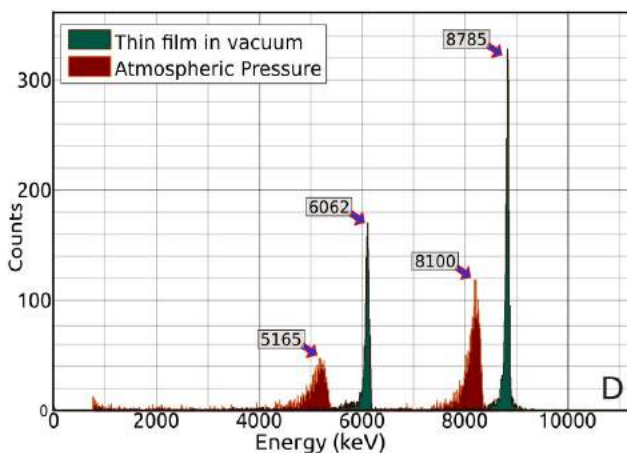


AlphaSpec-1K

USB interfaced Alpha Spectrometer
with integrated 1K Multi-Channel Analyzer



- * 10 MeV Full-Scale Range
- * 1K Multi-Channel Analyzer
- * 16 Million Counts/Channel
- * Cross-Platform Software



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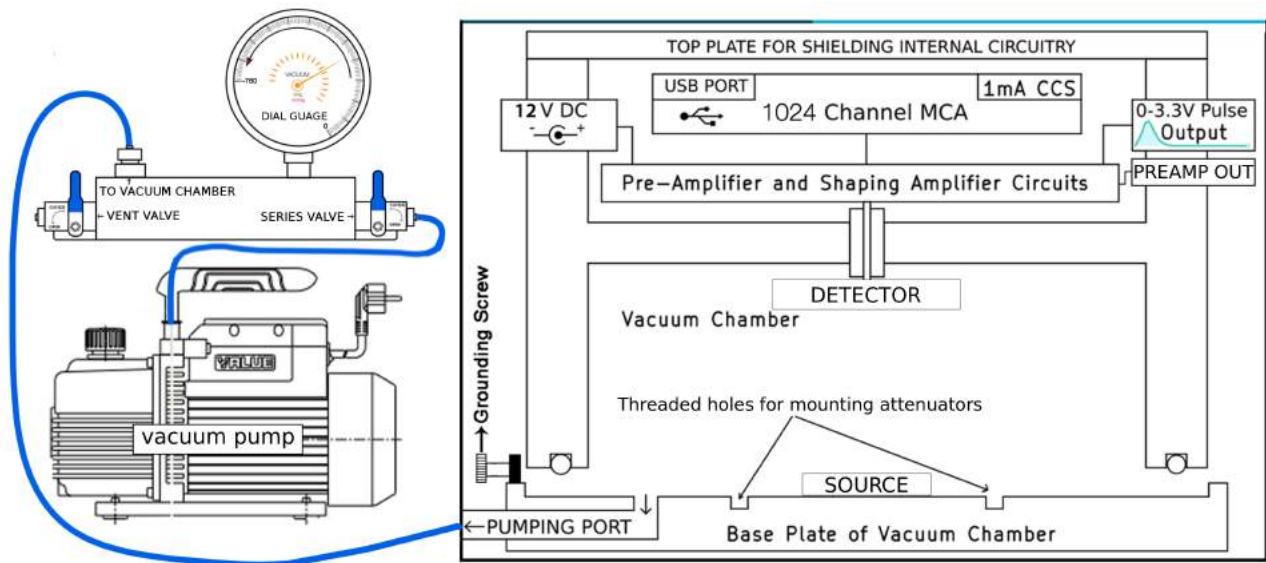


Figure 1: Source-Detector Enclosure Design along with the Vacuum pump and its assembly

1 Introduction

Nuclear science has immense importance in fields ranging from medical sciences to power generation, and defence. However, factors such as a lack of indigenous equipment, high prices, and highly regulated processes for procurement of sources, has resulted in neglect of a more hands-on approach to studying this field. Human resource development is integral to economic and scientific progress in this field, and this requires education at the graduate level and beyond.

Therefore, there is an urgent need to indigenously develop instrumentation for research and teaching in nuclear physics, as well as work out experiments which rely on easily accessible apparatus and raw materials without compromising on pedagogical value.

This document explains a device that can measure the energy of Alpha particles and also some of the experiments that can be done without using any enriched radioactive source. The device is based on the open-sourced preamplifier and shaper designs available on the [website](#) of IUAC, New Delhi. It has an ultra compact design that incorporates all necessary pulse processing tools and a 1k channel MCA in a single chamber. A constant current source and adjustable DAC for threshold setting are included. In addition, only a vacuum pump and a computer are required.

2 Acknowledgements

We would like to thank Prof.(Dr.) O.S.K.S Sastri from the Central University of Himachal Pradesh and his physics education research group for his valuable inputs which have been essential for developing the instrument from an education perspective for UG and PG laboratories. We would also like to thank Swapna Gora from the same group for fine tuning the bismuth extraction process, and publishing the same in Physics Education-IAPT[1] . An instrument modeling paper has also been accepted for publication in an international journal[2]. Our gratitude towards Prof Devinder Mehta, and Dr. Ashwini Jain from Panjab University cannot be expressed enough. Their support and feedback were present throughout the prototyping stages, and were essential in the designing stages.

We are indebted to the Phoenix project from IUAC, New Delhi, for making the reference schematics for preamplifiers and shapers available open-source, which were modified to suit our photodetectors.

Special mention must be made for the developers of the Python project, and various analytical and visualization modules such as numpy, scipy, and pyqtgraph, without which software development could not have taken the form it has.

The following publications have been accepted for this instrument.

- Jithin B.P, V. V. V. Satyanarayana, S. Gora, *et al.*, “Measurement Model of an Alpha Spectrometer for Advanced Undergraduate Laboratories,” 2019
- Swapna Gora, Jithin B.P, V. Satyanarayana, *et al.*, “Alpha Spectrum of ^{212}Bi Source Prepared using Electrolysis of Non-Enriched ThNO_3 Salt,” 2019



Figure 2: The Alpha Spectrometer

3 Instrument Design

A schematic of the equipment is shown in [Figure 1](#), and a labelled graphic provided in [Figure 2](#). The radioactive source is kept on the base plate. The base plate is provided with threaded holes, for mounting attenuators as well as varying distance parameters to studying the energy loss of alpha particles in materials. The base plate locks onto the rest of the chamber, and is vacuum sealed using an O-ring .

To open the chamber, lift the upper portion of the chamber. The rubber O-ring is on the upper part of the chamber and it should not be kept on rough or dirty surfaces. It is recommended to keep it horizontal, or inverted when the chamber is opened. The pumping port is a 6mm diameter tube projecting from the side of the base plate, and an appropriate KF-10 terminated tube is also separately available if required. A screw is fixed on the side to ensure electrical contact between the top and bottom plates since the insulating O-ring might prevent a perfect Faraday cage for electrical noise isolation . Do not use any screw driver to tighten it. Tightening by hand will suffice. There are two threaded holes on the bottom plate where a small assembly can be mounted to place attenuator foils between the source and the detector.

