Physics 115B
Lab 4: Radioactivity

In this lab, we will study radioactivity. You probably know a bit, and you will learn more in this course, about the technological, political, and health impacts of radioactivity. From a scientific and philosophical point of view, however, radioactivity and the associated radiation are a direct, observable connection to the atomic and sub-atomic world.

Though some of the sources of radioactivity we will use are created for scientific purposes, several are from the grocery store or the hardware store and are found in almost every home. We will get the radioactive atoms for one part of the lab from the air! None of the sources used in this lab are dangerous. Still, we will apply sensible rules that should always be applied to radioactive sources.

1. Minimize contact. Hold the needle sources by the stopper only. Keep them in their tubes when not in use. Hold the plastic disk sources by the edge. Don’t touch the actual source in the smoke detector. Decide what you are going to do with a source before you pick it up, and then do it.

2. Keep track. If your group is using one or more sources, each member should know where each source is. Never put the source in your pocket or somewhere hidden where it can’t be seen. Return the source to an AI when done.

3. No eating (or food) or drinking in the lab. Wash your hands before leaving the lab.

4. When in doubt, ask an AI.

To start this lab, look at the Learning Goals and the questions in Part III; use them to guide your investigations in Parts I and II.
Learning goals

• Perform measurements of things you cannot see.
• Distinguish different types of radiation and different types of radioactive materials by measuring their penetration power, half-life, and tracks in the cloud chamber.
• State evidence that radioactivity is made of particles.
• Explain how half-life is a property of exponential decay while the amount of radiation exposure changes as \( \frac{1}{r^2} \).
• Measure radiation from everyday objects.

Group demo

Just to get everyone familiar with equipment and handling sources we will have a short group demo.

BIG PICTURE: Radiation as Particles

In a radioactive material, individual nuclei *decay* to other nuclei, emitting particles in a process we call *radiation* (the old name was *rays*). **Radiation means transporting energy from one place to another.** In radioactivity, the most common particles transporting energy: *alpha rays* are helium nuclei (these are made of two protons and two neutrons, an especially stable configuration that can be emitted as a unit from a larger, less stable nucleus); *beta rays* are electrons, and *gamma rays* are *photons*, the quantum-mechanical particles of light, but with energies much higher than visible light. *X-rays* are just less-energetic gamma rays.

*NOTE: Even lower energy photons (like visible light) are radiation but are too low in energy to be detected by the Geiger counter OR damage cells. We’ll talk more about light as a particle and wave later.*

Note how the particle model is “obvious” here: we *count* them. (We’ll address this again in a later lab.) The particles have specific
properties, notably mass and electric charge. The most intuitive property, the particles’ sizes, turns out to be unimportant here. They are all so small compared to the size of atoms that none of our measurements reveal any information about particle size.

Part I: Geiger-Mueller counter

The Geiger-Mueller counter is a very sensitive device that can detect the passage of individual particles (beta and gamma and maybe alpha rays) from radioactive decays. Because it can detect individual decays, it allows you to count them, hence “counter.” Your AI can describe how it works. Our G-M counters (GM-45s) are connected to computers, so the results can be stored and plotted. The computers are trained to make the traditional “clicks” that let you get a sense of how many decays are detected without plotting. We will find it most useful to measure the rate of detected decays. The computer does this by counting for a minute, plotting the result, then doing the same thing for the next minute, etc. The displayed rate is the counts per minute, or CPM.

Note that the counting is a statistical process governed directly by quantum mechanics – it is fundamentally random. Even with measurements of perfect precision, we do not expect to get the same number of counts in each minute! This means that we must do some averaging, either numerically or by eye. It also means that we must be patient and let the average unfold.

The first thing to measure is the room background, the rate of counts with “no source present”. This may be partly an occasional misfire of the GM-45, but it is mostly radioactivity in the materials used to make the device itself and in the air and other surroundings (including you). Record this number in logbook – you will want to subtract it from all measurements of other sources.
Let's investigate the activity of 2 sources: a smoke detector, a commercial radioactive disk source.

- Ask the AIs for a source. Write down what your source is. Place it gently on the GM-45 (caution: the mesh is fragile). Make sure you know where the radioactive part of the smoke detector is located. Record the approximate rate. Qualitatively check how the rate changes with distance just to get some idea of distance dependence.

