Observing Gamma Radiation

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Abstract

The minute interactions of fundamental particles are of great interest to experimental physicists. The observation of a radioactive source an give an insight into these energetic particles. In this experiment I observe gamma rays and calculate basic properties of gamma radiation.

1 Introduction

During the process of radioactive decay, atoms in a material change energy levels and thus release particles. In the case of Cesium-137, this decay results in the emission of high energy photons, called gamma rays. Gamma rays have the highest energy of any wave in the electromagnetic spectrum and are created from galactic sources such as pulsars, supernovae, and neutron stars, but these rays are emitted in low levels from certain radioactive decays.

γ rays are very important in the fields of chemistry and physics, as they provide information about the excited states of atoms, a fundamental part of quantum mechanics. Moreover, the spectrum of gamma rays emitted from a material can indicate the isotope present [1].

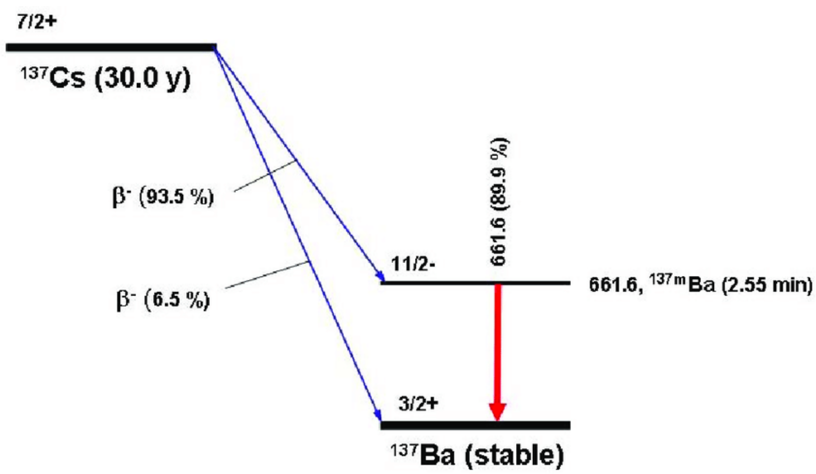

Figure 1: energy levels of Cesium-137 showing radioactive decay [2]

Gamma ray detection is an interesting problem since the wavelengths are so short the particles barely interact. γ rays do not reflect off of mirrors and can pass undetected through most materials due to the size of the wavelength, and therefore it is a challenge to detect them.

I am looking the rate of counts per second in this experiment, and in a counting experiment we often look at probability distributions to better understand the data. Two popular ones used in this report are the Gaussian distribution:

$$G_{\sigma\bar{x}}(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-(x-\bar{x})^2}{2\sigma^2}} \tag{1}$$

and the Poisson distribution:

$$P_{\mu}(\nu) = \frac{\mu^{\nu}}{\nu!} e^{-\mu} \tag{2}$$

2 Experiment

Cesium-137 is a radioactive source. The levels are not dangerous, but small samples of this material will emit gamma rays at a measurable rate. My goal was to determine the emission rate in two instances, first when the source is emitting at full capacity, and secondly when the source was emitting at a low rate. These are called the 'high count' and 'low count' trials.

The experimental setup was centered around a scintillation detector. A scintillation detector takes in emitted gamma photons and passes them through a NaI crystal. This crystal maximizes the chance a photon will interact, and therefore gives the most accurate result. When a photon is detected, an electric pulse called a 'photopeak' is emitted and registered on an oscilloscope. The detector sends a pulse for all detections greater than a threshold. We tuned this threshold by tweaking the voltage settings on the inputs to the detector, in order to only observe the radioactive decay particles.

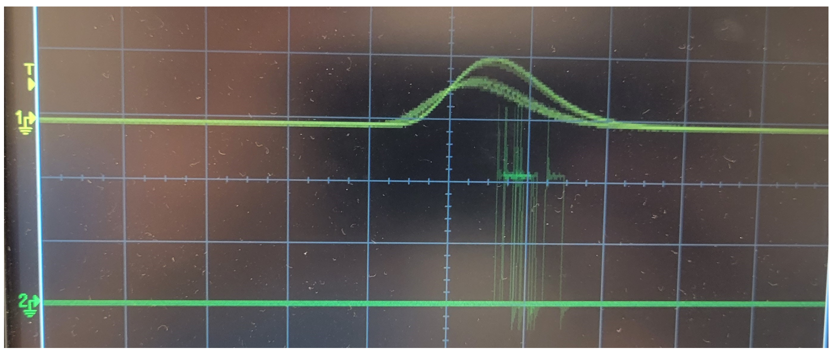

Figure 2: Oscilloscope output showing detected particles (top) and those accepted by the threshold detector (bottom)

3 Analysis

As mentioned before, the first trial was the high count trial, where the rate of emission for gamma rays was high. The source was placed fully into the detector apparatus and the counter was set to count for ten seconds. One hundred different counts were recorded over ten second intervals. The histogram of this trial was fitted with a Gaussian distribution (equation 1).

