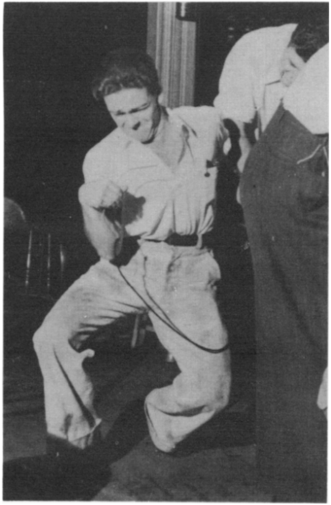

Figure 1: Determination of let-go current. *Dalziel, C. F. (1956). Effects of electric shock on man (Figure 10a).*

- Wall outlets in the US output 120 VAC (RMS)
  *a wall outlet **can** kill you if you short it*
- Charged capacitors
  capacitors can carry a significant amount of electric charge, and can produce a very high current discharge if shorted
- Photomultiplier tubes (PMTs)
  PMT has a chain of dynodes, each with a progressively higher potential reaching max voltages btw. 1 kV and 2 kV
- Lasers
  e.g. He-Ne gas lasers use high voltages to excite the gas inside a reservoir
- Transformers, etc.

Safety Guidelines to Prevent Electrical Shock

- NEVER WORK ALONE OR TIRED IN A LAB!
- Power down the equipment before adjusting cabling.
- Avoid wearing rings, metallic watch bands, and other metallic apparel when working with electrical equipment.
- Whenever possible, use only one hand for any manipulation of circuits or control devices; keep the other hand in pocket.
- Never handle electrical equipment when your hands, feet, or body are wet.

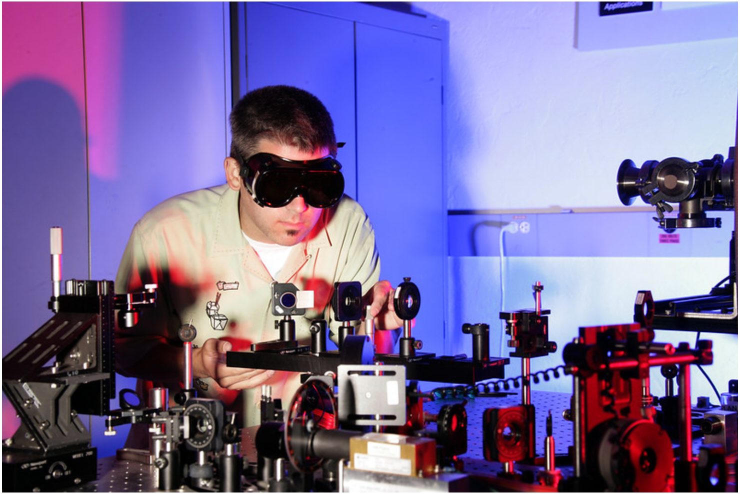

Figure 2: Laser optics research at Idaho National Laboratory. (Image courtesy of Idaho National Laboratory (INL) on Flickr. CC BY 2.0.)

- **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation
- Laser radiation is characterized by an extremely high degree of:
  1. Monochromaticity.
  2. Coherence (both temporal and spatial).
  3. Directionality.
  4. Irradiance (power per unit area).
- A 100 W light bulb has 10^5 times the power of a typical 1 mW laser, but the laser delivers a power per unit area on your retina that is about 2 million times greater than that from the light bulb when both are viewed from a distance of 5 meters.
- Solar radiation reaching the Earth's surface delivers about 1 mW of power per square millimeter (max normal surface irradiance).

- Laser beams can be hazardous, particularly for the eye and sometimes for the skin.
- Damage can result from both photochemical and thermal effects.
- Laser damage to the eye is not always immediately noticed: it is possible e.g. to burn peripheral regions of the retina, causing blind spots which may be noticed only years later.
- Some lasers emit radiation that is not visible to the eye and, thus, are particularly hazardous (785 nm laser in **Diode Laser Exp**).
- Lasers can operate in two modes: pulsed and continuous wave (CW). Generally, pulsed lasers are more hazardous than CW lasers.

