Radioactive Half-Life

In this lab we will measure the radioactive half-lives of two isotopes of silver. Along the way we will measure the background radioactivity due to cosmic rays. We will learn how to estimate the risk associated with exposure to radiation.

RADIATION SAFETY

This experiment involves the use of various radioactive sources, including a neutron howitzer containing an intensely radioactive plutonium source. The principal hazard is the (remote) possibility of contamination with plutonium leaking from the sealed source. The following rules should be followed in this lab, as in any lab where radioactive materials are present:

1. **No eating or drinking in the lab.**
2. **Wash your hands at the end of the lab.**

I. Theory

Background Radiation

Whether we like it or not, we are constantly being bombarded by ionizing radiation from a variety of sources. A major source is cosmic rays which originate in supernovae. These very energetic primary cosmic rays interact with nuclei in the upper atmosphere and produce showers of secondary cosmic rays, a few of which reach the surface of the earth. (The cosmic radiation is twice as intense in Denver as in San Francisco, due to the difference in altitude.) Other sources of background radioactivity are radioactive elements in the concrete of this building and radon gas diffusing up out of the ground. This background rate is very low. We will measure it.

Radioactivity of Silver Atoms

The nuclei of most elements will readily absorb neutrons. The addition of another neutron to a given nucleus changes it to a different nuclear species, or isotope. Naturally occurring silver consists of two isotopes, silver-107 and silver-109. They absorb neutrons as follows:

$$^{107}Ag + n \rightarrow {}^{108}Ag$$

$$^{109}Ag + n \rightarrow {}^{110}Ag$$

The two new isotopes produced are both unstable to beta decay:

$$^{108}Ag \rightarrow {}^{108}Cd + \beta^- + \overline{\nu}$$

$$^{110}Ag \rightarrow {}^{110}Cd + \beta^- + \overline{\nu}$$

Here β^- represents a beta-minus particle, or an electron, and $\bar{\nu}$ represents an anti-neutrino. The electron is detected by the Geiger counter, while the neutrino passes undetected out through the walls of the building.

II. Experimental Procedure

A. Background Radioactivity

1. The neutron howitzer.

Use the green Technical Associates radiation monitor to measure the radiation level, in mR/hr, near the howitzer. (The black mR/Hr scale on the plastic window corresponds to the x1 gain setting.) You are counting mainly gamma rays, highly penetrating radiation which can pass through several inches of lead shielding. Notice the decrease in the radiation level with increasing distance from the source. [Note: to save time, the instructor may carry out this measurement for you.]

Now take the radiation level just measured, and assume that it is averaged over the body of a person standing near the source. Then multiply this by 1/60 hr, the time you will have to stand near the source to get your activated foil. This is the amount of radiation you will be exposed to during this time. Use the approximate relation that 5000 person-R of exposure causes one cancer death to estimate the probability that you will die of cancer as a result of this exposure.

For comparison, Californians drive about 150,000,000,000 miles a year, with about 4000 traffic deaths; so, 37,500,000 person-miles cause one traffic death. Suppose that you travel ten miles to get to school and home again, and calculate the probability that you will die in a traffic accident as a result of this trip. Compare with your probability of dying of cancer due to radiation exposure during today's lab.

As a double check the person in the lab the closest to the neutron source should wear a Xetex 415A personal radiation dosimeter during the lab. Record the reading of this dosimeter at the beginning and near the end of the lab, and compare this integrated exposure over the lab with the exposure you will get when you pick up your radioactive foil.

2. The Geiger Counter

Plug in the Geiger-tube detector and connect its data plug to digital channel 1 of the interface. Place a ^{60}Co gamma source under it and make sure that the red LED is flashing. For each flash, an ionizing particle is detected. Move the tube as near to the source as possible, to get the highest count rate. **Note:** the thin end window of the Geiger tube is protected by a plastic tube, but it is still delicate; please do not touch it.

Now start the Science Workshop, by clicking on the "sciwkshp" icon on the computer screen. Drag the digital plug to Channel 1, and select Geiger counter (new method). Set up a table of counts per time period for digital channel 1. Under Experiment and Sampling Options, choose 10-second samples. With the gamma source under the tube, monitor a few counts. When you are ready, record eight 10-second counts, then stop.

The Square-Root-of-N Law for Counting Statistics says that when a counting experiment detects **N** un-correlated events, there is an intrinsic variation, or error, on the value of **N,** given by

$$\sigma_N = \sqrt{N}$$

That is to say, repeated counts will not give the same result each time, but will show a typical variation σ_N about the "true" value.

We can test this experimentally, as follows. For your eight 10-sec. counts, have the statistics option (the **Σ** button) calculate the mean and standard deviation. Compare the actual standard deviation, as calculated by the program, with the square root of the average number counted (you have to calculate this).

Q1. Is it *reasonably* accurate to say that the error (standard deviation as calculated by the computer) is equal to the square root of N?

3. Measuring background radiation

Move all sources (cobalt-60 disks, etc.) at least a few feet from the Geiger tube. Open a new Science Workshop experiment. Set up to take 60-second counts. Take 5 counts and find the average. This is the average number of cosmic-ray particles passing through the Geiger tube in 60 seconds.

