Study of Gamma Ray Spectroscopy by SCA and MCA

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We investigate gamma-ray spectroscopy of several materials using a Scintillation detector in both SCA and MCA modes. Using Cs-137's known energy spectrum, we determine that the working voltage is 600V with a resolution of 10.11%. In MCA mode, we calibrated the channels using known peak energy sources, Ba^{133}, Co^{60}, and Cs^{137}, and determined the peak energy for Na^{22} from the calibrated curve. We computed the mass absorption coefficient of Al by sandwiching different thicknesses of aluminium blocks between the detector and the source, which came out to be $0.641 gm/cm^3$.

I. THEORY

A. Gamma spectroscopy:

Gamma spectroscopy studies the energy spectrum of gamma-ray sources. Gamma rays produced by radioactive sources are of various energies and intensities and can interact with matter in several ways. Three significant ways are:

1. **Photoelectric (up to several hundred keV):** A photoelectric effect occurs when a low-energy gamma photon interacts with a substance. After interacting with the photon, the electron is expelled with an energy equal to the initial photon energy minus the electron's binding energy. This is an advantageous procedure for spectroscopy because it produces an output pulse in a detector that is proportionate to the gamma-ray energy, as all of the gamma-ray energy is delivered to the detector. This results in a distinctive full-energy peak in the spectrum, which may be used to identify the radioactive substance.

   The photo-electron is most likely to emerge from the K shell at typical gamma-ray energy, with typical binding energies ranging from a few keV for low-Z materials to tens of keV for materials with larger atomic numbers. The atom must recoil in this process to conserve momentum, but its recoil energy is relatively modest and is frequently ignored. If mono-energetic gamma rays are present, the total electron kinetic energy equals the incident gamma-ray energy. The differential distribution of electron kinetic energy for a sequence of photoelectric absorption events would be a simple delta function under these conditions. The single peak arises at the entire electron energy, which corresponds to the incoming gamma ray energy. For non-monoenergetic rays, multiple Gaussian peaks are observed.

2. **2.Pair production predominates(above 5-10 MeV)** Pair formation is a major phenomenon at energies above 2.5 MeV and can occur when the gamma-ray energy is larger than 1.022 MeV. The process generates a positron and electron pair, which slows down due to scattering interactions in materials. The incoming gamma-ray photon is converted into electron and positron kinetic energy during the process:

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

   For typical energies, electron and positron travel a few millimeters at most before losing all their kinetic energy to the absorbing medium. When the positron comes to rest it annihilates with an electron producing a pair of 511 keV gamma rays that are emitted back-to-back.

   The probability of pair production is 0 up to the energy threshold of twice the electron mass (1.022 MeV/c2) and it increases with energy up to 100 MeV where it becomes constant.

3. **3.Compton scattering** In the Compton effect, the gamma ray scatters from an electron, transferring an amount of energy that depends upon the angle of scatter.

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

   here $E^{'}$ is the scattered energy of the gamma-ray, E is the incident gamma-ray energy, θ is the angle of scatterring, the term m_0c^2 is the electron's rest mass, equal to $511keV$. The energy given to the electron is: $E_e = E - E^{'}$. The maximum energy given to an electron in Compton scattering occurs for a scattering angle of 180°. These impacts will be especially pronounced for low-incident gamma-ray energy. They entail smoothing off the increase in the continuum towards its top extreme and adding a limited slope to the Compton edge's abrupt drop. These effects are frequently obscured by the detector's finite energy resolution, but they can be seen in spectra from detectors with high inherent resolution.

B. Scintillation Detector

It is made up of a Sodium Iodide crystal that is optically connected to a photomultiplier. There are three connections available: UHF, circular I/O, or Minihex & BNC. The detector's high voltage (operating voltage) is supplied by the HV module and attached to the UHF connection. The Minihex 5 pin I/O connection is used to deliver low voltages from the Minibin power supply to the pre-amplifier. A BNC cable connects the detector output to the linear amplifier input. A NUCLEONIX scintillation detector or its equivalent can be linked to the NUCLEONIX Gamma Ray Spectrometer electrical unit.

The spectrometer's resolution is determined by the statistical detection procedure. The detector's energy changes unleash the amount of photons that reach the cathode, as well as a variable number of photoelectrons. The total number of electrons reaching the photomultiplier's anode is proportional to the detector's energy expenditure and is determined by the inter-dynode voltage. The resolution of the detector is defined as the whole width at half maximum of the photopeak spectrum and is independent of the linear amplifier gain.

