Radioactive Absorption

Goals of this lab

- **understand how radiation flux changes with distance from the source**
- **understand how intensity of a light source changes with distance from the source**
- **observe the affect of intervening absorbers on radiation from the source**

WARNING: The Cobalt-60 radioactive source used in this experiment is quite harmless when properly used; NONETHELESS, HANDLE THE SOURCE AS LITTLE AS POSSIBLE.

Overview

One of the isotopes of Cobalt, ${}^{60}_{27}Co$, is radioactive and decays with the emission of electrons (0.31 Mev) and high energy photons or gamma rays (1.17 and 1.33 Mev). Its half-life is 5.3 years. The emitted electrons are absorbed by the encapsulating material and need not concern us further. Gamma ray flux is the number of photons hitting a unit area in unit time. We will study the way in which the gamma ray flux varies with distance from the source, and the way the gamma rays are absorbed by dense materials.

A point-source of this radioactive material emits its radiation in all directions. Therefore the gamma ray flux should obey the inverse square law characteristic of all point sources of radiation.

Radioactive decay is a *statistical* process. Many repetitions of the same measurement will lead to a set of results that have a spread of values centered on some number, *N*, with a range of $\sqrt{N}$. Accordingly, the uncertainty in the number of counts for a given time interval is the square root of the measured number of counts.

Distance law for radiation

We will study the way the counting rate falls off as the distance between the GM-tube and the radioactive source is increased.

The Cobalt source is mounted in a clear plastic rod and covered by a black plastic cap. The source is very close to the black plastic cap. The GM-tube is about 7 cm long and any ionization along its length will give a count. That means the distance between the source and the GM-tube is actually the distance from the source to some point in the tube where the ionization occurs *on the average*. We can express the distance between the source and the GM-tube as $\boldsymbol{a + x}$, where $\boldsymbol{a}$ is the distance from the end of the GM-tube to the average ionization point and $\boldsymbol{x}$ is our measured distance from the end of the GM-tube to the source.
The counting rate should fall off as the inverse square of the distance between the GM-tube and the source:

$$N = \frac{K}{(a+x)^2} \qquad (1)$$

> **Prelab Question 1:** Long ago, in a time before Egg McMuffin monopolized the breakfast market, physicist Eric Rogers proposed the following situation. A harried chef can't keep up

with his breakfast orders and decides to automate the process with a "butter gun". The gun provides a 10 gram burst of butter spray with each hit of the trigger. He starts with a rack that holds one piece of toast 1 meter away. The demand again exceeds supply and rather than spend more money on a second gun, he realizes he can use the same gun to produce more toast by placing a larger rack at a greater distance. He finds that a four-slice rack works at a distance of 2 meters. Pleased with profits he carries the idea a step further and puts a holder 3 meters away, maintaining a 10 gram spray as shown in **Figure Prelab 1**.

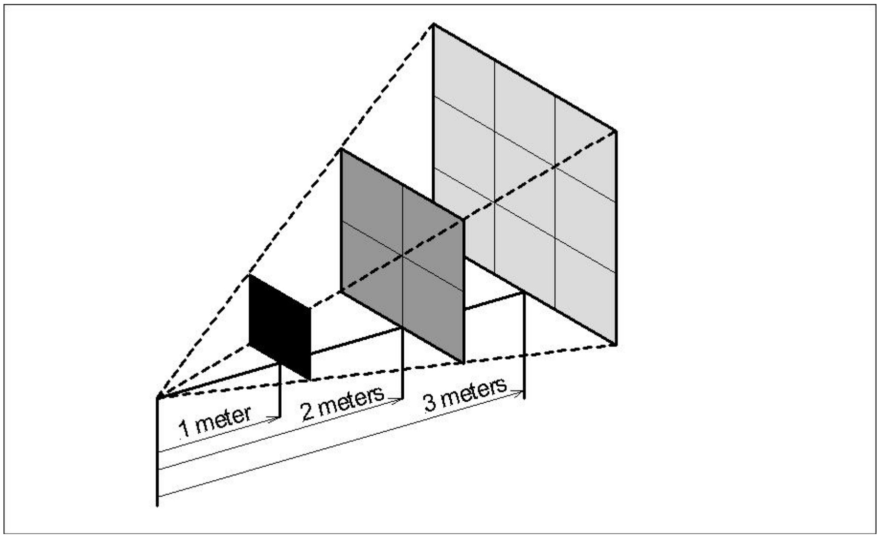

Figure Prelab 1: The butter gun evolving setup

1) If one spray entirely covers a single slice at one meter, can it entirely cover 4 slices at 2 meters? Why or why not?

