AST4007W - Computational Methods
Project 2 Curve Fitting

The Problem

The energy spectrum of a radioactive source emitting gamma-rays of unknown energy has been measured using a scintillation detector as a spectrometer.

Your task is to use the measured spectra of radioactive sources with known gamma-ray energies to calibrate this spectrometer, and use this to determine the energy of the gamma-rays emitted by the unknown source.

1 Background

The scintillation detector consists of a crystal scintillator mounted on a photomultiplier tube. The scintillator is ionized by the gamm-ray radiation, producing lower energy ultraviolet radiation that the photomultiplier can detect. The photomultiplier emits a voltage pulse when it detects a photon. These voltage pulses are recorded digitally, binned into channels according to their strength. Throughout the process the gamma-ray energy absorbed in the scintillator is linearly proportional to the channel number [2]. The data is recorded as photon counts in each voltage channel.

The measured energy spectrum is a result of measuring both low energy background radiation and the ultraviolet radiation from the scintillator due to interactions between the gamma-ray and the medium of the scintillator.

The background radiation largely consists of low energy cosmic radiation (as long as there are no active sources of radiation present). Consider the spectrum of a background reading (no active material placed in front of the detector) in Figure 1.

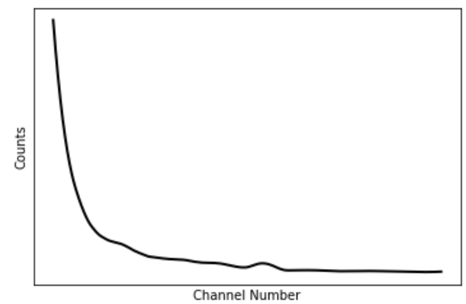

Figure 1: Measured spectrum of the background radiation.

When a gamma-ray enters the medium of the scintillating crystal it can interact with the material in three main ways. It can be absorbed by an electron through **photoelectric absorption**, it can collide with an electron, causing **Compton scattering** or it can form an electron-positron pair in the shielding material, **pair production** (this only occurs with high energy gamma-rays). Each of these interactions gives the resulting spectrum it's characteristic features.

The distribution of detections from **photoelectric absorption** of the original gamma-ray, or gamma-rays from the annihilation of the **pair production** positron, forms a **photopeak**. This **photopeak** is characterized by a Gaussian shape. The spread in measured energies is unavoidable (the process of **photoelectric absorption** isn't guaranteed to absorb all of the gamma-ray energy) and is a characteristic of the scintillator used. The centroid of the **photopeak** corresponds to the energy of the gamma-ray captured by the detector.

Compton scattering in the shielding material produces a peak in the distribution called the **backscatter peak**. **Compton scattering** in the scintillator itself causes a higher energy peak in the distribution called the **Compton edge**. Fitting a functional form over these peaks is not as straight forward as the **photopeak**, though the drop-off from the **Compton edge** can be modeled as a decaying exponential.

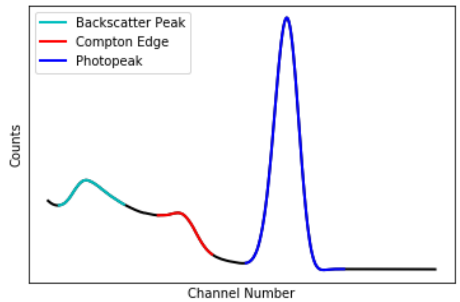

Figure 2: Measured spectrum of a gamma-ray source.

Your Task

In the data files provided the spectra are recorded as the number of gamma-ray counts in each voltage channel of the spectrometer. Note that not all of the information in the data file is important for this project. In particular the header doesn't contain any information that you need and there is an empty column in each file. All this needs to be taken into mind when reading/formatting the files.

The potential difference of the channels are linearly spaced, which means the channel numbers are linearly proportional to the energy of the ultraviolet photons that are measured. The channel values of the **photopeak** centers are thus linearly proportional to the energy of the incoming gamma-rays.

In order to find the energy of the gamma-rays emitted by the unidentified source, the spectrometer must be calibrated by finding the relationship between the channel number and the gamma-ray energies. Do this by finding the channel numbers of the **photopeak** centroids in the distributions of the calibration sources. For the uncertainties of the centroids you can use the standard deviation of the Gaussian function fitted over the peak.

Some things to considering when finding the centroids of the photopeaks:

- Where possible isolate the photopeaks by extracting segments of the data (with some background on either side).
- Don't forget fit the background and drop-off from the Compton edge as a decaying exponential.

The (linear) relationship between the channel number and the gamma-ray energies can be found using the measured channel values of the photopeak centroids and the known gamma-ray energy values given in the table below [1]:

Isotope	Gamma Energy (keV)	Uncertainty (keV)
^{137}Cs	661.660	± 0.003
^{60}Co	1173.238	± 0.04
	1332.502	± 0.005
^{22}Na	511.003*	
	1274.542	± 0.007

Table 1: The energy values of the gamma-rays emitted from the calibration radioactive sources. ** This gamma-ray is due to annihilation radiation resulting from pair production and it's value is calculated precisely.*

Some things to consider when finding the relationship between channel number and gamma-ray energy:

- Which uncertainties are (proportionally) larger? The energy or the channel number?
- How can you use (some) of the uncertainties in finding this relationship?

Seeing as we have not covered propagation of uncertainties through least squares minimization, you are not expected to determine the uncertainty of the measured gamma-ray energy.

Submission Guidelines

You are not expected to use any tools or methods that are more advanced than those already covered in this course.

Submit your source code as well as a short writeup of your methodology for performing the data analysis above. Record/plot any intermediate results you get as well as your final result. You need not give a background to or methodology for the experiment where the data was taken.

References

[1] Gilmore, G. and Hemingway, J. 1995. *Practical Gamma Ray Spectrometry.* 1st ed., John Wiley & Sons

[2] Krane, K. 1987. *Introductory Nuclear Physics.*John Wiley & Sons