EXPERL14ENT 13

THE GEIGER PLATEAU
AND THE HALF-LIFE OF BARIUM-137

The operating voltage of a Geiger-Mueller tube is found. The tube is used to count the radioactive decays of barium-137 whose half-life is then determined.

THEORY, Part 1

A Geiger-Mueller (G-M) tube is used to detect high energy particles and radiation. It consists of a cylindrical container filled with an Inert gas. A wire is stretched along the axis of the cylinder and a high voltage is applied between the wire and the cylinder. When a light energy particle or radiation enters tile tube through the G-M tube "window," the particle or radiation collides with and ionizes an atom iii the tube. Because of the high voltage between the wire and the cylinder, the two parts of the ionized atom accelerate toward their respective collectors and collide with and ionize other atoms. The resulting cascade of ions produces an electrical pulse in the detector.

All G-M tubes do not operate at the same voltage because of differences in the construction of the tubes. If a radioactive sample is positioned so that the radiation enters the tube and the voltage supplied to the tube is gradually increased from zero, then the atoms in the tube will not ionize until the voltage reaches a starting potential. (Refer to Figure 1.) As the voltage is increased beyond this point, a rapid increase in the count rate takes place. This voltage is known as the threshold. Past the threshold, further increase in voltage results in a negligible increase in counting rate. This region is called the plateau. An operating voltage is selected within this plateau.

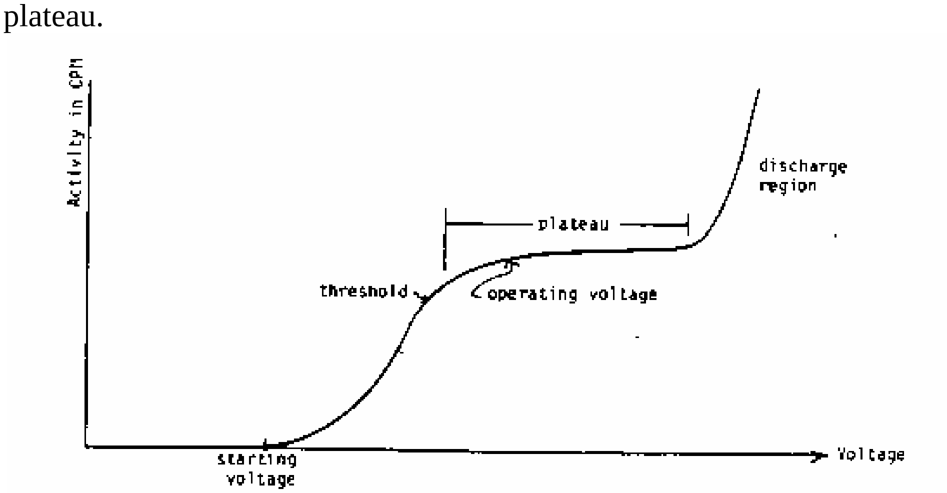

Figure 1. The activity of a radioactive sample as detected by a G-M tube at various operating voltages.

To help preserve the life of the tube, the operating voltage is usually selected within the lower 25% of the plateau (near the threshold). If the voltage is increased further past the plateau, then another rapid rise in the count rate takes place. This region is called the discharge region. In this case the voltage is large enough to cause the atoms to self-ionize. Operating a G-M tube in this region will quickly ruin the tube.

THEORY, Part 2

The rate at which radioactive nuclei decay is proportional to the number of radioactive nuclei that are present. This can be expressed as

$$\frac{dN}{dt} \;\; a \;\; N, \tag{1}$$

where N represents the number of radioactive nuclei. When proportionality constant is introduced (1) becomes

$$\frac{dN}{dt} = -\lambda N, \tag{2}$$

where k is called the decay constant 'of the radioactive material. When the variables are separated and the results integrated, the number of radioactive nuclei present after a time t is

$$N = N_o e^{-t\lambda}, \tag{3}$$

where N_o is the number originally present. Equation (3) indicates that the number of radioactive nuclei decrease exponentially with time.

