

Measuring the Radioactivity of a Smoke Detector Spring 2013

Introduction

In this experiment you will measure the activity of Americium (“Am-uh-RISH-ee-um”; Symbol: *Am*), and estimate the amount found inside a smoke detector. You will also examine the penetrating power of alpha (α) particles. Information on how a smoke detector operates can be found at the end of these instructions.

Safety Warning:

Treat all radioactive sources with respect. You should never eat or drink in the lab when working with radioactive sources, and always wash your hands after handling sources, even relatively low-level ones such as smoke detectors. Be sure to replace the cover on the smoke detector when you are finished measuring the radiation emitted.

Experiment

1. Locate the Americium isotopes on a chart of the nuclides ($Z = 95$). Identify which isotope is likely to be inside the smoke detector; you’ll want an isotope *and* its decay product that are very stable (a long half-life). Find the half-life and the decay product(s) of this isotope from the table. List the possible isotope candidates and their decay products, along with their half-life, and explain your choice and why the other isotopes were rejected.

2. Now you will measure the activity of the smoke detector’s source. Turn ON the power switch on the back of the *Science Workshop 500 Interface*, and then start *DataStudio* using the icon on the taskbar (at right). You’ll hear the *Geiger-Müller (G-M)* counter counter begin to chirp as it detects background radiation.



3. When *DataStudio* starts, you are asked to open an activity from the T: drive. Scroll down to the *Phys104* folder, and select the *SmokeDetector* file within. As the file opens, you’ll see a message that the program searches for and finds the *Science Workshop 500* interface.

Troubleshooting note: If the *Science Workshop* interface can’t be found, the ‘Start’ button at the top left of the screen of the screen will be greyed out. Quit *DataStudio* and unplug the USB cable from the computer; plug the cable back in to a different USB port, start up *DataStudio* and open the *SmokeDetector* file again.

4. Carefully remove the protective cap from the end of the *G-M* counter. The cap protects a delicate window made of mica at the end of the *G-M* counter. *Do not touch the mica window!* Be sure to carefully replace the protective cap when you are finished with your measurements.
5. Open up the smoke detector and remove the black cover surrounding the source. Lower the *G-M* counter so that it is resting *directly on* the source; you’ll notice that the chirping has increased to an annoying rate.
6. Click the **Start** button at the top left of the *DataStudio* window. The program will measure the number of counts (decays) in 5-second intervals. The program automatically stops measuring after 60 seconds. Three *DataStudio* windows are presented: a counter displaying the number of counts every 5 seconds; a graph of counts vs. time; and a table of your data. After the timer stops, raise the *G-M* counter to reduce the intensity of the chirping.
7. Double-click on “Run #1” in the left-most window, and change the name of this run to “Directly on Source XXX”, where XXX are your initials. Click OK, and then ‘Yes’ to rename the data in the table. All of your subsequent data runs will appear in the data table window, so this will help distinguish between runs.
8. Use the average (‘mean’) number of counts per 5-second interval to calculate the activity rate in *counts/sec*, and compare it to the manufacturers value, which appears on the black cover that surrounds the source. The published activity rate is given in units of *Becquerel (Bq)* and *Curie (Ci)*, where $1 \text{ Bq} = 1 \text{ count/sec}$, and $1 \text{ Ci} = 3.7 \times 10^{10} \text{ Bq}$. Why do you think there is a large discrepancy between the published activity rate and your measured value?

9. Perform other runs with 1, 2, and then 3 pieces of paper between the source and *G-M* counter (make sure the counter is still resting directly on the source). Be sure to give an appropriate name to each run to distinguish data sets in the table. Compare the average measurements to your earlier run without any paper. Three sheets of paper should block all α particles – do you still register counts? Why *isn't* the number of counts zero (you may need to refer to the nuclide chart again)?
10. There are assorted pieces of metal (zinc, copper, steel, tin, lead) available. Place one between the detector and source, and again measure the counts for one minute. Try a couple of these materials, as well as an air gap of about 1 *cm*. Do a relative comparison of the average number of counts in each case.
11. Before printing your data, click the data table window to select it and expand it to full-screen, then choose *Print Setup* from the *File* menu, choose the correct printer for this room, and select *Landscape*. You can then print out a copy of the data table for each member of your group.

You have now finished measuring the radioactivity of the smoke detector, so you can quit DataStudio, turn off the switch on the Science Workshop interface (to stop the incessant chirping) and **carefully** cover the *G-M* counter with its protective cap.

12. The radiation consists mostly of wimpy alpha particles, most of which don't make it out of the source container and through the window of the *G-M* counter. A more reliable estimate of the activity of the source is printed on the cover that surrounds the source. Use *this manufacturer's value* and the half-life to calculate the approximate number of Americium nuclei in the smoke detector. With N_0 as the initial number of Americium nuclei, and A being the activity rate, we have:

$$N = N_0 e^{-\lambda t}$$

and

$$A = -\frac{dN}{dt} = -(-\lambda) N_0 e^{-\lambda t} = \lambda N$$

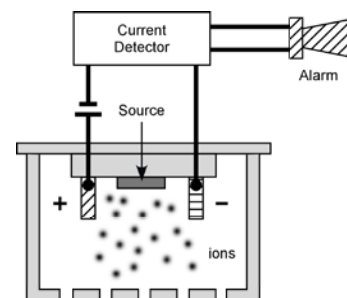
So, $A = \lambda N$, or $N = \frac{A}{\lambda}$, where the decay constant, λ , is given by:

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

13. Use your result of the number of nuclei from step 12, Avogadro's number ($N_A = 6.02 \times 10^{23}$ atoms per mole), and the atomic mass to calculate the mass (in grams) of Americium in the smoke detector.

How an Ionization-Type Smoke Detector Works¹

There are two types of smoke detectors available to consumers. One kind indicates the presence of smoke when it interferes with a photoelectric beam of light in the detector. The smoke detectors we will examine in this experiment are ionization-type detectors. The detector consists of an ionization chamber, a sensitive current detector, and an alarm. A weak radioactive source ionizes the air in the chamber of the detector, creating a region of charged particles. A voltage is maintained between the plates inside the chamber, setting up a very small current in the external circuit. As long as the current is maintained, the alarm is deactivated. However, if smoke drifts into the chamber of the detector, the ions become attached to the smoke particles. These heavier particles do not drift as readily as do the lighter ions, which results in a decrease in the detector current. The external circuit senses this decrease in current and sets off the alarm.



¹ From *College Physics*, 3rd Ed. Serway & Faughn, p. 1025