3.1 Silicon PN junction based Detector

Typically an alpha detector consists of a semiconductor PN junction connected in reverse bias mode. The depletion region thus created acts as an ionisation medium which converts the alpha particle energy into a corresponding number of electron-hole pairs. The small amount of charge generated as a result of one alpha particle depositing its entire energy in the depletion region is proportional to its energy, and this charge is then fed to the signal processing electronics, followed by spectrum generation by the multi-channel analyzer(MCA).

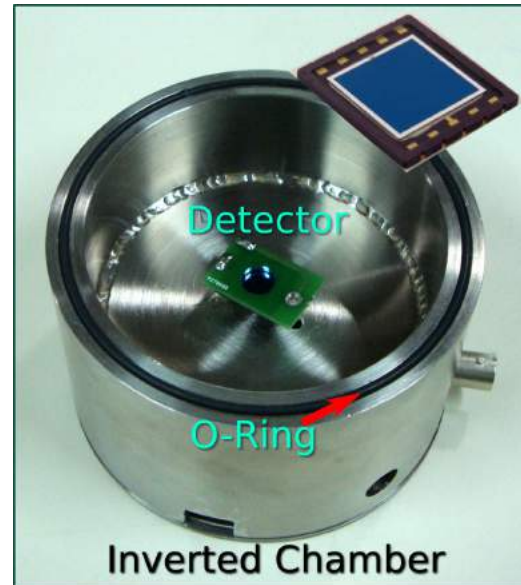


Figure 3: Inverted vacuum chamber showing the detector with the collimator on top

The detector used in this instrument has $10mm \times 10mm$ surface area with a circular collimator of 8mm diameter placed in front to prevent alpha particle incidence near the boundary of the detector where its behaviour is not very linear. An inverted chamber showing the detector, and an inset of the same is shown in Figure 3 .

3.2 Signal Processing Electronics

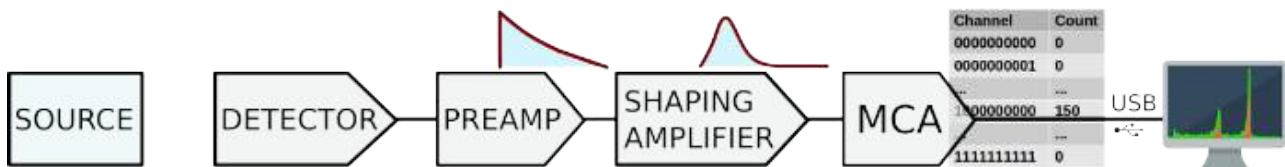


Figure 4: Flow diagram for the entire process

3.2.1 Pre-amplifier

The charge generated by an incident alpha particle is converted into a corresponding output voltage by utilising a charge sensitive preamplifier. The main role of the preamp is to ensure impedance matching between high impedance at the detector side (i.e. input), with the low output impedance of the post-processing electronics. This also improves the signal-to-noise ratio (SNR).

The output of the preamplifier is available for monitoring as shown in [Figure 6](#).

3.2.2 Shaping Amplifier

The output of the Shaping amplifier is a Gaussian shaped pulse. The amplitude varies from 0 to 3.3 volts, depending on the energy of the alpha particle. The amplifier gain is factory set to give 3.3 volts for 10MeV alpha energy. There is an electrical jumper on the circuit board that can be shorted to reduce the gain, to study the fragments from fission reactions. The shaping amplifier's gaussian pulse output is available on a BNC connector for monitoring purposes. Refer to [Figure 6\[G\]](#). The same signal goes to the input of the built-in Multi Channel Analyzer.

3.3 Multi-Channel Analyzer(MCA):

The hardware performs a variety of tasks ranging from detection of the pulse, post-processing of the signal, and sorting the signals on the basis of their peak height into predefined bins. The MCA does the sorting and histogram generation, and it is designed to have 1024 channel(1K) resolution, with an input voltage range of 0 – 3.3V. It has a USB interface, and the software works with Linux based systems such as Debian/Ubuntu and Fedora, as well as Windows 7/10.

Threshold Setting: Input pulses are only accepted if the amplitude exceeds a threshold value (to reject low energy peaks which might not be due to alpha particles) which is set to 80mV. This can be set via the software.

3.4 Vacuum Pump and accessories

Alpha particles are easily attenuated, and lose energy while passing through air. Therefore, measurements need to be performed under vacuum. A small pumping system as shown in [Figure 5](#) can be used. Schematic representation of the same is shown in [Figure 1](#). Vacuum down to 1 mbar is sufficient to reduce scattering by air molecules to a negligible statistic.

- To evacuate the chamber : close the vent valve and open the series valve : Closing the vent valve isolates the chamber from the atmosphere, and opening the series valve connects it to the vacuum pump which can then evacuate the entire cavity.
- To open the chamber : The vacuum must be vented. Close the series valve first, to isolate the pump, and then open the vent valve so the air pressure can equilibrate with the atmospheric pressure. The chamber can now be opened. Refer to [Figure 1](#) for details.



Figure 5: Photo of vacuum pump and pumping assembly connected to the spectrometer

3.5 Constant Current Source (13mA)

A 13 mA constant current source is provided for preparing alpha sources from a solution of thorium nitrate. The procedure is explained in the experiments section. The load connected to the CCS must have a resistance lower than 150 Ohms.

3.6 Power Supply

The unit draws power from the USB port of the host device such as a laptop , or PC. Once it is plugged into any USB port with a 5V output, the preamplifier and shaper outputs start functioning right away, and the outputs can be monitored using an oscilloscope. In order to activate the MCA, the software must be launched.

