Gamma Spectrocopy of Radioactive Cesium-137

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Abstract

Gamma ray spectroscopy is important in many fields relating to quantum physics and materials science. To determine the spectroscopic properties of Cesium-137 we use a multi-channel-analyzer to collect multiple known spectra. These plots are used to calibrate the analyzer to map the correct energies to the channels. This provides an accurate spectrum of Cesium-137 which we discuss based on the calibrated energies.

1 Introduction

The scintillation detector consists of an NaI crystal that interacts with photons generated by a source the experimenter is attempting to measure. The NaI crystal has both compton scatter and photoelectric interactions with photons [1] which increases the chance that a gamma ray will be detected. The purpose of this report is to discuss how these interactions lead to different features of spectra and how we can use these features to identify unknown sources.

The photoelectric effect is a quantum-mechanical phenomenon in which photons excite electrons off the surface of a metal [2]. This process is detectable as moving electrons register as a current. In the scintillation detector, incoming gamma rays excite the easily freed electrons from the NaI crystal, causing them to be detected.

Other gamma rays intersect with electrons, sending both a photon and an electron scattering. This process is called Compton scattering [2]. The photon travels down the photomultiplier tube, and registers as a detected gamma ray. The equation to understand how Compton scattering may be reflected in a spectrum is the Compton shift formula [2]:

$$\lambda' - \lambda = \frac{h}{m_e c}(1 - \cos\theta) \tag{1}$$

In words, the wavelength of the scattered photon depends only on the scattering angle. The scattered photon is always of larger wavelength than the incoming one.

2 Experimental Procedure

The process to determine the radioactive properties of Cesium-137 began with the multi-channel-analyzer (MCA). This device records detected gamma rays and bins them based on energy. However, the raw output from the machine is in the form of counts per channel. We do not know the count associated with a given energy, only channel. Thus, we need to find the mapping from a given channel to the assocated energy, in other words we need to calibrate the MCA. The calibration mapping is found by recording the spectra for materials for which the spectra is known. Then we can associate channels with energies and find a relationship.

The known materials were Cobalt-60, Cobalt-57, Barium-133, and Americium. The following table records the values of the channels associated with known energies.

Source	**Energy** [keV]	Channel Number
Am	59	193
Co-57	122	379
Ba-133	302	890
	356	1049
Co-60	1121	3307
	1332	3743

Table 1: experimentally determined channel values associated with known energies

Now that the relationship was known, we could take a spectrum of Cesium-137 and find the energy of all the features in order to understand why they appear.

3 Analysis

To understand the relationship between the channels and energies, a linear fit was determined for the known values.

