46 Radioactivity

Half-Life

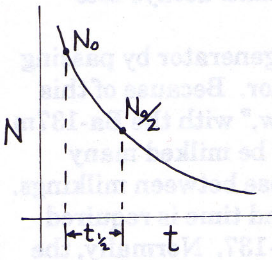
Purpose

To measure the half-life of a radioactive substance.

Required Equipment and Supplies

LabNet Geiger Interface and software from PASCO
Apple II series or IBM compatible computer (with game-port interface card)
ringstand
clamps
Cs-137/Ba-137m Minigenerator with 0.04 HCl-saline solution
watchglass
Data Plotter graphing program (optional)

Discussion



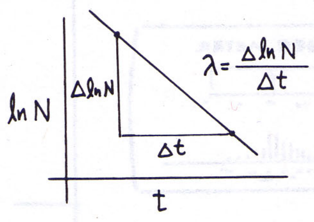
Probably no single phenomenon has played so significant a role in the development of nuclear physics as radioactivity. The decrease in the activity of a radioactive isotope is characterized by its *half-life*—the time required for one-half of the nuclei of a sample to decay. Although the nuclei of a sample cannot be counted directly, the activity or the rate of emission of nuclear radiation decreases by one-half as one-half of the nuclei decay. By monitoring the sample with a Geiger counter, you can determine the half-life by determining when the count *rate* decreases to half its original value.

Since the activity of a radioactive isotope is proportional to the quantity of isotope, the radioactive decay process is described by an exponential function,

$$N = N_0 e^{-\lambda t}$$

$$= N_0 e^{-t/\tau}$$

where N is the number of nuclei in a sample at time t, N_0 is the original number of nuclei in the sample at time $t = 0$, λ is the *decay constant* of the process, and $\tau = 1/\lambda$ is the *time constant* (see "Getting All Charged Up" for a discussion of exponential functions). A large value of λ corresponds to a rapid decay, a small value to a slower decay. The variable N can also represent the activity (counts per minute or cpm) of an isotope sample.



The half-life, $t_{1/2}$, is the time it takes for the number of nuclei in a sample to decay or the activity to decrease by one-half ($N = N_0/2$). Hence,

$$\frac{N}{N_0} = \frac{1}{2} = e^{-\lambda t_{1/2}}$$

Taking the natural logarithm of both sides,

$$\ln\left(\frac{1}{2}\right) = \ln\left(e^{-\lambda t_{1/2}}\right)$$

$$-0.693 = -\lambda t_{1/2}$$

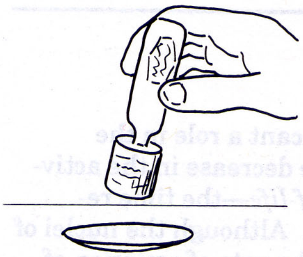
so that

$$t_{1/2} = 0.693/\lambda$$

or,

$$t_{1/2} = 0.693\tau$$

Thus, the half-life can be computed if the time constant, τ, or the decay constant, λ, is known.

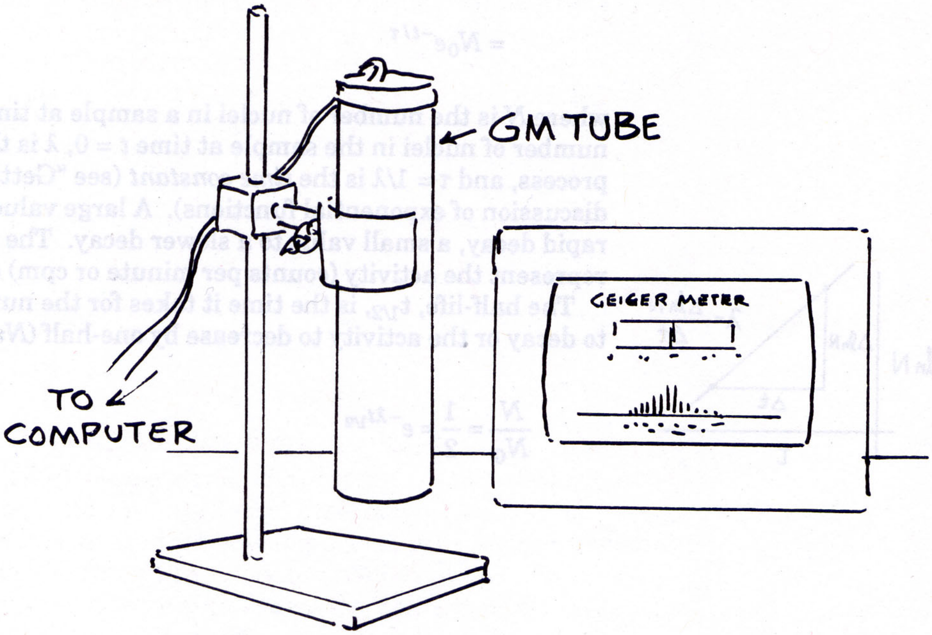


The Cesium-137/Barium-137m Minigenerator is an eluting system in which a short-lived daughter radioactive isotope is eluted (separated by washing) from a long-lived parent isotope. A small "generator" contains radioactive Cs-137, which has a half-life of 30 years. Cs-137 beta-decays into Ba-137m, which is an isomeric state of the nucleus Ba-137. The excited isomer Ba-137m has a relatively short half-life and gamma-decays into Ba-137.