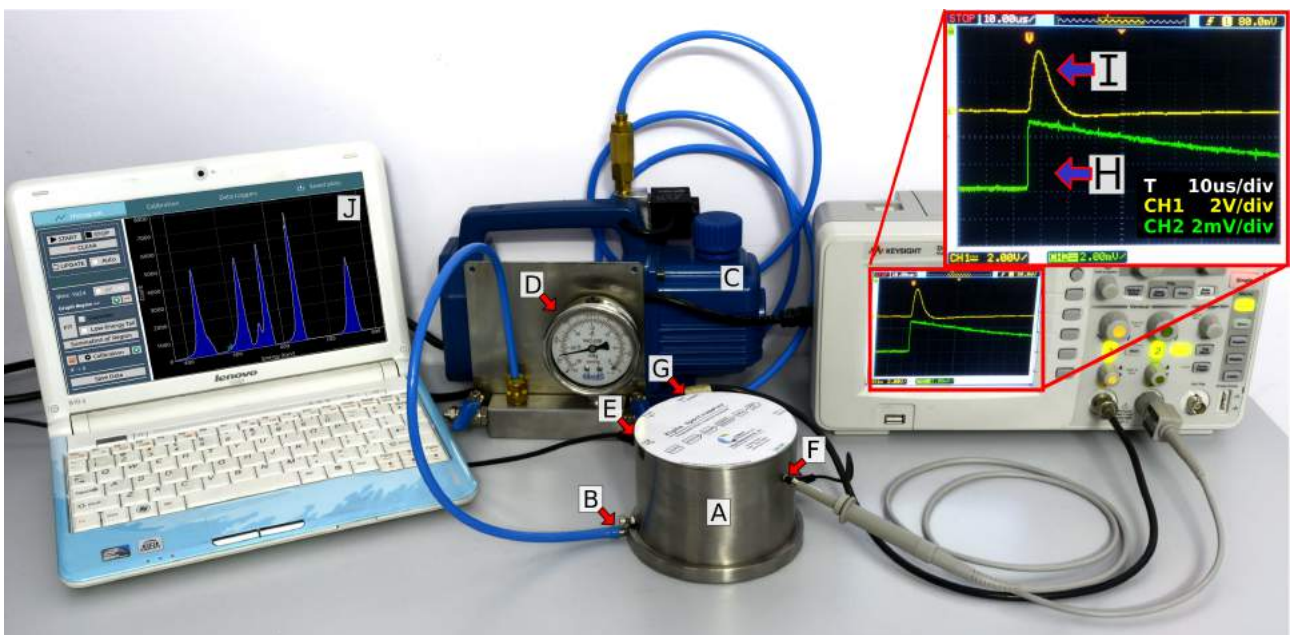
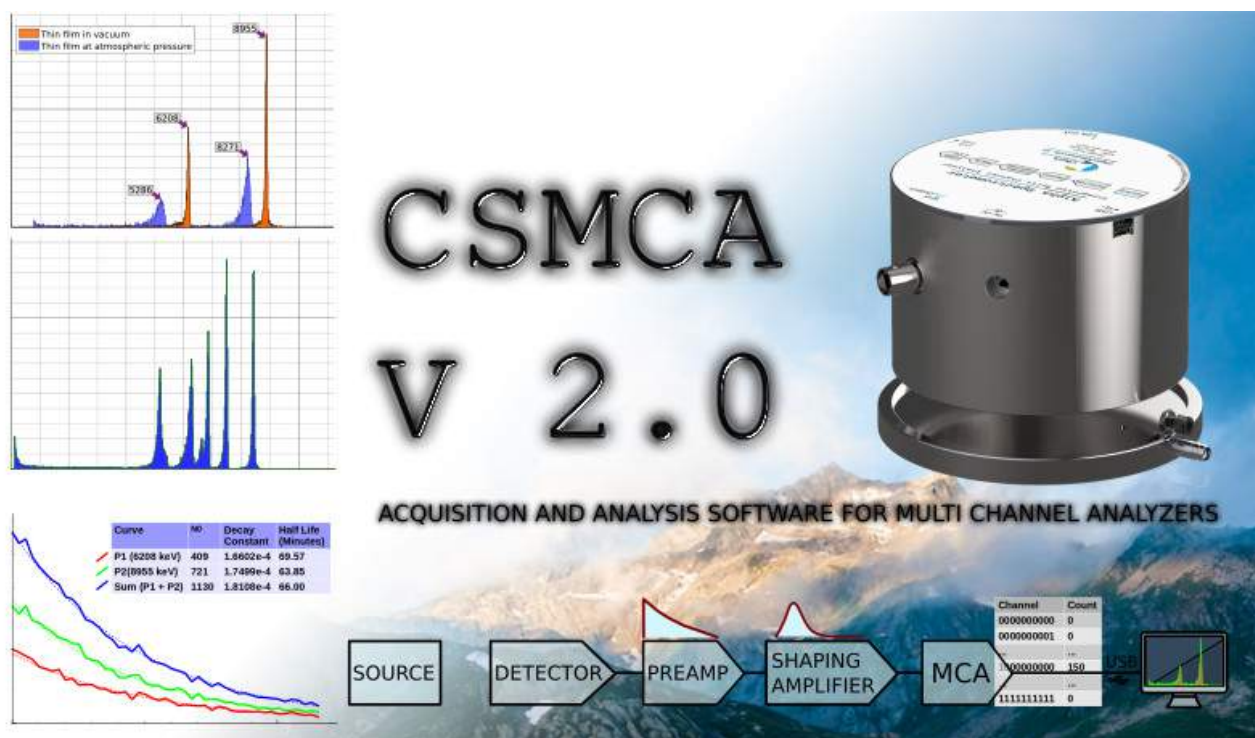


Figure 6: Entire experiment setup of the Alpha Spectrometer '**AlphaSpec-1K**' showing the source-detector enclosure, with pressure monitoring by a dial gauge. Also shown is a laptop connected via the USB port with an example spectrum. Signal outputs from the pre-amplifier(F) and shaping amplifier(G) are connected to a 50MHz oscilloscope where the nature of these signals are shown as traces (H) and (I) respectively(Signals have been offset for clarity)



4 Software

The software *CSMCA* is capable of plotting the acquired data in real-time and has a host of utilities for data analysis. The open-source software is written in the Python programming language, and employs a variety of powerful utilities such as Numpy, Scipy, and PyQtGraph for various mathematical and visualization purposes.

It acquires the data from the hardware, and plots it in the form of a histogram showing channel number (corresponding to peak voltage proportional to alpha energy) on x-axis, and the number of charged particles received at each channel on the y-axis, as shown in [Figure 7](#).

Analytical features incorporated as of now in the software are 3-point calibration, fitting with Gaussian plus low-energy tail (Lorentzian part) to obtain peak information, and a summation utility to obtain the total number of counts corresponding to a peak. It also has data-loggers to automatically estimate half lives of peaks based on pre-selected channel regions.

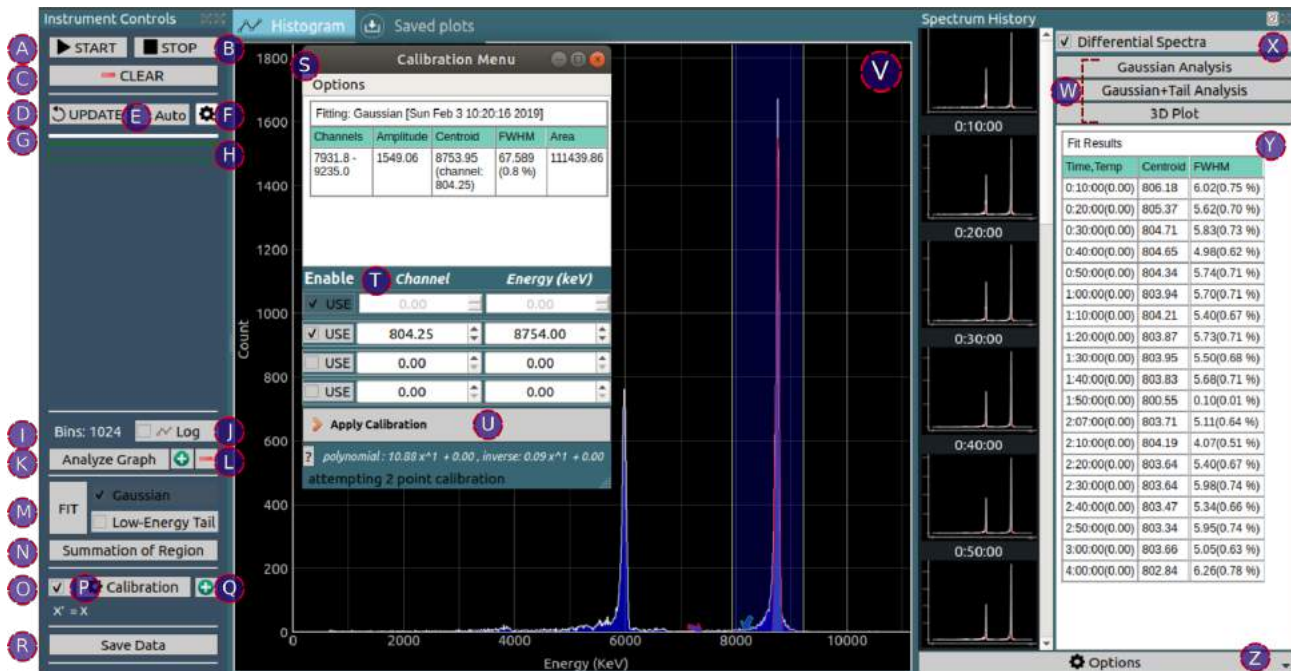


Figure 7: Open-source software provided with the Alpha Spectrometer 'CNSPEC':

