EXPERIMENT

Gamma spectroscopy

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1 General theory

1.1 Gamma ray interaction with matter

There are three dominant gamma-ray interactions with matter:

1. Photoelectric effect
2. Compton scattering
3. Pair production

Photoelectric effect

The photoelectric effect is a common interaction between a low-energy photon and a material. In this process the photon interacts with an electron in the material losing all of its energy. The electron is ejected with an energy equal to the initial photon energy minus the binding energy of the electron. This is a useful process for spectroscopy since an output pulse in a detector is produced that is proportional to the gamma-ray energy, as all the energy of the gamma ray is transferred to the detector. This produces a characteristic full-energy peak in the spectrum that can be used for the purpose of identifying the radioactive material. The probability of the photoelectric effect is strongly dependent on the atomic number Z of the atoms in the matter and the photon energy; it is the dominant process at low photon energy. The probability has discontinuities at the binding energies of the electrons in the constituent atoms in the matter because the probability of transferring the energy to an electron with higher binding energy than the incoming photon energy is zero. The probability of photoelectric effect therefore rapidly decreases when transitioning from a photon energy just above the binding energy of the electrons to an energy just below it.

Compton scattering

In the Compton effect, a gamma ray (photon) scatters from an electron, transferring an amount of energy that depends upon the angle of scatter given by

$$E' = \frac{E}{1 + \frac{E}{m_0 c^2}(1 - \cos\theta)}, \tag{1}$$

where E' is the energy of the scattered gamma ray, E is the incident energy of the gamma ray, θ is the angle of scatter, m_0 is the mass of the electron and c is the speed of light. The term $m_0 c^2$ is the rest mass energy of the electron, equal to 511 keV. The energy given to the electron is:

$$E_e = E - E' \tag{2}$$

The maximum energy given to an electron in Compton scattering occurs for a scattering angle of 180°, and the energy distribution is continuous up to that point (since all scattering angles up to 180° are possible). This point is known as the Compton edge and can be easily calculated using Eq. (1) for gamma-rays of known energies. If the photon is on a trajectory towards the detector, it can Compton scatter at a small angle and still result in hitting the detector. However, since all Compton scattering transfers some energy to the electron, the scattered photon will not deposit its full initial energy in the detector, and it will not contribute to the full-energy peak (photo-peak).

Pair production

Pair production can occur when the gamma-ray energy is greater than 1.022 MeV and is a significant process at energies above 2.5 MeV. The process produces a positron and electron pair that slows down through scattering interactions in the matter. 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. Figure 1(a) shows the mass attenuation coefficient for photons in lead as a function of photon energy and figure 1(b) shows the probability of the three dominant interaction processes in matter as a function of photon energy. The figure 1(b) displays the discontinuity at the binding energy of the electrons in the atom, the decrease of the probability of photoelectric effect when the energy increases, the dominance of Compton scattering at medium energies and the dominance of pair production at higher photon energies. The probability of pair production is zero up to an energy threshold of twice the electron mass (1.022 MeV/c^2) and it increases with energy up to 100 MeV where it becomes constant.

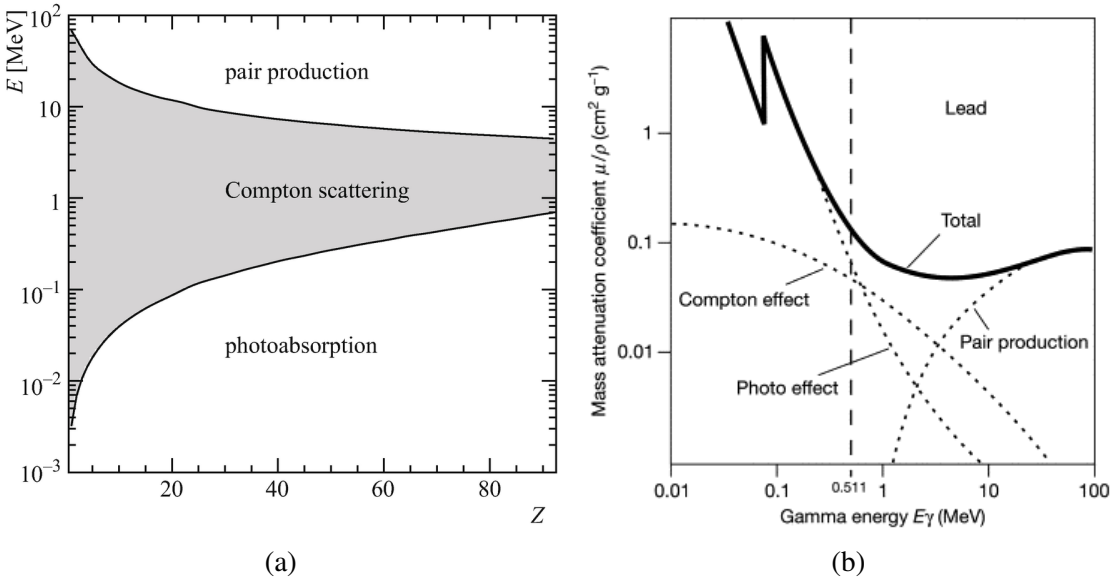


Figure 1: (a) Probability of photon interaction with matter as a function of Z [1]. (b) Mass attenuation coefficient of photon as a function of photon energy in lead [2].

1.2 Gamma-ray spectroscopy

Gamma ray spectroscopy is a technique to find the distribution of the intensity (or spectrum) of gamma rays with various photon energies. Scintillation detectors with Single-Channel Analyzers (SCA) are one of the most common detector systems used for spectroscopy. A schematic is shown in figure 2. The interaction of ionizing radiation with a detector produces charged particles which are collected by applying an electric field. The collected charge from the detector is converted to a voltage pulse which is fed to the preamplifier.

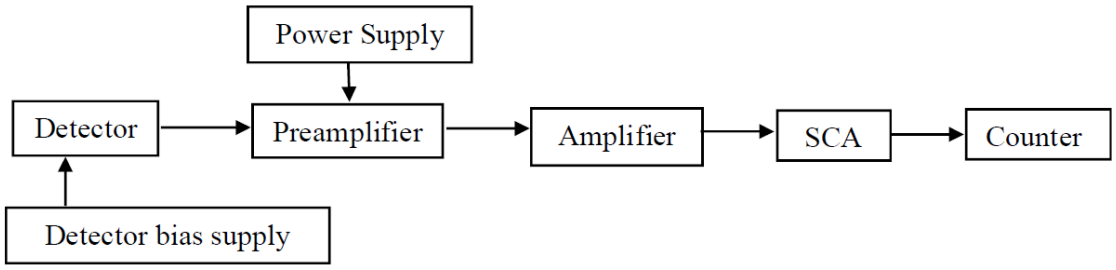


Figure 2: Schematic of a gamma-ray spectroscopy system.

The preamplifier amplifies the signal and acts as an interface between the detector and the amplifier. It acts as a high impedance load for the detector and a low impedance source for the amplifier. Preamplifier is kept as close as possible to the detector unit to minimize the signal loss and to maximise the Signal to Noise Ratio (SNR).

The linear amplifier changes the pulse shape and increases its size. The single channel analyser (SCA) sorts the pulses by pulse height and counts the number of pulses within individual pulse height intervals which then plotted as a spectrum.

