Absorption and Half Life of Radiation

Equipment Beta and Gamma sources, Spectech isotope generator kit, Geiger tube with power supply and counter, sample tray, meter stick, 2 trays, stop watch, box of rubber gloves, two glass dishes

Safety Considerations

This experiment uses weak radioactive sources that, if used prudently, are not dangerous. Nevertheless, use care when handling these materials, and avoid spilling the solutions. Always use rubber gloves when handling radioactive sources and do not drop them on the ground. If you do drop any of the sources tell the teaching assistant!

1 Purpose

There are two parts in this lab. First, absorption of radiation. This deals with determining the absorption of beta (β=negative electrons) and gamma (γ=high energy photons) radiation through various materials. Measurements are done with a Geiger-Muller tube and scaler. Second, half life of radiation. The half life of atomic nuclei have excited states that decay with the emission of radiation such as photons or particles. An important characteristic of these radioactive nuclei is the time it takes for half of them to decay. This is called half-life, or $T_{1/2}$. In this part you will measure the half-life of $_{56}Ba^{137m}$, where the "m" means that the Ba is in a metastable state and decays to the ground state with an emission of a higher energy photon (gamma ray).

2 Part 1 Absorption

3 Geiger-Muller Counter

The Geiger-Muller tube (the tube) detects ionizing radiation (Fig. 1). It consists of a wire inside of a cylinder that contains a gas at low pressure. A high electric voltage (HV) is maintained between the wire and the metal walls of the tube. When radiation passes into the tube through a thin window it ionizes some of the gas inside. The liberated electrons are accelerated towards the collector wire, and in their flight they strike other molecules with sufficient energy to cause further ionization. Each additional electron also is accelerated and will cause further ionization. An electron avalanche takes place. On reaching the collector wire there is a sufficient number of electrons (many millions) that a detectable pulse of current can be sensed electronically. This is registered on an appropriate display. Because of differences in construction, all Geiger-Muller tubes do not operate satisfactorily at the same voltage, **so the operator must determine the correct voltage value.**

If a radioactive sample is placed close to the tube window and the voltage is slowly increased from zero, the tube will not start counting until the voltage reaches its starting threshold. As the voltage is increased beyond threshold a rapid increase in the count rate takes place as the avalanche becomes effective. Somewhat past threshold the counting rate increases only slightly as the tube voltage is increased. This is the plateau region. The tube should be operated in this region. If the voltage is further increased another rapid rise of the count rate takes place. This is a region of continuous discharge and is produced by the electric field itself, **not by the ionizing radiation.** Operating the tube in the continuous discharge region will ruin the tube, and is undesirable anyway since the pulses are not related to the radiation of the source. **To help preserve the life of the tube (yes, they are expensive) the tube should be operated in the lower 25% of the plateau. This means a tube voltage of around 400 V.**

4 The apparatus

The tube is oriented vertically with the window facing down. It is placed on top of a box that has one open side with six pairs of horizontal slots. Starting from the top, number the slots 1, 2, 3, 4, 5, and 6, with slot 1 nearest the tube and slot 6 the furthest from the tube. A tray that holds the "radioactive source" (source) can be placed in any pair of slots. Various absorbers are placed on top of the source. A coaxial cable from the top of the tube goes to a power supply-scalar (scaler). A scaler is a device that counts pulses. The scaler unit supplies high voltage (HV) to the tube. The HV is controlled by two knobs labeled COARSE and FINE. The coarse knob has discrete steps and adjusts the HV from 0 to 1800 V in steps of 200 V. PLEASE DO NOT EXCEED 400 V WITH THE COARSE KNOB. The fine knob continuously adjust the HV from 0 to 200 V. The voltage supplied to the tube is the sum of the two settings. The scaler itself can be set to count pulses for a set period of time (in minutes, 0.1, 0.5, 1, 2, 5, 10, etc.) or to count time for a given number of pulses (500, 1 k, 2 k, 5 k, etc.). Note that times less than a minute are decimal. A toggle switch chooses which mode. The scaler has a six digit decimal readout. There are a set of 5 push buttons. When each button is pushed it lights up when activated.

THE BUTTONS' NAMES AND FUNCTIONS ARE:

- POWER - Turns power to the scaler on and off.
- TEST - Puts the scaler into a test mode in which line voltage is counted (60 Hz) after the COUNT button is pressed. This is not a check of the tube.
- COUNT - Starts the scaler counting ONLY if the STOP and RESET buttons are activated (lit). The counting stops whenever
    1. The STOP button is pressed.
    2. Preset time or pulses is reached.
- STOP - Stops the counting if preset time or preset counts does not do so first. This button lights up when preset time or preset counts is reached.
- RESET - Sets the scaler's register to zero. Be sure to record the counts or time before clearing the register. Clear the register before beginning a new set of counts.