4.1 Key Elements

The Alpha Spectrometer's companion software features can be broadly classified into the following subheadings

- (A) Start Histogram : The hardware will start sorting input pulses into their respective bins
- (B) Stop Histogram : The hardware will ignore all pulses until the next start command is issued
- (C) Clear Histogram: The energy spectrum stored in the hardware will be cleared , along with the plot.
- (D) Update : Energy spectrum is fetched from the hardware , and plotted on the screen. An auto-update option is also provided for repeating this at 0.5 Second intervals [Analytical tools are disabled in the auto-update mode].
- (E) Auto-Update : Automatically fetch spectrum in fixed intervals. These are also automatically added to the spectrum history section.
- (F) Auto-update interval in seconds.

- (G) Time left for next automatic spectrum update.
- (H) Pulse Counter : Shows total input pulses in real time. It can be used to determine if an update is necessary. Clicking on the counter resets its value to 0.
- (I) Total number of bins in the spectrum shown.
- (J) Display the Y-axis in log base 10.

Analytical tools

- (K) Open the graph selection utilities dock.
- (L) Region Selection : Add or remove graph region selectors used for defining regions for fitting, summation etc.
- (M) Gaussian Fit : A selection region can be added and relocated to accommodate a peak. The peak can be fitted against a standard gaussian function to extract parameters such as centroid, FWHM, and amplitude. If the theoretical energy value of the peak is already known, the centroid value can also be used to utilize it as a reference point to calibrate the plot.
A low energy tail can also be added to the fitting function to accomodate attenuation by scattering agents.
- (N) Obtain total events present inside a selected region. At least one region must be present on the graph in order to use this.
- (O) Enable Calibration: Calibration with polynomials up to 3 orders is possible. Calibration points can be added in different ways
- (P) Open the calibration window
- (Q) Add a manual point for calibration (channel vs energy in keV). You must first click on the relevant peak in the graph (this places a red marker next to the peak) to identify it.
- (R) Click on this button to open a spreadsheet with numerical values for the histogram. The spreadsheet will allow saving the data in raw form, or as an image.
- (S) **Calibration menu:**
- (T) Channel vs energy table. If only a single pair is specified, the origin coordinate is also used to make a 2 point calibration.
- (U) Apply the calibration to the histogram. The polynomial is shown below the button.

- (V) The spectrum of channels/energies Vs. counts.
- (W) **Spectrum History** : The entire spectrum is saved into an array every time it is fetched from the hardware. In the differential spectra mode, new events recorded in each spectrum is used, and this allows for analysing various parameters such as centroid shifts, and half lives.
- (X) Various different analysis options, including a 3D growth profile plot is available.
- (Y) The analysis results are displayed in a table, and can also be saved into a collection of files into a directory.

The 'SAVED PLOTS' tab displays thumbnails of saved data. Select the appropriate directory, and click on any plot to load it to the main tab. You can then use the math utilities to further analyze your saved data.

4.2 Additional features

1. **Constant Current Source** : The 1mA constant current source also features a voltage readback that is displayed in the bottom left corner. The readback value will indicate if the current source is being used, or if the user has failed to make proper connections for electrolysis.

Data Logger : Data loggers are automatically activated for each selection region. These monitor the total events in the region, and also plot the activity as a function of time. Acquisition interval can be preset, and the loggers automatically calculate decay constants and half-lives once adequate data is available. *The auto-update button must be selected for the logger to work.*

2. **Threshold setting** : Allows users to ignore low energy channels which under electrically noisy environments can accumulate counts unrelated to alpha particles.

4.3 Installation

The software has been packaged for Windows as well as Ubuntu.

4.3.1 Installation on Windows

Download the setup file from <https://csparkresearch.in>, and follow the instructions to install it.

4.3.2 Installation on Ubuntu

Download the deb file from <https://csparkresearch.in>, and install it using a package installer such as Gdebi.

4.4 Installation from source

The source code for the software is Python based, and can be downloaded from github. On Ubuntu :

Install dependencies (Command to be run only once. requires an internet connection)

- `sudo apt-get install python3-pyqt5 python3-pyqt5.qtsvg python3-serial python3-pyqtgraph scipy numpy`

Run the software:

- `python3 MCA.py`

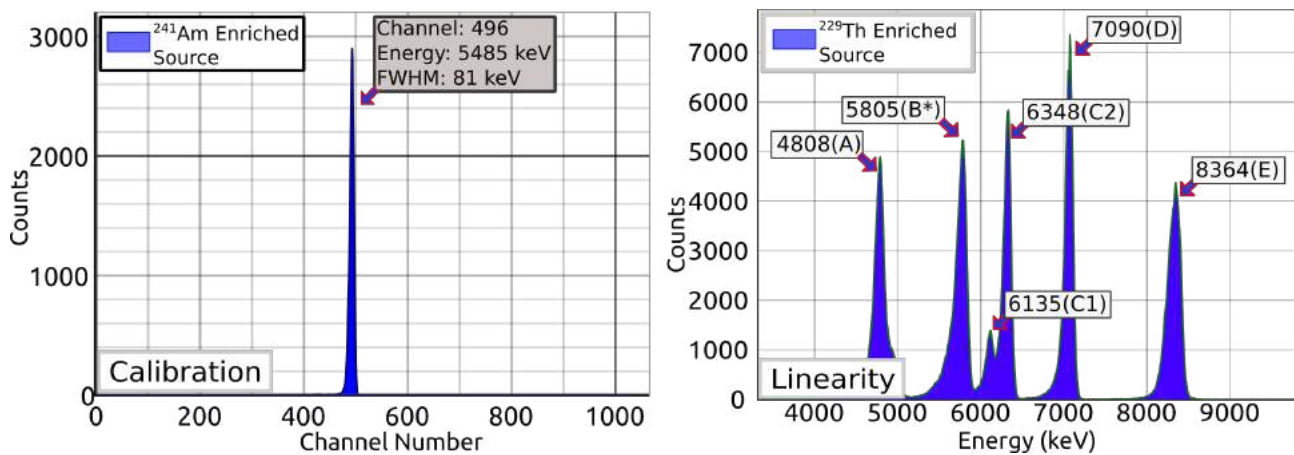


Figure 8: Single point calibration using ^{241}Am , and linearity check with ^{229}Th

4.5 Calibration using ^{241}Am

An ^{241}Am source has a monoenergetic spectrum, and can be used to apply a single point calibration which is composed of a scaling factor. Higher order calibration polynomials can be generated using multi-peak sources such as ^{229}Th or ^{212}Bi .