1.3 Scintillation detector

Scintillation detectors are used for determining the high-energy part of the X-ray spectrum. The primary electrons produced by gamma-ray interaction with the scintillation detector raises secondary electrons to the conduction band, leaving holes in the valence band. In some cases, the energy given to the electron may not be quite sufficient to raise it to the conduction band. Then, the electron and hole could remain electrostatically attracted to each other as an entity called an exciton. In terms of the band structure model, this represents elevation to an extra band just below, but continuous with, the conduction band, as illustrated in figure 3. If the electrons are allowed to de excite by falling back to the valence band, they will emit electromagnetic radiation. If this radiation is in, or near, optical wavelengths, it can be detected by a photomultiplier or other light-measuring device to provide the detector signal. This is the basis of the scintillation detector. The properties of a good scintillation detector are:

1. there must be a reasonable number of electron-hole pairs produced per unit of gamma ray energy;

2. it would be very desirable for the material to have a high stopping power for gamma radiation (which means, in practice, high density and atomic number);

3. for spectrometry, the response must be proportional to energy;

4. the scintillator must be transparent to the emitted light so that the light does not get absorbed in the material itself;

5. the decay time of the excited state must be short to allow high count rates;

6. the material should be available in optical quality in reasonable amounts at reasonable cost;

7. the refractive index of the material should be near to that of glass ($\eta \sim 1.5$) to permit efficient coupling to photomultipliers.

Some materials obeying these properties are sodium iodide (NaI), caesium iodide (CsI), calcium fluoride (CaF_2), bismuth germanate (BGO) and, recently, lanthanum halides. In this experiment NaI is employed as the scintillator material. The scintillation mechanism depends on the structure of the crystal lattice. In a pure inorganic crystal lattice such as NaI, electrons are only allowed to occupy selected energy bands. The forbidden band or band gap is the range of energies in which electrons can never be found in the pure crystal. The absorption of energy can elevate electrons from the valence band to the conduction band leaving a gap in the valence band. However, the return of an electron to the valence band with the emission of a photon is an inefficient process. Few photons are released per decay, the energy is emitted by other mechanisms. In addition, band gap widths in pure crystals are such that the resulting emitted photon is too high to lie within the visible range.

This difficulty was eliminated by the introduction of an activator (about 10^{-3} mole fraction) that produces lattice defects which give rise to extra levels within the forbidden band i.e., between the valence and conduction bands. The activators are the impurities added to the crystal. Tl is added to NaI in trace amounts. They create special sites in the lattice at which the band gap structure and the energy level structure, is modified. The energy level structure of the overall crystal is not changed, just the energy level structure at the activator sites. At the few activator sites within the sample, the energy level structure is modified. When an electron–hole pair is formed, the hole may migrate to a nearby activator site. Electrons in the conduction band and within the exciton band will tend to be captured by the excited activator states. When these levels de-excite (mean lifetime is about 0.1 μs) the energy released will be lower and the electromagnetic radiation will be of a longer wavelength, perhaps in the visible range that can be easily detected by the photomultiplier tube.

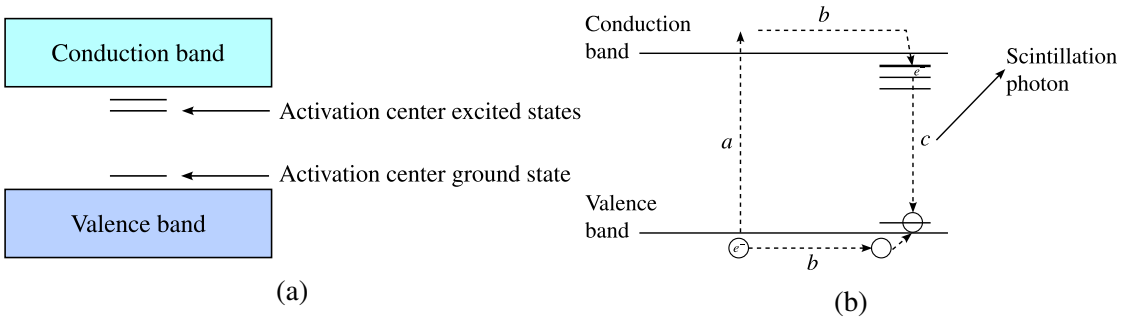


Figure 3: (a) Band diagram in scintillation crystal. (b) Illustration of the process of scintillation.

1.4 Photomultiplier Tube

The light output from a scintillator material is very low and that needed to be enhanced prior to the measurement. This is done by the photomultiplier tubes (PMT) (shown in figure 4) whose function is given below.

1. The light photon strikes a light sensitive layer, the photocathode, causing it to emit a photoelectron.

2. The photoelectrons are focused electrostatically onto the first of a series of electron multiplier stages, called dynodes. These emits more electrons than they receive, thus amplifying the signal.

3. The dynodes are kept at gradually increasing negative potential by using the resistor as the voltage divider (shown in the figure 4). The electrons from the first dynode are multiplied at the second dynode, and again at the third, all the way down the chain. This is the electron multiplication stage.

4. The amplified signal is then collected at the anode and passed out to the measurement circuits. The electrons are then collected at the anode to produce a signal.

1.5 Preamplifier

The detector set up is followed by a pre-amplifier. The purposes of a preamplifier are to amplify the relatively small signals produced by the radiation detector, to match impedance levels between the detector and subsequent components in the system, and to shape the signal pulse for optimal signal processing by the subsequent components.

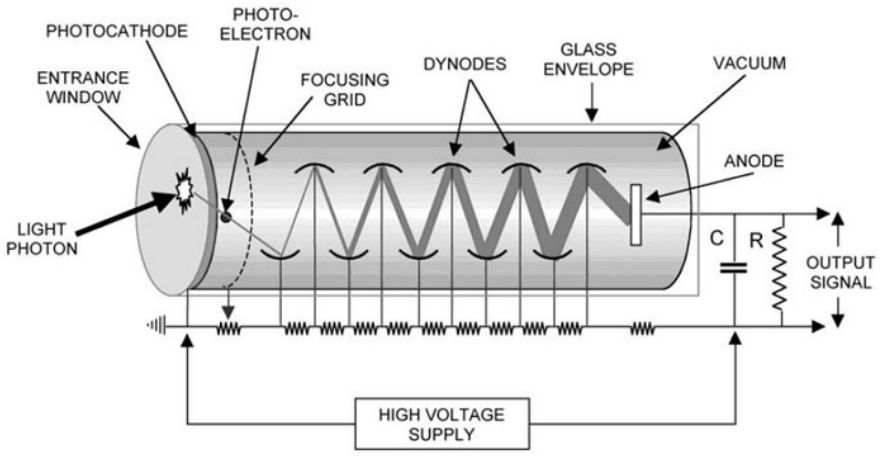


Figure 4: Working of a Photomultiplier Tube [3].

1.6 Amplifier

Many of the Nuclear Detectors give small amplitude pulse outputs. These output pulses cannot be directly counted or analysed by scalers, count rate meters and single channel analysers, without being first amplified. The amplifier in a nuclear detection system is designed to amplify the still relatively small pulses from the preamp to sufficient amplitude (volts) to drive auxiliary equipment (pulse-height analyzers, scalers, etc.), and to reshape the slow decaying pulse from the preamp into a narrow one to avoid the problem of pulse pile-up at high counting rates and to improve the electronic signal-to-noise ratio (SNR).

