Lifetime Measurement

1. See *Appendix A* for information about the word-processing files of the student experiments, as well as any other electronic resources available for this book.

2. Calculator users: If you are collecting data with TI graphing calculators, an application such as VST Apps or DataRad may need to be installed on the calculators. You can determine which app you need at www.vernier.com/til/2672

   The calculator instructions for this experiment are not intended for use with TI-Nspire handhelds or computer software. Radiation Monitors cannot be used with color-screen TI-84 Plus calculators (TI-84 Plus C Silver Edition and TI-84 Plus CE).

3. Sources are available from these suppliers:
   - Spectrum Techniques: voice: (865) 482-9937, fax: (865) 483-0473, www.spectrumtechniques.com
   - Flinn Scientific: voice: (800) 452-1261, fax: (866) 452-1436, www.flinnsci.com

4. Detailed directions for preparing the isogenerator are not given because the method varies with manufacturer. You may want to insert the instructions appropriate to your isogenerator in the Procedure.

5. Students often confuse the decay constant parameter λ with the half-life $t_{1/2}$. The decay constant λ is larger for more rapidly decaying elements and has dimensions of time^{-1}, while the half-life has dimensions of time, and is smaller for more rapidly decaying elements. The decay constant λ is equal to the fit parameter C in the Natural Exponential fit of Logger *Pro* and LabQuest. The two parameters can be related in the following manner. After one half-life has elapsed, half of the radioactive nuclei have decayed, and so the activity is also cut in half. From the rate equation we can relate the decay constant to the half life.

$$R = R_0 e^{-\lambda t};\ \text{at } t = t_{1/2} \text{ we know that } R = \frac{1}{2} R_0$$

$$\frac{1}{2} R_0 = R_0 e^{-\lambda t_{1/2}}$$

$$\frac{1}{2} = e^{-\lambda t_{1/2}}. \text{ Taking the log of both sides,}$$

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

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

   There is sufficient information in the student guide to perform this conversion, although some students with weak algebra skills may have difficulty with it. You may choose to work through this step with your students.

6. The cesium-137 in the isogenerator decays to a metastable state of barium. The metastable barium decays with a half-life of 2.552 minutes by gamma emission, making this system an ideal one for studying in the classroom. A 30 minute experimental run covers almost 12 half-lives, so that the observed activity drops to about 0.3% of the initial value.

7. The lifetime obtained depends strongly on the correct subtraction of background (in this case, non-barium) counts. As written, the activity instructions call for a 30-minute data collection period. If time permits, use a 45 or 60 minute period, and measure the count rate for the final 10 or 15 minutes. A longer experiment will ensure that essentially all the barium will have decayed. The sample data shown here yield a lifetime of 2.50 minutes, but if the background value obtained during the last 10 minutes of a 60 minute run is used, the lifetime changes to 2.57 minutes.

8. Many isogenerators allow some cesium to leak through into the barium extract solution. The cesium results in a nearly constant background activity. This background count is often much larger than the environmental background, and the analysis must take it into account. That is why the experiment is written to run for 30 minutes. The final 5 minutes of data can be used to determine the count rate from the combination of cosmic rays and leaked cesium. If you have an isogenerator that does not leak significant amounts of cesium, you may want to shorten the experiment to fifteen minutes.