Steps to calibrate the instrument

- place the source in the chamber, and acquire the corresponding spectrum under vacuum.
- The main energy peak will appear as a number of counts building up around a particular channel number. Insert a selection region, and ensure that it covers this peak
- Click on the fitting routine.
- After a successful fit, the software automatically switches to the calibration tab where the fit parameters are shown.
- Click on the '+' icon in the row of parameters to use the peak for calibration.
- In the pop-up window that is now displayed, enter the known energy of the peak. For Americium, it is 5485 keV.
- In the bottom section, you will now observe an entry showing channel number vs the corresponding energy, and also a calibration polynomial.
- Click on 'Apply calibration polynomial' to apply this calibration.

- The tab will automatically switch to the main plot window, and you will observe that the X-axis now displays energy units rather than channels
- Finally, you may clear the spectrum, and repeat with an unknown source to determine its energy.

The final spectrum obtained by placing ^{241}Am at a distance of 2 cms and a pressure of 50 mBar is shown in [Figure 8](#). The centroid of the spectrum is found to be located at channel number 496 via the gaussian fitting routine, and since the energy of this peak is well known to be at 5485 keV, one can fit a calibration polynomial as follows:

$$Energy = \frac{5485}{496} \times channelnumber \quad (1)$$

^{241}Am enriched source is commonly employed for single point calibration purposes since it produces a single peak at a known energy. However, since single point calibrations are not equipped to correct offset errors, it is advisable to use a source with at least two decay processes with alpha particle emissions at known energies, such as ^{212}Bi . We can now cross-check if our calibration remains linear over the entire range of 10 MeV. A good source for checking this is the multi-peak source ^{229}Th whose energies have been labelled based on the single point calibration. Cross checking with known values in the ENSDF database confirmed a better than 1% linearity.

5 Experiments

Using this equipment, one can study the decay patterns of various radioactive elements. It is also possible to study the energy loss of alpha particles in materials, by using thin attenuators, or varying source-detector distances at atmospheric pressures. In this section we explain several experiments that can be done with this equipment.

5.1 Energy spectrum of ^{241}Am

Americium 241 is a radioactive isotope that emits α particles. The energies are 5486 keV for 85% of the time (the one which is widely accepted for standard α -decay energy), 5443 keV for 13% of the time, and 5388 keV for the remaining 2%. The peaks are almost merged and will be visible as an asymmetry in the shape of the 5486 keV peak. The results of this experiment have been shown in [Figure 8](#) in the previous section.

5.2 Energy loss of Alpha particles in air

5.2.1 To study the effect of source-detector distance at atmospheric pressure

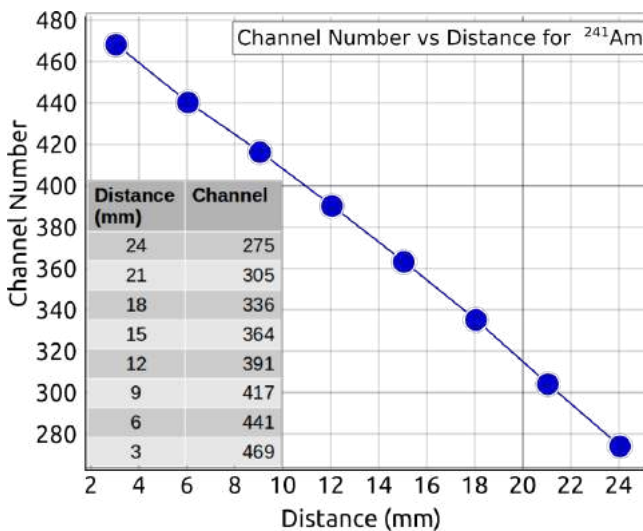


Figure 9: Energy loss of alpha particles as a function of source-detector distance at atmospheric pressure

The ^{241}Am source was placed at a distance of 25mm from the detector, and the average channel number (corresponding to energy) of its lone peak was measured. For this, we have implemented a least square fit routine which uses a standard gaussian function, and recorded the centroid value (average channel number) for each dataset. The source-detector spacing referred to distance, was reduced in steps of 3mm and the centroid was noted for each distance. In the distance versus channel number plot shown in [Figure 9](#), the linear dependence of energy loss with source-detector distance at atmospheric pressure demonstrates that the scattering of alpha particles is proportional to the distance travelled in air.

5.2.2 To study the effect of air pressure

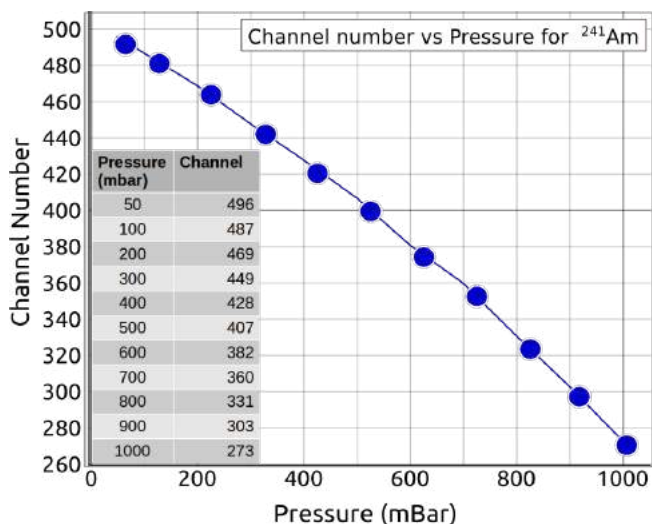


Figure 10: Energy loss of alpha particles as a function of air pressure at a fixed source-detector distance of 30mm

The ^{241}Am source was placed at 30mm from the detector. The vent valve was closed, and the pressure inside the chamber was slowly decreased from 1000mbar to 100mbar in steps of 100mbar. The average energy of the peak that accumulates at a particular channel number is obtained at various pressures and plotted in Figure 10. At 200mbar itself, the peak energy is obtained at channel 469 which corresponds to placing the source at a distance of 3mm from the detector as shown in the previous section. That is, at 200mbar, the scattering losses are almost negligible. Further reducing the pressure to 50mbar is equivalent to placing the source almost in contact with the detector.

5.3 Study of ^{212}Bi isotope extracted from Thorium Nitrate salt via electrolysis

5.3.1 Spectra of $\text{Th}(\text{NO}_3)$ obtained at Atmospheric Pressure:

In the first iteration, the experiment is performed by simply placing approximately 2gm of Thorium Nitrate powder inside the chamber at a distance of 2cm from the detector. The vacuum pump is switched off and the chamber is at atmospheric pressure. The data is acquired for a period of 2 hours and the obtained spectrum is calibrated using manufacturer's data (Supplied separately with each instrument) and is shown in [Figure 11](#).

