Experiment 3

Sumit Roy
23MS090

PH3105
03/09/2025

Title : Study of γ-ray energy spectrum using a scintillation counter with Single Channel Analyzer (SCA).

Aim :
1. To Observe the γ-ray energy spectrum with the help of a scintillation counter with Single Channel Analyzer (SCA),
2. determine the photopeak and Full width at half maxima (FWHM).
3. Find out the resolution of the SCA instrument.

Source : We took a radioactive isotope of cesium (${}_{55}Cs^{137}$) as our γ-ray source.

Theory :

- **Gamma (γ) decay** : Cesium-137 which has a half life of ≈ 30.17 years mainly undergoes β-decay. It can be of 2 types:

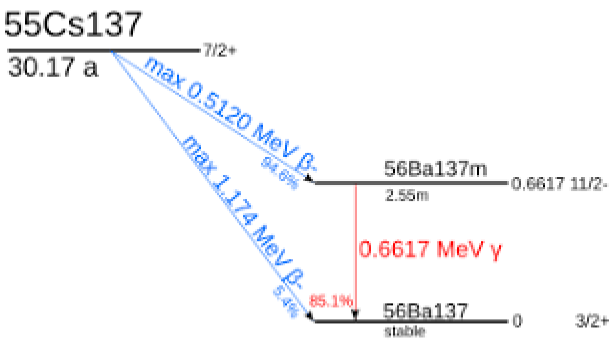


fig: Cs^{137} decay energy levels

I. It emits a β particle (electron) with energy 0.512 MeV and gets to an unstable daughter ${}_{56}Ba^{137m}$ which later gets stable by emitting a γ-ray of 0.6617 MeV.

$$^{137}_{55}\mathrm{Cs} \xrightarrow{\beta^-} {}^{137m}_{56}\mathrm{Ba} + e^- + \bar{\nu}_e$$

$$^{137m}_{56}\mathrm{Ba} \xrightarrow{\gamma} {}^{137}_{56}\mathrm{Ba}\ (\mathrm{stable})$$

II. It directly decays to stable ${}_{56}Ba^{137}$ (rare phenomena, around 5.4%).

❖ **Gamma interactions** : High energy γ photons can interact with matter mainly in 3 ways.

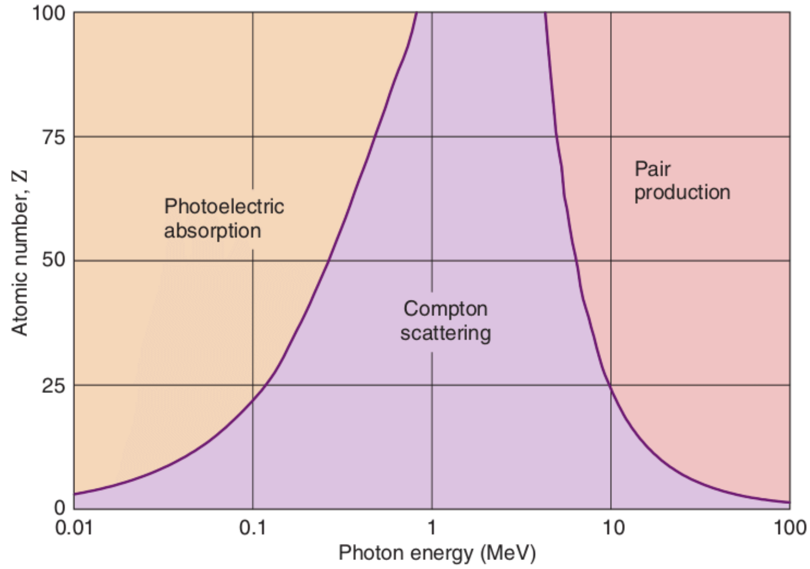


fig: $Z - E$ *Diagram of photon interactions*

A. Photoelectric Effect :

Complete absorption of photon resulting ejection of an electron.

$$E_{kin} = h\nu - E_B$$

The process only takes place with K or L-electrons and occurs more often with substances with a high atomic number (Z). When the photon energy is too high, a nucleus with a high Z cannot handle the surplus of impulse either,that is why the photoelectric effect only occurs up to a limited energy value.

