Absorption Of Radiation (1) Lab 4

1 Purpose

In this experiment the absorption of beta (β=negative electrons) and gamma (γ=high energy photons) radiation by various materials is studied. Measurements are done with a Geiger-Muller tube and scaler.

2 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 toward 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, and 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.

3 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. Each button lights up when activated. The buttons' names and function are:

- POWER-Turns power to the scaler on and off. This button toggles.
- 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. This button toggles.
- 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, or
  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.
- CLEAR-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.

4 Testing the Scaler

Set the scaler to count for 1 min. Push TEST, STOP, CLEAR, and COUNT. Do you get the expected reading?

5 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.

6 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. CLEAR 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 HV control to zero. Set the counting time to 1 min. Starting at the HV just determined, count for 1 min. Repeat, raising the HV in 20 volt steps. Plot your data as you take it, and determine the plateau of the tube. Choose an operating HV about 25% along the plateau.

7 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 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. This procedure 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. Let N 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.

8 Absorption of Beta Particles

Beta particles are emitted from radioactive nuclei with a range of energies lying between zero and some maximum energy for 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, 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, counts per unit time. 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.) 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 minutes. 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. Invert the time to get the counts per minute, 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 a graph of the results on semi-log paper, putting 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?

9 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.

10 The Square-Root Rule

Devise an experiment to check the square-root rule which is discussed in sections 3.2 and 11.2 of "Error Analysis" by John Taylor. If you have time, take enough data so that you can investigate the Poisson distribution. This last experiment would probably be more interesting and less time consuming if the average number of counts is around 3 or less. See Fig. 11.1 of Taylor.

11 Finishing Up

Please leave the bench as you found it. Thank you.

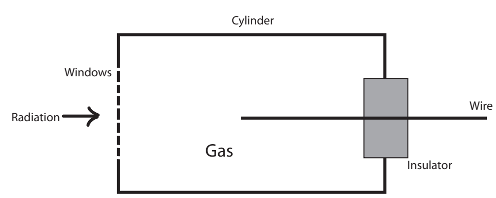

Figure 1: Geiger-Muller tube