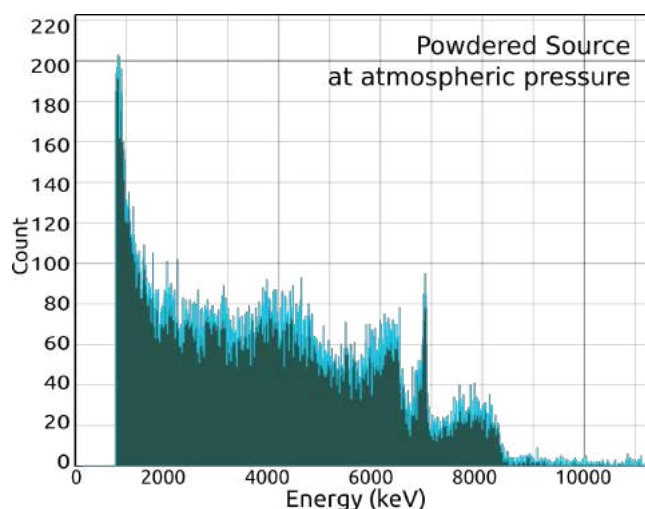


Figure 11: Alpha Spectrum of $\text{Th}(\text{NO}_3)$ salt at atmospheric pressure

The energy spectrum does not show well resolved peaks as expected from ^{232}Th , and is instead smeared over the entire region. A large build up of peaks appears at the lower end of the spectrum, that is, the cutoff/threshold energy. Certainly as a first guess, this loss in energy of alpha particles could be attributed to its interaction with air. So, the experiment is repeated with vacuum turned on.

5.3.2 Spectra of $\text{Th}(\text{NO}_3)$ obtained at 1 mbar Vacuum:

Again, 2gm of Thorium Nitrate powder is placed inside the chamber at a distance of 2cm from the detector. Vent valve is closed so as to isolate the chamber from the atmosphere and the series valve is opened to connect the chamber to the vacuum pump to evacuate the chamber slowly to reach 1 mBar pressure. The data is once again acquired for a period of 2 hours and the spectrum is shown in [Figure 12](#).

The large peak which was present near 800keV (channel 100) due to the minimum threshold setting has certainly been reduced and a sharper peak has appeared at the far side of the spectrum matching the expected 8785 keV line of ^{232}Th series. The rest of the spectrum however, is a smear. None of the other expected peaks are clearly defined and are all lost in a

somewhat unexpected background. Now that the scattering losses due to air are minimized, the only interactions probably are due to the source itself, and this phenomenon is described in the following paragraph.

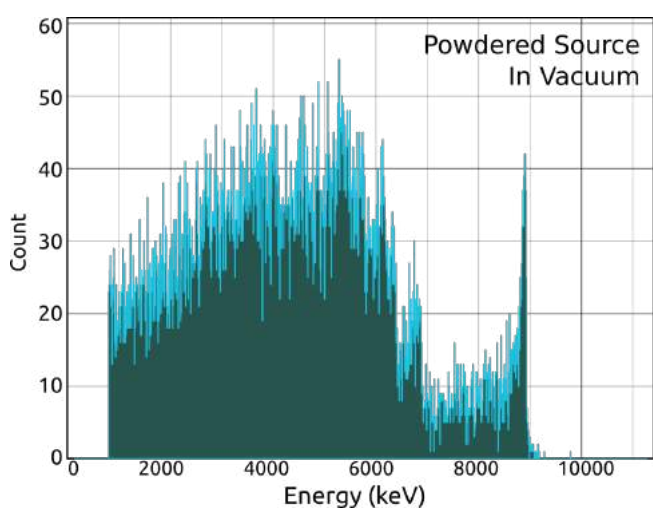


Figure 12: Alpha spectrum of Thorium nitrate salt in vacuum

If the thickness of the source were large, then the lines of the spectrum are broadened to lower energies which is due to the interaction of alpha particles with various nuclei present along the various layers. Alpha particles emitted from the surface will have their original energy, but those present inside the bulk of the salt will lose some of their energy trying to escape through the salt lattice. This phenomenon is known as self-absorption. To reduce the losses due to self-absorption, we need to prepare a thin film source. There are different ways of preparing thin film sources and here we have chosen to prepare one using electrolysis.

5.3.3 Spectra of ^{212}Bi Source with Vacuum:

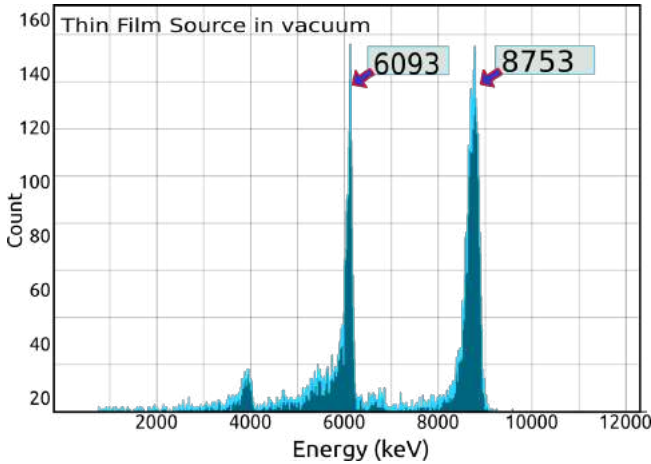


Figure 13: Thin film of ^{212}Bi under vacuum

The process of preparing thin film sources using electrolysis is an open-ended experiment in itself. In the course of our efforts, we have realized that optimizing the electrolysis process has many parameters.

We have to vary only one of the parameters while keeping all others fixed, and perform the experiment to understand the causal relationship on the quality of obtained alpha spectrum. This must be taken up in a systematic fashion.

Examples of parameters:

- Concentration: The amount of the salt in the aqueous solution (one can try other solvents).
- The type of electrode materials to be employed: Lead, Aluminium, Copper etc..
- Constant current (typically in mA) to be passed through the solution, and the potential difference.
- The time for deposition; typically a few minutes.

Here, we only present and analyse the results for the spectrum obtained by selective deposition of ^{212}Bi .

In the initial trial for obtaining the thin film source, we have dissolved approximately **3 gm of $\text{Th}(\text{NO}_3)_3 \cdot 5\text{H}_2\text{O}$ in 5 gm of water** and performed electrolysis with Lead (Pb) electrodes by passing **10 mA of current** (with 450 mV potential difference) for **10 minutes**. The obtained spectrum is shown in [Figure 13](#).

Factory calibration data with Am-241 source (5485 keV energy corresponding to channel number 495.6 for this particular instrument) was used.

Figure 14: The energies, FWHM, Resolution, Intensity and Branching ratio for the two peaks in inset of Figure 16 corresponding to ^{212}Bi and ^{212}Po are shown. The best values from ENSDF/Nuclear data tables are shown below in brackets

Peak	Energy (keV)	FWHM (keV)	Resolution (%)	Intensity (Total Counts)	Branching Ratio (%)
^{212}Bi	6093 (6062)	133	2.1	1811	33.2 (35.94)
^{212}Po	8753 (8785)	254	2.9	3640	66.8 (64.06)

We find that there are two peaks, at 6093 keV and 8754 keV respectively as shown in Figure 13.