1.7 Single Channel Analyzer (SCA)

A Single Channel Analyzer is essentially used for pulse height analysis. It has THREE modes of operations namely INTEGRAL, NORMAL & WINDOW. In Gamma Ray Spectrometer the scintillation detector pulse output is proportional to the gamma energy and hence accurate measurement of pulse height by an SCA will give the energy information.

1.8 Multichannel Analyzer (MCA)

MCA (Multichannel Analyzer) is an electronic instrument widely used in radiation spectroscopy to measure and analyze the energy distribution of radiation detected by a detector. It receives electrical pulses from a radiation detector, measures the pulse

heights (which are proportional to radiation energy), and sorts them into many channels to produce an energy spectrum.

Main functions of an MCA

1. Converts detector output pulses into digital data using an ADC (Analog-to-Digital Converter).
2. Sorts pulses according to their amplitude (energy) into different channels.
3. Displays a spectrum showing counts versus energy.
4. Helps identify radioactive isotopes and determine radiation energies.

Table 1: Comparison between SCA and MCA

Feature	SCA	MCA
Number of channels	One energy window at a time	Hundreds to thousands of channels
Output	Counts within a selected energy range	Complete energy spectrum
Data collection	One energy region per measurement	All energy regions simultaneously
Speed	Slower for spectrum analysis	Much faster
Isotope identification	Limited	Excellent
Energy spectrum	Not obtained directly	Obtained directly

1.9 Counter Timer

Microcontrolled based state-of-art counter/timer designed around a eight bit microcontroller chip. It can count both positive and negative pulses in the range of 100 mV to 10V and upto a maximum frequency of 1 MHz.

1.10 Resolution

In ideal scenario every gamma-ray of the same energy detected should give rise to a count in the same channel of the gamma-ray spectrometer. But in real situation peaks are spread over several channels, with preponderance at a central point, which can be identified as gamma-ray energy (E). This deviation may be due to the uncertainties

in the emission spectrum of the gamma rays or within the detection and measurement processes. The parameter used to express the energy resolution is FWHM – the Full Width of the peak at half maximum height, usually expressed in keV or units of energy. The resolution (R) is defined as:

$$R = \frac{\text{FWHM}}{H_0} \times 100 \quad \text{(where } H_0 \text{ is the centroid of the photopeak)} \tag{3}$$

The resolution is a dimensionless quantity usually expressed in percentage. It is evident that smaller the value for the energy resolution R the better the detector will be able to distinguish two energies lie closer. In general, the scintillation detectors used for gamma ray spectroscopy have a resolution in the range 3 - 10 %.

2 Energy calibration of NaI scintillation detector and identification of an unknown source

2.1 Equipment required

1. NaI(Tl) detector assembly
2. Gamma-ray spectrometer and cables for connection
3. Oscilloscope
4. Radioactive sources (^{137}Cs, ^{60}Co and unknown source)

2.2 Introduction

This experiment focuses on the qualitative analysis of the energy spectrum of gamma-rays emitted from a radioactive source ^{137}Cs or other. Here we would like to plot counts vs. energy and identify photopeak or full energy peak, Compton distribution and Compton edge. It may be noted that a spectrum from a source with only one gamma-ray energy consists of a peak (the photo peak or the full energy peak) and a distribution on the low-energy side (to the left) of the photo peak. If there are several photo peaks in a spectrum, the studied radiation must contain several different energies.

In the experiment we do not measure the energy. Here we measure the counts vs. voltage or channel number. For a given set of parameters like operating voltage of detector, amplifier gain and discriminator voltage etc., one can perform the energy calibration using the radioactive sources with known gamma-ray energy.

There are different gamma-ray emitting radioactive sources like ^{22}Na, ^{54}Mn, ^{60}Co, ^{137}Cs etc. The high energy photons are produced in nuclear transitions. The nuclei in excited states can move to lower energy states by means of beta decay, inverse beta decay or electron capture. A resulting by-product of these decay mechanisms is a gamma ray photon. A few decay processes are shown below.

2.2.1 ^{60}Co

The excited state of ^{60}Co decays to stable ^{60}Ni by beta decay through various excited states of Ni with a half-life of 5.2 years. The reaction is as follows:

$$
\begin{aligned}
{}^{60}_{27}\mathrm{Co} &\rightarrow {}^{60}_{28}\mathrm{Ni}^{*} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}} \\
{}^{60}_{28}\mathrm{Ni}^{*} &\rightarrow {}^{60}_{28}\mathrm{Ni}^{*} + \gamma_{(1.173\ \mathrm{MeV})} \\
{}^{60}_{28}\mathrm{Ni}^{*} &\rightarrow {}^{60}_{28}\mathrm{Ni} + \gamma_{(1.332\ \mathrm{MeV})} \\
{}^{60}_{27}\mathrm{Co} &\rightarrow {}^{60}_{28}\mathrm{Ni} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}} + \gamma_{(1.173\ \mathrm{MeV})} + \gamma_{(1.332\ \mathrm{MeV})}
\end{aligned}
$$

2.2.2 ^{137}Cs

The excited state of ^{137}Cs decays to stable ^{137}Ba by beta decay with a half-life of 30 years. The reaction is as follows:

$$
\begin{aligned}
{}^{137}_{55}\mathrm{Cs} &\rightarrow {}^{137}_{56}\mathrm{Ba}^{*} + \mathrm{e}^{-} + \bar{\nu}_{\mathrm{e}} \\
{}^{137}_{56}\mathrm{Ba}^{*} &\rightarrow {}^{137}_{56}\mathrm{Ba} + \gamma_{(0.662\ \mathrm{MeV})} \\
{}^{137}_{55}\mathrm{Cs} &\rightarrow {}^{137}_{56}\mathrm{Ba} + \bar{\nu}_{\mathrm{e}} + \mathrm{e}^{-} + \gamma_{(0.662\ \mathrm{MeV})}
\end{aligned}
$$

