γ ray spectroscopy using a scintillation detector

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Contents

I. Introduction

The experiment aims to find out the γ ray spectra for a $^{137}_{55}$Ce using a scintillation detector using a Single Channel Analyser (SCA).

II. Gamma Ray Interaction with Matter

There are three dominant interactions of γ ray with matter, namely photoelectric effect, compton scattering and pair production. Since we dont work with high enough energies, pair production cannot happen.

II.1. Photoelectric Effect

An incident γ-ray photon undergoes an interaction in which it hits a bound electron, transfers its energy completely and then an energetic **photoelectron** is emitted. These photoelectrons have almost the energy of the γ ray emitter by the source, minus a small amount of binding energy. We also note that photoelectric effect cannot happen with free electrons.

The probability of photon interaction taking place at a certain distance from the nucleus is given by

$$\tau \propto \rho \frac{Z^n}{E_\gamma^{3.5}}$$

where n varies between 4 and 5, Z is the atomic number and E_γ is the energy of the γ ray. We also see jumps in interaction probability when the energy of the γ ray is close to the binding energy of certain shells like K etc. The probability of photon interaction is given below. The electrons ejected due to photoelectric effect are almost all of the same energy, thus they form a delta like peak in the energy spectrum.

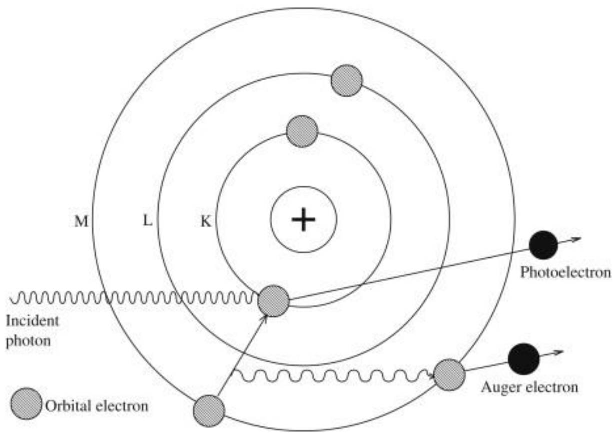

Figure 1 :: Photoelectric Effect in an atom. Source: The Internet.

II.2. Compton scattering

The next kind of interaction is called Compton Scattering. Here an incident γ ray photon scatters off of an electron and then transfers part of its energy to the photon based on the angle of scattering. We also know that scattering can take place between the photon and the electron at any angle between 0 and π. Thus we observe a compton continuum in the energy spectrum.

The scattering probability increases linearly with Z(atomic number). The kinetic energy of the electron after Compton scattering at an angle θ is given by

$$E_e = h\nu \left(\frac{h\nu / m_0 c^2 (1 - \cos\theta)}{1 + h\nu / m_0 c^2 (1 - \cos\theta)} \right)$$

Thus the energy of the electron has a maximum and minimum energy since the range of θ is limited between 0 and π. This range in the energy spectra is called the **Compton Continuum** with the end, being called the **Compton Edge**.

