Introduction:

(Slide 1)

Gamma rays are a very high energy, high frequency form of nuclear radiation that is emitted as the result of relaxation of an excited nucleus. This is very similar to the emission of visible light photons from the excitation of atomic electrons. However, due to nucleons having energy states dictated by the strong force, the energies of the photons emitted are massive in comparison; as much as seven orders of magnitude higher than those released by electron relaxation.

Additionally, since gamma ray photons are uncharged and do not create any direct ionization o excitation of the material they pass through, they are effectively invisible, forcing us to rely on various interactions within the absorbing material to gain any insight as to the nature of the incident gamma.

(Slide 2)

One of the most common ways a nucleus can find itself in an excited state is via nuclear decay. The ones we are concerned with in this lab are the three we have listed: alpha decay, positive beta decay, and negative beta decay. When these decays occur, a parent nucleus decays into a daughter nucleus, plus some other particle, which may be in an excited state.

Alpha decay is when a parent nucleus decays into some daughter nucleus plus an alpha particle (i.e. a Helium-4 nucleus). This is due both in part to the extreme closeness of the strong force, as well as the repulsion of like-charges in the electric forces. The strong force dominates between roughly 1 to 3 fm, where it then quickly drops to zero. In larger nuclei, there is a possibility that a proton will not feel the strong force from every other nucleon in its proximity, and will instead feel a net-positive, repulsive electric field upon it. In certain circumstances this can result in the expulsion of 2 neutrons and 2 protons.

Both types of beta decay are the result of the weak force. In positive beta decay, we see a proton decay into a neutron, positive beta particle (positron), and an electron neutrino. In negative beta decay, we see a neutron decay into a proton, negative beta particle (electron), and an anti-electron neutrino.

Finally, gamma emission is strictly the release of a gamma ray from an excited nucleus, like those from the three other processes.

(Slide 3)

Said above, we have to rely on specifically fast electron interactions to gain any insight into an incident gamma ray. These are the photo-electric effect, Compton scattering, and pair production. The photo-electric effect is most likely at lower energies; roughly in the 10s of eV. Alternately, pair production takes place on the higher end of our energy spectrum; starting to occur at 1022 keV, twice the rest mass of an electron. However, the interaction we are most concerned with in this experiment is Compton scattering. Simply, Compton scattering is the result of an incident photon scattering off of an electron, to which it transfers a fraction of its energy. Since gamma rays are so high energy, Compton scattering proves to be help in “slowing them down” to the point where they’re energy can be converted into measurable electric energy.

Detector:

(Slide 5)

We used a scintillation detector made of sodium iodide. It’s made of two components: (1) a scintillator and (2) a photomultiplier. The first step, the gamma rays will enter the scintillator where they will interact with the atoms in the crystal lattice. These interactions will result in the transfer of energy, which in some cases will result in the bound electrons to jump to an excited state. These electrons will then relax back to their ground state, releasing a visible light photon in the process. This visible light photon then interacts with the photocathode at the entrance of the photomultiplier. Upon doing that, it knocks an electron out of place, via the photoelectric effect. This primary electron is then pulled into an electric field that is generated by an anode and is pulled towards a dynode, where is knocks several other electrons out of place, causing each one of them to pulled into another, stronger electric field towards another dynode. This process repeats 10 times and generates a measurable electrical signal that can then be digitized by an ADC converter. We then can read the digitized pulse data.

Data Analysis:

(Slide 7 and 8)

We first collected our data by doing a 5-minute run for each material. We were given a series of peaks.

Each peak follows a typical structure, defined by having a large full energy peak, and two smaller Compton peaks. We used this structure to try and analytically locate the channel number of the most obvious peaks. In particular, these were the large peaks for materials that only had one measurable gamma in our energy range. We then ran over the data with a piece of python code to get the specific values for each channel with their uncertainty. For multiple peak materials, especially those with overlapping peaks like barium, we used a ratio of a known channel number and corresponding energy to algebraically solve for a likely range of channel number to analyze.

After finding peaks for each of the known gammas, we made a Energy vs Channel number plot, with a line of best fit that was found using the `linregress()` function from scipy.stats.

(Slide 9)

We then used the same methods to gather our data for the unknown compound. We saw that there were two visible peaks, with one being substantially smaller than the other.

The error in the channel calculation was found using the `curve\_fit` function from the scipy library to find a covariance and taking the square root.

We found the energies for the unknown materials gamma rays using the linear line-of-best-fit equation.

We then calculated the error in the unknown energies with the equation for the propagation of error, where x\_i indexes the three components of the line-of-best-fit equation.

We then looked up which materials these two gammas corresponded to, we determined that it’s most likely the unknown compound is some combination of Cesium-137 and Zinc-65.

Special Calculation:

(Slide 10)

One thing that would help in identifying the full energy peak of gamma rays, would be the identification of one, or both of the Compton peaks. As it turns out, it’s fairly easy to identify both the energy of the Compton edge, as well as the gap between the Compton edge and the full energy peak.

We can use the following equation to find the energy of the recoiled electron due to Compton scattering, where \nu is the frequency, m\_0c^2 is the rest energy of an electron, and theta is the scattering angle.

There are two extreme cases we can see. When theta is about 0, we can see that the energy of the photon is roughly equivalent to what it was before the scattering. In this case, the recoiled electron barely gains any energy, while the incident gamma retains nearly everything. When theta is roughly equal to pi, we get the maximum possible transfer of energy from the gamma to the electron. In this case, the gamma is backscatters towards its direction of origin and the electron scatter in the direction of incidence. This latter case gives us the energy of the Compton edge.

Similarly, we can take the energy of the Compton edge and subtract it from the full energy peak, to identify how large the gap ought to be between the two, which helps us come up with some rough estimate for where to expect it, thus giving us more sure footing when attempting to find a specific peak by identifying its characteristic, ancillary peaks.