Clearly, the second peak corresponds to the decay of ^{212}Po . The first peak at 6093 keV is close to those from ^{212}Bi , but have not been resolved into separate peaks due to limitations of the instrument. Specifically, the FWHM of the ^{241}Am peak which was around 80 keV tells us that we must not expect to observe peaks with lesser spacing than this to be resolved.

5.3.4 Branching ratio of ^{212}Bi peaks:

^{212}Bi has an α -branch with 35.94% probability, and a β -branch with 64.06% probability. Its β decay daughter ^{212}Po has a 100% α -decay route with an extremely short half-life of only 299 ns and hence gives rise to a large peak at 8785 keV. The α branch gives a single peak at the weighted average of two possible energies which are very closely spaced (6050.78 keV and 6098.88 keV with 69.91% and 27.12% probability), and appears at 6062 keV.

An analysis of the spectrum can be seen in Table 2.

5.3.5 Effect of air scattering on spectral lines:

To gain appreciation for the effect of energy loss due to scattering with air alone, the experiment is repeated with a second set of parameters for the thin film source prepared with 3.5gms of $\text{Th}(\text{NO}_3)_4 \cdot 5\text{H}_2\text{O}$ dissolved in 5 gm of water, using Pb electrodes and passing current of 19mA (with a potential difference of 350mV) for 10 minutes. The experiment is performed in two steps. Initially the spectrum is obtained with vacuum for 30 minutes duration and then the vacuum is turned off and then the vent valve is opened to release air into the chamber and obtain a second spectrum.

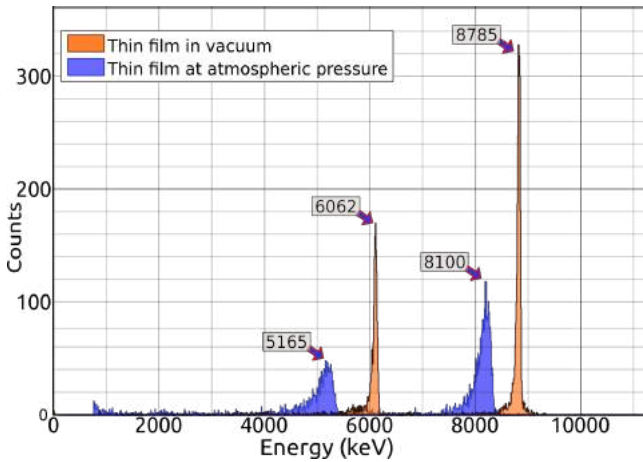


Figure 15: Comparison of ^{212}Bi spectrum in 1 mbar vacuum and under attenuation due to 1 Bar atmospheric pressure.

known energies to apply a two point calibration to the spectrum. Since the lower energy peak seen around 6093 keV is a combination of two energies, a weighted average of 6062 keV has been considered for it. The higher energy peak has a known energy of 8785 keV.

Both peaks have lost energy and shifted to 8100 keV and 5165 keV from 8785 keV and 6062 keV respectively. It can also be noted that the higher energy alphas have lost lesser energy as compared to the ones corresponding to the lower energy peak. The loss in energy corresponding to higher energy peak is 684 keV and to that of lower energy peak is 897 keV. This can be attributed to the fact that the higher energy alpha particles spend less time travelling through air, and therefore face a lower chance of getting scattered.

The peak amplitudes have reduced from 157.54 to 47 for peak at 6062 keV and from 319.54 to 114 for peak at 8785 keV. As compared to the spectrum taken under vacuum, the sharp peaks previously observed have now spread over a lot more channels because scattering is highly probabilistic in nature, and the alpha particles undergo varying levels of scattering and subsequent energy loss depending on the number of air molecules encountered along the way. The lower energy peak has spread in a wider range of channels as compared to the higher energy peak.

The orange colored histogram in Figure 15 corresponds to the energy spectrum of ^{212}Bi thin film in vacuum (1mbar) taken for 30 minutes, and after venting the vacuum and bringing the chamber to atmospheric pressure, the blue histogram was acquired.

Care was taken to ensure that the total number of events recorded in both spectra are nearly similar in order to make a comparable study. The effect of attenuation due to air can be clearly observed. Since we have already determined that the film deposited yields a majority of ^{212}Bi isotope, we can now use its

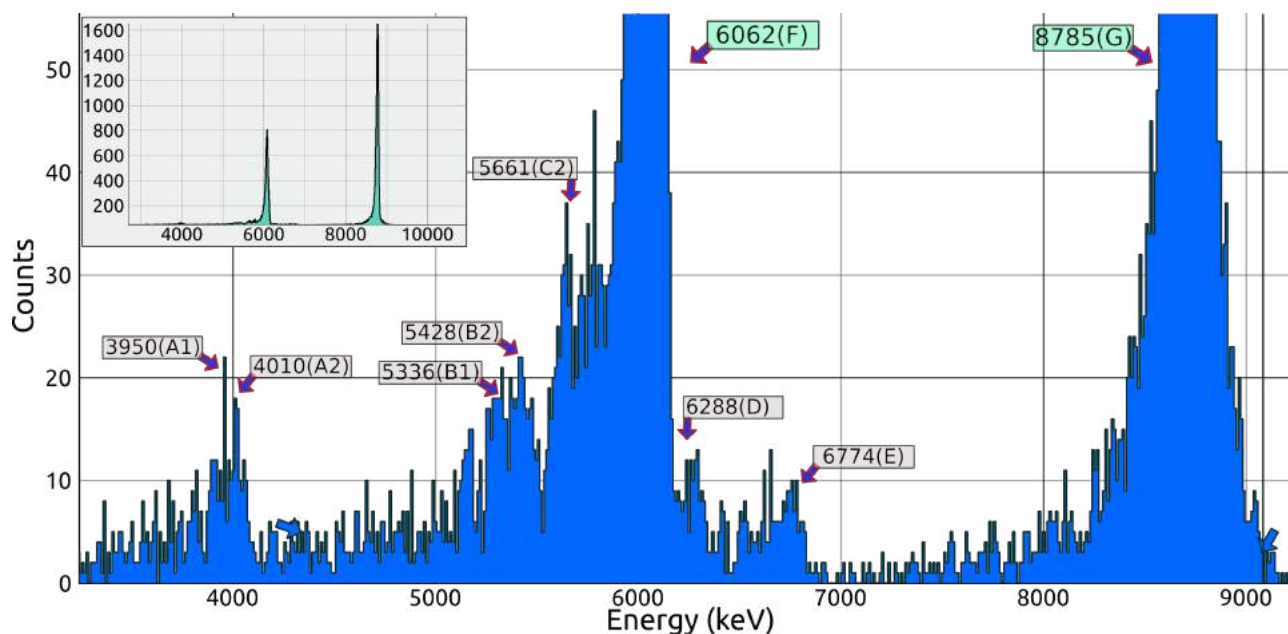


Figure 16: Spectrum obtained from a thin film of ^{232}Th under 1mbar pressure showing prominent peaks for ^{212}Bi , as well as trace amounts of other isotopes. Acquisition time was 4 hours. The complete spectrum is shown as an inset.