Q2. Compare the size of your body to the size of the Geiger counter and *roughly* estimate how many cosmic-ray particles pass through your body in 60 seconds.

B. Measuring the half-lives of silver.

The instructor will irradiate the silver foils for you. While you are waiting for your sample foil, set up to take 10-second counts. Lower the Geiger counter as far as practical, still leaving room to put the silver foils under it. You should start taking 10-second counts the instant that the foils are placed under the Geiger counter, since the half-life is short. Collect 40 counts of 10 seconds each. (Someone has to be assigned to keep track of the counts, or otherwise decide when you have 40.) When you finish taking the data, save it on your directory, as decay.sws . (Your directory is c:\labs\122\secn\radioactivity\ .)

While you are waiting for the data, figure out the expected background counting rate, R_{bk}, which is the expected number of counts from cosmic rays during a 10-second interval. You can figure this out from your earlier measurement of background radiation for counts in 60 seconds - just divide by 6!

To analyze these data, open the Excel spreadsheet template for this experiment, halflife.xls, as follows. Click on the Excel icon on the computer screen. Select File, then Open. Find the file C:\labs\122\secn\radioactivity\halflife.xls, where secn is the appropriate section for your group, and double-click on it. Now copy the data from the Science Workshop table and paste it into cell B2 of the Excel spreadsheet. A graph of the data should appear.

To determine the half-lives of the isotopes of silver present, you need to fit your experimental data to a theoretical curve of the form

$$R(t) = R_{bk} + R_a*\exp(-t*0.693/T_a) + R_b(\exp(-t*0.693/T_b)$$

The first term represents a constant background count rate. The second term is the counting rate due to isotope **A,** where Ra is the counting rate at t = 0, and Ta is the half-life for isotope **A.** In a similar way, the third term gives the counting rate due to isotope **B.** This formula has already been entered into the Excel template. There are also values for the five constants R_{bk}, R_a, R_b, T_a, and T_b.

Your job is to try to find the numbers for R_{bk}, R_a, R_b, T_a, and T_b that makes the curve fit well with your data. To begin with, for R_{bk} you should enter your estimate of the expected background counting rate. Now, assume there is only one decaying isotope. The spreadsheet has been set up for this situation, with $R_b = 0$. Your job is to adjust the values of R_a and T_a, while watching the graph, so as to get the best fit to the data.

Q3. Why can't you get a perfect fit between the theoretical and experimental graphs when you adjust only R_a and T_a?

Once you are satisfied that your data matches the curve as best as possible, start adjusting R_b and T_b. For R_b, you might try an initial guess of 50 counts/second, and for T_b try 300 sec. Then adjust the values of all the parameters except R_{bk} to get the best fit. Write down the values of T_a and T_b.

To print out the graph for your lab book, first select it (double-click); then click on the printer icon.

Before comparing with accepted values, each partner should repeat the adjustment of the parameters for the best fit. DO NOT try to get the same values as the others - just try to get the best fit. Then take the values from all of the partners, and calculate the average value <T>, the error σ_T on a single measurement, and the error $\sigma_{<T>}$ on the average value. Write down your team's experimentally determined value and error for each of the two half lives. [See the first lab, "Data Analysis and the Use of Excel on the IBL PC," for details on how to do this.]

Now compare with the accepted values and determine the quality of agreement, in the usual way. [See the appendix on "Theory of Statistics," section IV, for details on how to do this.] The accepted values for the half-lives for silver are 24.6 seconds for ^{110}Ag, and 2.41 minutes for ^{108}Ag.

Q4. You can look at the curve of ln N versus t by clicking on the scale of your graph and changing it to a log scale. Plotted this way, a single exponential decay should look like a straight line. Does your curve for ln N vs. t look like a straight line? If not, why not?

Q5. Is it possible there are more than two radioactive isotopes present? How sure are you that there are only two isotopes?

III. Equipment

Pasco Model SG-7997 Geiger-tube counter
Pasco CI-6560 Interface
Pasco Science Workshop
Sealed cobalt-60 gamma source (old orange plastic sources and new "Spectrum Techniques 1.0 μCi Co-60" sources)
1-curie neutron howitzer
Silver foils irradiated in the neutron howitzer
(One) chart of the nuclides
(One) Technical Associates Model PUG1 AB survey meter with P-11 probe
(One) Xetex Model 415A personal dosimeter
(One) orange Fiesta-ware cream pitcher (radioactive Uranium glaze!)
(One packet) Coleman lantern mantles (radioactive)

IV. Appendix: The Neutron Howitzer

The neutron source is rather interesting in itself. It contains a fairly hot plutonium source. This source alpha-decays. The alphas interact with beryllium nuclei to produce fast neutrons via the interaction

$$ {}^{4}_{2}\alpha + {}^{9}_{4}Be \rightarrow {}^{12}_{6}C + {}^{1}_{0}n $$

The neutrons from this reaction are "fast" (energetic), and have to be slowed down. For this purpose, the source is surrounded with paraffin. The neutrons lose their energy in elastic collisions with the protons in the hydrogen. The slow neutrons which result interact with the silver nuclei, and produce the unstable isotopes which we study in this experiment.