C. Mass absorption coefficient

We know that gamma rays interact with matter. The total mass absorption coefficient can be measured from Lambert's law. the decrease in intensity of radiation as it passes through the absorber is given by:

$$I = I_0 e^{-mx}$$

where
I = intensity after absorption
I_0 = intensity before absorption
m = mass absorption coefficient
x = density thickness in g/cm^3

Density thickness is the product of material density times thickness in cm. the half-value layer(HLV) is defined as the density thickness of the absorbing material at which intensity is reduced to half of the original value.

D. Materials required

1. SCA setup
2. MCA-setup
3. source (Cs-137,Na-22,Ba-133,Co-60)
4. Aluminium blocks
5. oscilloscope

II. SCA

A. Objective

To study the dependence of energy resolution on the applied high voltage and to determine the best operating voltage for the scintillation detector.

B. Observation and analysis

1. Operating voltage=500v

The experimental observations are tabulated in table I and the graph is shown in figure 1.

V	count
3.2	413
3.3	448
3.4	517
3.5	707
3.6	1190
3.7	2093
3.8	3651
3.9	5371
3.92	5609
3.94	5616
3.96	5625
3.98	5703
4	5726
4.02	5756
4.04	5501
4.1	4460
4.2	2567
4.3	1121
4.4	455
4.5	136

TABLE I: V vs counts data for 500v

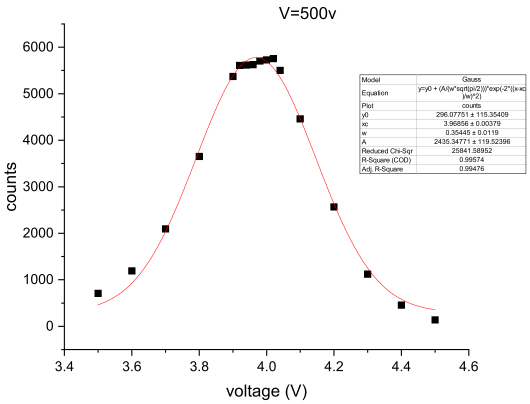

FIG. 1: V vs counts graph for 500v

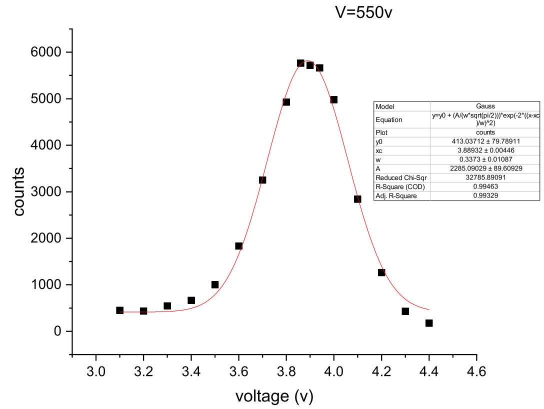

FIG. 2: V vs counts graph for 550v

2. Operating voltage=550v

The experimental observations are tabulated in table II and the graph is shown in figure 2.

v	counts
1.9	1586
2	1540
2.2	1440
2.4	1496
2.5	1375
2.7	1057
2.8	792
3.1	451
3.2	433
3.3	545
3.4	664
3.5	1002
3.6	1835
3.7	3250
3.8	4928
3.9	5721
4	4977
4.1	2839
4.2	1261
4.3	431
4.4	175
3.86	5764
3.94	5666

TABLE II: V vs counts data for 550v

3. Operating voltage=600v

The experimental observations are tabulated in table III and the graph is shown in figure 3.

v	count
3.2	518
3.3	742
3.4	1251
3.5	2132
3.6	4054
3.7	5556
3.72	5838
3.74	6124
3.76	5843
3.78	5816
3.8	5755
3.9	3963
4	2018
4.1	801
4.2	243
4.3	126
4.4	64

