Modern Physics Lab

Radioactive Decay Experiment

Theory: When a nucleus is unstable it may release excess energy by emitting electromagnetic radiation or by ejecting particles or both. This will result in a nucleus with less energy and it can even be a different element if the nuclear charge changes. This transformation is called radioactive decay. If the process happens spontaneously (as opposed to stimulated) the material is said to be radioactive.

For a sample of radioactive nuclei containing N nuclei, the number of particles that decay is random, but on average the decay per unit time (the activity, A) is directly proportional to N, according to.

$$A = \lambda N$$

Where λ is a constant of proportionality known as the decay constant and has units of inverse of time or counts per unit time. Dimensionally in the SI, activity has a unit of s^{-1} as counts are dimensionless. This constant is different for different radioactive materials and varies widely from one isotope to another. Starting with the above equation one can derive the following:

$$A = A_0 e^{-\lambda t}$$

Where A_0 is the activity at time zero and A is the activity at some later time, t.

The half-life of a substance is defined to be the time for the number of nuclei to decrease by a factor of two, but since activity is directly proportional to the number of nuclei at any time t, the half-life will also be the time for the activity to decrease by a factor of two. Normally it is much easier to measure activity than the number of nuclei present.

So when $A = A_0/2$ then $t = t_{1/2}$ or

$$\frac{A_0}{2} = A_0 e^{-\lambda t_{1/2}}$$

Solving for the half-life we get

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

That is, the half-life is the natural log of 2 divided by the decay constant. Also notice that the average lifetime is given by $1/\lambda$.

Goal: Measure the radioactive decay of a metastable isotope of barium. You will get the activity as a function of time that you will compare to the generally accepted (GAV) value of 2.55 min. Besides this goal and witnessing the radioactive decay, you will learn to use the Geiger Muller counter and analyze the data obtained in the experiment.

Cs/Ba-137m Generator

Crucial to an experiment like this is to obtain a sample of a radioactive isotope that has a short half-life, so it can be observed during a normal class session. If we were using carbon-14, for example, we would have to wait many years to observe a good fraction of its half-life of 5700 years. But if you had a sample of short half-life, let's say 5 minutes, then you would have to do the experiment immediately after getting it and then it would have negligible activity the following semester or even the following week! The answer to this problem is to use the "Generator" that we have in the lab.

In the generator you have a sample of Cs-137, which is unstable, but has a half-life of 30.1 years, so it can stay active for many semesters in our lab. Cesium decays by two channels. The first channel is a straight jump to the ground state of barium-137 by emitting a beta particle with a release of 1.174 MeV of energy:

$$Cs^{137} \rightarrow Ba^{137} + e^{-}$$

Approximately 5.4% of the cesium-137 nuclei will decay through this channel.
The other possibility, with 94.6% probability, is a decay to an intermediate daughter nucleus, barium-137m, which is a metastable isotope. This is done with the release of a beta particle and 0.512MeV of energy:

$$Cs^{137} \rightarrow Ba^{137m} + e^{-}$$

The metastable barium isotope main channel for decay into the ground state (85% probability) is through emitting a 661.6keV gamma photon according to the equation.

$$Ba^{137m} \rightarrow Ba^{137} + \gamma$$

This is the decay that we want to measure in the experiment today. Its half-life is 2.55 minutes, which makes it perfectly suitable for a lab session since we can observe several half-lives in a few minutes.

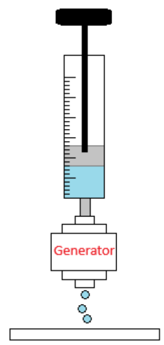
The generator is constantly generating Ba-137m, which of course decays fast, but at any given moment you will have a sample of Ba-137m available. In order to extract the barium, but not the cesium, we take advantage of their different chemical properties, since Cs and Ba have different valences. Using a dilute solution of HCl we "milk" a few drops of out of the generator to run our experiment. Perhaps making a cup of espresso is a good metaphor here.

Procedure:

Get acquainted with the Geiger-Muller counter. You can check its workings with a sample of any radioactive sample. Perhaps you can take readings every 30 seconds or every 10 seconds. Decide on your own the best way to do this.

Use gloves to handle the radioactive sample.

Milk around 7 drops of solution by injecting the diluted HCl in the generator with the syringe.



Immediately start measuring the counting rate at the pace previously decided.

Stop when the counts become too low (perhaps after 10 minutes).

Analysis:

Use the acquired data to confirm the radioactive decay curve.

You have several options for analysis: Traditional graphing log(N) vs time on paper and finding the slope, same in a spreadsheet program, minimization of square errors by selection of 2 parameters or 3 parameters, minimization of xi-square instead of just the errors squared. This is a good chance for you to learn these techniques for any other experiments and for you career as a professional engineer or scientist.

Once you decide on the best analysis that you can do, compare the half-life you measured against the GAV and compute the error.