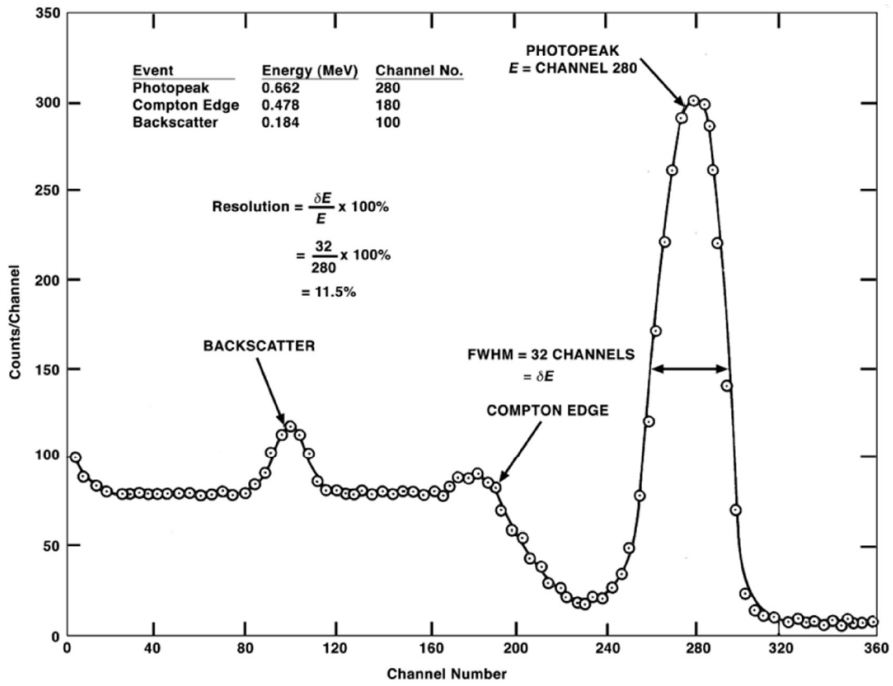


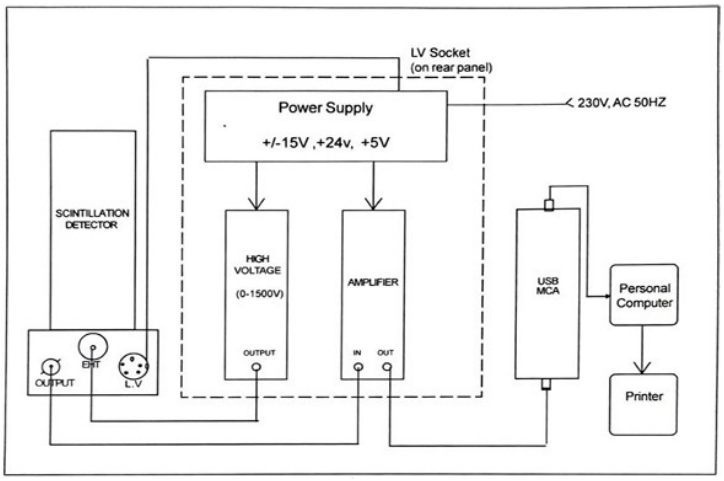
Figure 5: A typical Gamma-ray spectrum of ^{137}Cs from NaI(Tl) detector [4].

A typical ^{137}Cs spectrum is shown in figure 5. In this figure, the counts are plotted as a function of channel no., where a channel no. corresponds to some voltage value that is related to the energy. The energy distribution to the left of the photo peak originates from gamma, which have collided with electrons in the detector crystal or in the lead shielding. The collision takes place in such a way that only part of the original energy of the gamma quantum is absorbed in the detector. This kind of collision is called Compton scattering and the low-energy distribution is the so-called Compton distribution. The Compton distribution always forms a background to the left of the photo peak with which it is associated.

It may be noted that there is always a discriminator setting, which rejects the lowest energetic gamma and the electronic noise. The discriminator setting can be adjusted but should not be changed during a measurement.

2.3 Procedure

(a)



(b)

Figure 6: (a) Gamma-ray spectrometer system GR611M (HV supply + Linear amplifier +) and (Right) Detector assembly (NaI + PMT + preamplifier). (b) Block diagram of connections.

The experimental setup in the laboratory is shown in figure 6(a).

1. Turn off the power to the MINI BIN, Power supply and HV 502 power supply of Gamma-ray spectrometer GR611M.

2. The detector assembly (tower like structure shown in the right side of figure 6)(a) consists of NaI scintillator, PMT and Preamplifier. Three terminals shown are for power supply to preamplifier, HV supply to detector system and signal output of preamplifier.

3. Make the connections as shown in figure 6(b)

4. Switch on the power supply of spectrometer GR611M. Switch On the high voltage supply module HV 502. Increase the voltage slowly to the detector operating voltage (500 V).

5. See output signal of Preamplifier (typically of the order of few mV) in an oscilloscope.

6. Invoke the 'ANUSPECT' software on PC by double clicking on the 'ANUSPECT' icon on the desktop. Then the main screen of the software appears as is shown in figure 7.

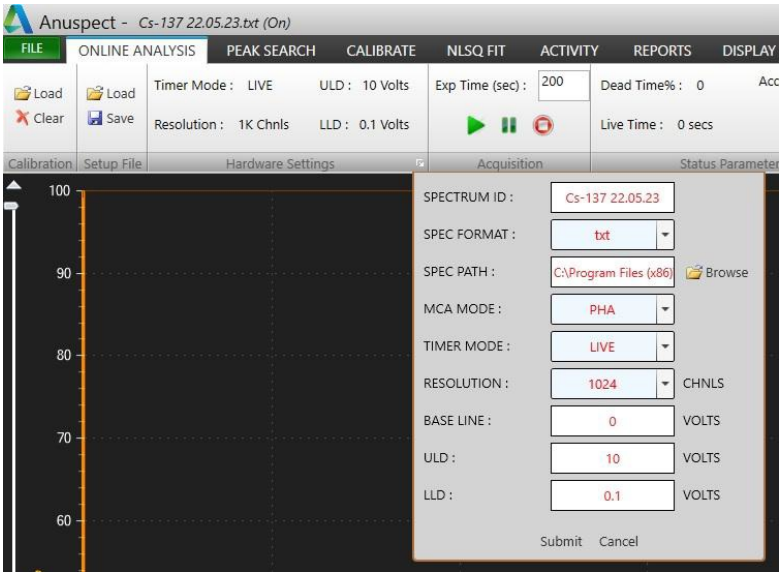


Figure 7: Main screen of ANUSPECT software.

7. **Hardware settings**

   (a) Go to file menu $\Longrightarrow$ Spectrum
   (b) Open the desired file
   (c) Go to Peak Search Menu
   (d) And search the peaks
   (e) Right click on the spectrum and select cursor option
   (f) Right click again and click ROI $\Longrightarrow$ Add ROI
   (g) Adjust the limits by dragging the green bars
   (h) If you want to delete the ROI
   (i) Select the ROI and right click ROI $\Longrightarrow$ Delete ROI

8. Put the radioactive source (^{137}Cs) near to the detector ($\sim$ 2 cm away). Start acquisition and set the gain of the Linear amplifier such that the signal peak is around 300 channels.

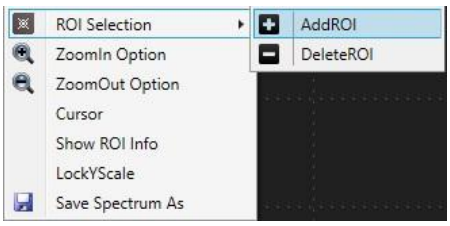


Figure 8: ROI selection in ANUSPECT.

9. Acquire the spectrum for around 300 s to get a fine spectrum after giving the default setting and file name. Pause the spectrum at 300 s.

10. Replace ^{137}Cs by ^{60}Co and record the spectrum for another 300 s and save the file.

11. Click file menu, spectrum and load the spectrum to calibrate the MCA.

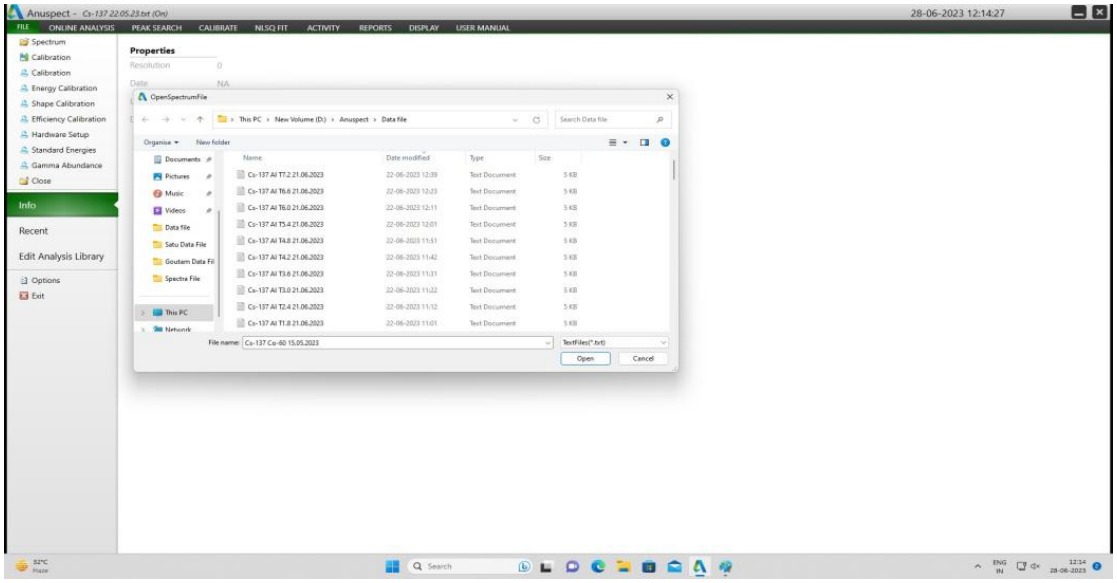


Figure 9: Screen for loading spectrum.

