Experiment 3
PH3105
19MS151

7 October

1 Aim

To study of gamma energy spectrum using a scintillation counter with Single Chanel Analyzer (SCA) and determine the resolution of the intensity peak.

2 Theory

2.1 Interaction with matter

As discussed last time, γ rays consist of high energy photons on the Electromagnetic spectrum. They have a very small wavelength of around 10^{-11} to 10^{-12} m. There are multiple ways in which γ rays 4interact with matter. These include.

- **Photo electric effect**: This is a phenomenon in which incoming electromagnetic radiation liberates an electron from the surface of a metal. This requires the photons to have a greater energy than the work function of the electrons.
  The equation for Photo-electric effect is $h\nu = \frac{1}{2}mv^2 + \Psi$
  where Ψ is the work function of the electron and ν is the incoming photon frequency.

- **Compton scattering**: This is a phenomenon in which an incoming photon knocks an electron off it's trajectory. Generally, when a photon strikes an electron, the outgoing photon has energy less than that of the incoming photon, the rest of it's energy and it's momentum is transferred to the electron.
  $\lambda_f - \lambda_i = \frac{h}{mc}(1 - \cos(\theta))$.
  In our case, the interaction is between a γ photon and a free electron in the $NaI(TI)$ crystal. The energy of the outgoing photon in terms of the incoming photon turns out to be
  $$E_{\gamma'} = \frac{E_\gamma}{1 + 1.96E_\gamma(1 - \cos(\theta))}$$

- **Pair production**: This is a process in which a γ ray photon spontaneously produces an electron-positron pair near a large nucleus. This process can only happen in the vicinity

of a large nucleus because the nucleus gives some sort of a inertial frame.
This process cannot happen in vacuum because of kinematic reasons, as one could easily move into a frame where the momentum along the line of photon's motion disappears for the electron-positron pair, but one cannot move to a frame where the photon is at rest. The interaction threshold is 1.033 MeV.

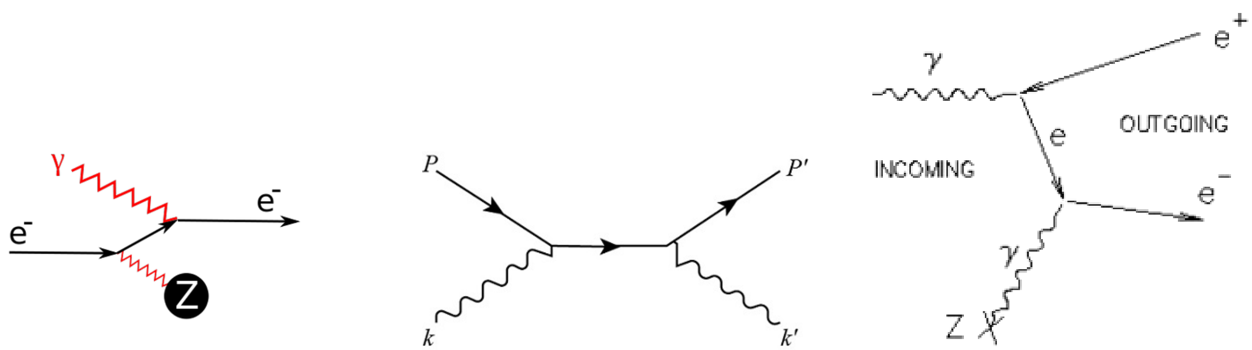

Figure 1: Feynman diagrams for Photoelectric, Compton effects and Pair production

Moving electrons are produced and cause ionization of the atoms in the detector material (Here NaI is used). In the NaI crystal, the moving electrons also ionize impurity atoms in the NaI crystal that are deliberately placed in the crystal during its fabrication. This impurity is thallium (Tl). These impurity atoms de-excite by emitting photons. NaI detectors are sometimes referred to as NaI(Tl) detectors for this reason.
The photons emitted by the NaI(TI) crystal are detected by a photomultiplier tube which consists of a photocathode and several stages of electron multiplying surfaces called dynodes.

2.2 Scintillation detectors

A scintillation detector is a radiation detector which uses the effect known as scintillation. Scintillation is a flash of light produced in a transparent material by the passage of a particle (which can range from an electron to a high-energy photon). A scintillation detector contains,

- **Scintillator**: A scintillator generates photons in response to incident radiation.
- **Photodetector**: A sensitive photodetector, which converts the light to an electrical signal and has electronics to process this signal.

When radiation strikes the scintillator it causes it to give off photons of visible light. These photons pass through the crystal and they strike a thin metal foil called a photocathode, then the light enters the second part of the detector called a photo- multiplier tube (PMT). When the photon hits the photo-cathode it causes an electron to be ejected from the photocathode. Just past the photocathode there is a set of metal cups, each with a voltage applied to it (typically several hundred to a thousand volts), the electron is accelerated by this voltage to a high energy and it strikes the cup with enough energy that it knocks loose a number of other electrons. Each subsequent dynode impact releases further electrons, and so there is a current amplifying effect at each dynode stage. Each stage is at a higher potential than the previous to provide the accelerating field. Primary signal is multiplied and this amplification continues through 10 to 12 stages. Each of them, in turn, is accelerated towards the next metal cup, where each of the "new" electrons knocks loose a number of additional ones, by the end of the PMT the initial signal has been multiplied by a factor of a million or so. From there, it is used by the photodetector for further analysis.