The time that it takes half the radioactive nuclei to decay is the half-life of the material, $T_{1/2}$. So when $t = T_{1/2}$, $N = (1/2)N_0$, Note that when these are substituted in (3),

$$T_{1/2} = \frac{0.693}{\lambda}. \tag{4}$$

Expressions similar to (3) hold also for the mass of the radioactive sample and the rate of disintegration. For the mass

$$M = M_0 e^{-t\lambda}; \tag{5}$$

and for the rate of disintegration

$$R = R_0 e^{-t\lambda}. \tag{6}$$

The shape of the graph for the number of radioactive nuclei, N. the mass of the radioactive material, M. and the rate of disintegration, R, are identical. Figure 2 shows the graph of the three quantities versus time and their values after successive half -lives.

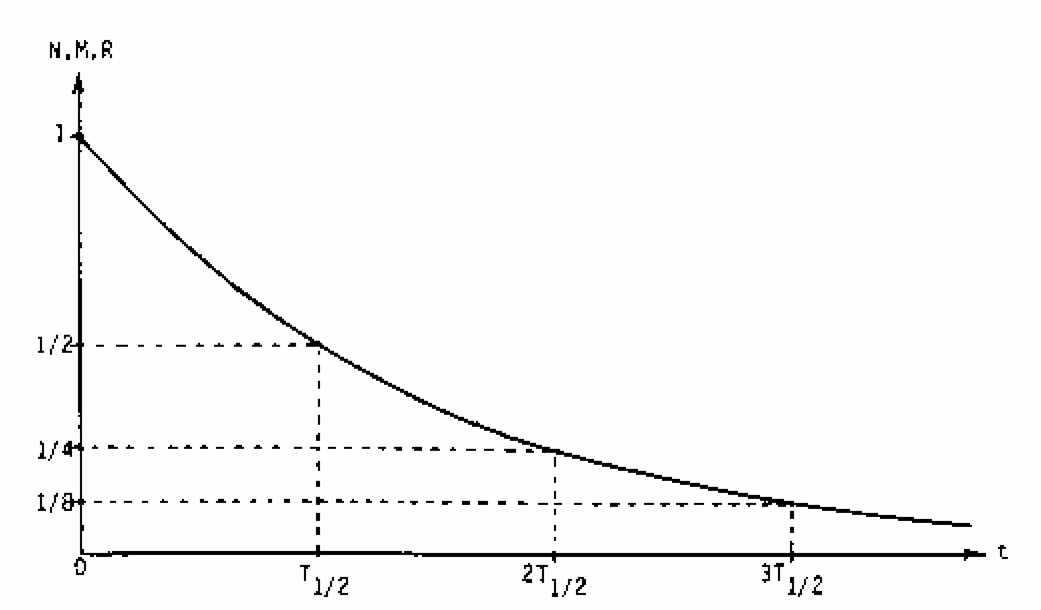

Figure 2. Graphs of number of nuclei, mass, and rate of disintegration for radioactive nuclei.

APPARATUS

- Geiger-Mueller tube
- scalar
- cesium-137 source
- barium-137 source to be obtained from the instructor
- tube stand and sample holder
- stopwatch

The Geiger-Mueller tube is inserted in the tube stand and connected to the scalar. The scalar is nothing more than an adding machine that counts the number of pulses coming from the G-M tube.

PROCEDURE, Part I

In the first part of the experiment, the operating voltage of the G-M tube is to be determined. The voltage supplied to the tube is to be increased by 25 volt increments, and radioactive disintegrations will be counted over one minute interval. These data will be graphed as they are being collected In order that the voltage supplied to the tube not exceed a safe maximum value.

a) Turn the voltage knobs on the scalar to their lowest values (completely counterclockwise). Turn on the power switch and allow the instrument to warm up.

b) Place the plastic-coated cesium-137 source on the planchette and slide the planchette into the second set of slots below the G-M tube.