- Laser devices are assigned to different safety classes.
- **Class 1**. Incapable of causing injury during normal operation. Examples: CD/DVD players, laser printers.
  Class 1M: same, unless collecting optics is used.
- **Class 2**. Laser radiation is limited to the visible spectral range (400–700 nm) and to 1 mW accessible power.
  Incapable of causing injury during the aversion response time of $\sim 0.25\,\mathrm{s}$ (the blink reflex).
  Examples: some (but not all) laser pointers, demonstration lasers for classroom use, rangefinding devices.
  Class 2M: same, unless collecting optics is used.

- **Class 3A**. Eye hazard for chronic viewing or use of collecting optics. Continuous wave (CW) with up to 5mW of accessible power. Examples: many laser pointers, scanners, He-Ne lasers in **Laser properties, Interferometry, and Cavendish experiments**.
- **Class 3B**. Eye and skin hazard for direct beam exposure. Up to 500 mW is permitted in the visible part of the spectrum. Diffuse radiation should normally be harmless. The blink reflex will not save you. Require laser safety goggles. Example: **Diode Laser Exp** (785 nm, 30 mW).
- **Class 4**. The accessible radiation is very dangerous for the eye and for the skin. May be hazardous for the eye even from diffuse reflections. May cause fire or explosions. Examples: lasers in surgery, cutting, drilling, and welding.

Laser Safety Guidelines

- NEVER look into the primary beam of a laser.
- NEVER fight the eye's blink response.
- NEVER direct the laser beam towards people, doors, moving vehicle, aircraft, etc.
- NEVER allow a laser beam to escape from its designated area of use.
- Remove all unnecessary reflective objects from the working area (watches, jewelry, tools, etc.)
- Position the laser well above or below eye level (both standing and sitting).
- Don't use lasers in the dark.
- Do not take apart lasers (including laser pointers).

Cryogenic and Heat Hazards

- Liquid nitrogen used in **Johnson Noise** Exp boils at 77 K.
- It is chemically inert, but can cause severe frost bite.
- Wear gloves and protective glasses when transferring or transporting LN.
- Avoid touching cold metal surfaces or anything that comes out of the dewar where LN is stored.
- Splashing against the skin should be avoided.
- Gas-discharge lamps used in **H-D Shift Exp** can get really hot. Do not touch them with your bare hands and do not store flammable materials near them.
- Do not store flammable materials near the hotplate used in the **PNMR Exp** and turn it off when it is not in use.

Figure 3: International ionizing radiation trefoil symbol on a reproduction of the warning sign from Chornobyl.

- Radiation capable of producing ionization in tissue is harmful because it destroys individual cells and may cause genetic mutations, tumors, and cancer. At high doses burns and radiation sickness are likely.
- The radiation dose you receive in Physics 128A Lab will be only a small fraction of the annual dose you recieve from natural background.
- Common types of ionizing radiation found in laboratories include α-, and β-particles, x-rays and γ-rays.

α- and β-particles and γ rays

- Alpha particles are ^{4}He nuclei spontaneously emitted by heavy unstable nuclei. They have a discrete spectrum with energies between 4 MeV and 9 MeV. Alpha particles have a range of only about 0.04 mm in tissue or about 3 cm in air.
- Beta particles are fast electrons or positrons resulting from the decay of a neutron or proton inside the nucleus with an excess of the corresponding nucleon. Betas have a continuous energy spectrum with the maximum energy from tens of keV to a few MeV. Can penetrate 0.5 cm deep into tissue, or about 4 meters of air, although this is strongly dependent upon the energy of the beta.
- Gamma rays are highly penetrating energetic photons emitted in transitions between discrete energy states of a nucleus, with typical energies from a few hundred keV to a few MeV. They can be attenuated by using shielding materials with high density and atomic number (e.g. lead).

- The ALARA principle:
  As Low As (is) Reasonably Achievable
- Quantity — use the smallest amount that does the job.
- Time — minimize the time of contact with the source.
- Distance — stay away, avoid direct contact.
- Shielding — use proper shielding for each type of radiation.