12. Click NO for loading Previous Calibration.

13. Click Peak search menu, search now all the peaks will be detected in the acquired spectrum (figure 11)

14. Go to Calibrate menu & click on energy after that right click on the spectrum, click input text box.

15. Enter the energy in it, and drag it to the corresponding peak as shown in figure 12

16. Repeat it for the other peaks as shown in figure 13

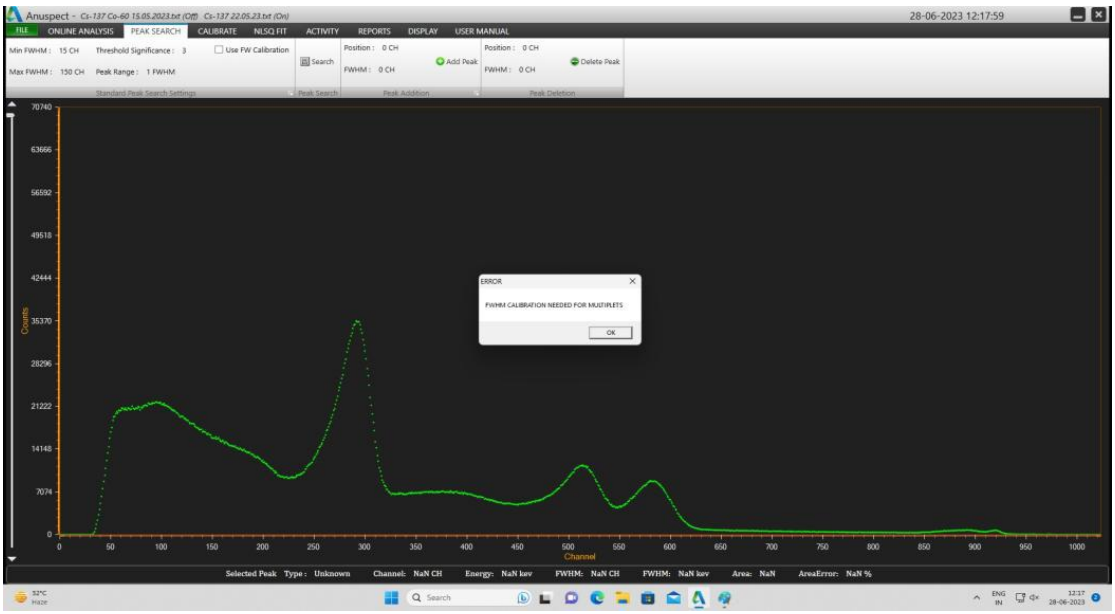


Figure 10: Calibration required.

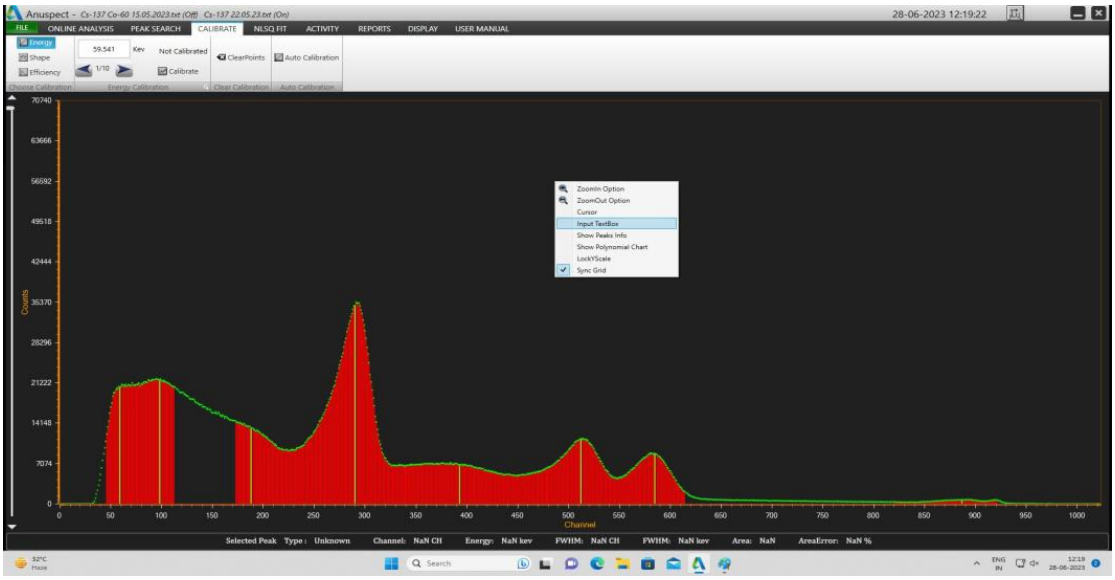


Figure 11: Peaks identified.

17. Click on Calibrate

18. We can see the polynomial equation & we can use this equation to find out the energy of unknown sample

19. To see the polynomial chart as shown in 14, right click on the spectrum, select show polynomial chart

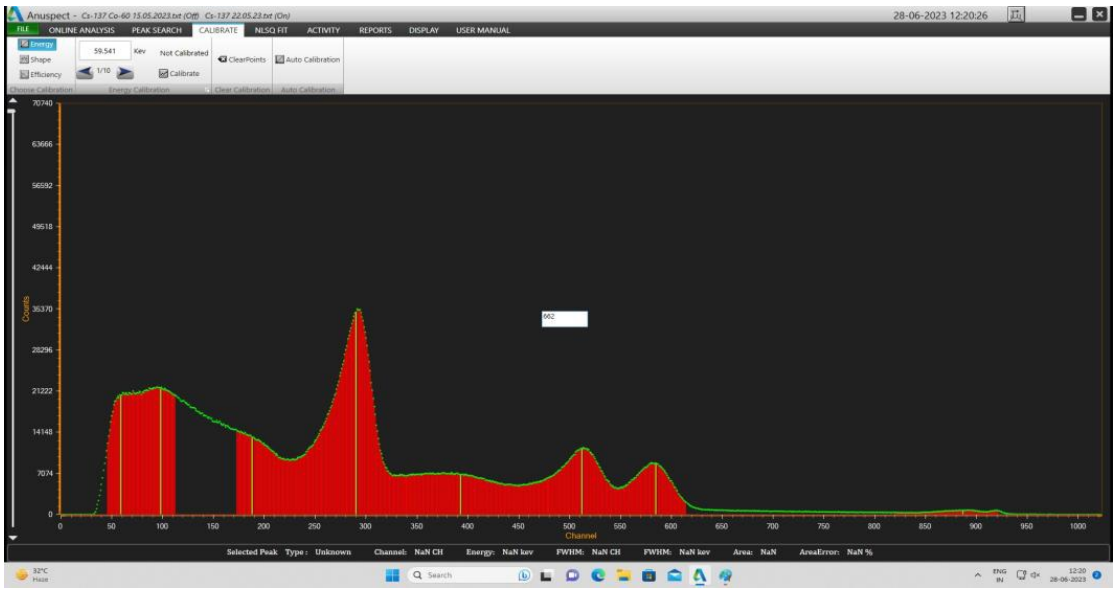


Figure 12: Setting peak energy.