c) Adjust the voltage to 25 volts. Reset the counter by pressing the reset button, and set the timing interval to one minute. Press the count button. The scalar automatically will stop after counting the number of radioactive disintegrations in one minute.

d) Repeat step (c) at 25 volt intervals. While the data is being collected, plot the data on a voltage versus activity graph. The activity is in counts per minute (CPM). Do not exceed a voltage value that is 10% above the average plateau value. Continuous discharge can take place and will drastically shorten the life of the G-M tube.

e) From the graph in (d), choose an operating voltage for the G-M tube. The voltage should be a value that is approximately 25% from the threshold along the plateau. Report this operating voltage clearly.

f) Remove the cesium-137 source and place it at least one meter from the G-M tube in order to minimize its effect on the subsequent measurements.

PROCEDURE, Part 2

In this part of the experiment, the half-life of barium-137 is determined. Thirty second counts are to be made during each minute that elapses. The continuous timer and the counter are started simultaneously. After thirty seconds the counter stops. The number of counts is recorded and the counter reset. When the continuous timer shows that one minute has elapsed, the counter is started again. This procedure continues until the counts (in CPM) drop to approximately twice the value of the background count. These values are then converted to activity in CPM from which the background radiation count is subtracted. The resulting values are then graphed against time.

a) Set the voltage on the scalar to the operating voltage of the G-M tube. A background radiation count is to be made. Slide a clean planchette into the second set of slots below the G-M tube. Take a one minute count and record this data as the activity in CPM due to background radiation.
b) As soon as you are sure of the procedures for the thirty second count every minute, inform the instructor. The instructor will provide you with a radioactive sample that is placed on the clean planchette in the second slot. Immediately slide in the planchette. Be sure that the scalar is reset, and start the count and the continuous timer simultaneously.
c) Take thirty second counts until the activity of the counts in CPM approaches twice the background count. (A suggested form for a data table is shown in Figure 3.)

Time (min)	Thirty Second Count	Activity, Gross (CPM)	Activity, Net (CPM)
0			
1			
2			
3			
	(etc.)		

Figure 3. An example of a table that can be used to record half-life data. Activity, Net = Activity, Gross - Background Count.

d) When the thirty second counts are completed, remove the planchette with the radioactive sample and pour the sample into the beaker provided at the front of the lab. Clean your planchette with water, dry it, and replace it in the holder.

e) Take another one minute background count.

ANALYSIS, Part 1

In this part the operating voltage of the G-M tube Is found. A graph of the activity versus the voltage supplied to the tube is plotted, and the plateau region located. The operating voltage is chosen to be slightly greater than the threshold voltage. Report clearly the value of the operating voltage.

ANALYSIS, Part 2

Three different methods are used to find the half-life of barium-137.

1. From the data collected for the decay of barium-137, select a Net Activity count. Choose another count that Is more than three minutes later, and use these data to find the half-life using (3) and (4). Repeat this for two more pairs of points. Find the average half -life of the three values

2. Plot the data points for the Net Activity versus time. Draw a smooth curve through the points. The curve should have the shape of an exponential decay. Choose a point of the curve corresponding to a convenient value of Net Activity (e.g., a nice round number). Find a second point on the curve that has a Net Activity that is half that of the first point. The time from the first point to the second point represents the half-life of the material. Repeat this two more times. Find the average half-life of the three values.

3. Again plot the data points for the Net Activity versus time, however, this time use semi-log graph paper obtained from the instructor. Plot Net Activity on the logarithmic axis and time on the rectangular axis. Draw the best straight line through the data points. Choose a point on the line corresponding to a convenient value of Net Activity (e.g., a nice round number). Find a second point on the line that has a Net Activity that is half that of the first point. The time from the first point to the second represents the half-life of the material. Repeat this two more times. Find the average half-life of the three values.

In a table, report the three sets of the values of half-life, the average half-life of each of the sets, the "true" value of the half-life, and the percentage errors between the "true" value and each of the average values. Take the "true" value to be 2.6 minutes.