2) How many slices can one spray cover with a 3 meter arrangement?

3) How do these changes affect the amount of butter on each piece of toast?

4) Our up-and-coming chef moves the gun back to 5 meters. Predict how much toast he can spray and how much butter each piece gets.

5) Explain how he could duplicate the original single-slice toast at 5 meters from the gun.

Distance law for light

We will study the way the intensity of a light source falls off as the distance from the source is increased. For this part of the experiment, we will use a light sensor interfaced to a computer. The relative decrease in intensity with distance is the same as for radiation.

Absorption

Dense materials (e.g., lead) strongly absorb gamma rays. Let the intensity of radiation incident on one side of a very thin slab of absorbing material of thickness dx be *I*, and the intensity of the emerging radiation be $I - |dI|$. The quantity dI is negative corresponding to a decrease in intensity. dI is proportional to the thickness of the absorber and to the intensity itself. The more radiation there is, the more that can be absorbed which is expressed mathematically as $dI \propto -Idx$ (1).

The coefficient of proportionality is called the *linear coefficent of absorption* and is conventionally denoted by the symbol μ. It is a characteristic of the material and varies greatly from substance to substance. Thus, the intensity of radiation satisfies

$$dI = -\mu I dx \tag{2}$$

This equation can be easily solved for *I*:

$$I = I_0 e^{-\mu x} \tag{3}$$

where I_0 is the incident intensity, x is the thickness of the material, μ is the absorption coefficient, and *I* is the emergent intensity.

Prelab Question 2: Picture a society in which each weekly paycheck physically passes through the hands of each of the governments in the area. Each administration "absorbs" a tax of 10% from the check they receive and passes on a new check for the reduced amount. Arthur Anderson lives in an area with federal, state, county and township governments. His $1000 weekly check goes to them in that order, with the federal tax first.

1) Exactly how much money is left in Mr. Anderson's paycheck after it passes through four 10% "absorbers"?

2) Explain why his check is still larger than $600 when he finally gets it after four 10% "absorptions".

3) If you were the township tax collector, would there be any reason to try to change your position of last in line to get the paychecks?

The Geiger Counter

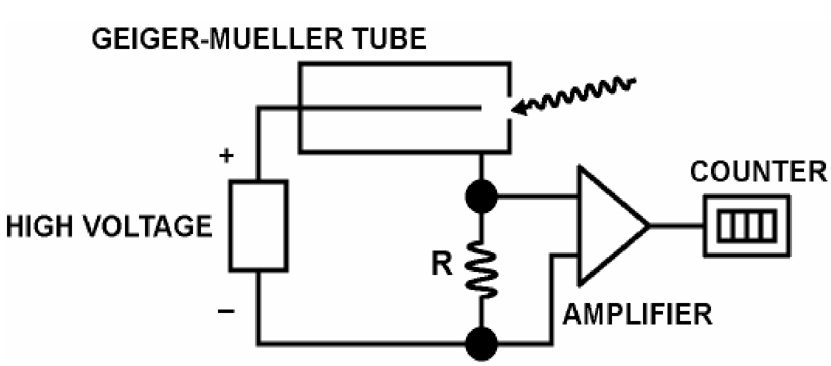

Figure 2: The Geiger-Mueller tube and related electronics.

We detect radioactivity using a Geiger-Mueller tube. The tube consists of a wire mounted coaxially within a metal cylinder and electrically insulated from it. The cylinder is filled with a combination of gases at very low pressure. One end of the metal cylinder has a very thin mica window that allows photons and electrons to enter. A cut-away model is in the laboratory for your inspection.

In operation a high voltage (approximately 1 kV) is applied between the thin wire and the metal cylinder. The wire is the anode, positive with respect to the cylinder, as shown in Figure 2. When an electron or gamma ray enters the tube it can ionize an atom. The electron produced is rapidly accelerated toward the anode by the strong electric field and gains enough energy to ionize additional atoms --- the process cascades until a large number of electrons and positive ions are produced. The effect of the cascade is to produce a large electron current flowing onto the anode and through the circuit where it triggers the external circuitry: a *count* is recorded. The current also produces a voltage drop across the resistor, which decreases the voltage across the tube itself, and causes the cascade to stop.

Prelab Question 3: The easiest type of graph to analyze is a straight line plot. That is why we always try to manipulate the data in any way possible to generate a straight line plot. This process is called linearizing and is described in the **Linearizing Data** section of the lab manual. In this example, complete the data table. If $y = 4x^2$, find $f(x)$ that will produce a straight line plot when used on the x axis. Make the straight line graph of y *vs* $f(x)$.

