Physics 220: lab 9

Radioactive decay and half-life (two methods)

Introduction:

The activity of a radioactive isotope is defined as the number of decays per unit time. The activity decreases with time exponentially, as $R = R_0 e^{-\lambda t}$, where R_0 is the initial activity and λ is the decay constant (probability of decay per unit time), which is related to the half-life $T_{1/2}$ by $T_{1/2} = \frac{\ln 2}{\lambda}$.

One method of finding the half-life experimentally is to use a detector to measure the count rate from a radioactive source at different times. Assuming that the detector detects a constant fraction of the radiation emitted by the source, the measured count rate is proportional to the activity. The half life of the source can then be determined by fitting the count rate vs. time data with an exponential. If there is background radiation (as there almost always is), it must either be subtracted before doing the fit, or the fit must include a background term. Assuming that the background doesn't change with time, this means using an equation of the form $R = R_0 e^{-\lambda t} + B$ to fit the data.

This simple procedure doesn't work if the half life is long compared to the maximum possible counting time. In this case, we can use a different method of finding the half-life. Since λ is the probability for one nucleus to decay per unit time, the activity of a collection of them is $R = \lambda N$, where N is the total number of radioactive nuclei present. If we can determine N (for example, from knowing the chemical formula and the mass of the atoms making up the sample), then by measuring R we can determine λ and thus $T_{1/2}$.

We will use the first method for ^{137}Ba, and the second for ^{40}K. We will measure the gamma rays emitted in the decays using the same scintillation detector we used last week.

Procedure:

Experiment 1: exponential decay measurement of half-life

Set up the scintillation detector and calibrate it so that you can measure gamma-ray energies up to about 1.6 MeV. For the calibration, last time you used a two-point calibration with a ^{22}Na source. This week, try a three-point calibration with both the ^{137}Cs and ^{60}Co sources present to give you three peaks.

Set up with a sample of the radioactive material you'll be using, and set the discriminator level to cut out any low-energy electronic noise. Then use the resources available to you (the MCA manual, the help function, and/or me) to learn how to use the multi-channel scaling (MCS) mode to automatically record the number of counts as a function of time.

In setting up the MCS mode, you'll need to input the "dwell time," which is the time per channel. The total time for the measurement will therefore be 1024 channels x dwell time. You want this total time to last until most of the activity has decayed away and you're left mostly with background. Look up information about the decay of ^{137}Ba, and use that to decide a reasonable value for the dwell time. Hint: by how much will the activity have gone down after one half-life? two? three? four?

Let me know when you're ready to take data. While the MCS mode is counting, work on the Review of Uncertainties in Counting Statistics exercise.

Once you have your data, export it in comma- or tab-delimited form so that you can analyze it in Graphical Analysis.

You might want to set up the other experiment and start it running before finishing your analysis for this part.

Using Graphical Analysis, plot a graph of count rate vs. time for your data. Include error bars. Fit the data with a function of the proper form. Remember that there may be some background—in this case, we haven't separately measured the background, but we can include a constant background in the equation we're using to fit the data. When you're happy with your fit, use the results to estimate the half-life of your sample, including uncertainty. Compare your results with the accepted value of the half-life.

Experiment 2: Half-life from measuring activity and number

Go back to pulse height analysis mode. Check the calibration with a ^{137}Cs source (it should still be OK—see me if not).

Now you will measure the count rate from ^{40}K. Your source of ^{40}K is a container of salt substitute (KCl). Since naturally occurring potassium (even that in your body) has a certain small fraction of the long-lived radioactive isotope ^{40}K, natural potassium may have detectable radioactivity from the small amount of ^{40}K present. (^{40}K is chemically identical to the other, stable, isotopes of potassium that make up most of natural potassium.)

To maximize your count rate, set up the salt substitute close to the scintillator and along its axis (ask me for suggestions on how to do this). Take a run long enough to clearly see a photopeak at the ^{40}K gamma ray energy of 1.462 MeV. You'll want something like 2000 counts (gross) in the photopeak. Record the gross number of counts in the photopeak. The live time (LT) tells you how much time elapsed during which counts could be recorded.

Then take a background run for the same time (note that you can use Settings/preset to set the live time to be the same). For the same ROI that you used for the ^{40}K data, record the number of background counts.

Subtract the background from the ^{40}K counts and calculate an uncertainty. Then calculate a background-subtracted count rate (counts per second) and its uncertainty.

Now you need to correct the count rate for the fact that the detector does not detect 100% of the gamma rays the source emits. There are two such corrections: one for the detector geometry and one for the chance that a gamma ray will leave all of its energy in the photopeak. These correction factors can be gotten from graphs in the Marion reference (ask me for help).

The other needed correction is for the fact that not all ^{40}K decays produce a gamma ray. The decay information is available from the NNDC database (again, ask me for help).

Correct the count rate and its uncertainty for these factors. Now you have R, the activity of the source.

Next you will need to estimate how many K atoms are in the container (you have its weight in oz, and you know nearly all is KCl). Once you know the number of K atoms, you can use the % abundance of ^{40}K from the Chart of the Nuclides to determine the number of ^{40}K atoms present.

Now that you have R and N, you can calculate the decay constant λ and use that to find the half life. Propagate the uncertainty through these calculations. Report your result and compare to the accepted value of the ^{40}K half-life.