

Neutron Activation and Half-Life

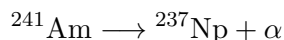
Background

In this laboratory experiment, we will be measuring the half-lives of some relatively short-lived isotopes. We do this by measuring the decays per set time interval as a function of time:

$$R = R_0 e^{-\lambda t}$$

We can then plot R vs. t on a semi-log¹ plot: the slope of the line will then give us the activity λ , from which we can find the half-life $t_{1/2} = \frac{\ln 2}{\lambda}$.

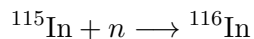
In order to produce those isotopes in the first place, we use one of two processes. The first process is known as *neutron activation*, in which an element is bombarded with neutrons so as to produce another isotope of the same element. To produce the neutrons, we use a *neutron howitzer*. This consists of a neutron source surrounded by shielding material, with ports so that samples may be placed near the source. Our neutron source consists of an Am-Be slug surrounded by plastic beads. The americium decays by α -emission:



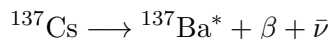
The α particle then reacts with beryllium:



which releases the neutrons. Since neutrons have no charge, they are more likely to react with other nuclei if they are moving slowly (“thermal” neutrons). Lower speeds mean that they spend more time in the vicinity of the nucleus, thus increasing the probability of capture. The plastic surrounding the neutron source supplies a large number of protons (hydrogen nuclei) which slow the neutrons by repeated collisions. Once thermalized, the neutrons then react with the sample, i.e.

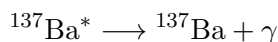


The second isotope production method is the “Cesium-Barium Cow”. This is a small container filled with a resin matrix containing ^{137}Cs . ^{137}Cs is radioactive, with a half-life of 30.1 years. It decays to ^{137}Ba via β decay:



¹Semi-log plots have a logarithmic y axis and a linear t axis.

The ‘*’ on $^{137}\text{Ba}^*$ indicates that the barium is in a metastable state: it’s at a higher energy than would be stable, but that state is stable enough that the barium does not immediately decay to the stable configuration. When it *does* decay, it does so by γ emission:



where the energy of the γ ray is approximately 662 keV.² This particular decay chain is useful for our purposes because although Cs is insoluble in the “cow”, Ba is soluble: so with some careful chemistry we can “milk” the cow and extract the short-halflife Ba from the long-halflife Cs. Instructions are provided with the Cs-Ba source. Follow them *exactly* for good results.

Equipment Overview

For our radiation sensor we will be using a Geiger-Muller (GM) tube. The GM tube is one of the earliest (and simplest) radiation detectors: it consists of a chamber of low-pressure gas containing two electrodes. External electronics maintain a strong electric field in the gas, which in normal circumstances does not conduct electricity. When ionizing radiation passes through the gas, however, it creates ion pairs by separating electrons from the gas molecules. These ion pairs are drawn by the strong electric field to the electrodes: on the way they collide with (and ionize) other gas molecules, which causes a small avalanche of charge at the electrodes. This charge pulse is amplified and sent to the desired counting device, which could be anything from a speaker to a computer interface board.

Cautions

- GM tubes can be fairly fragile. The tube itself needs to be at a low pressure, which is easy to maintained by a simple metal cylinder. But the tube also needs to allow entry of β and ideally α radiation. This requires a window of some less dense material, typically mylar. Any contact with this window can cause catastrophic failure, so don’t touch the window!
- The high-voltage supply can be dangerous, both to the user and to the GM amplifier. Do not turn the HV supply on until it is properly

²This 662 keV γ ray is considered to be the “radiation signature” of ^{137}Cs , even though it actually comes from $^{137}\text{Ba}^*$. This is because the only practical way of getting $^{137}\text{Ba}^*$ is by ^{137}Cs β decay.

attached and everything else is working. Do not turn the HV supply on “suddenly”: turn the voltage down to zero, then turn the supply on, then ramp the voltage up to the desired level.