Note: In this example we know more about the values of *y* than we would if they were raw data measured in an experiment. In general, the slope can be used to find unknown constants.

x	*y*	*f(x)*
1	4	
2		
3		
4	64	

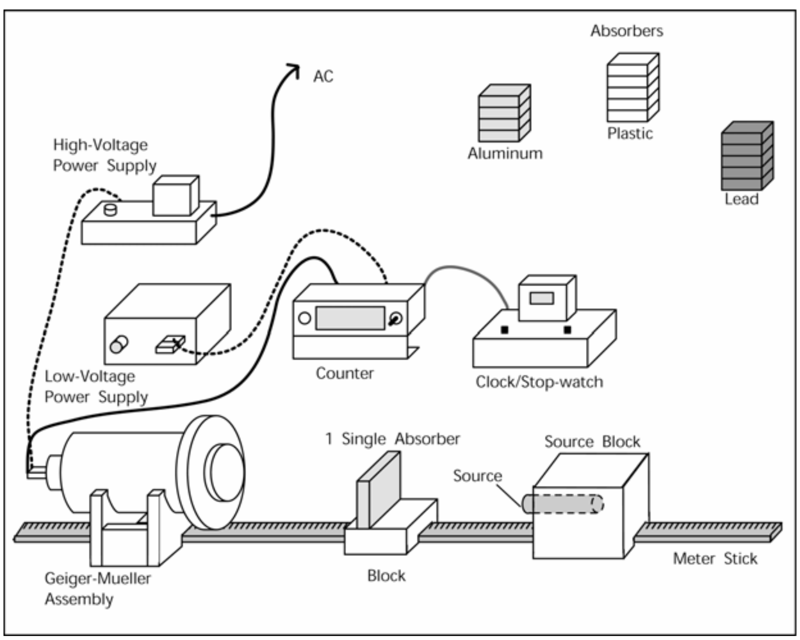

Figure 3: The equipment used to measure the absorption of the Cobalt source.
This figure is not drawn to scale, and orientations are only for illustration.

Questions

Part II

1) What is the count rate at 90 cm as compared to the rate at 45 cm?

2) Does your graph of N_C vs. $f(x)$ agree with the predicted relationship within experimental uncertainties?

3) How is the graph of light intensity vs. distance related to the graph of counting rate vs. distance?

Part III

1) Compare the absorption coefficients of lead and aluminum with their respective densities (lead, 11.3gm/cm^3; aluminum, 2.7 g/cm^3). What do you conclude?

2) What thickness of lead and what thickness of aluminum would diminish the incident radiation by a factor of two (this is the half-value thickness)?

Procedure Part I: Background count

1) Make sure the counter is turned on (as indicated by the red display numbers on the counter).

2) Set the power supply voltage to 950 volts.

3) Remove the source as far away from your GM tube as possible and count for 2 minutes; those counts are due to cosmic rays radiation coming through the walls and ceiling, other sources in the room and spurious events. Take such a *background* count about every 30 minutes. Subtract the background count from your measurements to obtain the corrected counting rate.

Procedure Part II: The Distance law for radioactivity and light

The radioactive source:

1) Make sure the radioactive Cobalt source (i.e. the black cap) is facing the GM-tube. All distance measurements should be made from that end of the holder.

2) Take 2-minute counts (N_C) with the source at six different distances between 20 and 90 cm from the end of the GM-tube as measured along the meter stick.

3) Plot N_C vs. some function of x that will result in a straight line. Show appropriate error bars for the data points. From this graph estimate the average ionization distance in the GM tube(a). Show your calculations.

The light source:

4) To collect data with the light sensor, align the light sensor with the light source on the meter stick. Open the "Light vs Distance" file on the computer desktop. Click the <Collect> button and then the <Keep> button. A window will appear that allows you to enter data. Once you enter your data the intensity and distance will be entered in the table automatically.

5) Plot Intensity vs. some function of x which results in a straight line, using at least 6 data points. Show appropriate error bars. Compare this graph with the graph for the Cobalt source.

Procedure Part III: Absorption

- Move the source a convenient distance along the meter stick from the GM-tube. Make 30-sec counts with 0, 1, 2, 3, 4 and 5 pieces of lead placed on the block provided, keeping the lead as close to the source as possible. Measure the total thickness of the different numbers of absorbers. Repeat this for the aluminum absorbers and the plastic absorbers.

- Plot your data in such a way that you can determine whether it can be represented by equation (3). Determine the linear coefficients of absorption of lead, aluminum and plastic. (Hint: $\ln(ab) = \ln a + \ln b$)