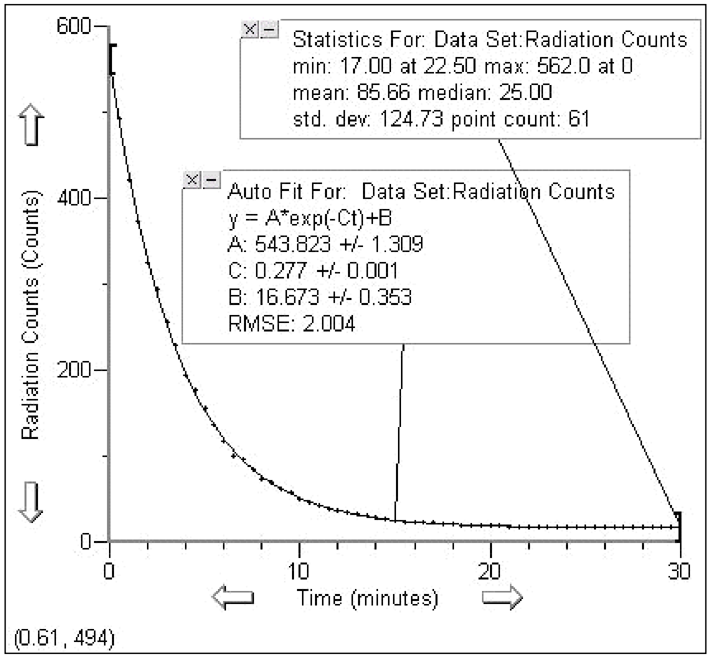
9. In Step 4 of Analysis, students perform a curve fit on only the first 15 minutes of data. This is important because the fit will sometimes be poorer if all 30 minutes of data are used. The counts during the first 15 minutes are largely due to the barium, while the counts in the last 15 minutes are mostly from non-barium sources. The many noisy points in the tail of the exponential may unduly influence a fit of the entire run.

   You may want to have students investigate this effect, or to try various selections of data during the first 15 minutes (e.g., 2–13 minutes, or 5–15). The resulting value for the lifetime will vary somewhat, giving an indication of the uncertainty of the measurement. Using our data we get variations about 0.05 minutes around the typical value shown here.

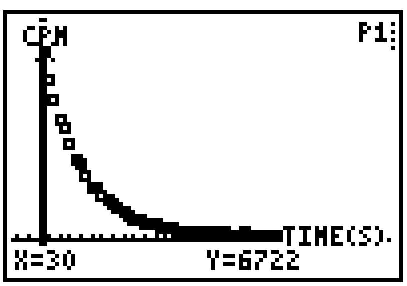
10. Note that the calculator, computer, and LabQuest versions of the activity use different notation for the fitted equation. Unlike Logger *Pro* and LabQuest, the calculator program, DataRad, uses seconds as the x-axis time unit so that the exponential fit parameter must be converted from s^{-1} to min^{-1} (s^{-1}= 60 min^{-1}) to obtain a lifetime in min^{-1}.

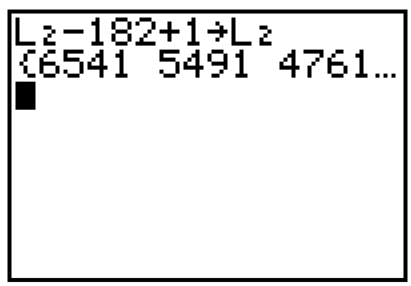
11. Alert readers may notice that the Preliminary Questions are the same as those in Experiment 24, "Capacitors" of *Physics with Vernier*. This duplication is intentional, as both the decay in capacitor potential in an RC circuit and radioactive decay are described by exponential functions. You may wish to call your students' attention to this.

SAMPLE RESULTS

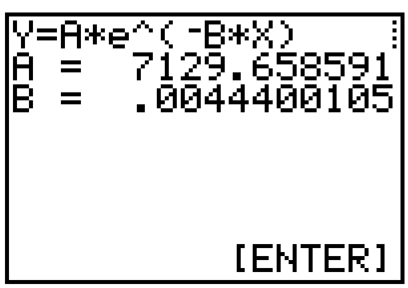


Raw data from calculator and background subtraction step:





