Gamma Ray Spectroscopy

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Abstract

The relationship between the position of an energy peak, H_0 and the photomultiplier voltage, V are investigated in a gamma ray spectrometer consisting of a scintillator, a photomultiplier and a multichannel analyser. It was found that $H_0 \propto V^n$. We then investigate the spectra of Cs^{137}, Co^{60} and Na^{22} and found that they agreed with the decays associated with the isotopes. We also measured the detector efficiency to be 0.39. Finally, we found the activity of a KCl source and compared it with a theoretical estimate but found that they did not agree.

⋆ Introduction

Gamma ray spectroscopy is the measurement of the energy spectra of a gamma ray source. The equipment used in this experiment consists of a scintillator, a photomultiplier and a multichannel analyser. The photomultiplier works by allowing a photon to hit the photocathode. This ejects an electron that is then accelerated to a sequence of dynodes by a potential difference. Each time an electron hits a dynode, it emits more electrons, say m electrons. At the end, the electrons hit an anode and this is registered as a voltage. The voltage is proportional to the initial energy of the electrons and hence, we can measure the energy of the gamma ray from the voltage. Since each collision at the dynode releases m electrons; by the end, 1 electron releases m^n electrons where n is the number of dynodes. m is proportional to the mean voltage across each dynode V_d which is proportional to the total voltage across all the dynodes. Hence, $H_0 \propto V^n$ where H^0 is the position of the energy peak.

Spectrum

The electrons that are ejected by the gamma rays can be ejected by a number of ways. This gives rise to different features of the energy spectrum.

1. Photoelectric Absorption
   A gamma ray ejects an electron from the shell of an atom. An x-ray photon is then generated when the hole is filled. This x-ray photon is very likely to undergo photoelectric absorption. The total energy then of both photoelectrons is E_γ. This peak is referred to as the total energy peak.

2. Compton Scattering
   The gamma ray photon is scattered by an electron by compton scattering. From the Compton effect,

$$\lambda' = \lambda + \frac{h}{mc}(1 - \cos\theta)$$

$$\frac{c}{\nu'} = \frac{c}{\nu} + \frac{h}{mc}(1 - \cos\theta)$$

$$h\nu' = h(\frac{1}{\frac{c}{\nu} + \frac{h}{mc}(1 - \cos\theta)}$$

$$\Rightarrow h\nu' = \frac{h\nu}{1 + \frac{h\nu(1-cos\theta)}{mc^2}}$$

This means the energy of the photon varies from $\frac{h\nu}{1+\frac{2h\nu}{mc^2}}$ to $h\nu$ while the energy of the electron varies from 0 to $h\nu(1-\frac{1}{1+\frac{h\nu}{mc^2}})$.

3. Pair Production
   It is also possible for e^+e^- pair production to occur if the gamma ray has sufficient energy. The pair will then annihilate and create two gamma ray photons of energy 0.511 MeV to conserve energy and momentum.

$\star$ Experimental Method

We aim to find the effects on the spectrum whilst varying the photomultiplier voltage; measure the spectra of Cs^{137}, Co^{60} and Na^{22} and analyse them and investigate the dependence of the resolution on the gamma ray energy. We also want to determine the detector efficiency of the spectrometer and to measure the activity of K^{40} of a sample of Potassium Chloride. The resolution, R is defined to be $R = \frac{FWHM}{H_0}$ where $FWHM$ is the full width at half maximum. The apparatus consists of a scintillator, a photomultiplier and a multichannel analyser.

Varying Voltage

Set up the apparatus and ensure the equipment is calibrated. Measure the $FWHM$ and H_0 whilst varying voltage, V for a Cs^{137} source. Plot a graph of $\ln V$ vs $\ln H_0$.

Spectra

Allow the spectrum to be recorded for the samples of Cs^{137}, Co^{60} and Na^{22}. Ensure the equipment is properly calibrated. Record the values for the peaks (backscatter, Compton, etc) and FWHM. Measure R for each total peak.

Efficiency

If A is the activity of the Na sample and ϵ is the efficiency of detection, then the count rate for that peak is $2A\epsilon$. The count rate for the sum peak is $A\epsilon^2$. Thus, we can find ϵ by getting the spectrum of a Na^{22} sample and reading the values from the spectrum.

Activity of KCl

Allow the spectrum to be recorded for a day for a 3.625g KCl sample. Measure the count rate from the count and time run.