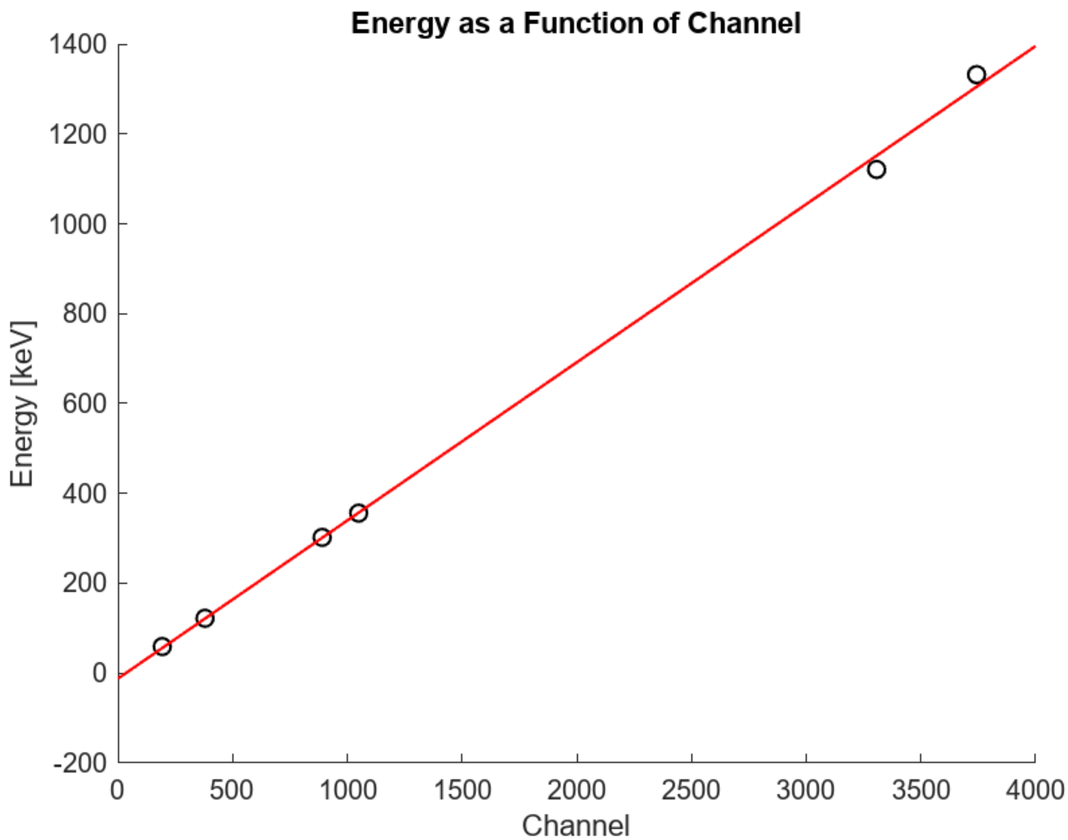

Figure 1: linear relationship between MCA channel and energy

The slope of the line (with 68% confidence intervals) is 0.352 ± 0.007 KeV / Channel. This slope gives the mapping from channels to energy that can be used to identify features of a spectrum. The raw cesium-137 spectrum is shown in figure 2:

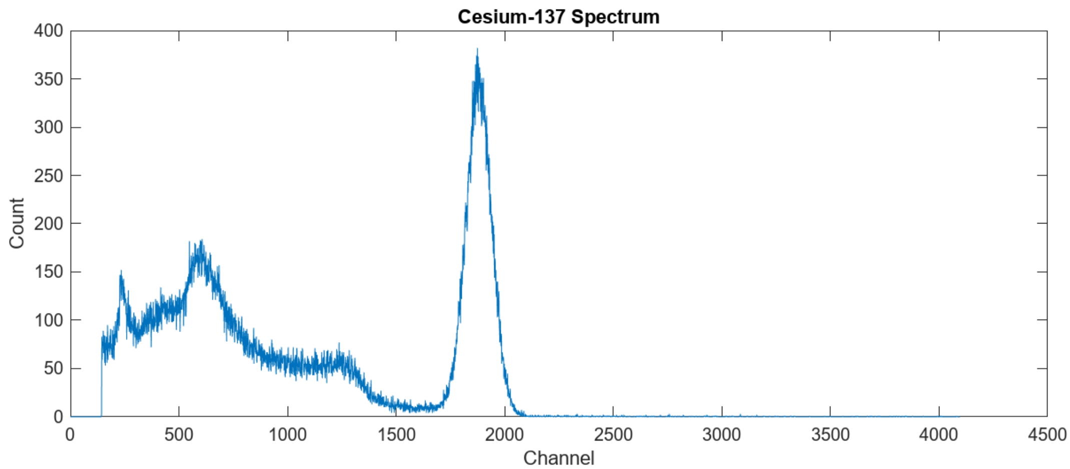

Figure 2: raw spectrum of cesium-137

4 Discussion

After mapping the channels to energy, we can begin to identify the features of the cesium-137 spectrum.