Now sufficient electrons are available to produce a pulse of sufficient magnitude. This pulse carries information about the energy of the original incident radiation. The number of such pulses per unit time also gives information about the intensity of the radiation. In single channel analyser gamma rays having energy between E to $E + \delta e$ are recorded others are ignored. Hence the name single channel analyser. In our experiment E is specified by baseline voltage and δe is specified by window voltage. And we note the reading in steps of δe. Thus we obtain the desired relevant part of the energy spectrum data is obtained. We will analyse this obtained data.

Resolution; The resolution of a spectrometer, R, is a measure of its ability to resolve two peaks that are fairly close together in energy. It is given by, $R = \frac{\delta E}{E} \times 100$.
Here δE is the full width of the peak at half it's max count.

3 Data and Plots

The data for this experiment has 93 readings from 0 to 2.8 V. Cs^{137} γ source was used.

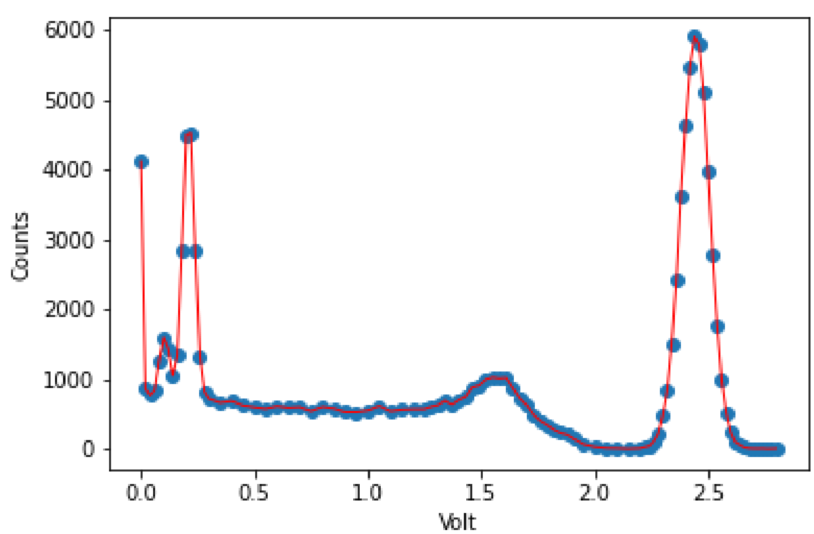

Figure 2: Plot of Lower level voltage vs. Counts

Volt	Count	Volt	Count	Volt	Count
0.00	4117	1.10	538	2.20	8
0.02	860	1.15	560	2.22	26
0.04	767	1.20	567	2.24	41
0.06	835	1.25	568	2.26	105
0.08	1257	1.28	604	2.28	214
0.10	1595	1.31	626	2.30	474
0.12	1433	1.34	691	2.32	838
0.14	1052	1.37	634	2.34	1508
0.16	1344	1.40	699	2.36	2418
0.18	2825	1.43	744	2.38	3624
0.20	4493	1.46	879	2.40	4624
0.22	4518	1.49	909	2.42	5465
0.24	2827	1.52	993	2.44	5897
0.26	1327	1.55	1023	2.46	5782
0.28	820	1.58	1009	2.48	5101
0.30	718	1.61	1017	2.50	3966
0.35	661	1.64	870	2.52	2770
0.40	685	1.67	724	2.54	1778
0.45	620	1.70	628	2.56	982
0.50	595	1.73	493	2.58	514
0.55	572	1.76	400	2.60	238
0.60	611	1.79	343	2.62	97
0.65	587	1.82	275	2.64	57
0.70	598	1.85	230	2.66	21
0.75	538	1.88	202	2.68	8
0.80	601	1.91	140	2.70	5
0.85	577	1.95	67	2.72	4
0.90	527	2.00	29	2.74	6
0.95	526	2.05	11	2.76	1
1.00	547	2.10	7	2.78	2
1.05	613	2.15	1	2.80	5

4 Results

The peak of the plot (the third peak) is at $E = 2.44V$ at count of around 5897.
The half values, i.e. where the count value is half(2945) are at $E_1 = 2.36V$ and $E_2 = 2.56V$.
Resolution (R) becomes

$$R = \frac{\delta E}{E} \times 100 = \frac{E_2 - E_1}{E} \times 100 = \frac{20}{2.44} = 8.19$$

5 Conclusion

In our plot, there are 3 clear features. A huge peak near $0.25V$, a bulge near $1.6V$ and a larger peak at $2.5V$.

The wide peak at low energies does not correspond to any known photon from the source. Such a feature, termed a Backscatter peak, is due to gamma-rays which first interact by Compton scattering with the shielding. Backscattered gamma-rays are those scattered through a large angle (≥ 120 degrees) by the shielding.
The figure also contains two other regions, the large peak is called the **photopeak** and the bulge is the **Compton smear**. The Photopeak results because of Photoelectric absorption of the gamma-rays from the radioactive source.
The other component of our spectrum is the Compton Smear. It represents a range of output voltages which are lower than that for the Photopeak. It is therefore indicative of the partial absorption of the energy of gamma-rays in the NaI(Tl) crystal.