5 Testing the Scaler

To Insure that the scaler is working we need to run a test count. Set the scaler to count for 1 min. Push POWER, TEST, STOP, RESET, and COUNT. Do you get the expected reading?

6 Which Side Is Up?

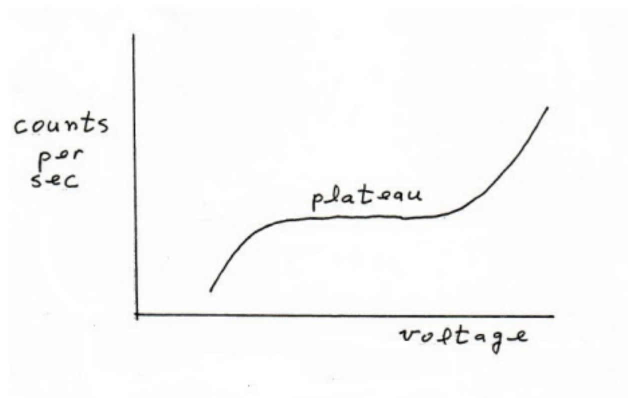
Set both HV knobs to zero, turn the scaler on, and give it a few minutes to warm up. The radioactive sources are disks, and one side has a label. **Should the label side be up or down, or does it not make a difference?** Set the HV to 400 V. Put the β source on a tray and insert the tray into slot 3 of the apparatus. Count the pulses for 0.5 min. Turn the source over and repeat. **Which gives more counts, label up or down?** Use the way that gives the largest number of counts. Repeat for the γ source. It has been found that the best way varies from source to source.

7 Investigating the Tube Characteristics

A beta source is used to find the plateau of the tube.

- Place the beta sample provided to you on shelf 2.
- RESET the scaler, set it to count for 5 minutes, and set the HV at zero.
- Press COUNT and increase the HV from zero in small increments until a noticeable increase in count rate is observed. To avoid jumps of 200 V, before increasing the coarse HV control, turn the variable fine HV control to zero.
- Set the counting time to 1 min. Starting at the HV just determined, count for 1 min. Repeat, raising the fine control HV in 20 volt steps.

Plot your data as you take it, and determine the plateau of the tube. Look at figure below on how the curve should look. **Note: Choose an operating HV about 25% along the plateau.**



8 Background Radiation

We are constantly exposed to a wide variety of natural radiation. This radiation comes from cosmic rays (radiation from space), and from radioactive atoms in the air, soil, building materials, and our bodies. This background radiation adds to the count rate of interest and should be subtracted out to find the radioactivity for the sample of interest. This is particularly important when the sample activity is low. Lead shielding can be placed around the tube and its stand and will prevent much of the background radiation from reaching the tube. Lead shielding will not be used here.

Prepare the scaler for counting as outlined in the previous section. Be sure to set the tube at the proper operating voltage as found from your plateau curve. No radioactive source will be used in this part. **Keep sources far away from the counting area.** Take five three-minute counts of the background with no shielding around the tube and stand. Record all data. N will be the average number of counts for your five readings. Calculate N. Roughly, the five values of the three minute readings should fall within the $\sqrt{N}$ of N. **Do they?**

Convert N into counts per minute. Use this value to correct your data for the background radiation, remembering to take into account the time you counted. For example, if you counted for two minutes, you would have to subtract from your counts twice the background counts per minute.

9 Absorption of Beta Particles

Beta particles are emitted from radioactive nuclei with a range of energies lying between zero and some maximum energy of a given isotope. The velocity of a beta particle can range from zero to nearly the velocity of light. In this experiment the time necessary to attain a given number of counts, such as 1,000=1 k counts, will be measured for a number of absorbers. This makes the counting uncertainties the same for all the measurements. Invert this time to obtain the intensity of the beam, per unit time of counts. Remember to correct for background.

- Place the beta source in the sample holder and insert it in shelf 3 of the tube stand. (You can use shelf 2 if the counting rate seems too low.)
- Use the toggle switch on the right and set it to PRESET COUNTS
- With no absorber, determine the time necessary to attain some given number of counts. Experiment some to find a reasonable number of counts that will take maybe 0.5 minute. Remember that the times will get longer as absorbers are added. Use the same number of counts for your measurements when the absorbers are added and correct for background.
- Now lay the thinnest absorber on top of the source and take another set of data. Keep doing this with thicker absorbers until the counting time gets too long.