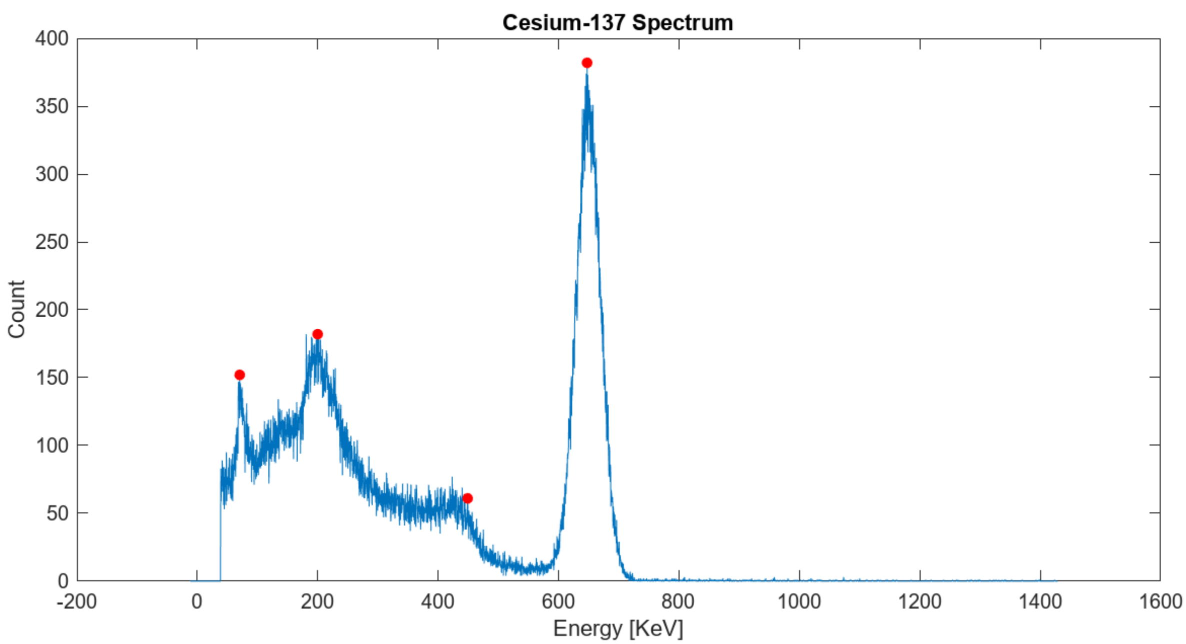

Figure 3: gamma spectrum of cesium-137 with the x-axis mapped to the correct energies. The thicker points represent different features of the graph, different peaks or shoulders

There are five distinct features of the spectrum. For some reason, the MCA refused to output anything but zeros for channels 143 and below, but there should be an x-ray peak close to 0 KeV. When cesium-137 decays (through beta decay) into a barium isotope the atoms are in an excited state. The transition into the lower ground state releases an x-ray photon which is less than 100 KeV.

The second peak (this time thankfully viewable in figure (3)) sits at approximately 70 ± 1 KeV. This peak is another x-ray peak from the radiation of lead.

The next two peaks are both results of Compton scattering. From the shift equation (1) we see that the left side of the equation has a range of values, which are all the possible scattering angles. The first peak at 200 ± 4 KeV is the backscattering peak, for when the angle sends the scattered photon backwards. The next one is more of a shelf, called the Compton shelf. This is the other extreme angle, and where the range of Compton scattering ends. The shelf is approximately at 449 ± 8 KeV. The nature of the Compton formula is that there exists a continuum of angles that the resultant photon can scatter, and this is the curve between the two peaks. The curve represents scattering over the entire range of angles.

The final feature of the cesium-137 spectrum is a gamma photopeak located at approximately 650 ± 13 KeV. This peak represents high energy gamma radiation from the source.

It's important to note that cesium-137 is considered a 'monoenergetic gamma ray emitter' so the first four features were actually generated from x-rays emitted by isotopes of other materials, transformed from cesium in a decay process.

5 Conclusion

Calibration of the MCA is a useful skill in the observation of radioactivity. In this report I walk through the process of calibrating the MCA to associate each channel with an energy. The energy is needed to create the spectrum, and analyze the properties of the source. The source in this experiment was the radioactive isotope cs-137. Cs-137 is a monoenergetic gamma ray emitter which means it generally only emits gamma rays at a certain energy. One of the peaks in the spectrum (specifically the highest energy one) exemplifies this radiation. The other features come from decay into other isotopes of materials like barium and lead, most likely alpha or beta decay. The process outlined in this report can be used to identify unknown sources if their radiation energies are known.

References

[1] A. C. Melissnos and J. Napolitano, *Experiments in modern physics*, 2nd ed. (Academic Press, 2003).

[2] R. Harris, *Modern physics*, 2nd ed. (Pearson Education Inc., 2014).