NAME PERIOD DATE

THE DECAY OF METASTABLE BARIUM - 137

How does the radioactivity of a substance change over time? If radioactive decay is a random event, how can it be modeled mathematically? How is the half-life of a substance measured?

Objectives

- Measure the radioactivity from a source with a Geiger counter
- Analyze the measurements to create a mathematical model
- Compare the measured counts to the model

Materials and Equipment

- Data collection system
- Wireless Geiger counter
- Isotope generator kit
- Steel Planchet (in kit)
- Threaded rod
- Ring stand
- Right angle clamp

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles at all times.
- Notify your instructor of spills and clean up as directed.
- If chemicals get on your skin, immediately rinse thoroughly with running water and notify your instructor.
- Dispose of chemicals in the proper waste container as directed by your instructor.
- Wash your hands thoroughly when finished with the investigation.

Procedure

1. Attach the threaded rod to the Geiger counter and attach it to the ring stand with the right-angle clamp.

2. Adjust the height so it is about 0.5 cm above the table. Place the steel planchet next to it so that the Geiger counter can be rotated to a position directly over it after the radioactive sample has been added to it. See Figure 1.

3. Turn on the Geiger counter and connect it to the data collection system. The beeps can be silenced by pressing the on button for about a half second or by unchecking the Enable Beeps box in the software.

4. Create a graph display of Count Rate and set the sample interval to 10 s.

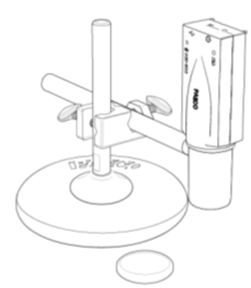

Figure 1

5. Start recording data. Stop after 60 s have elapsed. Use the tools of the data collection system to get the mean count rate and record it below. This is called the background count because there was no radioactive source nearby. The background radiation is produced by small amounts of radioactive elements in the environment and radiation produced high in the Earth's atmosphere when cosmic rays collide with atoms.

   Background count = __________ counts/10s

6. Set up a stop a stop condition in the data collection software so that data collection stops after 10 min (600 s).

7. Inform your instructor that you are ready to measure the radioactive source. After they place the liquid sample in the steel planchet, rotate the Geiger counter directly over it being careful not to bump it. Start recording right away.

8. The first count rate will display after 10 s. It should be in the hundreds or more. If it is not over 200 counts/60s, you may need to move the Geiger counter closer to the sample, get a fresh sample, or increase the data collection interval. Consult your instructor for help.

9. Monitor the graph over the next 10 minutes and answer the following questions while you wait for data collection to stop.

10. The radioactive substance in the liquid is metastable barium - 137 or Ba - 137m. It is produced by the radioactive decay of Cs-137. Your instructor used a chemical solution to remove Ba - 137m from an isotope generator, leaving the Cs - 137 behind. Although it has the same mass, it behaves differently chemically. What type of radiation does Cs-137 produce? How can you tell without looking it up?

11. The atomic number of Cs - 137 is 55. How many protons does Cs-137 have? How many neutrons does it have?

12 What is the atomic number of Ba - 137m? How can you answer this question without consulting a periodic table?

13. How many protons does Ba-137m have? How many neutrons does it have?

14. The half-life of Cs - 137 is 30 years. How many years until 1 g of Cs - 137 is left of an 8 g sample? What happened to the other 7 g?

15. A radioactive sample contains 3 g of Cs-137 and 9 g of Ba-137. How long ago could this sample have been 12 g of Cs - 137?

16. Data collection should stop automatically after 600 s. If it doesn't, click stop after 600 s. The count rate should have decreased substantially during the 600s. If it did not, inform your instructor.

Questions and Analysis

1. Ba - 137m gives off a gamma radiation when it decays to Ba - 137. What can you conclude from the graph about the radioactivity of Ba-137m compared to its daughter product, Ba-137?

2. Use the tools of the data collection system to find the initial count rate and record it below. Compare it to the average background count rate measured earlier. Is it greater than 1% of the initial count rate? If so, you may want to use the tools of the data collection software to create and graph a calculation that subtracts it from the count rate.

3. From the graph, estimate the time it took for the initial count rate to drop to half the value and record it below. Knowing that Ba - 137 is not radioactive, what is this time an estimate of?

4. What is the count rate at a time equal to 2 half-lives? How does it compare to the initial count rate?

5. Two students are discussing their answer to the questions above. One student thinks their data is wrong because the count rate should drop the same amount in the second half life, reducing it to zero. The other student thinks their data is OK because the count rate is about 1/4 of the initial value. They say it drops by 1/2 of what is left each half-life and that 1/2 of 1/2 if 1/4. Which student do you agree with and why?

6. Quantities that continue to decrease by a consistent fraction in equal time intervals are said to experience exponential decay. If you withdrew half of the money in a bank account each day, the balance would exponentially decay. If you ate 10% of the peanuts in a bag every hour the remaining number of peanuts would exponentially decay. Radioactive atoms behave this way. In a given time, a fixed fraction will give off radiation and decay. Think of another example of exponential decay and describe it below.

7. The equation that describes exponential decay is $N = N_0 e^{-\lambda t}$. N is the number of radioactive atoms left, N_0 is the number of radioactive atoms at $t = 0$, and λ is the decay constant. The Geiger counter does not measure every radioactive decay, but it can be assumed the count rate is proportional to the decay rate. In this case N is the count rate and N_0 is the count rate at $t = 0$. Use the equation, values from your graph, and your estimate for the half-life to solve for λ. Show your result and work below. *Hint: the natural log of* $e^2 = 2$.

8. Use the tools of the data collection system to fit a natural exponential fit to the graph. Record the value of the decay constant λ from the curve fit below. Find the percent error between it and your value from the above step.

9. Substitute the numerical values from the natural exponential curve fit into the equation $N = N_0 e^{-\lambda t}$ and write it below. Use it to solve for the half life. *Hint: What is the value of N/N_0 after one half-life?*

10. The actual half-life of Ba - 137m is 153 s. Find the percent error of the half-life found from the exponential curve fit.

11. Use the equation of the exponential curve fit to solve for how much time it will take for your radioactive sample to be safe to dispose of. Disposal is safe after the count rate has been reduced to 1/1000 of the initial count rate.

12. Use the equation of the exponential curve fit to solve for the count rate at 12 min. Do you think the count rate will ever reach zero? Explain.

13. The half-life of Cs - 137 is 30 years. Solve for the decay constant λ of Cs -137. How many years will it take until a sample of Cs - 137 is safe to dispose of?

14. Another group forgot to click start right away. By the time they noticed, they had an initial count rate of only 200 counts/60s from their sample of Ba - 137m. How will the half-life value of their graph compare to yours? Explain.

15. Explain how knowledge of nuclear science and the mathematics is important for someone working with radioactive material like a doctor, geologist, or a science teacher.