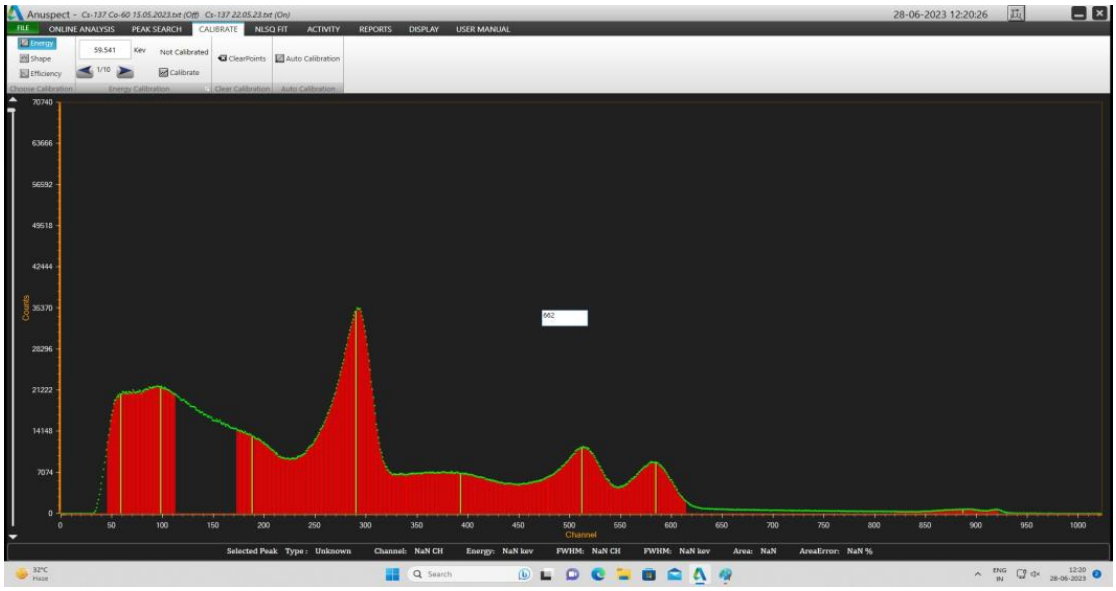


Figure 13: Setting peak energies for remaining peaks.

20. Now replace the sources with an unknown source and acquire data for 300 s.
21. Load that spectrum and click on the peak channel (where the height of the photo-peak is maximum) and Note down the peak channel no.
22. Now extrapolate this channel no. On to the Energy Linearity Graph to calculate the energy of the unknown peak.
23. The energy thus obtained should be used to identify the unknown source.

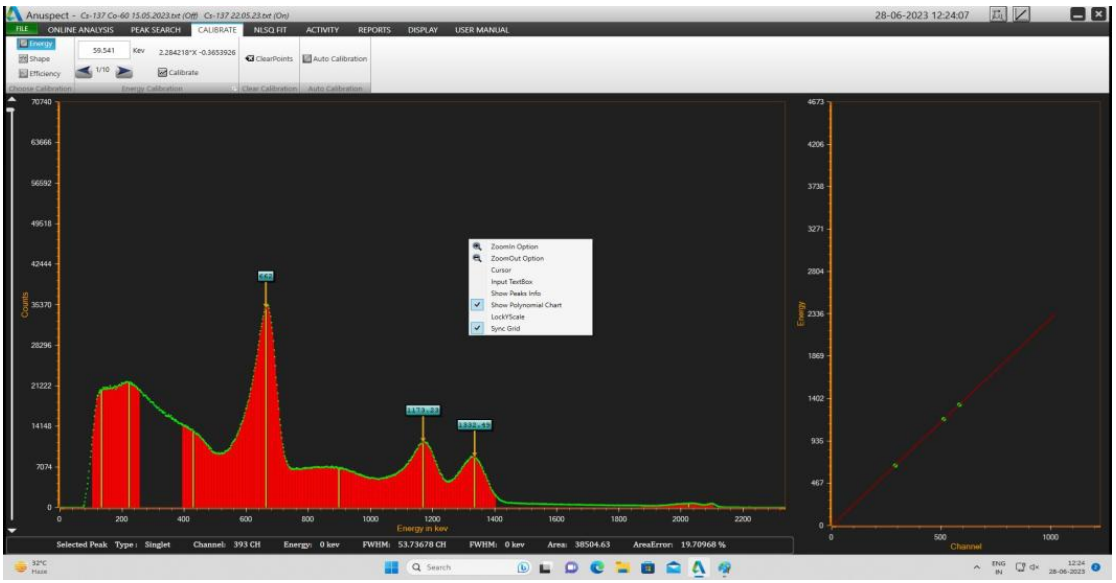


Figure 14: Polynomial fit.

2.4 Results

The energy of the unknown source is found out to be _____ keV and the source is identified to be _____.

3 To determine the energy resolution and its variation with gamma-ray energy and PMT high voltage

3.1 Introduction

The width of the photopeak is a measure of the energy resolution of the detection system. The smaller the width, the closer two gammas can become in energy and still be observed as separate peaks in the pulse height spectrum. Consider a photopeak appearing in a pulse height spectrum at voltage V and having a full width at half maximum (FWHM) of ΔV. The energy resolution R is commonly expressed by the ratio of the photopeak's FWHM (in energy units) $\Delta E = m\Delta V$ to its energy $E = mV + C$, where m and C are the parameters obtained from the calibration relation in the previous experiment. The energy resolution is easily obtained from the pulse height spectrum as

$$R = \frac{\Delta E}{E} \tag{4}$$

The value of R is 5-10% for NaI(Tl) detectors for 0.662 MeV gamma of ^{137}Cs. Because of the Poisson statistics of light production in the scintillator and light detection in the PMT, the FWHM is expected to increase as the square root of the gamma ray energy. Consequently, the resolution R should improve (go down) as the square root of the energy. The energy resolution will also depend on the PMT supply voltage. A typical photopeak from a ^{22}Na spectrum is shown in figure 15.

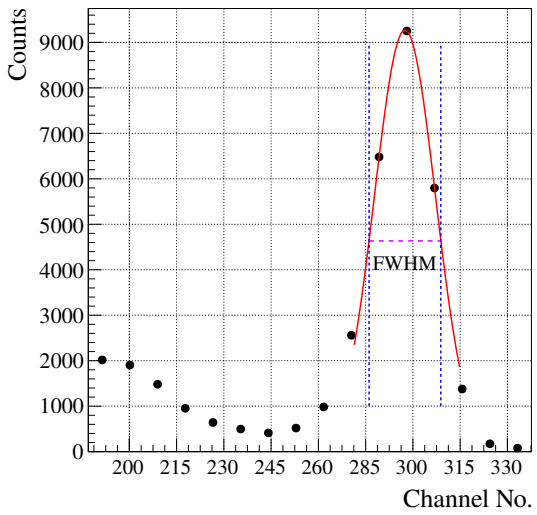


Figure 15: Gaussian fit to the 0.662 MeV photopeak from a ^{137}Cs spectrum.

