

# Radioactivity

PHYS 1301

## Introduction

This lab will simulate the behavior of a radioactive material, such as a clump of carbon-14 nuclei. Radioactivity is the spontaneous decay or transformation of a nucleus containing some number of protons into another nucleus containing a different number of protons. The number of protons may either increase or decrease. This process is spontaneous in the sense that you don't have to do anything to the radioactive nucleus in order for this transformation to occur. You do not have to shine light on the nucleus, heat it, hit it, apply pressure to it or anything else. As a result of this transformation, particles are emitted from the nucleus. These particles are either electrons, anti-electrons (called positrons), helium nuclei (called alpha particles) or photons of high energy (so-called gamma rays). These photons have too high an energy, and hence too small a wavelength, for your eye to detect them.

Radioactivity is surprisingly common in nature. For example, carbon-14, an isotope of carbon whose nuclei contain 6 protons and 8 neutrons versus the 6 protons and 6 neutrons of the more common carbon-12 isotope, occurs in nature at a relative concentration of about 1 part in a billion compared to that of carbon-12. Although this may sound like a miniscule abundance, carbon-14 is a practical tool for dating the age of many formerly living objects.

It is also the case that at least one common household device relies on radioactivity for its operation. Most smoke detectors in houses, apartments and schools have a quantity of the radioactive element *Americium* in them. The nuclei in a particular isotope of this element (so-called Americium-241) undergo radioactive decay and emit helium nuclei in the process. These helium nuclei ionize the surrounding air and the positively and negatively charged ions drift towards oppositely charged electrodes of the smoke detector and produce an electrical current. When this electrical current is stopped or reduced because of the presence of smoke between the electrodes of the smoke detector, the smoke detector's electronic circuitry sounds an obnoxious buzzer you sometimes hear.

The rate at which radioactive nuclei decay is often summarized by the notion of its "half-life." A half-life is the amount of time it takes for one-half of an arbitrary amount of radioactive material to radioactively decay. The half-life of a given radioactive material is constant, although the exact time at which a particular radioactive nucleus will decay is random. (An event is said to be random when you cannot predict it.) Although this seems weird, there is no contradiction here. The notion of a half-life is a probabilistic one and applies to the behavior of a large collection of radioactive nuclei. Strictly speaking, you cannot meaningfully speak of the half-life of a single radioactive nucleus because when it decays, all of it decays and not just half of it. This probabilistic nature of radioactivity makes it a uniquely quantum mechanical phenomenon.

## **Procedure**

1. Goto the web page the instructor writes on the board.
2. You first need to understand the display. Click Reset and then Start and watch the display.

The program automatically keeps track of the number of *remaining* radioactive nuclei (the red ones), the number decayed (black), and the time elapsed in units of some fixed time T.

3. Press Pause to halt the decay at any given time and Resume to restart it. Now Reset the display. There should be 1000 undecayed nuclei.
4. **Question 1.** I want you to fill out Table 1. You will Start and Stop the display in intervals of  $0.5 T$ , recording the number of *surviving* nuclei at the end of each interval  $N$ . You do not need to Pause at exactly  $0.5 T$  intervals, just come as close as you can. You might want to practice a bit before you start for real. Continue recording numbers until the elapsed time equals  $5 T$  or so.  
**Question 2.** Plot the number of surviving nuclei versus time. (Yes, this means you need to find some graph paper.) Do your data points fall on a straight line? Do they fall on a curve? Your graph should look similar to the one on the display.
5. The interval T is the half-life of the radioactive sample. Any interval of time of length T on your graph should result in a halving of the number of undecayed nuclei. We will test this in the next question.
6. **Question 3.** Reset and fill out Table 2. To do this, you will need to Start and Stop the display in consecutive intervals of time T. This means you will Start the simulation and record the number of radioactive nuclei at the start of the interval  $N_0$ , and then Stop the simulation after interval T has elapsed. You will then record the number of surviving radioactive nuclei  $N$ . This number of surviving nuclei will then become the *starting* number of nuclei for the next interval T, and so on. **Question 4.** What is your average value for  $N/N_0$ ? Is it *exactly* equal to one half? What do you make of this?
7. Again Reset the display. Now you are going to Start and Stop the display in intervals of time T again.
8. **Question 5.** I want you to fill out Table 3. For each interval T record the initial and final number of undecayed nuclei (each row represents one interval). As before, the number of surviving nuclei  $N$  from one interval is the initial number in the next interval. Fill out the last column as well. This is the number of nuclei that decayed in the interval T; the *activity* of the radioactive substance is this number divided by T, the number of decays per second. The activity is not a property of a particular radioactive nucleus. **Question**

6. Plot the number of decayed nuclei for each interval versus the starting population  $N_0$ .

Draw a smooth curve through these data points.

(Smooth means smooth. The curve should not look like the stock market report.)

**Question 7.** Can you form a conclusion about the activity of a radioactive substance and the size of the starting population?

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PHYS1301

Name: \_\_\_\_\_ Section: \_\_\_\_\_

**Abstract:**

## Questions

**Question 2:**

**Question 4:**

**Question 7:**



Table 3.

$N_0$	$N$	$N_0 - N$

**Conclusion**