B. Compton Scattering :

Photon partially transfers its energy to electron, changing the photon's direction.

$$E_{\gamma}^{'} = \frac{E_{\gamma}}{1 + \frac{E_{\gamma}}{mc^2}(1 - cos\theta)}$$

C. Pair Production :

Only if γ-ray energy is above 1.02M eV ,photon converts into electron and positron.

❖ **Scintillation counter** : It emits flashes of visible light whenever a photon (here γ-ray) deposit energy on it. γ-ray can intercat in all of the 3 ways mentioned earlier.

- **Photomultiplier Tube (PMT)** : It takes visible light photons emitted by scintillator and converts them into electrons via photoelectric effect. Then those electrons are multiplied through a series of dynodes which eventually results in a noticeable current pulse.The efficiency of a PMT tube is about 30%.

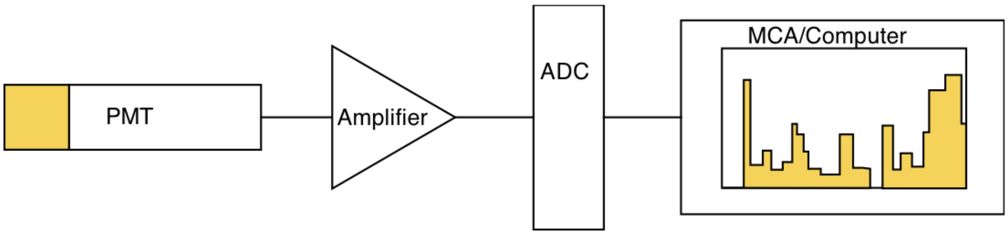


fig: Schematic of the data acquisition with PC

- **Single Channel Analyzer (SCA)** : It takes the electrical pulses of different heights (voltages) and sorts them according to the set Lower Level Discriminator (Baseline) within a narrow energy window. As the pulses are directly proportional to the energy absorbed by γ interaction, we can plot the counts of gamma deposited with the energy window.

Apparatus and settings :

1. Nai(Tl) crystal scintillation detector with photomultiplier tube (***HV = 590V***).
2. Preamplifier and Amplifier with total ***gain of 6.5x*** .
3. Single channel analyzer with fixed ***window of 20mV***.
4. Counts recorded ***2*** times over ***30 seconds*** each per baseline.
5. Baseline was taken from ***60 to 3540 mV***.
6. Oscilloscope for checking pulse.

Experimental Procedure :

1. We set the HV, gain, window length as mentioned above.
2. ${}_{55}Cs^{137}$ source was placed on the top of the scintillation detector and the lid was covered.
3. We started baseline from 60 mV and took 2 counts of 30 seconds for each step by varying the baseline by 60 mV. We continued taking counts until the baseline hit 3540mV.
4. The average of 2 counts are taken.
5. Graph of Count vs Baseline (mV) was plotted to obtain the γ-ray energy spectrum.
6. Analysis was done, photopeak, FWHM determined.

Data In Tabulated Form :

Baseline (miliVolt)	Count			Baseline (miliVolt)	Count		
	Take 1	Take 2	Average		Take 1	Take 2	Average
60	12	9	10.5	1800	12807	12676	12741.5
120	50	46	48	1860	12342	12471	12406.5
180	162	178	170	1920	10852	10647	10749.5
240	515	517	516	1980	8241	7965	8103
300	1330	1363	1346.5	2040	6121	6058	6089.5
360	9173	9444	9308.5	2100	4792	4635	4713.5
420	5823	5724	5773.5	2160	4151	4154	4152.5
480	3533	3513	3523	2220	4402	4293	4347.5
540	2682	2641	2661.5	2280	5880	5767	5823.5
600	2640	2509	2574.5	2340	8452	8587	8519.5
660	2764	2785	2774.5	2400	15434	15254	15344
720	3248	3208	3228	2460	33203	32064	32633.5
780	4103	4083	4093	2520	60660	60181	60420.5
840	4713	4744	4728.5	2580	87544	87924	87734
900	5869	5793	5831	2640	95346	95057	95201.5
960	8166	8117	8141.5	2700	81437	81026	81231.5
1020	9679	9259	9469	2760	56756	56703	56729.5
1080	9976	9776	9876	2820	21452	21188	21320
1140	9596	9582	9589	2880	8993	9112	9052.5
1200	9219	9297	9258	2940	3274	3297	3285.5
1260	9052	9164	9108	3000	1924	1918	1921
1320	9532	9452	9492	3060	1712	1642	1677
1380	9546	9657	9601.5	3120	1621	1584	1602.5
1440	9878	9889	9883.5	3180	1545	1400	1472.5
1500	10236	10079	10157.5	3240	1396	1448	1422
1560	10948	10898	10923	3300	1277	1390	1333.5
1620	11166	11232	11199	3360	1300	1282	1291
1680	11724	11766	11745	3420	1212	1298	1255
1740	12053	12291	12172	3480	1177	1183	1180
				3540	1105	1099	1102