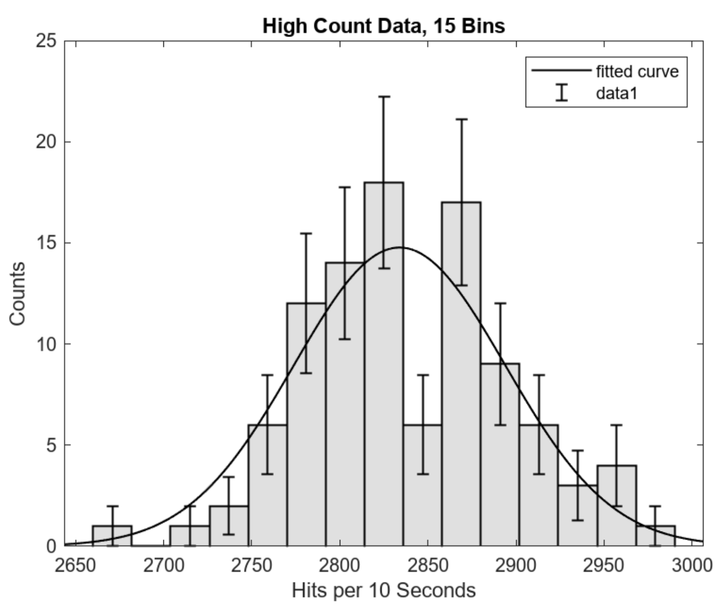

Figure 3: Gaussian fitted distribution of high count data for detected γ rays

The mean and standard deviation of this distribution are respectively 2834 and 60. To get a more accurate value, I measured the background particles, recording 155 counts in 100 seconds, meaning a background rate of 1.55 counts per second. Without adjustment for background, the expected rate of detection was 283 ± 6. Notice that the uncertainty is actually greater than the background rate, so it may not be necessary to take it into account. With adjustment for background the expected rate is still 283 ± 6 due to the number of significant figures.

For the second experiment I pulled the source almost completely out of the detector so that the count rate of gamma particles was about two in one second. We then measured a distribution of 100 counts over 1 second.

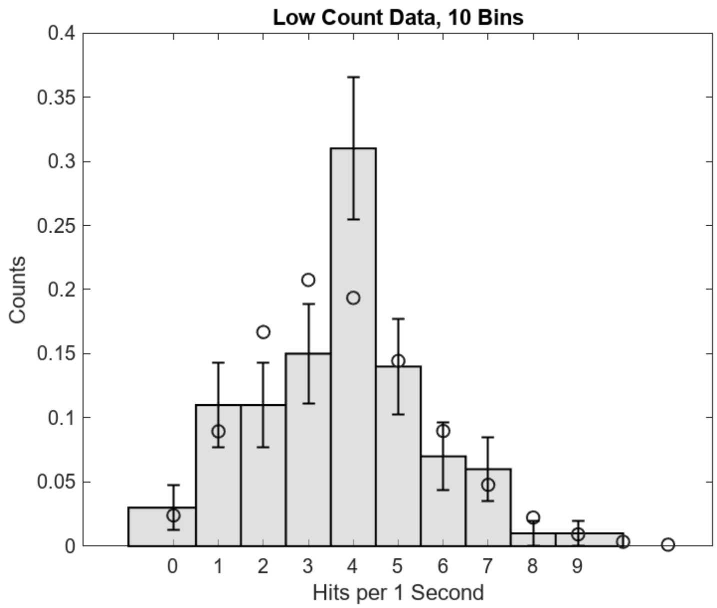

Figure 4: Distribution of low count data with a Poisson distribution (circles) superimposed on top of the histogram

A Poisson distribution (equation 2) was fitted over this distribution, and plotted on top of the histogram. The Poisson distribution is a useful model for random counting experiments that are discrete. The μ parameter was fitted to be 3.73.

The goodness of each fit can be determined by the chi-squared test. The best fit minimizes the value of the chi-squared parameter χ^2.

$$\chi^2 = \sum \frac{(y_i - y_{th,i})^2}{y_{th,i}} \tag{3}$$

Where y are the observed values and y_{th} are the theoretical or expected values. I calculated the chi-squared value for each fit and found the Gaussian fit (fig 3) had $\chi^2 = 14.4$. The Poisson fit (figure 4) had a chi squared of $\chi^2 = 0.126$. The chi squared should be around equal to the number of bins if the fit is a good one, so it appears the Gaussian fit is pretty good since the number of bins was 15. The Poisson distribution (due to the way matlab does it) was normalized so the actual chi squared was 12.6, which is close to 10, the number of bins in that histogram. Overall both fits were pretty good.

4 Conclusion

γ rays are integral to observing quantum mechanics at work. They reveal the hidden discrete energy levels of different atoms and provide evidence for particle interactions. Observing this radiation is an interesting challenge in the lab, due to the shortness of the wavelengths, but through a scintillation detector I collected counting data on the emission rate of gamma rays in situation where a high count is expected and situations where a low count is expected. In the first situation, I measured an emission rate of 283 ± 6 particles per second. The fit for this distribution was Gaussian, with a chi-squared value 14.4. This value is close to the bin count of 15, demonstrating the 'goodness' of the fit.

A Poisson distribution was fitted to the low count data, with a paramter value of 3.73. The chi-squared value was calculated to be 12.6, close to the number of bins which was 10. Both distributions have merit in these situations, but the Poisson distribution makes a lot of sense in the low count case, since the bins are very discrete.

References

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

[2] T. Bjørnstad, J. Portela, P. Brisset, N. Chankow, J. Charlton, M. Solis, C. Dagadu, A. Dash, F. Díaz Vargas, G. Din, J. Jin, L. Jinfu, L. Anrique, A. Ferreira, J. Palige, F. Roesch, S. Jung, and C. Vargas, *Radiotracer generators for industrial applications, iaea radiation technology series no. 5* (Apr. 2013).