The Ba-137m isotope is washed, or eluted, from the generator by passing a hydrochloric acid-saline solution through the generator. Because of this process, the generator is commonly referred to as a "cow," with the Ba-137m being "milked" from the cow. The generator "cow" may be milked many times, but like an actual cow, a time interval must elapse between milkings.

Eluting removes the Ba-137m from the generator, and time is required for the "regeneration" of Ba-137m from the decay of Cs-137. Normally, the parent and daughter isotopes exist in equilibrium in equal activities. After eluting or milking of the cow, it takes about 15 minutes for the Ba-137m to build up again and reach equilibrium with the Cs-137.

In this experiment, you will determine the half-life of Barium-137m.



Procedure

Step 1. Your instructor will have the Geiger counter apparatus set up for you. The counter measures activity due to background radiation activity as well as from the Ba-137. First, use the counter apparatus to measure the background radiation over a 5 minute interval.

Step 2. Mount the Geiger probe so that a watchglass with the radioactive Ba-137m sample can be quickly and carefully placed below and near the probe opening at a fixed distance.

Step 3. "Milk the cow" by squeezing between 5–10 drops of liquid through the generator onto a watchglass. Care should be taken in handling the sample. The milking should be done over a paper that can be discarded in case of a spill. If you should come in contact with the sample, immediately wash your hands.

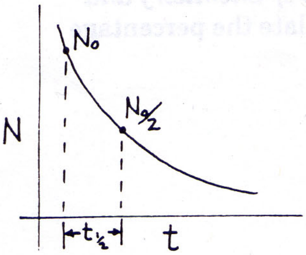
Step 4. Select "Meter" and begin measuring the activity of the Ba-137m. Record the average value shown on the screen at the end of the first three intervals. If you are using a Geiger counter with a scaler-counter, proceed directly to Step 6.

Step 5. Quickly (so the activity rate does not decrease significantly) "Escape" to the Main Menu and select "Graph" and press "Return." Select "15" minutes, enter "0" for the minimum rate, and a maximum rate that is equal to the rate found in Step 4. After entering the correct information, press the spacebar to begin graphing. When the graphing is complete, make a sketch of your graph. Your data can be saved on a disk. Record representative data in Data Table 46.1.

Step 6. If you are using a Geiger counter that does not incorporate the computer, use the following procedure. When the sample is in place, the laboratory timer is started (t = 0) and allowed to run continuously. Simultaneously with the starting of the timer, the activity is measured on the Geiger counter for 15 seconds, and the count rate (cpm), together with the time elapsed on the timer, is recorded in Data Table 46.1. If you are using a rate meter, the average of the high and low meter readings over the 15-second interval is taken as the count rate. If a scaler is used (with or without an internal timer), the count rate in cpm must be computed. For example, suppose that 500 counts are observed for the 15-second (1/4 minute) interval. The count rate is then 500 counts/ 1/4 min = 500 · 4 = 2000 cpm.

After another half minute has elapsed on the timer, take another 15-second count of the activity. Repeat the 15-second count at the beginning of each half minute for 15 minutes. Performing a dry run of this procedure is helpful.

Analysis



Method 1: Analyzing Activity vs. Time

1. Subtract the background radiation activity from that of your sample Ba-137. Using your data from Data Table 46.1, make a graph of sample activity, *N*, in cpm as a function of the elapsed time, *t*, in minutes. If available, use *Data Plotter* and make a printout of your graph. One way to determine the half-life is to simply inspect your graph. Near the beginning of the graph label an initial value, N_0. Locate and label the point on the

Data Table 46.1

BACKGROUND COUNT (CPM) = ________		
ELAPSED TIME t	OBSERVED ACTIVITY N'	CORRECTED ACTIVITY N

graph where the activity decreases to $N_0/2$. The corresponding time interval it took to drop from N_0 to $N_0/2$ is the half-life. Express your answer in minutes.

$t_{1/2}$ = ________

2. Look up the half-life of Ba-137m in the *Handbook of Chemistry and Physics* or from some other published source. Calculate the percentage error.

published half-life = ________

measured half-life = ________

percentage error = ________

Method Two: Analyzing Log_e Activity vs. Time (Optional)

3. The following questions pertain to determining the half-life by analyzing a semilog plot of the activity vs. time. Although interesting, it is mathematically more complicated.

The activity at any time, *t*, is given by

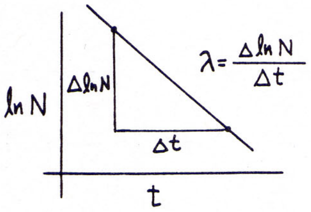
$$N = N_0 e^{-\lambda t}$$

or

$$\frac{N}{N_0} = e^{-\lambda t}$$

Taking the natural logarithm of both sides of the equation,

$$\ln\left(\frac{N}{N_0}\right) = -\lambda t$$



Solving for λ

$$\lambda = \frac{-\ln(N/N_0)}{t}$$

Therefore, the decay constant, λ, is the slope of the natural logarithm of the activity vs. time graph. Using your data, select "Graph Set-Up" and make a plot of $\ln N$ vs. t. (The graphs $\ln(N/N_0)$ vs. t and $\ln N$ vs. t have the same slope.) Make a printout of your graph. Calculate the decay constant, λ, from the slope of your graph.

$\lambda =$ ________

4. Calculate the half-life, $t_{1/2}$, in minutes.

$t_{1/2} = 0.693/\lambda$

$t_{1/2} =$ ________

5. Finally, calculate the percentage error. Which method for determining the half-life is more accurate? Since both methods involved using the same data, how do you account for any discrepancy?

percentage error = ________