Analysis :

- **Plots** :With the data we collected from the experiment, we made a histogram using originlab. Where we put the baseline voltage as x-axis and the average counts as y-axis.

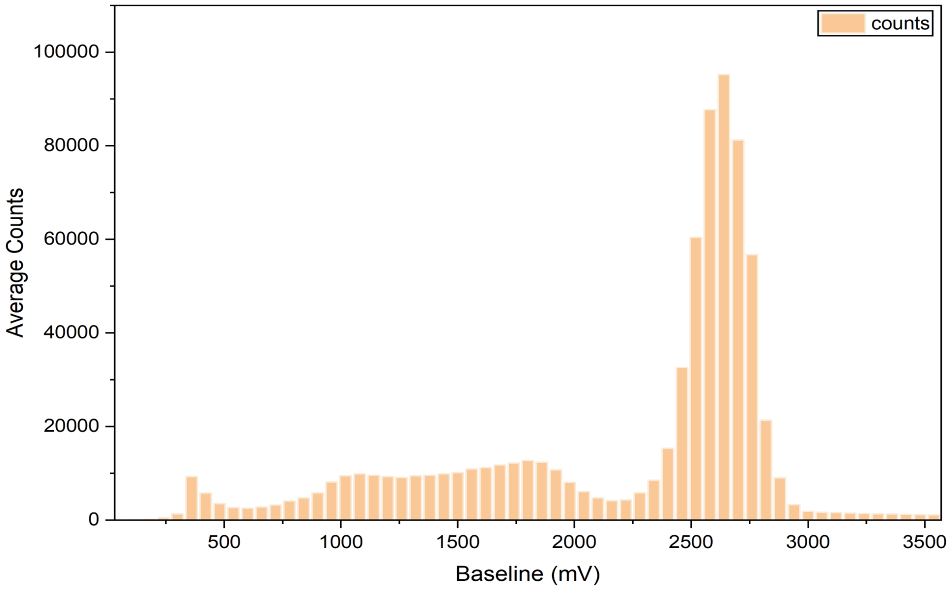
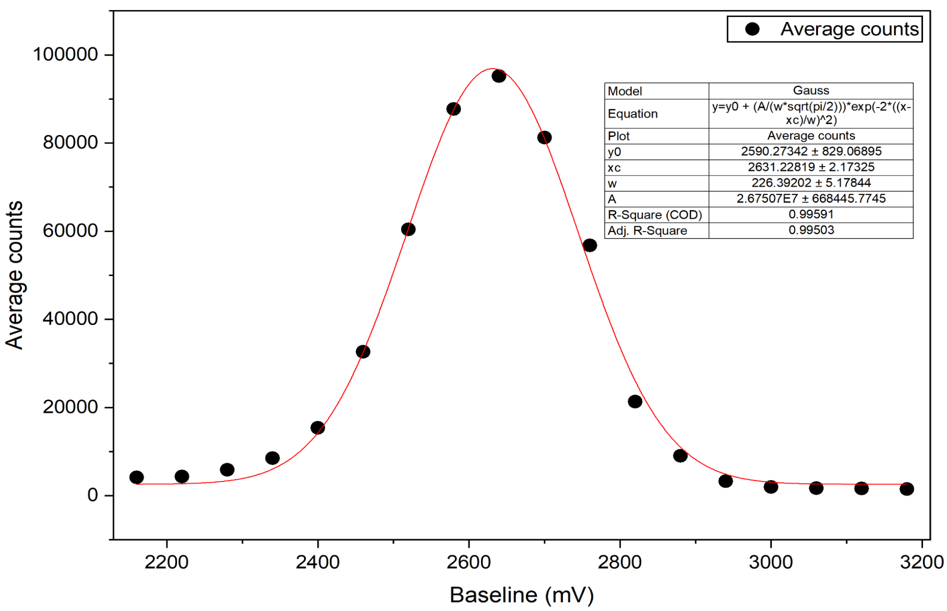