TABLE III: V vs counts data for 600v

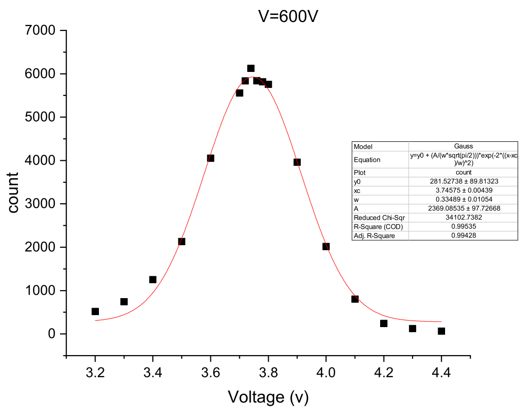

FIG. 3: V vs counts graph for 600v

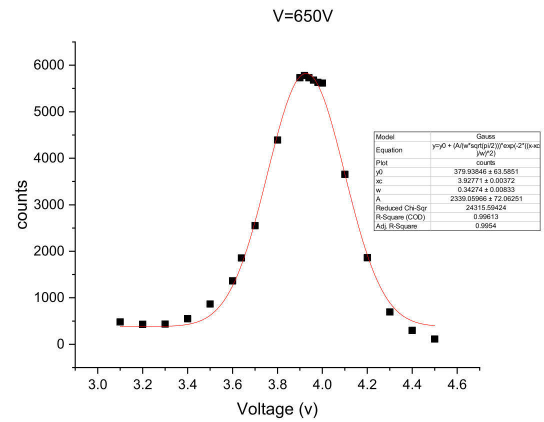

FIG. 4: V vs counts

4. Operating voltage=650v

The experimental observations are tabulated in table IV and the graph is shown in figure 4.

v	counts
3.1	481
3.2	432
3.3	436
3.4	551
3.5	866
3.6	1365
3.64	1857
3.7	2551
3.8	4394
3.9	5732
3.92	5779
3.94	5732
3.96	5680
3.98	5634
4	5618
4.1	3657
4.2	1861
4.3	696
4.4	300
4.5	113

TABLE IV: V vs counts data for 650v

5. Summary

The summary of the observations is tabulated in table V and the graph is shown in figure 5.

Operating voltage		FMWH	Resolution(%)
500		0.41734	10.38
550		0.39714	10.18
600		0.3943	10.48
650		0.40354	10.29

TABLE V: Operating voltage vs FMWH and resolution

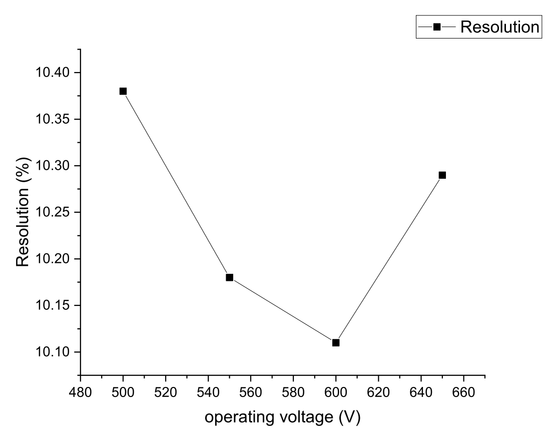

FIG. 5: V vs counts

Thus from Fig.5 we have the best operating voltage as 600v with a maximum resolution of 10.11%.

III. MCA

A. Study of Cs-137 spectrum and calculation of FWHM and resolution.

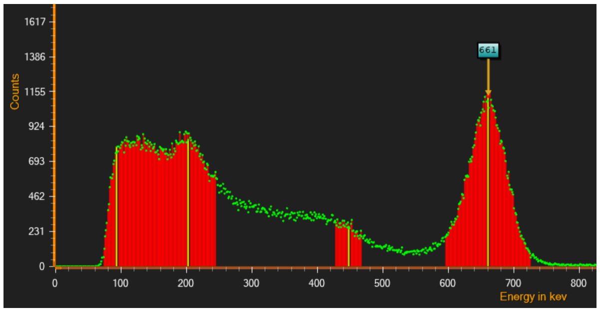

FIG. 6: Cs-137 spectrum

Table 6

Start	398
End	512
Number of Peaks	1
Peak	463.1764
FW(C)	46.8672
TM/HM	1.7803
FM/HM	2.1577
Gross	57839
Net	47546.5

TABLE VI: Cs-137 Peak Report

from Table 6 we have FWHM = 46.8672

Resolution is defined as the ratio of FWHM and peak channel.

$$\boxed{\text{resolution}=7.21\%}$$

B. Energy calibration of gamma-ray spectrometer with energies of different Gamma Sources

Three different sources are placed in front of detector at once and spectrum is analysed to obtain the calibration curve.

