Measuring the Radioactivity of a Smoke Detector
Spring 2020

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 (think about what the active life span of a working smoke detector has to be). Find the half-life and the decay product(s) of this isotope from the table. List all the possible isotope candidates you considered, their decay products and respective half-lives. *Explain your choice and why the other isotopes were rejected*.

2. Now you will measure the activity of the smoke detector's source. Start *Logger Pro* using the icon on the taskbar (at right). The LabPro computer interface is connected to a *Vernier Radiation Monitor*, which contains a Geiger-Müller (*G-M*) tube. A red LED beneath the Vernier logo on the detector will blink occasionally as it detects background radiation.

3. When Logger Pro starts, open a file on the T: drive: scroll down to the *Phys152* folder, and select *Smoke Detector.cmbl* (if a "Sensor Confirmation" window opens, click the **Connect** button). You will see three windows in this file: a table to hold all of your data; a *Radiation Counts* window that will show the most recent measurement in the 5-second interval; and a graph of Radiation (counts) vs. time. The vertical axis of the graph will automatically scale once data collection begins.

4. Remove the Radiation Monitor from the clamp, and you'll see a circular wire screen on the bottom. This screen protects a delicate window made of mica at the end of the *G-M* tube. *Be sure to carefully align this window with the source when you are ready to collect your data*.

5. Open up the smoke detector and remove the black cover surrounding the source. Return the Radiation Monitor to its clamp, and lower the clamp so that the Radiation Monitor is resting *directly on* the source; you'll notice that the small red LED flashes at an increasing rate.

6. Click the green **Collect** button at the top of the Logger Pro window. The program will measure the number of counts (decays) in 5-second intervals, and will automatically stop measuring after 60 seconds. *The data will be printed, so you don't need to record it in your report*.

7. When data collection has finished, click the *Experiment* menu, then choose *Store Latest Run*. Double-click on "Run 1" in the column header, and change the name of this run to "Directly on Source". Click **OK** to rename this set of data. Be sure to store and rename subsequent data runs since they will all appear in the same data table.

8. Now click on the *Analyze* menu, and choose *Statistics*. Select the data set you just saved and you'll get a window on the graph that displays the minimum, maximum and mean (average) number of counts for a 5-second interval from that run. Again, be sure to analyze all subsequent data runs with this command.

9. Use the mean number of counts per 5-second interval to calculate the activity rate in *counts/sec*, and compare it to the manufacturer's 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 *Bq* = 1 count/sec, and 1 *Ci* = 3.7×10^{10} *Bq*. Why do you think there is a large discrepancy between the published activity rate and your measured value? (*Hint: it is not because the smoke detectors are old!*)

10. Perform additional 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 and properly aligned). Be sure to give an appropriate name to each run to distinguish between the 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? (Be sure to refer to the nuclides chart again!)

11. Perform a run with an air gap of about 1 *cm* between the source and monitor, and then try additional runs with two of the pieces of metal (zinc, copper, steel, tin, and lead) that are available. Place each metal piece on the source, and rest the detector on the metal, again taking care with the alignment.

12. Rank all the materials (and the air gap) tested by comparing the average number of counts per 5-second interval to the average measurement when directly on the source. Therefore, if the average counts on source is 4700 and the average through one of your materials is 50 counts, then the material reduced the counts to $^{50}/_{4700} = 1\%$. Which material was most effective at blocking α particles?

13. Before printing your data and graph, neatly arrange the *Statistics* boxes on the graph so that there is no overlap. Chose *File*, then *Page Setup*, choose the correct printer for this room, and click the *Landscape* button. Click OK, and then chose *File*, and then the *Print Preview* menu to check its appearance. If it looks ok, click the **Print** button, type your names in the *Print Footer* box in the next window, and then click **OK**. Print a copy of the data table and graph for each member of your group.

14. 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. You will use *this manufacturer's value* and the half-life ($t_{\frac{1}{2}}$) of the Americium isotope to calculate the approximate number of Americium nuclei in the smoke detector. The number of atomic nuclei, N is calculated as:

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

and

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

Since the *activity*, *A* (the rate at which the isotope is decreasing) is λN, calculate the number of Americium nuclei $\left(N = \dfrac{A}{\lambda} \right)$ in the detector, where the decay constant, λ is calculated as follows (*remember to convert the half-life units to seconds!*):

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

15. Use your result of the number of nuclei from step 14, Avogadro's number (6.02×10^{23} atoms per mole), and the atomic mass to calculate the mass (in grams) of Americium in the smoke detector.

$$\text{mass}(Am) = N \times \frac{1 \, mole}{6.02 \times 10^{23} \, atoms} \times \frac{(atomic \, mass) \, g}{1 \, mole}$$

How an Ionization-Type Smoke Detector Works[1]
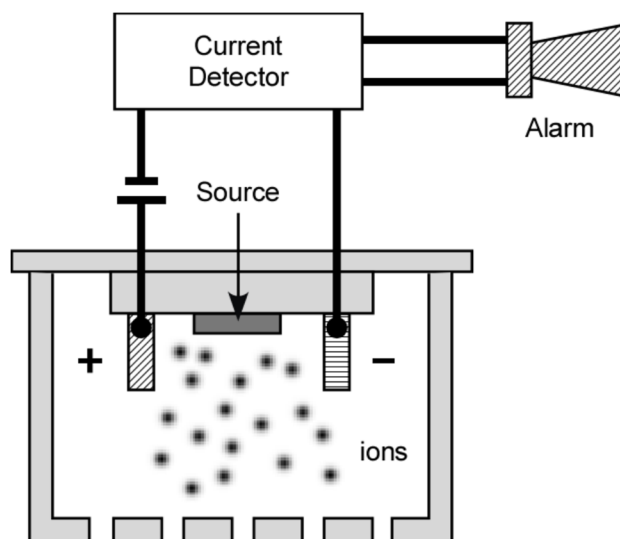
There are two types of smoke detectors available to consumers. One kind indicates the presence of smoke when it interferes with a photoelectric beam of light in the detector. The smoke detectors we will examine in this experiment are ionization-type detectors.

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.

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