

# HALF-LIFE MEASUREMENT

## LAB NR 4

From *Nuclear Radiation with Computers and Calculators*, Vernier Software & Technology, 2001.

## INTRODUCTION

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  $\lambda$  is the *decay constant*, commonly measured in  $\text{s}^{-1}$  or  $\text{min}^{-1}$ .  $R_0$  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  $\lambda$  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  $\lambda$ , but they can be determined from one another.

## PURPOSE

The purpose of this experiment is to use a radiation counter to measure the decay constant and half-life of barium-137 and to analyze the data to see if it is consistent with simple radioactive decay.

## SAFETY

- Always wear goggles and an apron in the lab.
- Use care to avoid spills and contamination of work surfaces. Inform your teacher immediately of any spills.

## MATERIALS

Laptop computer  
LabPro or Universal Lab Interface  
Logger *Pro*

Vernier Radiation Monitor  
Cesium/Barium-137 Isogenerator  
2.54 cm steel planchet for Barium  
solution  
rubber gloves

## PRELAB 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 planchet to receive the barium solution.
2. Connect the radiation monitor to DIG/SONIC 1 of the LabPro. Turn on the monitor.
3. Prepare the computer for data collection by opening "Exp 03 Lifetime" from the *Nuclear Radiation w Computers* experiment files of Logger *Pro*. One graph is displayed: count rate vs. time. The vertical axis is scaled from 0 to 1200 counts/interval. The horizontal axis is distance scaled from 0 to 30 minutes.
4. With no source of radiation within 1 m of the monitor, measure the background radiation.
5. Put on rubber gloves.

6. Prepare your isogenerator for use as follows:  
(Work quickly between the solution extraction and the start of data collection in step 7, because the barium begins to decay immediately.)
  - a. Attach the plastic tube on the syringe and draw the eluting solution into the syringe.
  - b. Remove the tubing from the syringe and the stoppers from the generator column.
  - c. Hold the generator vertically.
  - d. Insert the syringe firmly into the hole of the top of the generator and force approximately seven drops of solution through the generator into the planchet.
  - e. After use, remove the syringe from the column and replace the stoppers.
7. 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.
8. 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.
9. 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 SHEET

Name \_\_\_\_\_

Name \_\_\_\_\_

Period \_\_\_\_\_ Class \_\_\_\_\_

Date \_\_\_\_\_




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### DATA TABLE

Average background counts	
fit parameters for $Y = A \exp(-C \cdot X) + B$	
A	
B	
C	
$\lambda$ ( $\text{min}^{-1}$ )	
$t_{1/2}$ (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 correct for the counts not due to barium. To do this:
  - a. Select the data on the graph between 25 and 30 minutes by dragging across the region with your mouse.
  - b. Click on the statistics button on the toolbar.
  - c. Read the average counts during the intervals from the floating box, and record the value in your data table.
  
4. Fit an exponential function to the first fifteen minutes of your data.
  - a. Select the first fifteen minutes with the mouse.
  - b. Click the curve fit button . Select Natural Exponential from the equation list. 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.
  - c. In the number-entry box labeled B value, enter the average background count rate you determined in the previous step, then click . A best-fit curve will be displayed on the graph. If your data follow the exponential relationship, the curve should closely match the data.
  - d. When you are satisfied with the fit, click .
  
5. Print or sketch your graph.
  
6. Record the fit parameters A, B, and C in your data table.
  
7. From the definition of half-life, determine the relationship between half-life ( $t_{1/2}$ , measured in minutes) and decay constant ( $\lambda$ , measured in  $\text{min}^{-1}$ ). Hint: After a time of one half-life has elapsed, the activity of a sample is one-half of the original activity.

8. From the fit parameters, determine the decay constant  $\lambda$  and then the half-life  $t_{1/2}$ . Record the values in the Data Table.
  
9. Is your value of  $t_{1/2}$  consistent with the accepted value of approximately 2.552 minutes for the half-life of barium-137?
  
10. 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?

### **EXTENSIONS**

1. How would a graph of the log of the count rate *vs.* time appear? Using *Logger Pro*, *Graphical Analysis*, 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.