3.2 Equipment required

1. NaI(Tl) detector assembly
2. Gamma-ray spectrometer and required cables
3. Oscilloscope
4. Radioactive sources (^{137}Cs and ^{22}Na)

3.3 Procedure

1. Turn all the electric units ON, set the detector assembly voltage to 500 V (don't exceed the HV beyond 600 V), adjust the gain of the amplifier and discriminator voltage as done in expt. 2.

2. Put the sources ^{137}Cs and ^{22}Na and collect the spectra separately as done in the previous experiment.

3. Export the collected data to text files and perform gaussian fitting to obtain FWHM for ^{137}Cs and ^{22}Na sources.

4. Calculate the resolution of the single photopeak in ^{137}Cs and two PhotoPeaks in ^{22}Na in energy units using the calibration relation obtained as before.

5. Prepare a data table as shown in table 2.

6. Plot energy resolution as a function of gamma-ray energy and interpret the observations.

7. Put the ^{137}Cs source and collect the spectrum as done in the previous experiment for various HV values ranging between 400 V to 600 V.

8. Prepare a data table as shown in table 3.

9. Plot resolution vs. voltage and interpret the observations.

3.4 Observations

Table 2: Table of energy resolution and photopeak energy.

Event	Energy (MeV)	Energy resolution
^{137}Cs Photopeak	0.662	
^{22}Na Photopeak	0.511	
^{22}Na Photopeak	1.275	

Table 3: Table of energy resolution and voltage.

Event	HV (V)	Energy resolution
^{137}Cs Photopeak	400	
	420	
	440	
	...	
	600	

3.5 Results

1. The energy resolution of the NaI detector for 662 keV gamma (^{137}Cs) is obtained to be _____ %.
2. The energy resolution of NaI detector _____ with energy.
3. The energy resolution of NaI detector _____ with voltage.

References and further reading

[1] H. Bichsel and H. Schindler. *The Interaction of Radiation with Matter*. Ed. by C. W. Fabjan and H. Schopper. Cham: Springer International Publishing, 2020, pp. 5–44. URL: https://doi.org/10.1007/978-3-030-35318-6_2.

[2] K. P. Schäfers et al. "1.10 - High-Resolution Small Animal Imaging". In: *Comprehensive Biomedical Physics*. Ed. by A. Brahme. Oxford: Elsevier, 2014, pp. 181–211. URL: https://www.sciencedirect.com/science/article/pii/B9780444536327001106.

[3] *Photomultiplier Tubes (PMT)*. Online. URL: https://www.sense-pro.org/lll-sensors/pmt.

[4] G. F. Knoll. *Radiation detection and measurement*. 4th ed. John Wiley & Sons Inc., 2010. 864 pp.

A Details about the gamma ray spectroscopy system

Nal Scintillation detector based gamma ray spectroscopy system with 8k / 4k / 1k MCA consists of the following consistent units.

1. MINBIN with power supply (MB403)
2. High Voltage (HV501)
3. Spectroscopy Amplifier (SA524) or Linear Amplifier (LA520)
4. 8k / 4k / 1k Multi channel Analyzer with processing software
5. Nal Scintillation detector ($2'' \times 2''$ / $3'' \times 3''$ Flat / Well type)
6. Lead shielding (40 mm)
7. Personal computer system
8. Gamma Reference Sources Set

This system finds wide applications in Gamma Ray Spectroscopy measurements. Highly recommended for various Health Physics Labs of Nuclear Power Plants, Environmental survey labs & other labs for basic & applied research purposes. System also can be used in teaching labs of Nuclear Sciences & Engineering. Multi-Channel Analyzer (MCA) is an important part of nuclear spectroscopy system. The major requirement of MCA is for nuclear pulse height analysis in energy spectroscopy. The USB-MCA presented here, incorporates state of art technologies like FPGA, USB bus interface and precision analog electronics to meet the stringent system requirements in nuclear pulse spectroscopy. The resolution supported by the USB-MCA ranges from 256 channels to 8k channels selectable via software, making it suitable for all spectroscopy applications from low resolution (e.g. Nal-PMT) to high resolution (e.g. HPGe) systems.The USB bus interface of the MCA provides an excellent connectivity with most of the new PCs and lap-top computers. The Anuspect application software provided with the USB-MCA, seamlessly integrates with the hardware, featuring a range of standard functions required for analysis and acquisition.

A.1 Features

- Excellent MCA performance in terms of DNL: ±1%; INL : ±0.05% of F.S. resolution etc.
- Supports both PHA & MCS modes of operation.
- Universal connectivity to a wide range of PCs and notebook computers.
- Gamma Ray Spectroscopy System uses Spectroscopy Amplifier or Linear Amplifier, HV module and Scintillator Detector including instrumentation BIN & power supply.
- Excellent processing software features.

- System can be used with different sizes of NaI scintillation detectors

A.2 MINIBIN and power supply (MB 403)

MINI BIN: Accommodates SIX/EIGHT single bit modules or combination of multiple widths witT Amphenol connectors. Minibin is primarily designed with the objective of conserving bench space and to achieve significant saving in cost of the Minibin based systems. Bussed wiring is provided to the power connectors to distribute ±12 V and ±24 V. A control panel with ON/OFF switch, low voltage test sockets is provided on the right extreme side of the bin.

- **Minibin dimensions**: 11.75″ width × 11.00″ depth (upto connectors) × 8.75″ height.
- **Power supply**: This is either two and half bit module or a compact box type enclosure fitted at the back of this bin, which generates highly regulated D.C voltages.
- **Input**: (230 V + 10%) AC, 50 Hz.
- **D.C Output**: +12 V @ 1 A, -12 V @ 1 A, +24 V @ 0.5 A, -24 V @ 0.5 A, 48 watts maximum.
- **Regulation**: Better than ±0.1%
- **Noise & Ripple**: Less than 3 mV
- **Stability**: ±0.5% after a 24 hr warm-up at constant line, load & ambient temperature

A.3 High Voltage Unit (HV 501)

1. Output voltage variable continuously from 0 V to 1500 V
2. Output current (max): 1 mA
3. Load & Line regulations: Better than 0.005% of full scale
4. Indefinite over load & short circuit protections and self recovery
5. Output ripple less than 20 mV.
6. Dimensions: Single / Two bit module

A.4 Spectroscopy Amplifier (SA524)

Spectroscopy Amplifier is a high performance nuclear pulse shaping amplifier, ideally suited for use with all types of detectors such as germanium, silicon surface barrier

and Si(Li) detectors. This is a single width NIM module with pile-up rejector (PUR), gated baseline restorer (BLR), auto threshold, diode limited unipolar output, BUSY and count-rate output as some of the key features designed into it. Some of the main applications of spectroscopy amplifier involve nuclear pulse height spectroscopy, nuclear timing spectroscopy, Counting Systems etc.

The input to SA524 can be either positive or negative signal from a detector preamplifier. The output pulses, 0 to 10V for unipolar pulse and ±10 V for bipolar pulse.