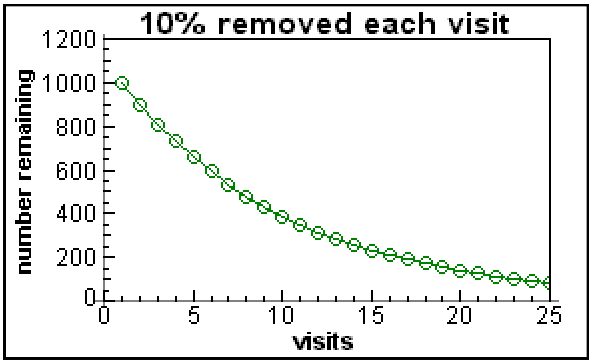
Exponential fit to the first 15 minutes of data after background subtraction:

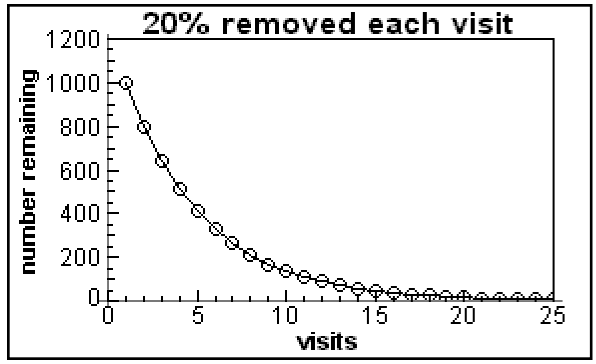


ANSWERS TO PRELIMINARY QUESTIONS

Graph is a decaying exponential. The first few values are 1000, 900, 810… (with integer part of 10% taken each time).

Second graph decays more quickly: 1000, 800, 640…





DATA TABLE

Logger *Pro* (computers) and LabQuest App

Average background counts	17
fit parameters for Y = A exp (– C*X) + B	
A	554
B	17
C	0.277
λ (min^{-1})	0.277
$t_{1/2}$ (min)	2.50

DataRad (calculators)

fit parameters for Y = A exp (– B*X) + C	
A	7129 cpm
B	0.00444 s^{-1}
C	182 cpm
λ (min^{-1})	0.266
$t_{1/2}$ (min)	2.60

ANSWERS TO ANALYSIS QUESTIONS

1. The count rate decreases in time, falling to less than 10% of the initial value. This is consistent with activity being proportional to the amount of remaining radioactive material, since as material decays, less remains, so the activity must decrease.

2. The three graphs have a similar decreasing shape, although the time-axis scale of the barium data is different from that of the candy graphs. The vertical axes have different units (candy remaining and counts/interval). They are similar because in each case the decay process proceeds at a rate proportional to the remaining candies or radioactive nuclei.

6. We start with the rate equation, and then use the definition of the half-life as the time it takes for the activity to drop to one-half the original value:

$$R = R_0 e^{-\lambda t}; \text{ at } t = t_{1/2} \quad R = \frac{1}{2}R_0$$

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

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

$$t_{1/2} = \frac{\ln 2}{\lambda}$$

8. The experimental half-life of 2.50 min is close to the accepted value of 2.552 s.

9. After 25 minutes, 0.11% of the original barium activity remains. ($e^{-25*0.272} = 0.0011$). Most, but not quite all, of the original activity has decayed. The assumption that the counts observed during the last five minutes of data collection are due only to non-barium is reasonable. Possibly a better background estimate could be obtained by waiting a longer time.

ANSWERS TO EXTENSIONS

1. A graph of ln(counts/interval) *vs*. time should be a straight line of negative slope. The slope is $-\lambda$, or the negative of the decay constant. If the background has been subtracted, the graph should be nearly linear. Without background subtraction, the graph will be curved.

2. Results will vary. A collection of lifetime measurements will allow the student to determine a range of values; the extent of that range is a measure of the uncertainty of the measurement. The range of data selected will also influence the measurement, as will the value used for the additive parameter B in the exponential curve fit.

3. Results will depend on the background radiation level. Experiments done at high altitude will experience larger background count rates due to reduced attenuation of cosmic rays by the atmosphere. To measure the background rate, change your set up to count with no source present. Note that the solution obtained from the isogenerator will contain some cesium, raising the count rate further above background from environmental radiation.