GNBN RADIOISOTOPE DECAY

In this experiment you will use a Geiger-Mueller tube to detect "counts" from radioactive decays in order to study decay statistics and decay rates for unstable nuclei. Geiger-Mueller tubes respond to gamma rays and beta particles (electrons), producing a pulse corresponding to each detection of a decay product. These pulses are to be counted and stored using a Spectrum Techniques UCS 30 in the Multi-Channel Scaler mode.

Theory

Radioactive nuclei decay is an exponentially decreasing function over time. Thus, if there are N_o nuclei present at time $t = 0$, there will be some smaller number $N(t)$ at some time t later. As we modeled in an earlier experience, this is given by:

$$N(t) = N_0 e^{-\lambda t} \qquad (1)$$

This should also look familiar to what you saw in the previous lab.

Half-life

Equation (1) is the most general form for expressing something that decays exponentially. The constant, λ, must have units of $(\text{time})^{-1}$. It is referred to as the decay constant and accounts for the rate at which the number of particles decreases. It is often more convenient and intuitive to write λ as

$$\lambda = \frac{\mathbf{0.69315}}{\boldsymbol{t_{1/2}}} \qquad (2)$$

Equation (1) then becomes

$$N(t) = N_0 e^{\frac{-.69315\, t}{t_{1/2}}} \qquad (3)$$

Although this might not look more convenient, the quantity, $t_{1/2}$, is called the half-life and represents the amount of time needed for half of the previous number of particles to decay. For example, if $t_{1/2}$ is 6 hours, then the number of particles left will decrease to one-half of what it was in six hours, one-fourth in twelve hours, one-eighth in eighteen hours, etc.

To be more precise, what we will measure in this lab is not the number of particles remaining as a function of time, but rather, the activity (A), or how many decays are occurring over each time segment. Activity is a measure of the change in the number of nuclei over a change in time:

$$A(t) = \frac{\Delta N(t)}{\Delta t} \qquad (4)$$

and has a similar relationship as a function of time as Equation (3)

$$A(t) = A_0 e^{\frac{-.69315t}{t_{1/2}}} \qquad (5)$$

Nuclear Theory

For this lab, we will produce radioactive isotopes of silver (Ag) by exposing silver foils to slow neutrons from our PuBe source. Naturally occurring silver is made up of two stable isotopes: 51% ^{107}Ag and 49% ^{109}Ag. Upon capturing a neutron, they become ^{108}Ag and ^{110}Ag, respectively, both of which are radioactive. Both of these isotopes subsequently decay into isotopes of Cadmium by the emission of beta particles (electrons):

$$^{107}Ag + ^{1}n \rightarrow \, ^{108}Ag \rightarrow \, ^{108}Cd + \beta^{-} + \bar{\nu}$$

$$^{109}Ag + ^{1}n \rightarrow \, ^{110}Ag \rightarrow \, ^{110}Cd + \beta^{-} + \bar{\nu}$$

Figure 1: Decay modes for activated Ag

Recall that $\bar{\nu}$ represents an anti-neutrino. which is a chargeless, nearly massless, high-energy particle that is created in every beta negative decay. These characteristics make neutrinos (found in positron decay), and anti-neutrinos, extremely difficult to detect. They play no role in this experiment.

Because there are two unstable isotopes created by the neutron bombardment, the radioactive decay of silver results in two superimposed exponential decays, one quite short with a half-life of 24.6 seconds, and one a few minutes long. For this experiment, we will let the short-lived isotope decay away and concentrate on measuring the decay of the longer-lived one.

Experiment

Familiarize yourself with the Spectech software in the Multi Channel Scaling mode, using a sealed plastic disk source instead of an activated silver sample. (Then shield your disk source!)

Notice that even with no sources in the vicinity of the detector, the counter continues to record counts every few seconds; this "background" is due to natural radioactivity. Set the dwell time to 400 seconds, restart the counter and accumulate these background counts in the 0^{th} channel. Then divide by 100 to determine the expected number of counts per 4 second dwell period.