- We can learn a bit about the radiation from the source by trying to block it. There are various sheets of materials from paper to metal in various thicknesses - ask for some from the AI and record how well the material blocks the source. Start with one piece, then 2, then more sheets of paper, then go to the heavier materials if still active.

- ONLY FOR DISK SOURCE: Determine quantitatively how the CPM reading changes (the “exposure” if you will) as a function of distance. Use the ring stand and clamp to hold the Co-60 or Cs-137 disk source at various heights above the GM-45, say 4, 8, 16,… cm. Plot the measured count rate vs. distance in logbook by hand or in excel (don’t forget labels). Keep in mind that the number will fluctuate a bit because of statistical variations.

- Discuss your result – does the measured behavior meet your expectations? (Hint: Looking at your graph, if the source distance changes by a factor of 2 by how much does the CPM change?). Sketch the setup in your logbook and explain what factors discussed in lab influence your results.
Half-Life

If the radioactive nuclei are decaying, should they eventually be gone entirely? Yes! For the sources we’ve been using so far, this takes years (Co-60), or tens of years (Cs-137, Sr-90), or hundreds of years (Am-241), or even billions of years (K-40), so you haven’t seen it in your measurements.

When radioactive nuclei decay, they do so in an odd way. Each type of unstable nucleus has its own half-life: the time it takes for half of the individual nuclei of that type in a sample to decay. Example: the half-life of Americum-241 is 432 years. The odd thing is that after 432 years, when half the original Americium is gone, it is not the case that the other half is about to kick. In fact, half of the remainder will live another 432 years, exactly as if the whole surviving half had just been born. Mathematically, this is exponential decay, which, along with exponential growth is observed in many natural phenomena.

The problem with doing experiments with radioactive nuclei with a half-life short enough to measure in a 3-hour lab is that if you buy some on Monday, it’s mostly gone by Tuesday. Instead, we need something that is made continuously that we can harvest and observe. Fortunately (in a sense, see below for the downside), uranium and thorium in the Earth’s crust is slowly decaying, and one of the resulting nuclei, Radon-222 (Rn-222), is a chemically inert but radioactive gas. It has a long enough half-life (about 4 days) that it can seep out of the ground. When it seeps into a basement, it can collect there, and, if levels are high, can become a health problem. The nuclei that Rn-222 decays to (see Figure 1 below) are metals. They stick to dust particles in the air, and we can collect and concentrate them onto a paper filter by using the yellow air samplers that have been running in the adjacent classroom. Note from the figure that lead-210 (\(^{210}\text{Pb}\)) has a long half-life. It is thus a bottleneck, and what we will see is the decays that precede this. We will be most sensitive to the beta-decays of lead-214 and bismuth-214. Because we are seeing a chain of

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linked decays, we will not observe a single half-life. For example, for a while, as long as there is $^{218}$Po (polonium-218), it will replenish the lead-214, and likewise, the decay of the lead-214 replenishes the bismuth-214. Still, the nuclei will decay in tens of minutes, and we can find when the number of decaying nuclei has dropped to about half of its initial value.

![Radioactive Decay Diagram]

- Figure 1. The radioactive decay sequence of uranium-238. The portions relevant to this lab are highlighted. The half-life of each nucleus is in its box (note the different units!), with the type of decay ($\alpha$, $\beta$) between it and the next box. (Note: a $\beta^+$ is a positive electron: a bit of anti-matter!)

- Note that we will be measuring the rate of decays (counts per minute), while our discussion of half-life above was in terms of surviving number of radioactive particles. Based on your understanding of half-life, sketch in your lab book a prediction of the shape of the measured CPM (counts per minute) vs. time you will see if you observe a sample with a
single type of radioactive nucleus for several half-lives. On your sketch, mark/label the location of one AND two half-lives.

**Measuring Half-Life**

- When you’ve read the above description, make another room background measurement with a piece of unused filter paper (ask AI) on the GM-45 to see if it changes the count rate.

- Go with an AI to get a new filter sample from the air samplers. Choose one and shut it off. Take the filter back to your bench and place it on your GM-45.