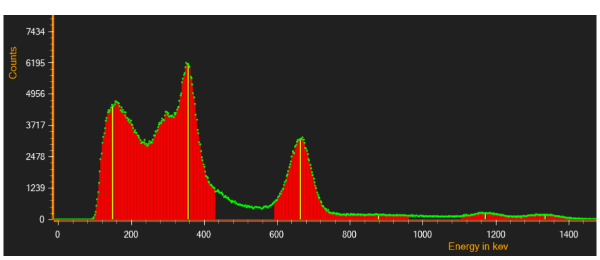

FIG. 7: Ba-133, Cs-137 and Co-60 spectrum

Table 7

Energy	Channel	FW (CH)	FW (EN)	
148.7619781	68	32.61084366	76.88145447	
355.5156555	156	31.41841316	73.56323242	
663.1218872	288.0596924	30.29399109	70.19688416	
877.6900635	381	36.08543777	83.00172424	
1170.310425	508.8700256	28.70510101	65.35279083	
1336.052124	581.8839111	29.6067009	67.00904083	
2253.693115	994.2141724	15	32.81540298	

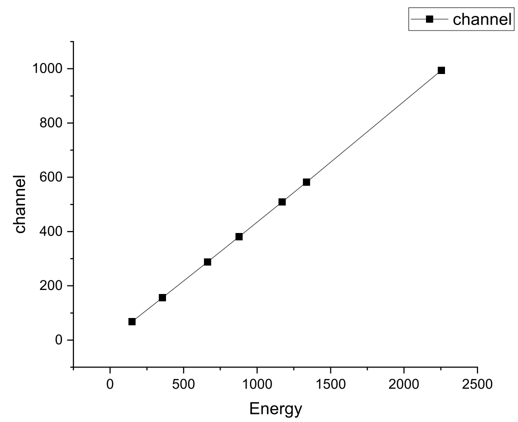

FIG. 8: Energy calibration curve

C. Find of energy of Na-22 source

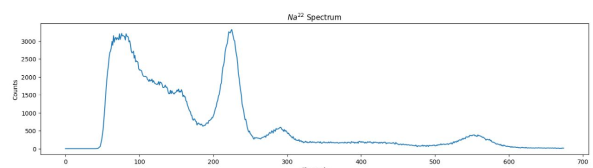

FIG. 9: Na-22 spectrum

Type	Channel	FW (CH)	
M	62.64506912	15	
m	81.37265778	15	
M	130.0105743	15	
m	157.321991	16.27744293	
	223.8300934	24.70108604	
	290.2333069	25.82227325	
M	408.0601807	35.67868042	
m	435	15	
	554.2346191	44.66348267	
	787.3337402	35.91174316	
	990	59.86914444	

From 8 and the energy calibration curve, we find that Na-22 has peak energies at 500KeV(ch-223),680 keV(ch-

290), 1220KeV(Ch-554).

D. Mass absorption coefficient of Al

For 662 keV gamma rays, the mass absorption coefficient of Al is measured by placing aluminum blocks of different thicknesses between the detector and the source.

Thickness(cm)	Count
0	3560
0.5	1633
1	1218
1.5	950
2	815
2.5	750
3	615

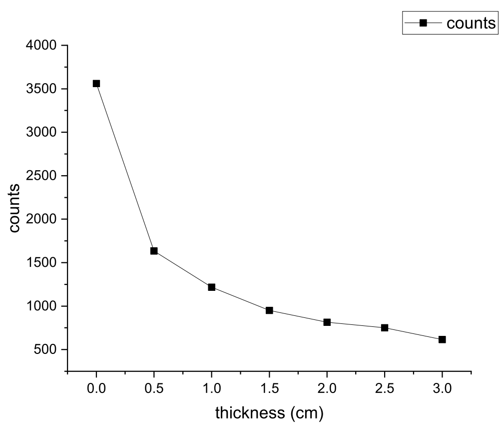

FIG. 10: Absorption curve

From the graph Observed value of HVL (thickness at which counts are reduced to half) is 0.4cm.
Density thickness=$0.4 \times 2.7gm/cm^3 = 1.08gm/cm^2$
the mass absorption coefficient,
m=$\frac{0.693}{1.08} = 0.641gm/cm^2$

IV. CONCLUSION

At 600V, we can observe that the detector has a resolution of 10%. We can also determine the Gamma energy peaks for unknown sources by calibrating MCA channels with known sources. In SCA, the error in fitting the Gaussian curve is modest and may be lowered further with more data points. Aluminium has a high estimated mass absorption coefficient, making it an effective material for blocking gamma radiation.

[1] SPS, Sca lab manual, Website (2022), https://www.niser.ac.in/sps/sites/default/files/basic_page/p341_2023/sca.pdf.

[2] SPS, Mca lab manual, Website (2022), https://www.niser.ac.in/sps/sites/default/files/basic_page/p341_2023/mca.pdf.