Now take the silver decay data. First, set a 4 second dwell time for the experiment. When this is set, one partner will take the tray to the source storage room to receive an activated silver sample from the instructor. As soon as the source is taken out of the irradiation chamber, that person starts a stop-watch. In about two and a half minutes (about six half-lives), the short-lived isotope will be down to about one percent of its original activity and will have little effect on the measurement of the longer half-life. So, place the sample under the Geiger counter and, when a full two and a half minutes elapsed, start a Spectech run. Collect at least 50 channels (200 seconds) before stopping the acquisition software. Extract your count values from SpecTech and import them into Excel. (See the **Getting Data out of the Spectech** on the next page.)

In Excel, create a new column in which you subtract your 4-second background value from your column of silver decay counts. If any background-subtracted data point is zero or negative, delete that point and all subsequent points. These are now your background-subtracted data values, proportional to the activity *A* of the source as a function of time.

Insert a new first column to get time values; 0, 4, ... up to your last row of data. A shortcut in Excel is to type "= (Row( )-1)*4 in the first row. Then copy it, highlight all the rows of the column to the bottom of the data, and paste.

Finally make a chart of your count rate vs. time. Add an exponential trend line (with equation, of course). Then, using Equation 2, find the half-life of the longer-lived isotope of radioactive Ag.

To turn in:

- Original handout as a cover page.
- Chart with data, trend line, and equation. For full credit, add a Title to the graph and label the axes – including the ***units.***
- One paragraph summary of important observations and insights relating to your results.

Pre-lab Questions

1. Find the value of $e^{-0.69315}$
2. In words, what does the ratio $\frac{t}{t_{1/2}}$ give you?
3. What is the value of $(e^{-0.69315})^{(t/t_{1/2})}$ for $t = t_{1/2}$? For $t = 2*t_{1/2}$? For $t = 4*t_{1/2}$?
4. Find accepted values for the half-lives of the relevant unstable isotopes of silver. (Cite reference sources used.)

Addendum A- Getting Data out of the SpecTech

To output spectra or MCS data from the UCS 30:

1. Go to the File menu, click on SAVE
2. Save the file as a Tab Separated File (TSV), selected in the bar below the filename.
3. Open the .tsv file in Excel.

Addendum B- Production of Thermal Neutrons or What's Going On Inside the Barrel

In order to convert stable, naturally occurring silver isotopes into unstable, radioactive isotopes, we bombard the silver foil samples with slow neutrons from our plutonium-beryllium alloy neutron source. The plutonium-beryllium is contained in a small, sealed stainless steel cylinder that is surrounded by paraffin, all contained in a steel barrel. The ^{239}Pu in the source decays, producing alpha particles that interact with the ^{9}Be in the source, yielding neutrons:

$$^{239}\text{Pu} \text{ ------> } ^{235}\text{U} + {}^{4}\text{He} + \textit{energy}$$

$$^{9}\text{Be} + {}^{4}\text{He} \text{ ------> } ^{12}\text{C} + {}^{1}\text{n}$$

These neutrons are traveling too fast to interact effectively with the silver nuclei; hence they must be slowed down by collisions with the hydrogen nuclei contained in the paraffin. (Note that collisions with hydrogen are most effective at slowing the neutrons because collisions of nearly equal mass particles, in this case neutrons and protons, are most efficient for energy transfer.)

Once the neutrons have been slowed, the following nuclear reactions proceed, activating the silver sample by creating unstable isotopes as described above:

$$^{107}\text{Ag} + {}^{1}\text{n} \text{ ------> } ^{108}\text{Ag} \qquad (10)$$

$$^{109}\text{Ag} + {}^{1}\text{n} \text{ ------> } ^{110}\text{Ag} \qquad (11)$$

These unstable isotopes of silver produce the beta decays detected in this experiment.