

Lifetime Measurement

The *activity* (in decays per second) of some radioactive samples varies in time in a particularly simple way. If the activity (R) in decays per second of a sample is proportional to the amount of radioactive material ($R \propto N$, where N is the number of radioactive nuclei), then the activity must decrease in time exponentially:

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

In this equation λ is the *decay 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.

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. The 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 λ 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 λ , 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.

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

LabQuest
LabQuest App
Radiation Monitor

Cesium/Barium-137 Isogenerator
cut-off paper cup for Barium solution

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 1 of LabQuest. Choose New from the File menu. If you have an older sensor that does not auto-ID, manually set it up:
 - a. Choose Sensor Setup from the Sensors menu.
 - b. Select Radiation Monitor from the DIG 1 sensor list.
 - c. Select OK.
3. Set up the data-collection mode.
 - a. On the Meter screen, tap Length.
 - b. Change the data-collection length to 30 minutes.
 - c. Enter 30 as the number of samples/minute.
 - d. Select OK.
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 5, 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. Start data collection. The number of gamma photons that strike the detector will be counted during the 30-minute data collection period. Do not move the detector or the barium cup during data collection.
7. As data collection continues a graph will be updated. When collection is complete, a final graph of radiation *vs.* time will appear. 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 $Y = A \exp(-B \cdot X) + C$	
A	
B	
C	
λ (min^{-1})	
$t_{1/2}$ (min)	

ANALYSIS

1. 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?

2. Compare your graph to the graphs you sketched in the Preliminary Questions. How are they different? How are they similar? Why are they similar?
3. 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 measure the counts not due to barium. To do this.
 - a. Tap and drag across the data on the graph between 25 and 30 minutes.
 - b. Choose Statistics from the Analyze menu.
 - c. Record the average (mean) value in your data table. You will use this value to compare with a curve fit parameter.
4. Fit an exponential function to the first fifteen minutes of your data.
 - a. Tap and drag from the first point across the graph to the data point that was collected at 15 minutes.
 - b. Choose Curve Fit from the Analyze menu.
 - c. Select Natural Exponent as the Fit Equation.
 - d. Record the fit parameters A, B, and C in your data table.
 - e. Select OK view the fitted curve with your data.
5. Print or sketch your graph.
6. From the definition of half-life, determine the relationship between half-life ($t_{1/2}$, measured in minutes) and decay constant (λ , measured in min^{-1}). Hint: After a time of one half-life has elapsed, the activity of a sample is one-half of the original activity.
7. From the fit parameters, determine the decay constant λ and then the half-life $t_{1/2}$. Record the values in your data table.
8. Is your value of $t_{1/2}$ consistent with the accepted value of approximately 2.552 minutes for the half-life of barium-137?
9. 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 right side of the graph would be due entirely to non-barium sources?

EXTENSIONS

1. How would a graph of the log of the count rate vs. time appear? Using LabQuest, Logger Pro, or a spreadsheet, make such a graph. Interpret the slope of the line if the data follow a line. Will correcting for the background count rate affect your graph?
2. Repeat your experiment several times to estimate an uncertainty to your decay constant measurement.
3. How long would you have to wait until the activity of your barium sample is the same as the average background radiation? You will need to measure the background count rate carefully to answer this question.