Plot your results on a logarithmic graph. Place the beam intensity on the log scale and absorber thickness on the linear scale. It is customary to express the "thickness" of the absorber in mg/cm^2. Use this as the independent variable on your graph. **What absorber thickness is necessary to cut this beta radiation to 1/2 of its original Values? Why do you think that nuclear physicists prefer mg/cm^2 as the unit for quoting results, instead of a simple linear dimension?** If your data points lie on a straight line, the beam attenuation is exponential with absorber thickness. **Is it?**

10 Gamma Rays

Gamma rays (γ), unlike alpha and beta radiation, consists of electromagnetic waves. Gamma rays are high energy photons which travel at the speed of light. They are produced by transitions within the nucleus of an atom between different energy levels. Gamma rays interact with matter in a variety of ways, any of which can prevent the gamma rays from reaching the tube of a Geiger-Muller counter if matter is placed in front of the tube. Make measurements with a gamma ray source similar to the ones you made with the beta sourse. Analyze your date in the same way.

11 Part 2 Half Life

12 Theory

If there are a number $N(t)$ of identical radioactive nuclei, at the time t, it is not possible to say when anyone of them will decay. The probability per unit time that one of them will decay is given by a decay constant λ. The change in N is given by the time dt and by $dN = -\lambda N dt$. This integrates to give

$$N(t) = N_0 e^{-\lambda t}, \tag{1}$$

where N_0 is the number of radioactive nuclei at time $t = 0$. The decay is exponential with respect to time. To find $T_{1/2}$ in terms of λ, let $t = T_{1/2}$ and $N/N_0 = 1/2$. The result is

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}. \tag{2}$$

13 Radioactive half life Source

The source is a cylinder that has two openings one on top and bottom. Both are capped with removable plugs. Inside the source is a small quantity (10 μCi) of ${}_{55}Cs^{137}$ which is radioactive and has a half-life of 30.1 y. Please see Fig. 2. This isotope of cesium is a β^- emitter and 94.6% of the time decays to a metastable state of barium, ${}_{56}Ba^{137m}$. This isotope of barium decays to the ground state by emitting a 0.662 MeV gamma ray photon. The half-life of ${}_{56}Ba^{137m}$ is 2.55 min and is the half-life that is the subject of this lab. The cesium is bound on an ion exchange medium and hopefully stays in the source. In the source, the amount of radioactive cesium stays essentially constant due to its long half-life. The concentration of radioactive barium will reach an equilibrium amount in 4-5 barium half-lives. When needed for the experiment, the barium is flushed out of the source by an "eluting" solution. Elute is a verb that means to remove an adsorbate from an absorbent by means of a solvent. The eluting solution is not supposed to remove any cesium. In less than an hour, the equilibrium concentration of barium is again established in the source and the source can be used again.

14 Strength of the Source

There are two radioactive items associated with this part. The first is the cylinder that contains the radioactive cesium. This will be referred to as "the source.". The second is the solution that contains the radioactive barium. This will be referred to as the "barium solution."

- Remove the trays and place the Geiger tube on its side at one end of the bench, with the open side (the side of the stand that has the slots for the sample trays) toward the bench top.
- Place the source as close to the window end of the tube as possible and find a suitable plateau voltage for the Geiger tube.
- Count for 0.1 min, record the counts, and then move the source 5 cm away from the tube window. Again count for 0.1 min. Repeat this procedure, building up a table of 0.1 min counts versus distance of the source from Geiger tube.
- When you're done turn the Geiger tube to the normal upright position

Questions

1. How far away does the source have to be before its presence makes no difference? When measuring the strength of the barium solution, keep the source a sufficient distance from the Geiger tube so that the source does not contribute to the counts.
2. How does the strength of the source fall off with distance? Discuss.

Important

Before proceeding, read and digest the rest of this write-up so that you can do the procedures expeditiously. The barium half-life is short, and you do not want to take too much time between drawing the barium solution and counting decays. On the other hand, you should not move so quickly that you risk spilling the barium solution.

15 Preparing The Barium Solution

From the isotope generator kit, locate the syringe, tubing, eluting solution, and planchet (small metal cup). Also have on hand two dishes and the sample tray that fits into the slots in the Geiger tube holder.

- Put on a pair of the disposable gloves provided.
- Place the planchet into the sample tray and place the tray into one of the dishes provided. (The purpose of the dishes is to contain any spills.)
- Remove the two caps from the source and put the source in a dish. Put the tubing onto the end of the syringe and push the syringe plunger all the way in. Stick the free end of the tubing into the eluting solution and draw about 2 ml of eluting solution into the syringe by pulling back on the plunger.
- While one end of the tubing is still in the eluting solution bottle, remove the tubing from the end of the syringe and let the solution in the tubing run back into the bottle. Place the tubing in a dish. Attach the syringe to the top of the source. **There is an arrow on the source that indicates the direction of flow of the solution through the source!**
- NOTE: If there is air between the eluting solution and the syringe and the top of the source, then the solution won't drip out until there is no air in the tube.

