PHYS 1301

Radioactivity

Introduction

Radioactivity is the spontaneous decay or transformation of the nucleus of an atom. The number of protons may either increase, decrease, or stay the same. 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 can be electrons or anti-electrons (called beta particles), helium nuclei (called alpha particles) or photons of high energy (gamma particles). The alpha, beta, gamma nomenclature is historical, before people knew what the particles involved really were. Gamma photons (gamma rays) 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, whose nuclei contain 6 protons and 8 neutrons (6+8=14) versus the 6 protons and 6 neutrons of the more common carbon-12, 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 Americium-241 undergo radioactive decay and emit helium nuclei in the process. These helium nuclei ionize the surrounding air, that is, the atoms in the air become electrically charged. The positively and negatively charged ions are attracted 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 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. (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. 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 750 per hour for the hour in question. Often the activity is measured per minute, but any measure of period can be used.

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, in the 1st part of the lab you will investigate half-life using 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.

The particles released from a radioactive material will be slowed down and eventually stopped when moving through another substance (such as air or another barrier) due to collisions with the atoms of that substance. This is analogous to the way light, another kind of radiation, is stopped to varying degrees depending on the transparency of a substance. In the 2nd part of the lab you will also investigate using very weak, and therefore safe, sources of radioactivity the penetrating power of alpha radioactivity.

1st Part

Equipment

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

Procedure

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.

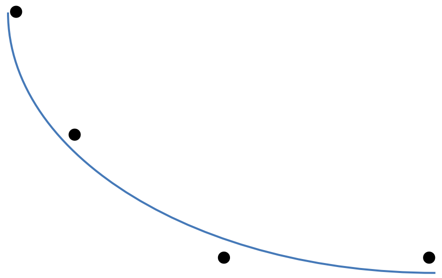
   The removed dice represent atoms that have decayed.

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.

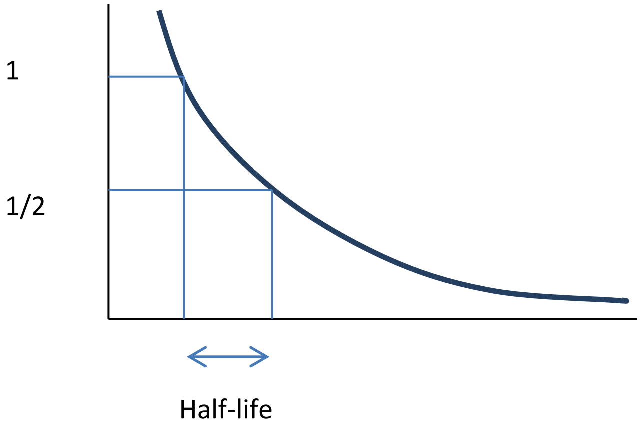
6. Plot the experimental data on the graph and draw the **<u>best</u>** **<u>smooth</u>** curve that approximates them. <u>Smooth</u> means smooooth…no wiggles, nor like a stock market report. Do not force the curve to go through each point exactly; generally they will scatter either side. <u>Best</u> 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:



<u>Analysis</u>

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

2. **<u>Use your smooth curve</u>** 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 (dpt) during the period covered by the first two throws.

6. What is the activity of your sample of dice per throw (dpt) during the period covered by the third and fourth throws?

7. 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?

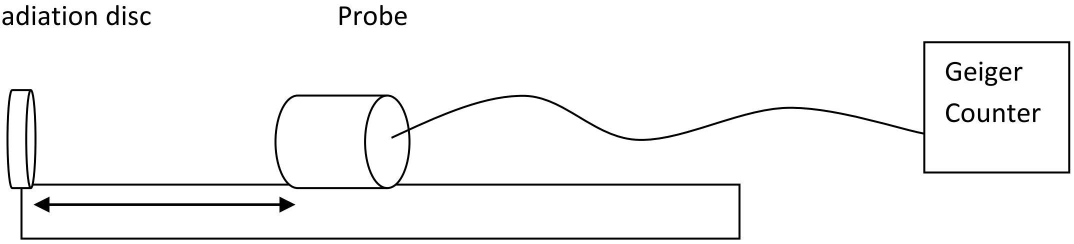
2nd Part

Equipment

Po-210 (weak alpha radioactivity source sealed in a plastic disc), Geiger counter, ruler.

Procedure

1. The alpha particles are emitted from the side of the disc without writing on it. Sealed weak sources are safe to handle but try to keep your fingers away from the alpha-emitting side of the disc. Stand the alpha radiation source disc on its edge. Set the ruler down so that the emitting side of the disc is exactly level with zero on the ruler.



2. Set the Geiger counter to x10 scale. Turn power on and turn the volume off (so as not to irritate).
3. Place the Geiger counter probe so that its end is exactly 1.0 cm from the emitting side of the disc and record the counts per minute (cpm). This can be read directly from the scale but you need to wait a minute or so to get a good reading and then x10 your reading.
4. Now slide the Geiger counter probe so that its end is exactly 0.5 cm from the emitting side of the disc and record the counts per minute. You may need to reset to the x100 scale if the reading is too big for the x10 scale.
5. Place a piece of paper between the source and the probe and record the counts per minute.

Turn off the Geiger counter and lay the source disc flat on the table (writing side up).

Analysis

1. Calculate the percentage of alpha particles that make it through 0.5cm of air (or 0.25 cm of air if you started with the probe at 0.75 cm).
2. What is the probability of an alpha particle being stopped per cm of air?
3. How would interpret the result for counts per minute with the paper barrier in place, compared to air barriers?

Conclusions

From your results, what can you conclude about the nature of half-life, activity, and shielding of radioactivity?