fig: Histogram of Baseline voltage vs Average counts

From this histogram, we obtained that photopeak is near 2640 mV, but yet fitting is needed for more accurate analysis. So we took the values in the vicinity of this photopeak and fitted the scatter plot in originlab.



Model	Gauss
Equation	y=y0 + (A/(w*sqrt(pi/2)))*exp(-2*((x-xc)/w)^2)
Plot	Average counts
y0	2590.27342 ± 829.06895
xc	2631.22819 ± 2.17325
w	226.39202 ± 5.17844
A	2.67507E7 ± 668445.7745
R-Square (COD)	0.99591
Adj. R-Square	0.99503

fig: Fitted plot of number of counts vs Baseline Voltage in the vicinity of photopeak voltage.

- **Calculation & Results** : From the above fitted plot we got,

Model	Gauss
Equation	y=y0 + (A/(w*sqrt(pi/2)))*exp(-2*((x-xc)/w)^2)
Plot	Average counts
y0	2590.27342 ± 829.06895
xc	2631.22819 ± 2.17325
w	226.39202 ± 5.17844
A	2.67507E7 ± 668445.7745
R-Square (COD)	0.99591
Adj. R-Square	0.99503

I. **Photopeak = 2631.22819 $\pm$ 2.17325 mV**

II. **FWHM** : We know that For a gaussian of the form

$$f(x) = y_0 + \frac{A}{w\sqrt{\pi/2}} e^{-2\left(\frac{x-x_c}{w}\right)^2}$$

The FWHM is related to the width parameter ω .

FWHM = $2\sqrt{ln\,2}\cdot\omega =$ 1.177 × 226.39 ≈ 266.5 mV

With the analyzed uncertainty.

FWHM = (266.5±6.1)mV

III. **Resolution** : Resolution of the detector is defined as

$$R = \frac{FWHM}{Peak\ position} \times 100\%$$
$$= \frac{266.5}{2631.2} \times 100\% \approx \mathbf{10.1\%}$$

IV. **Energy Calibration** : We know the photopeak corresponds to Cs-137 γ at **0.6617 MeV**. Therefore 2631.2 mV pulse corresponds to 0.6617 MeV energy of γ-ray. So, the calibration factor is :

$$\alpha = \frac{0.6617\ MeV}{2631.2\ mV} \approx 0.00025148\ MeV/mV$$

V. **Compton Edge (Theoretical)** :

$$E_c = \frac{2E_\gamma^2}{2E_\gamma + m_e c^2} = 0.477\,\mathrm{MeV}$$

Voltage Position:

$$V_c = \frac{0.477}{0.662} \times 2631 \approx 1895\,\mathrm{mV}$$

VI. **Backscatter peak (Theoretical)** :

$$E_{bs} = \frac{m_e c^2 \cdot E_\gamma}{2E_\gamma + m_e c^2} = 0.184\,\mathrm{MeV}$$

Voltage Position:

$$V_{bs} = \frac{0.184}{0.662} \times 2631 \approx 732\,\mathrm{mV}$$

Conclusion : The γ energy spectrum is successfully obtained using scintillation detector and SCA. The Photopeak was detected. By analyzing the plot further, we obtained FWHM and Resolution. The values of compton edge and backscatter peak were consistent with theoretical expectations.