⋆ Results and Analysis

Varying Voltage

Figure **??** shows that $H_0 \propto V^n$. The equation of the graph is $\ln H_0 = (7.8 \pm 0.4) \ln V$. Thus, $n = 8$ within error which is also the number of dynodes in the spectrometer. Taking the average of the resolution, we found it to be $R = 0.071 \pm 0.001$. R was found to be roughly constant.

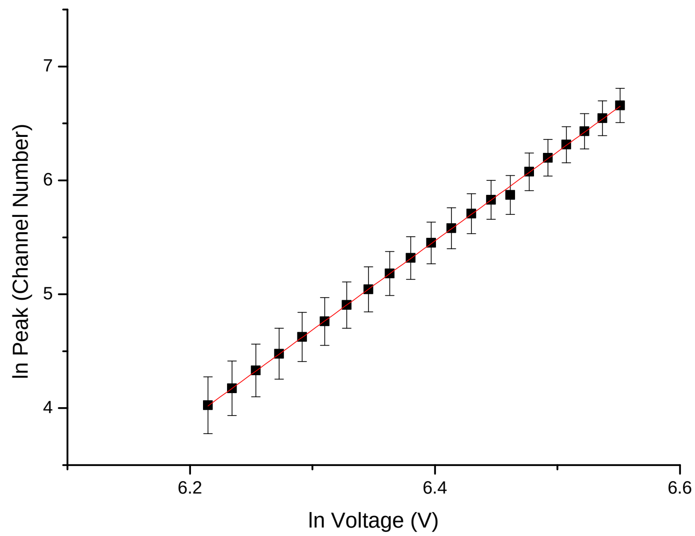

Figure 1: Cs^{137}

Spectra

Co^{60}	Energy(MeV) ± 0.01
Backscatter	0.23
Compton	1.07
E_1	1.15
E_2	1.30

Cobalt-60 can decay with gamma rays of 1.173 MeV and 1.332 MeV. This corresponds to the results measured.

Cs^{137}	Energy(MeV) ± 0.01
Backscatter	0.20
Compton	0.56
Total Energy Peak	0.66

Caesium-60 beta decays into Barium-137 which then decays by gamma ray of 0.662 MeV which corresponds to our result.

Na^{22}	Energy(MeV) ± 0.01
Backscatter	0.18
Compton	0.90
Total Energy Peak	1.01
Pair Production	0.51

Sodium-22 decays with emissions of a gamma ray of 1.275 MeV which is slightly off compared to our result. What is also interesting is the peak caused by pair production. This is because the gamma ray has sufficient energy to create an electron-positron pair which can then annihilate to form two gamma rays of 0.511 MeV which corresponds to our result.

The resolution should be inversely proportional to the energy. For the case of Co^{60}, $R_1 = 0.04 \pm 0.01$ and $R_2 = 0.04 \pm 0.01$. The product with the energy then should just be a constant. $R_1 E_1 = 0.05 \pm 0.01$ and $R_2 E_2 = 0.05 \pm 0.01$. As we can see, this relationship is confirmed within error.

Efficiency

$2A\epsilon$ is found to be 1.72. $A\epsilon^2$ is found to be 0.34. This gives $\epsilon = 0.39$.

Activity of KCl

The sample contained 3.625g = 0.049 mol of KCl. If the abundance ratio of K^{40} is 0.011%, then the number of K^{40} atoms is 3.24×10^{18}. Note that only 11% of the atoms undergo gamma ray emission. Then the number of particles undergoing gamma ray emission is 3.56×10^{17}. The count rate is $\frac{dN(t)}{dt} = \lambda N(t)$ where λ is the decay constant. If the half life is 1.26×10^9 years, this gives the theoretical count rate to be 6.22.

The count was found to be 19000 ± 100 and the experiment was run for 84300 seconds. This means the count rate is 0.225 ± 0.001. This is out by an order of magnitude suggesting that there is a large amount of error. Results could possibly be more accurate if we allowed the experiment to run longer than a day.

⋆ Conclusion

We have confirmed that $H_0 \propto V^n$ and the resolution is roughly constant for a spectrometer. The spectra of Cs^{137}, Co^{60} and Na^{22} were measured and agreed with their respective decay processes. The resolution was also found to be inversely proportional to the gamma ray energy. We found the detector efficiency to be 0.39. Unfortunately, the activity of KCl did not agree with the theoretical value. Attempts to reduce this error would be to allow the experiment to run even longer than a day.

⋆ References

Radiation Detection and Measurement, Glenn F. Knoll