- Ionizing radiation is quantified in several different ways.
- **Activity** of a source is measured in *curies* (Ci) or *becquerels* (Bq).
- A one-curie source (1 Ci) has activity of 3.7×10^{10} disintegrations per second (of any type); millicuries and microcuries are more common.
- The SI unit of activity is the *becquerel*, which is one nuclear decay per second: $1\ \text{Bq} = 1\ \text{s}^{-1}$.
- To quantify the impact of radiation on matter the important quantities are the radiation **exposure** and **dose**.
- Exposure is defined in terms of the *charge* produced due to ionization created by the secondary electrons formed within a certain fixed volume of dry air.
- Dose is defined in terms of *energy* absorbed per unit mass of material.

Units of Exposure and Absorbed Dose

- The original unit for radiation exposure is the *roentgen* (R). 1 R quantifies exposure due to x- and γ-rays that results in liberation (by ionization) of one electrostatic unit (esu) of charge per cubic centimeter of dry air under normal conditions (standard temperature and pressure):

$$1 \text{ R} = 2.58 \times 10^{-4} \text{ C/kg dry air.}$$

- For radiation protection, however, energy deposited in matter (living tissue) is more important, so another unit was defined, the *rad* (radiation absorbed dose):

$$1 \text{ rad} = 10^{-2} \text{ J/kg.}$$

- The SI unit of absorbed dose is the *gray* (Gy):

$$1 \text{ Gy} = 1 \text{ J/kg} = 100 \text{ rad.}$$

- An exposure to 1 roentgen would result in an **absorbed dose** of 0.88 rad or 8.8 mGy in air.

- To take into account the relative "effectiveness" of the various types of radiation in causing biological damage, the unit of **equivalent dose** was subsequently defined, the *rem* (roentgen equivalent man). The corresponding SI unit is the *sievert* (Sv): 1 Sv = 100 rem.
- Equivalent dose is the product of the absorbed dose, averaged over the entire tissue or organ, and the **weighting factor**, w_R, a measure of how damaging a particular type of radiation is to biological tissue (see next slide).
- A related concept of *dose equivalent* is very similar but refers to the dose measured *at a point* on the tissue.
- If more than one type of radiation is present, the sum of the absorbed doses for each type of radiation, weighted by the corresponding factor, is calculated instead.
- To account for the effects on particular organs, further *tissue* weighing factors (summed to 1) can be introduced.

Radiation Weighting Factor

- For **gamma** rays and **beta** particles $w_R = 1$.
- For **alpha** particles $w_R = 20$.
- For **neutrons** w_R is between 5 and 20 depending on the energy.
- For **protons** w_R is between 2 and 5.

- For an average individual, the annual *background* dose from cosmic rays and other environmental sources is 3.5 mSv.
- The recommended limit to controllable exposure for a member of the general public is 1 mSv/year (averaged over any consecutive 5 years).
- Other typical doses: 0.1 μSv from eating a banana, a typical daily background of 10 μSv, 40 μSv by flying from New York to Los Angeles, a chest x-ray (up to 0.1 mSv), a mammogram (up to 1 mSv), 2 Sv results in severe radiation poisoning, and 8 Sv is lethal dose.

Radiation Safety

- Don't ingest the sources.
- Wash your hands after lab, don't eat or drink in the lab.
- All sources in the lab are not are exempt quantity radiative sources, except for the one in the **Mössbauer Exp**.

How to Stay Safe in the Lab

- Look for safety-related information in the lab manual and equipment manuals.
- Start each experiment by doing an assessment of the safety issues.
- Include safety in the planning discussions with your lab partner.
- Identify, evaluate, and minimize the risks.
- Make sure you understand the process before proceeding. **Ask for help**.

How to Stay Safe in the Lab

- If something goes wrong, STOP. Find out why, and fix it first *before* trying again.
- You must **never work alone**. There must always be at least two people in the room.
- Never leave activated equipment unattended without approval from your instructor or TA.
- If any accident occurs, you must immediately **report it** to your TA, your instructor, and the lab manager.
- **If immediate medical assistance is required, call 911.**
- For more information, visit https://www.ehs.ucsb.edu/