PHYS 1301

Radioactivity

Introduction

Radioactivity is the spontaneous decay or transformation of the nucleus at the center of an atom. 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 – it just does it at random (we cannot predict exactly when). As a result of this transformation, particles are emitted from the nucleus. These particles can be electrons (called beta radiation), helium nuclei (called alpha radiation) or photons of high energy (gamma radiation). The alpha, beta, gamma nomenclature is historical, before people knew what the particles involved really were.

Radioactivity is surprisingly common in nature. For example, 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 Americium-241 undergo radioactive decay and emit alpha radiation in the process. These alpha particles ionize the surrounding air, that is, the atoms in the air become electrically charged (through loss of electrons) when an alpha particles collide with them. The positively charged ions are attracted towards 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.

Although a single radioactive nucleus will decay at random, one can nevertheless make precise statements about the average rate at which nuclei in a large sample of radioactive material decay; this is often summarized by the notion of its "half-life." A half-life is the amount of time on average 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. 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. For example, suppose a radioactive sample with a half-life of 30 minutes contains 1,000 atoms at time zero. After 30 minutes, we expect 500 will remain undecayed. After an additional 30 minutes, we expect 250 will remain, and so on. The actual numbers observed may be a little higher or lower but, the larger the sample, the closer to one half will be the fraction of undecayed atoms after each 30 minute period.

You should also be aware of another measure of the amount of radioactivity. The *activity* of a radioactive sample is the number of atoms that decay in a certain period divided by that period. This depends upon how much radioactive material you have as well as the half-life. In the example above, the activity of the sample would be 1000 per hour for the first ½ hour since 500 decay in one ½ hour. In the second ½ hour the activity would 500 per hour since of the 500 remaining, 250 will decay in the 2nd ½ hour. Often the activity is measured per minute, but any measure of period can be used.

Equipment

Container, dice of one color, graph paper, short ruler (for drawing axes).

Procedure

Radioactive sources that are safe to handle generally have long half-lives. For example, uranium-238 has a half-life of 4.5 billion years. This would obviously not be observable in the two-hour lab period. Sources with a half-life of a few minutes can be observed in the lab period, but are very dangerous to handle. For this reason, we will use a model of radioactive decay represented by throwing a set of dice. If the dice represent radioactive atoms about to decay, then (on average) after one half-life one half of them will remain undecayed. After two half-lives one quarter of the initial number will remain (on average). And so on.

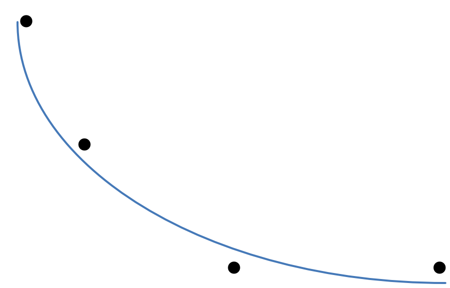
1. Note the color and count the total number of dice you have in your container.
2. Spill the dice on the table. Remove all the dice according to the following prescription:
   - those showing number 1 if you have white dice
   - those showing number 1 or 2 if you have red dice
   - those showing number 1, 2, or 3 if you have green dice.

   The removed dice represent atoms that have decayed.
3. Count and record the number of remaining dice (undecayed atoms), put them back in the container, randomize, and spill these dice on the table again.
4. Repeat until all the dice are gone (until all the atoms have decayed) or you run out of space in the Results Table.

#dice									
throw	0	1	2	3	4	5	6	7	8
#dice									
throw	9	10	11	12	13	14	15	16	17

5. Using the results table as a guide, draw suitable axes on graph paper to plot the number of dice (# dice) which have not yet decayed versus the throw number. Use as much of the page as possible.

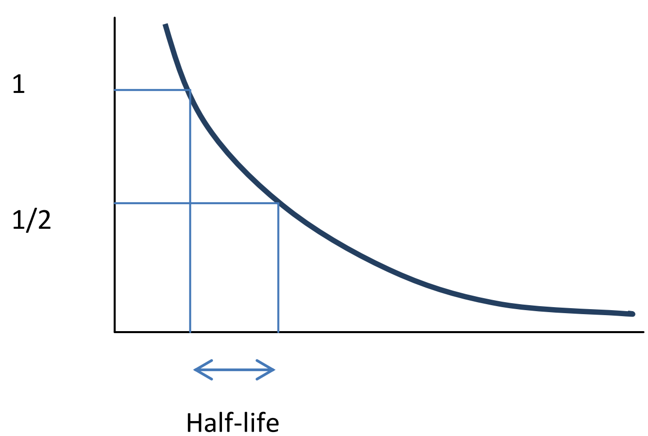
6. Plot the experimental data on the graph and draw the **best** **smooth** curve that approximates them. Smooth means smooooth…no wiggles, nor like a stock market report. Do not force the curve to go through each point exactly; generally they will scatter either side. Best means that groups of nearby points are not all scattered either above or below the curve. Here is an example of a best smooth curve:



Analysis

1. Why do your data points not agree precisely with the smooth curve?

2. **Use your smooth curve** in the following way to find the half-life of your dice model (the number of throws needed to halve the number of remaining dice). Choose an arbitrary number on the vertical axis, and half that number, and carefully draw lines across as shown to find the half-life interval on the horizontal axis. Note: in real radioactivity half-life is a \`time' but the answer for your model will be measured in units of "number of throws". And even though you cannot actually make a fraction of a throw, your result for half-life in general will not be a whole number since it is the result of a calculation.



3. Repeat part 2 for a few different choices of numbers on the vertical axis. Do you get roughly the same half-life values always?

4. Calculate your best estimate of the half-life by averaging your results and give an uncertainty on this average (recall the “Errors” lab).

5. Using your table, calculate the *activity* of your sample of dice per throw during the period covered by the first two throws.
What is the activity of your sample of dice per throw during the period covered by the third and fourth throws?

What can you say about the activity of a radioactive sample in relation to the size of the starting population and in relation to time?

6. Suppose a particular type of atomic nucleus has a half-life of five days. A sample is known to have contained one million atoms when it was prepared, but now only about 62,500 atoms remain undecayed. Estimate how long ago the sample was prepared.

Conclusion