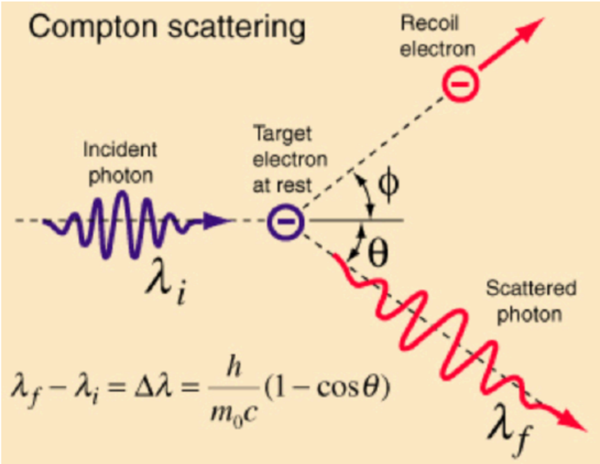

Figure 2 :: Compton effect, Source: The Internet

II.3. Pair Production

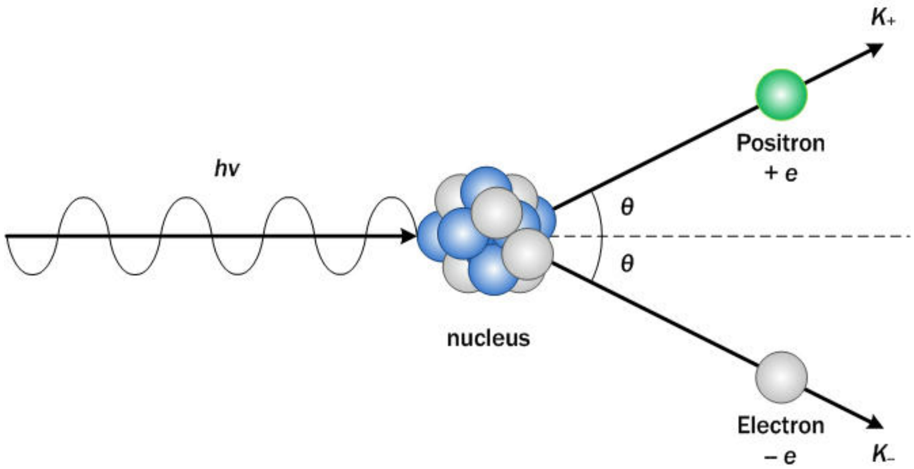

Figure 3 :: Pair production, Source: The Internet

Pair production is a phenomenon which in this case refers specifically to a photon creating an electron–positron pair near a nucleus. As energy must be conserved, for pair production to occur, the incoming energy of the photon must be above a threshold of at least the total rest mass energy of the two particles created. Thus, the process is only energetically possible if the photon energy exceeds -

$$2 m_0 c^2 \approx 1.03 MeV$$

For the purposes of conservation of momentum, the process must occur in the proximity of a third body - usually a nucleus. Practically, this process is only significant for photon energies exceeding ~$10 MeV$, so we do not observe the peaks related to the pair production phenomena in our spectrum. The excess energy of the photon is shared as the kinetic energies of the electron-positron pair that is created.

$$E_{e^-} + E_{e^+} = h\nu - 2m_0c^2$$

If the gamma ray has enough energy for pair production to occur, we observe a peak at an energy $1.02 MeV \approx 2m_0c^2$ below the photopeak (assuming that both of the gamma photons produced by the annihilation of the positron do not escape the detector).

It is also known that the crossection of this process scales as the square of the atomic number of the interacting material.

III. Scintillation energy detector

The Energy Spectra of the γ ray is measured using a scintillation detector. Scintillation literally means 'to emit light'. We use materials on which, when a γ ray falls, the material emits photons in the visible range. The no. of visible photons is proportional to the energy of the incident γ ray photon. The Scintillation detector consists of a Scintillating material on which the γ ray photon hits to release photons in the visible range, then there is the PMT(Photo multiplier tube) to amplify the signal so that it is picked up by the detector. Then the signal goes into the Single Channelr Analyser(SCA) from which we get readings for the plot.

In the Scintillation material, the number of visible photons are proportional to the deposited energy by the incident γ photon. In the PMT, the number of electrons are proportional to the number of visible photons.