Procedure

1. Use LabVIEW to build a program to record count rate versus time. Use an express vi to collect digital *counter* input. The counters on the ELVIS II board keep count *electronically*, independent of the LabVIEW program, so they are very accurate and easy to use. The express vi counter input just asks the counter for the current count each time it's called. Set up a loop that reads the counter at a user-selectable time interval and plots/saves the resulting time/count data for later analysis.
2. Check the output voltages on the bipolar power supply, then attach the supply to the GM Amplifier.
3. Attach the GM amplifier to the GM tube.
4. Attach the output of the GM amplifier to the ELVIS II board at the appropriate place for a digital counter input.
5. Turn on the bipolar power supply.
6. After making sure the high-voltage supply is off, attach the HV supply to the GM Amplifier.
7. Make sure the voltage adjust knob on the HV supply is at its minimum setting, then turn on the HV supply and ramp the voltage up to approximately 900V.
8. Using a ^{137}Cs button source, test to make sure that your LabVIEW program is working correctly.
9. Once you are satisfied that everything is working properly, remove the source you used to test that things were working during setup and take a background measurement. This should be many readings, to give you an accurate estimate of the counts per time interval that occur even when there is no sample present.
10. Finally, take measurements for actual samples. (Remember to subtract the background!) The samples available are indium (soft metal disks),

silver (tarnished metal disks or coins), and $^{137}\text{Ba}^*$. Save the data files for each run, and use curve fitting to find the half-lives of each sample.

The indium sample is fairly straightforward, and has a half-life on the order of an hour. It's the easiest of the three: start with that one. The rest are more difficult, for varying reasons which you will discover. The barium has a half-life of only a few minutes, and you can milk the "cow" every hour at the most, so get it right the first time. The silver sample also shows a fairly short half-life, so work quickly. Be particularly careful with your analysis of the silver: check the value of $\overline{\chi^2}$ on your curve fit and see if it's trying to tell you something. (See figure 1.)

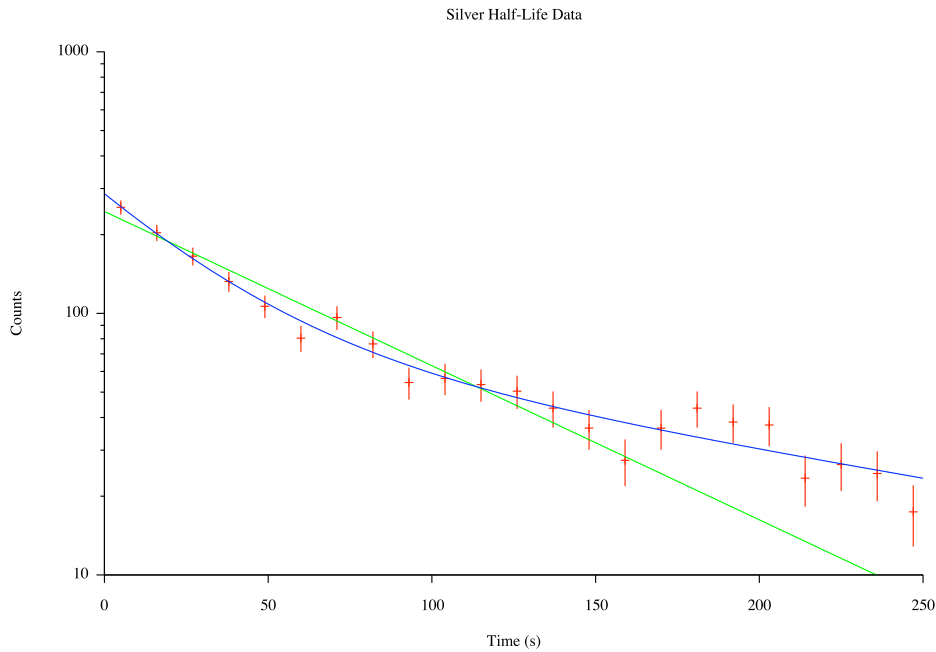


Figure 1: Sample data from neutron-activated silver

For best results, you will want to minimize the background radiation. One good way of doing this is to build a lead-brick "house" around your sample and detector. You will also want to configure your timing schedule for compatibility with your sample half-life: taking data every 10 seconds with the indium sample won't be particularly helpful, and taking data every 5 minutes with the barium will be even less helpful! Remember that $\delta N = \sqrt{N}$, and try to maximize the usefulness of your data.

Your short summary write-up should show the decay graphs for each sample, the time constant(s) and half-life(s) for each sample, and of course your uncertainty in each result. Also report for comparison the accepted values of the half-lives, which can be determined from the chart of the nuclides outside room 123. (If you are unfamiliar with the chart of the nuclides, please ask.)

References

- [1] J. H. Moore, C. C. Davis, and M. A. Coplan. *Building Scientific Apparatus*. Addison-Wesley, second edition, 1989.