One of the difficult things about this class (at least for me) is that we have to explore things in lab before we learn about the background physics in lecture. For example, we won’t be learning about nuclear spin for quite a while, but it is important for our lab work. My approach is to not focus too much on the “why” for right now, but just tell you what the result is.

1.1 What is nuclear spin, and why do we care about it?

Nuclear spin is angular momentum. Other examples of angular momentum include a spinning top, a figure skater whirling around in a circle, the moon orbiting the earth, and the earth rotating on its axis. If the nucleus of an atom had no nuclear spin, this is what our ground state and excited state would look like:

$\Delta E$

Excited state

Ground state

Exciting huh 😊. As a reminder, our goal is to measure that energy difference $\Delta E$. If we perform our spectroscopy, we expect a spectrum that looks like this:
0 on the horizontal axis is actually the $\Delta E$ we are trying to measure. The shape of this curve is called a Lorentzian. Because the nucleus has spin, both the ground state and the excited state “split”. Here is the ground state of Europium-151:

Don’t worry too much about the $F=1$, $F=2$, etc. right now. The important thing is that the ground state is not 1 level, but 6 closely spaced levels. The excited state is also split. As such, our actual signal ends up being a whole bunch of Lorentzians. Like, a stupid number of them. Here is a prediction for one of the transitions. I made up the amplitudes of each of the Lorentzians, but the horizontal positions should be close:

See! Stupid number of Lorentzians. The zero on the horizontal axis is where the single Lorentzian would be if the nucleus did not have spin. As a reminder, that zero is actually $\Delta E$ from above. This value is also called the “center of gravity”.

Our goal: We want to find that $\Delta E$. 
So, how do we get rid of nuclear spin? Theory ☺. Remarkably, quantum theory tells us that there are only 4 parameters that determine the position of each peak in the above plot: $A_g, B_g, A_e,$ and $B_e$. We call these the A and B hyperfine coefficients for the ground and excited states. Also, we already know what these values are from previous groups. Using theory and the known values of the hyperfine coefficients, we mathematically calculate $\Delta E$. Later in the semester, we will see the full formulas for calculating the splitting from the center of gravity. For now, our fitting program puts out the fitted values of $A_g, B_g, A_e, B_e,$ and $\Delta E$, all with uncertainty.

Next week we will talk about systematic uncertainties, which is anything that can mess up fitted values. Things like the argon pressure and the laser alignment are all things that can mess up the fitted values.

1.2 Experiment time: Prof. Will and/or the LA will help you.

- Let’s find the spectrum
- Next, we will play around with all the experimental parameters to try and optimize our signal/noise (see below)

1.3 Signal to noise

All data has noise. The size of a signal compared to the background noise is called signal to noise. Mathematically, signal to noise is:

$$S/N = \frac{A}{V_{rms, noise}}$$

where $A$ is the amplitude of a Lorentzian measured in volts and $V_{rms, noise}$ is the root-mean-square of the noise. Here are a few (simulated) plots with different signal to noise. Each signal has an amplitude of 1.

I added a guide for the eye for S/N=3