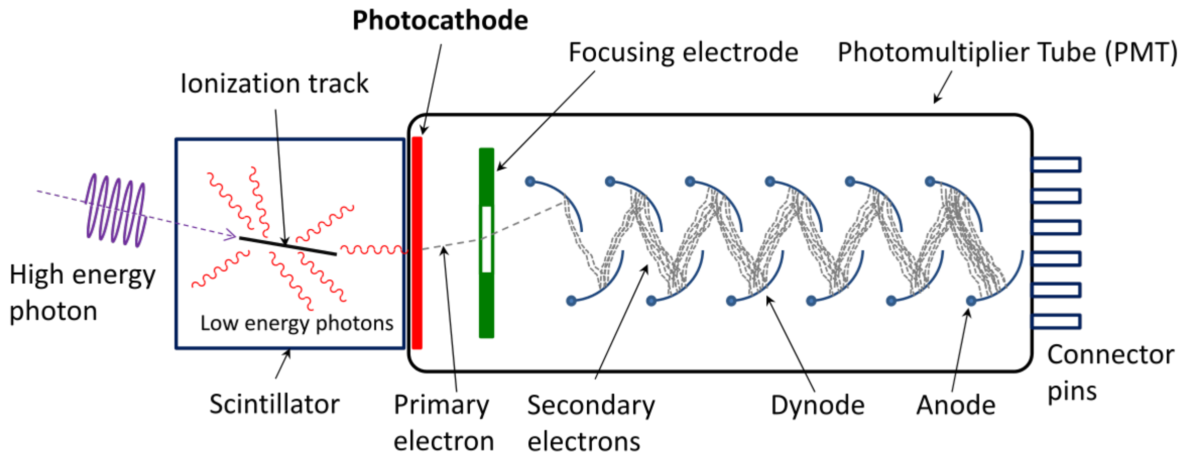

Figure 4 :: Scintillation Detector with PMT. Source: Internet

III.1. Scintillation Material

The scintillation material used here is NaI(Sodium Iodide) doped with Th. The incident γ ray photon hits the electrons in the valence band. The electron then jumps from the valence band to the conduction band. The activators create excited states in the forbidden band. The electron jumps to the activator excited state and then drops down to the valence band releasing photons in the visible range. The activator excited states increase probability of the visible photon emission. Also for a pure crystal the visble photon might get reabsorbed leading to lower efficiency.

III.2. PMT

A photo-multiplier tube amplifies the signal. The Scintillation material produces a low number of photons, which would give rise to a weak signal. So we use a photomultiplier tube. It consists of a photocathode, and then several dynodes.

The incident photons from the scintillation material hit the photocathode releasing low energy electrons. Then they are accelerated by an electrostatic field to the next dynode where they hit more electrons causing secondary electron emission, where more number of low energy electrons are released when hit by a higher energy electron. This process then repeats to the next dynode and so on. Thus before reaching the anode the number of electrons are amplified causing us to get a better signal. We measure the pulses from the PMT using the Single Channel Analyser to get the energy spectrum.

IV. SCA

A single channel analyzer (SCA) produces an output logic pulse on the condition that the peak amplitude of its input signal falls within the pulse-height window that is established by setting the baseline and then the pulse-height window. We then move the baseline keeping the pulse-height window fixed to map the whole energy spectrum.

V. Pulse height analysis

The pulse height analysis is presented below.