- Hold the bottom of the source over the planchet and carefully deposit 7 drops of solution into the planchet by pushing on the syringe plunger.
- Remove the syringe from the source and empty it into the eluting solution bottle. Put the empty syringe into a dish. Put the caps on the source and put the source in a dish. Insert the sample tray with the planchet into the top pair of slots of the Geiger tube holder. Record the time of day. (We will ask you to measure the strength of the source at the end of the lab and the time since the source was prepared.)

16 Taking Data

Set the counter to count for 0.1 s. Start the stopwatch and counter at the same time. As soon as the counter stops write down the number of counts and reset the counter. Do not stop the stopwatch. When the stopwatch reaches 30 s start the counter again, writing down the counts when the counter stops. Repeat this process, recording the counts every 30 s. Use your judgment for how long to do this, but probably 3.5 to 4.0 min should be sufficient. When finished, leave the planchet with the Ba solution under the Geiger tube.

17 Analysis

Plot your data on one or two cycle semi-log graph paper, with counts on the logarithmic axis and time on the linear axis. Draw what you consider to be the "best" straight line through your data points. Pick two widely spaced convenient points on this line whose coordinates are (N_1, t_1) and $N_2, t_2)$, where $t_2 > t_1$. Calculate the slope of the line which is the decay constant λ from the equation

$$\lambda = \frac{\ln \frac{N_1}{N_2}}{t_2 - t_1}. \tag{3}$$

Use Eq. 2 to calculate the half-life. Compare your result to the published value of $T_{1/2} = 2.55\ min$.

If your calculator will give you a least squares fit for a line, use your calculator and all your data points to give you such a fit. From the slope provided, calculate the half-life and compare to the value you got from the straight line on your graph.

18 Source Check

Measure the strength of the Ba solution by counting for 1 min. Remove the planchet and its tray from beneath the Geiger tube, put them in a dish, and move them to the far side of the bench. **Count the background, and note the time. If more than 20 min has passed since the Ba solution was prepared, there should be very little activity from the Ba solution. If this is not the case, inform the 2nd floor staff. It means that Cs is getting out of the source!** Leave the barium solution on the bench. The staff will dispose of it.

19 Finishing Up

Leave the planchet with the Ba solution on the bench. Dispose of your gloves and if any of the sources broke open notify the second floor staff or the teaching assistant. Put back the sources in the proper cases and straighten out the bench. Cheers.

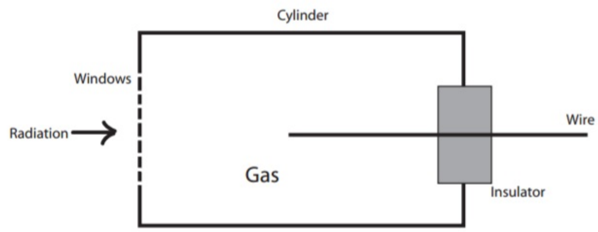


Figure 1: Geiger-Muller tube

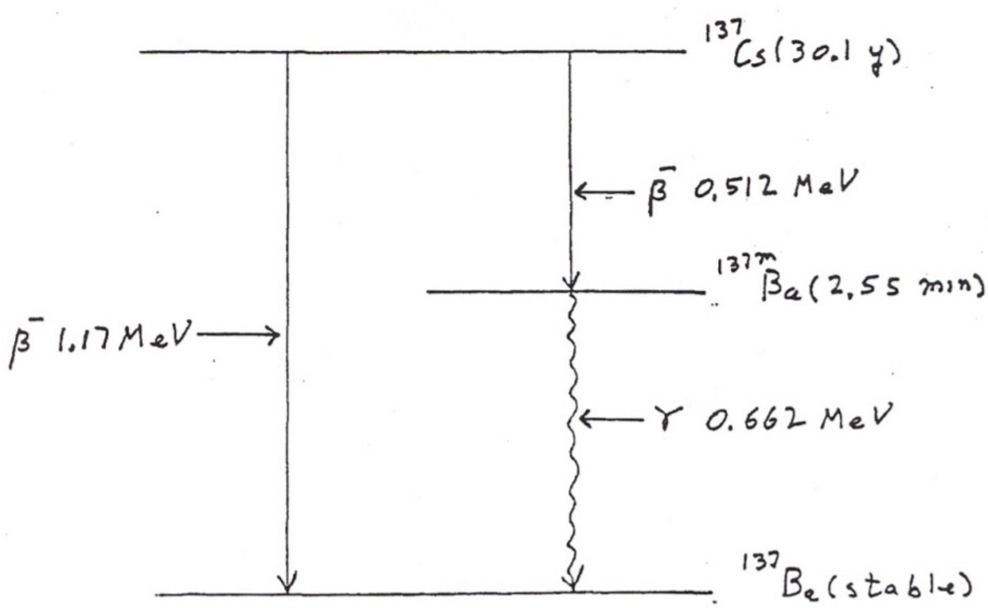


Figure 2: Decay of Cs-137