- *After this* Restart the “Rad” program to clear all data. Record the current time and the time on the blackboard that indicates when the air sampling started. (Note that holding the filter is no more dangerous than cleaning the filter in a clothes drier, which is doing the same thing that the air sampler did.)

***PAUSE HERE! You will leave this running for much of the rest of the lab. Do Part II and begin Part III while you collect CPM data. Only when done with other parts do the following:*

- Under FILE use the Print option to print the graph and place in logbook. Does the shape of the graph of CPM vs. time match expectations? Is it the same shape as the graph of CPM vs distance you made in Part I? Explain in logbook in your own words why not.

- Print the graph made by the computer and use it to estimate the half-life of this decay process. Look back at Figure 1 and think about whether your result for the half-life makes sense. *If not, talk to AI.*
Part II: Cloud chamber – seeing the rays

Set up:

IMPORTANT: Check periodically that there is still ice water in the bath and pump is submerged in water.

- In its operating state, the chamber should have isopropyl alcohol soaked all the way up the blue filter paper on the side, with a couple mm of liquid on the bottom. If the whole thing is dry, add about 30 ml of isopropyl.

- Make sure there is ice in the water cooling bath (a tub or Styrofoam cooler). Make sure the rubber hoses from the pump (small square black plastic thing) to the chamber and from the chamber to the bath are connected and the pump is submerged in the ice water. The pump should already be running and circulating water.

- There is a Peltier refrigerator in the base, cooling the bottom of the chamber and creating a fog just like about a lake on a cool morning. There is also a yellow grounding wire, which, if connected to the metal needle through the stopper, is intended to help clear any electric charge that may build up.

How it works:

The alcohol wicks up the sides of the chamber and evaporates near the top, forming a clear vapor filling the chamber. The vapor near the bottom is cooled by the fridge in the base. In fact, it supercools, falling below the temperature at which it would normally be liquid. This state is unstable, needing only a triggering event to cause condensation. When ionizing radiation, in this case a charged particle such as a beta or alpha ray (but not a gamma ray), passes through the vapor, it can remove electrons
from the atoms, leaving a trail of positive ions along the path of the ray. The ions trigger the condensation of the supercooled alcohol vapor along the path of the ray, and the resulting tiny droplets form a visible track. Neutral particles such as gamma rays do not make tracks. However, a gamma ray can strike an electron in an alcohol molecule, making the electron travel through the vapor. The electron (now identical to a beta ray) then leaves a track.

- When the chamber is working, you will see little blobs of fog near the bottom. You may also see the occasional longer tracks. These are due to traces of radioactivity in the lab and also perhaps to cosmic rays, that originates in space as high energy radiation then hit the atmosphere to produce secondary particles. Watch them for a while, commenting/sketching in note book what you observe.

- Count the number of events you see occur in the chamber in a 2 minute interval then divide by 2. This is a measure of the CPM using this device. Is it different than what you measured with the GM-45? Discuss what you expect to see and why. What might this mean for interpreting the amount of radiation exposure from a source.

- Have the AI bring you a radioactive source. The “thoria” and Po-210 sources produce alphas, the Sr-90 produces betas. These two needle sources can replace the stopper at the top of the chamber. Record notes on what you see in your notebook. Some sketches would be appropriate.
Part III: Discussion

Discuss these questions within your group and briefly note your conclusions in your notebook.

- How might you distinguish between alpha, beta, and gamma radiation with measurements, like those you’ve made today and others?
- What evidence have you seen today that some radiation is particles?
- List at least two ways to protect yourself from a source of radiation. (Let’s say it was small enough to carry, and you had to move it.)

****Assuming it has been recording for AT LEAST 30 minutes, NOW FINISH OFF YOUR HALF-LIFE MEASUREMENT BEFORE CONTINUING TO QUESTIONS BELOW.

- We often discuss radiation from everyday objects. **Predict what will happen if you place an active cell phone on the GM-45 counter** (e.g. downloading a web page or making a call). Now measure the rate (you may remove the paper for this measurement then replace it). Was it what you expected? Why or why not? What issues may affect the result?
Part IV: Radiation and radioactivity question(s)