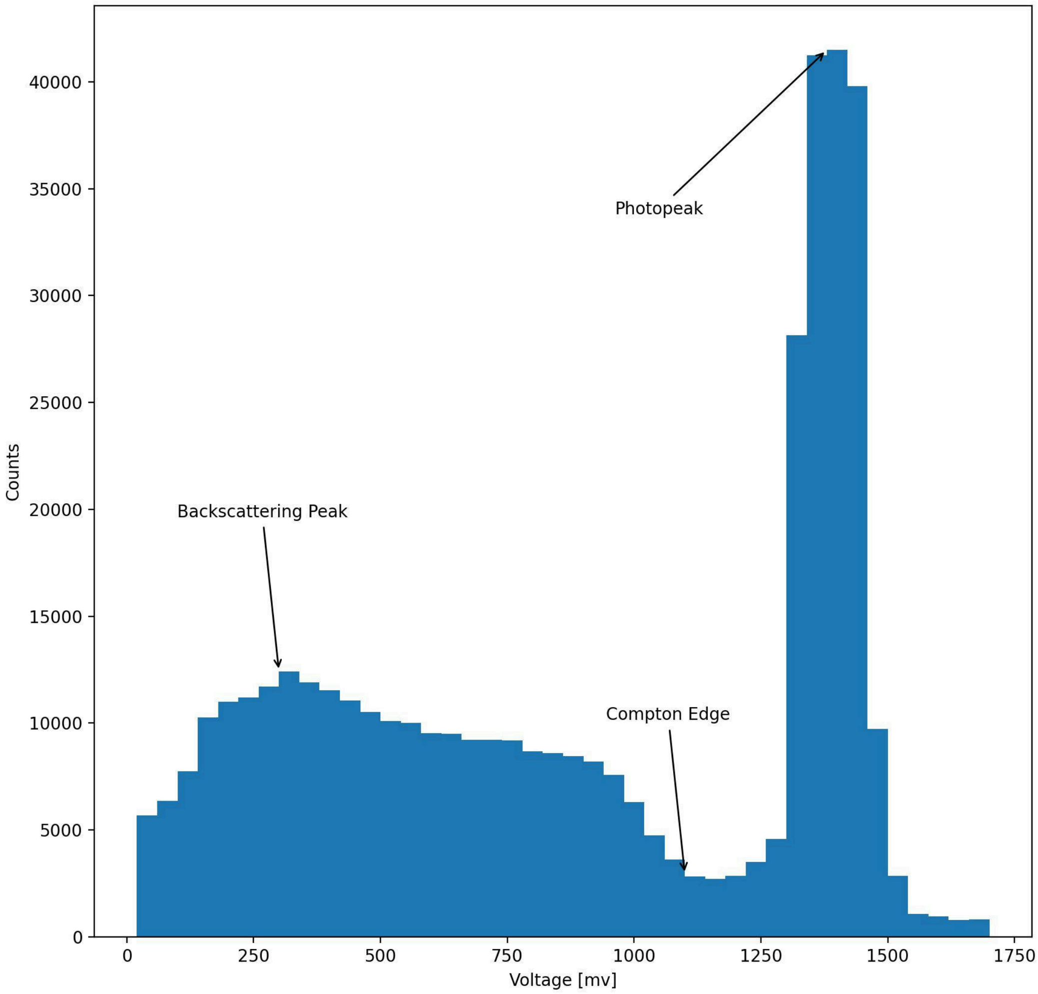

Figure 5 :: Pulse Height Analysis

We did 2 RUNS with 20mV window and changing the baseline by 40mV for 30s each. The average of the two runs has been plotted with the voltage in the X-axis. We obtain a backscatter peak, the compton edge and at the very end, the photopeak. The CRO showed an average pulse height of 1.52V. The Data table with the two runs with the baseline and step size outline is given in Section VII.(Supplementary).

It is to be noted that we get the photopeak at a baseline voltage of $1340mV$.

VI. Conclusion

The experiment concludes by obtaining the energy spectra of $^{137}_{55}$Ce using single channel analyser and a scintillation detector. We obtain a backscatter peak, the compton edge and the photopeak.

VII. Supplementary

The two runs for the spectrum are given below

Baseline Voltage(in mV)	Counts(RUN 1)	Counts(RUN 2)	Avg. Counts
20	5616	5729	5672.5
60	6500	6224	6362.0
100	7731	7784	7757.5
140	10256	10257	10256.5
180	10974	11054	11014.0
220	11114	11317	11215.5
260	11445	11994	11719.5
300	12642	12181	12411.5
340	11841	11970	11905.5
380	11625	11437	11531.0
420	11070	11071	11070.5
460	10370	10695	10532.5
500	10073	10109	10091.0
540	9942	10062	10002.0
580	9220	9865	9542.5
620	9495	9504	9499.5
660	9178	9263	9220.5
700	9308	9162	9235.0
740	9202	9195	9198.5
780	8606	8788	8697.0
820	8502	8698	8600.0
860	8448	8492	8470.0
900	8081	8302	8191.5
940	7546	7632	7589.0
980	6406	6189	6297.5
1020	4634	4853	4743.5
1060	3657	3587	3622.0
1100	2782	2894	2838.0
1140	2720	2728	2724.0
1180	2848	2864	2856.0
1220	3491	3501	3496.0
1260	4701	4470	4585.5
1300	25056	31210	28133.0
1340	43339	39142	41240.5
1380	40571	42408	41489.5

1420	37202	42400	39801.0
1460	10630	8807	9718.5
1500	2327	3387	2857.0
1540	1114	1008	1061.0
1580	1058	881	969.5
1620	796	800	798.0
1660	806	818	812.0