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

TI Graphing Calculator
LabPro or CBL 2
DataRad calculator program
Vernier 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 a DIG port of LabPro or CBL 2. Use the black link cable to connect the TI graphing calculator to the interface. Firmly press in the cable ends. Turn on the monitor.
3. Turn on the calculator and start the DataRad program. Press CLEAR to reset the program.
4. Prepare the DataRad program for this experiment.
   a. Select SETUPfrom the main screen.
   b. Select TIME GRAPH from the SETUP MENU.
   c. Select CHANGE TIME SETTINGS from the TIME GRAPH SETTINGS screen.
   d. Enter **30** as the count time interval in seconds. Complete number entries with ENTER.
   e. Enter **60** as the number of samples. This setting will give you a 60 ×30=1800 second (30 minute) data collection time.
   f. Select OK from the TIME GRAPH SETTINGS screen.
5. 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 7, because the barium begins to decay immediately.
6. Place the Radiation Monitor next to the cup so that the rate of flashing of the red LED is maximized. Take care not to spill the solution.
7. Select START from the main screen to begin collecting data. The calculator 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.
8. As data collection continues a graph will be updated. When collection is complete, a final graph of count rate *vs*. time will appear. Set the Radiation Monitor aside, and dispose of the barium solution and cup as directed by your instructor.

DATA TABLE

fit parameters for Y = A exp (– B*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 determine 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. You will have to do the adjustment outside of the DataRad program.
   a. Use the ▷ cursor key to scan across your graph. The coordinates of the highlighted point are shown on the screen. Determine the lowest count rate in the tail or right-hand region of the graph. Record this value in your data table as the additive constant C.
   b. Press ENTER to return to the main screen.
   c. Select QUIT from the main screen.
   d. Your count rate data are stored in list L2. To subtract the background counts from all the measured count rates, you need to enter L2 – C + 1 STO▸ L2, where C is the constant you determined in step a. This will replace the existing list L2 with the corrected values. The +1 term is necessary to avoid having any of the elements in the L2 list equal to zero, which would cause the exponential fit to fail. To enter L2 on the TI-83, TI-83 Plus, or TI-84 Plus (or any of the first six lists) press 2nd and then the corresponding digit. On the TI-73, access lists by pressing 2nd [STAT]. You will then see a list of available lists.

You will need to scroll down using the cursor keys to see all the lists. On other calculators directly enter the list name using the alphanumeric keys.

e. After you perform the list calculation, your screen will show something like L2 – 8 + 1 → L2, followed by the first part of the actual list contents.

f. Restart the DataRad program.

4. Now that you have removed the counts from the extra cesium, you can fit an exponential function to the first 15 minutes of your data. You will use only the first half of the data because the final 15 minutes now contain largely noise after the background subtraction.
   a. Select ANALYZE from the main screen.
   b. Select SELECT REGION from the ANALYZE OPTIONS screen.
   c. Leave the left bound cursor at the extreme left side of the graph. Press ENTER to mark this bound of the selection.
   d. Use the ▷ key to move the cursor to the 15 minute point (900 seconds).
   e. Press ENTER to mark this position as the right bound of your selection. The calculator will display a graph showing only the first fifteen minutes of data. Press ENTER again to return to the ANALYZE OPTIONS screen.
   f. Select EXPONENT CURVE FIT from the CURVE FITS screen.
   g. Record the fit parameters A and B in your data table.
   h. Press ENTER to see your graph with the fitted line.
   i. Print or sketch your graph

5. Press ENTER, select RETURN TO MAIN SCREEN, and then choose QUIT to leave the DataRad program.

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 your calculator, 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 the shape of 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.