

Experiment: Measurement of Ba-137 Decay & Half-life

OBJECTIVES

- Use a radiation counter to measure the decay constant and half-life of barium-137.
- Determine if the observed time-variation of radiation from a sample of barium-137 is consistent with simple radioactive decay.

MATERIALS

- Windows PC
- LabPro Interface
- Logger *Pro*
- Vernier Radiation Monitor
- Cesium/Barium-137 Isogenerator
- cut-off paper cup for Barium solution

INTRODUCTION

The *activity* (in decays per second) of some radioactive samples varies in time in a particularly simple way. The activity (R) in decays per second of a sample is proportional to the amount of radioactive material

$$R \sim N \text{ \{the number of radioactive nuclei\}}$$

Then the activity (R) must decrease in time as the number of radioactive nuclei decreases according to the relation:

$$R(t) = R_0 e^{-kt}$$

In this equation “e” is 2.718 and is called the natural exponent. You will note that there is likely an “e” key on your scientific calculator. k is the *decay constant* (not the Boltzman constant), commonly measured in s^{-1} or min^{-1} . R_0 is the activity at $t = 0$. The SI unit of activity is the becquerel (Bq), defined as one decay per second. Note, as you raise “e” to a negative power of time, it will decrease as the time interval increases!

You will use a source called an isogenerator to produce a sample of radioactive barium. The isogenerator contains cesium-137, which decays to barium-137. The newly made barium nucleus is initially in a long-lived “excited” state, which eventually decays by emitting a gamma photon (γ). A gamma photon is a high energy x-ray photon. The “relaxed” barium nucleus is then stable, and does not emit further radiation. Using a chemical separation process, the isogenerator allows you to remove a sample of barium from the cesium-barium mixture. Some of the barium you remove will still be in the excited state and will subsequently decay. It is the activity and lifetime of the excited barium you will measure.



While the decay constant k is a measure of how rapidly a sample of radioactive nuclei will decay, the *half-life* of a radioactive species is also used to indicate the rate at which a sample will decay. A half-life is the time it takes for half of a sample to decay. That is equivalent to the time it takes for the activity to drop by one-half. Note that the half-life (often written as $t_{1/2}$) is not the same as the decay constant k , but they can be determined from one another.

Follow all local procedures for handling radioactive materials. Follow any special use instructions included with your isogenerator.

PRELIMINARY QUESTIONS

1. Consider a candy jar, initially filled with 1000 candies. You walk past it once each hour. Since you don't want anyone to notice that you're taking candy, each time you take 10% of the candies remaining in the jar. Sketch a graph of the number of candies for a few hours.
2. How would the graph change if instead of removing 10% of the candies, you removed 20%? Sketch your new graph.



PROCEDURE


1. Prepare a shallow cup to receive the barium solution. The cup sides should be no more than 1 cm high.
2. Connect the radiation monitor to DIG/SONIC 1 of the LabPro Interface. Turn on the monitor.
3. Start LoggerPro then open the experiment file: "03 Lifetime" from the *Nuclear Radiation w/ Computers* directory.
4. Prepare your isogenerator for use as directed by the manufacturer. Extract the barium solution into the prepared cup. Work quickly between the time of solution extraction and the start of data collection in step 6, for the barium begins to decay immediately.
5. Place the radiation monitor on top of or adjacent to the cup so that the rate of flashing of the red LED is maximized. Take care not to spill the solution.
6. Click  to begin collecting data. Logger *Pro* will begin counting the number of gamma photons that strike the detector during each 30-second count interval. Data collection will continue for 30 minutes. Do not move the detector or the barium cup during data collection.
7. After data collection is complete, the  button will reappear. Set the radiation monitor aside, and dispose of the barium solution and cup as directed by your instructor.

DATA TABLE

Average background counts	
fit parameters for $Y = A \exp(-C \cdot X) + B$	
A	
B	
C	
$k \text{ (min}^{-1}\text{)}$	
Measured $t_{1/2} \text{ (min)}$	
Calculated $t_{1/2} \text{ (min)}$	
Slope of $\ln(\text{Corrected Counts})$ vs time (min^{-1})	

ANALYSIS

- Inspect your graph. Does the count rate decrease in time? Is the decrease consistent with an activity proportional to the amount of radioactive material remaining?
- Compare your graph to the graphs you sketched in the Preliminary Questions. How are they different? How are they similar? Why are they similar?
- The solution you obtained from the isogenerator may contain a small amount of long-lived cesium in addition to the barium. To account for the counts due to any cesium, as well as for counts due to cosmic rays and other background radiation, you can measure the background count rate from your data. By taking data for 30 minutes, the count rate should have gone down to a nearly constant value, aside from normal statistical fluctuations. The counts during each interval in the last five minutes should be nearly the same as for the 20 to 25 minute interval. If so, you can use the average rate at the end of data collection to correct for the counts not due to barium. To do this,
 - Select the data on the graph between 25 and 30 minutes by dragging across the region with your mouse.
 - Click on the **statistics** button on the toolbar.
 - Read the average counts during the intervals from the floating box, and record the value in your data table.
- Fit an exponential function to the first fifteen minutes of your data. Select the first fifteen minutes with the mouse. Then, click the curve fit button . Select Natural Exponential from the equation list then click . A best-fit curve will be displayed in the small graph window.

5. In the number-entry box labeled B value, enter the average background count rate you determined in step 3 above, then click . Notice that the Natural Exponential fit [$y=A*\exp(-C*Time)+B$] includes an additive term B. This term will account for the constant background counts due to non-barium sources (also, it should be close to the B value that the computer calculated). If your data follow the exponential relationship, the curve should closely match the data.
6. Print a copy of your graph in Word.
7. Record the fit parameters A, B, and C in your data table.
8. From your graph, estimate the half-life for your sample. Hint: After a time of one half-life has elapsed, the activity of a sample is one-half of the original activity.
9. What is the mathematical relationship between half-life ($t_{1/2}$, measured in minutes) and decay constant (k , measured in min^{-1}).
10. From the fit parameters, determine the decay constant, k . Record this value in the table.
11. Calculate the half-life ($t_{1/2}$, measured in minutes) using the decay constant value. Record this value in the table.
12. Are your values of $t_{1/2}$ (measured and calculated) consistent with the accepted value of approximately 2.552 minutes for the half-life of barium-137?
13. What fraction of the initial activity of your barium sample would remain after 25 minutes? Was it a good assumption that the counts in the last five minutes would be due entirely to non-barium sources?