A.5 Performance

1. Gain Range: Continuously variable from ×4 to ×1500.
2. Pulse Shaping: Quasi-gaussian and quasi-triangular.
3. Shaping time: 0.5, 1, 2, 3, 6 and 10 μs
4. Input Noise: 5 mV RMS with 3 ms shaping time
5. Overload: Recovers to within 2% of baseline in 15× shaping time from ×200 overload.
6. Integral Non-Linearity : $< 0.05\%$ from 0 to 10 V.

A.6 Controls

FINE GAIN	:	Front panel 10 turns precision potentiometer provides a continuously adjustable gain factor from 0.5 to 1.5.
COARSE GAIN	:	Front panel six-position switch selects gain factors of ×20, ×50, ×100, ×200, ×500 and ×1000.
PZ	:	Screwdriver adjustment of the PZ cancellation using 20-turn potentiometer on the front panel.
POS/NEG	:	Front panel toggle switch for selecting either positive or negative input signals.
ATN	:	A front panel toggle switch select an input attenuation factor of ×1 or ×2.5
SHAPING	:	Front panel six position switch for selecting shaping times of 0.5, 1, 2, 3, 6 and 10 μs.

A.7 Multi-Channel Analyzer (8k MCA)

Multi-Channel Analyzer (MCA) is an important part of the nuclear spectroscopy system. The major requirement of MCA is for nuclear pulse height analysis in energy spectroscopy. The USB-MCA presented here, incorporates state of art technologies like FPGA,USB bus Interface and precision analog electronics to meet the stringent system

requirements in nuclear pulse spectroscopy. The resolution supported by the USB-MCA ranges from 256 channels to 8k channels selectable via software, making it suitable for all spectroscopy applications from low resolution (e.g. NaI-PMT) to high resolution (e.g. HPGe) systems.

The USB bus interface of the MCA provides an excellent connectivity with most of the new PCs and laptop computers. The PHAST application software provided with the USB-MCA, seamlessly integrates with the hardware, featuring a range of standard functions required for analysis and acquisition.

A.7.1 Specifications

1. **Hardware features**:

   - MCA resolution. 256, 512, 1k, 2k, 4k and 8k channels.
   - Spectrum memory : 128k bytes single port SRAM.
   - Max counts / channel: 31 bit (2 Giga counts).
   - Pulse processing time: 7 μs including ADC conversion time of 5 μs.
   - Pile up rejection: Active high TTL input from spectroscopy amplifier
   - DNC: ±1%
   - INL ±0.05% F.S.
   - MCA Input: Single channel, 0 to +10 V
   - Power requirement: 5 V, −500 mA through USB cable directly (No external power supply required)

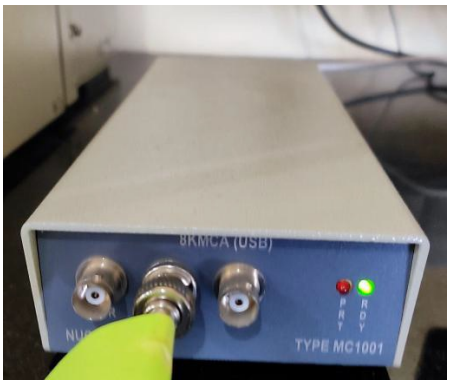


Figure 16: Picture of the MCA.

2. **Software features**: Important software features include spectrum display in two windows marker selection (two) for ROI Detection & bracketing the peaks of interest, multiple ROI selection, deletion of ROI etc.

3. **File Handling**: Involves storing, loading of complete spectrum.

4. **Print**: Print of Total graph, selective graph, peak report

5. **Acquisition**: With pause option

6. **Erase**: Erasing spedrum from memory

7. **Spectrum Analysis**: Find peak, Shape calibration, Energy calibration, Approx Calib, Efficiency Calibration, Activity Calculation, etc.

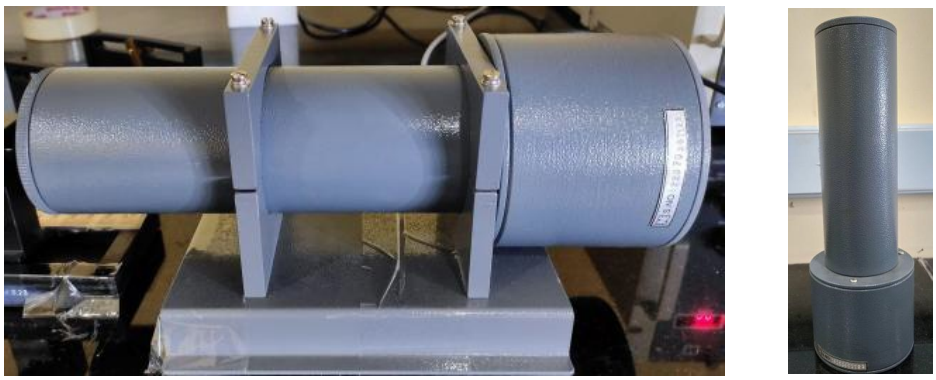
8. **Spectrum smoothing**: 3,5,7,9 & 11 point smoothing functions have been provide

9. **ROI Option**: Insert, Delect, Hide etc.

10. **Scale**: X-axis can be chosen as Channel number (or) Energy axis (in Kev) & Y-axis has range from 256 to 64M in binary steps with auto scaling option. Y-scale can be linear or log LLD, ULD & base line are soft selectable. In built isotope library for isotope selection & matching.

A.8 Scintillation Detector

Nucleonix Systems offers wide range of NaI scintillation detectors of different sizes both with flat & well type crystals, to meet the requirements of wide range of users for Gamma ray spectrometry measurements.



(a) (b)

Figure 17: (a) Horizontally oriented NaI detector. (b) Vertically oriented NaI detector.

Scintillation detectors offered include $2'' \times 2''$ & $3'' \times 3''$ NaI integral assemblies with built-in pre-amplifiers. These detector assemblies give excellent stability, superior performance & good resolution in the range of 8.0 to 9.5% for ^{137}Cs. Scintillation detectors of other size can be offered against user specific requirements also.

Important Specifications	Detector Type
Flat/Well type Nal crystal	SD 152/SD152 W
Crystal Sizes a. Flat crystal b. Well Size	 2″ (dia) × 2″ (height) 0.656″ (dia) × 1.546″ (depth)
Photo multiplier	EMI 9557 or 9266 or its equivalent
Resolution (Better than)	8.5%
Pre-amplifier	Built - in
Gain (Approx.)	25
Noise (RMS. Referred to input)	Less than 50 μV
Operating Voltage	700 to 900 V
Output	Positive Tail Pulse
Output impedance	90 Ω
Power Requirement (Typical)	−12 V @ 12 mA

A.9 Gamma reference standard set (GS290)

Gamma Reference Standard Set Type: GS290 consists of a set of FIVE Gamma sources evaporated & sealed on 25 mm (dia) × 5 mm (height) plastic disc covering SIX photopeak energies in the range of 3 to 5 μCi. A reference chart for this is given below. The accuracy of these sources is in the range of +1 − 10%. All these dics sources are enclosed in a box made of acrylic sheet and supplied.

Table 4: Picture of the source kit and table of sources.

Gamma Isotope	Energy (MeV)	Nominal Activity (kBq)	Half life Half life
^{57}Co	0.123	111	273 days
^{133}Ba	0.36 (Main)	150	7.5 years
^{137}Cs	0.662	111	30 years
^{60}Co	1.17; 1.33	155	5.3 years
^{22}Na	0.511; 1,280	115	2.6 years