5.4 Enhanced ^{212}Bi Spectrum showing trace amounts of parent nuclei

The electrolysis process predominantly deposits ^{212}Bi , however, trace amounts of ^{232}Th and its daughter nuclei are also deposited. The activities of all these isotopes belonging to this series also reflects in the final spectrum, but have only a few counts.

If the acquisition is carried out for a long time, say 4-5 Hours, these small peaks can also be identified. Figure 16 shows such a spectrum which has been zoomed to show the small peaks. The two major peaks at 6062keV and 8785keV have been used to obtain a 2-point calibration which is more accurate than a single point calibration for identifying the smaller peaks. The identified peaks have been labelled in Figure 16, and their actual values have been verified with ENSDF data compiled into Table 1 .

5.4.1 Half-Life calculations for ^{212}Bi

Consider the spectrum, shown in inset of Figure-4, obtained for 4 hours with thin film prepared using the second set of parameters and placed in vacuum. It has two well defined sharp peaks

Table 1: The radioactive decay chain of ^{232}Th with alpha energies (intensities > 5%)

Parent	Daughter	Type	$E\alpha$	$I\alpha$	$t_{\frac{1}{2}}$
^{232}Th	^{228}Ra	α	3974.2(A1) 4012.3(A2)	21.7 78.2	$1.4 * 10^{10}$
^{228}Ra	^{228}Ac	β	-	-	5.75a
^{228}Ac	^{228}Th	β	-	-	6.25h
^{228}Th	^{224}Ra	α	5340.36(B1) 5423.15(B2)	26 73.4	1.9a
^{224}Ra	^{220}Rn	α	5448.6(C1) 5685.37(C2)	5.06 94.92	3.63d
^{220}Rn	^{216}Po	α	6288.08(D)	99.886	55.6s
^{216}Po	^{212}Pb	α	6778.3(E)	99.99	0.145s
^{212}Pb	^{212}Bi	β	-	-	10.64h
^{212}Bi	^{212}Po	β 64.06%	-	-	60.55m
^{212}Bi	^{208}Tl	α 35.94%	6050.78(F1) 6089.88(F2)	69.91 27.12	60.55m
^{212}Po	^{208}Pb	α	8784.86(G)	-	299ns

and all the losses due to air scattering and self-absorption seem negligible. During the course of obtaining the spectrum, the intensities of both the peaks are saved after every twenty minutes for determining the half-life of Bi.

Procedure for recording Half-life

- Wait for a small peak to build up until the channels occupied by it are approximately evident.
- Insert a region selector, and drag its boundaries to mark the peak. [Figure 7](#)
- Use the summation utility to calculate total events belonging to that peak.
- Record the increment in counts every 10 minutes (Interval should be adjusted according to activity of the source)

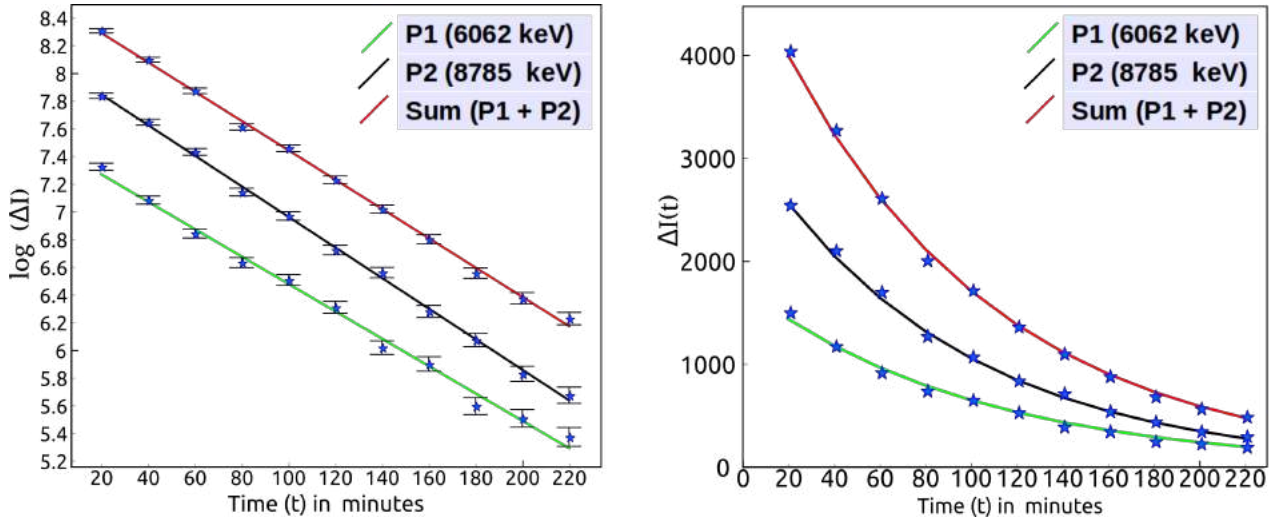


Figure 17: a) Log plots for counts per unit time obtained for both ^{212}Bi peaks as well as their sum in twenty minute intervals. b) Half life calculations for ^{212}Bi spectrum peaks at 6062 keV and 8785 keV using least square fit with a standard exponential decay function.

- Fit the counts with an exponential decay function to obtain the decay constant.
- Calculate half life from the decay constant as per theory given below.

Experimentally, the half life is determined by measuring the activity of the source, which is defined as the number of decays per unit time, and is expressed mathematically as,

$$A(t) = \frac{dN_d(t)}{dt} \quad (2)$$

where

$$N_d(t) = N(0) - N(t) \quad (3)$$

is the number of radioactive decay at time t, $N(0)$ is the radioactive nuclei at time $t=0$ and $N(t)$ is the number of nuclei left in the sample at time t expressed as

$$N(t) = N(0)e^{-\lambda t} \quad (4)$$

where λ is the decay constant.

Hence activity can be further expressed as;

$$\begin{aligned} A(t) &= \frac{dN_d(t)}{dt} = -\frac{dN(t)}{dt} = \lambda N(t) \\ &= [\lambda N(0)]e^{-\lambda t} = A(0)e^{-\lambda t} \end{aligned} \quad (5)$$

In our experiment, we determine the total number of counts $I(t)$, obtained using the summation option in the software. These counts $I(t)$ is directly proportional to the decayed nuclei per unit

Table 2: The curves P1 and P2 belong to Bi and Po respectively. The decay constants and their respective standard deviations from linear regression and the corresponding half-lives with uncertainties are presented below.

Data Set	Decay Constant (λ in 10^{-2} sec^{-1})	Standard Deviation in Decay Constant ($\Delta \lambda$ in 10^{-4} sec^{-1})	Half life ($t_{1/2}$ in minutes)	Uncertainty in Half-life ($\Delta t_{1/2}$ in minutes)
P1 (6062 keV)	0.99	2.62	70.08	1.87
P2 (8785 keV)	1.10	1.39	62.77	0.79
SUM (P1+P2)	1.06	1.38	65.45	0.85

time, whose alphas have been registered by the detector at a particular energy. The software's data logger utility saves these counts $I(t)$ related to a peak at regular intervals of time Δt as specified by the user. Here, we have chosen to save the total counts in twenty minutes interval. Now, approximating $A(t)$ as $\frac{\Delta N_d}{\Delta t}$ (reflected as $\frac{\Delta I(t)}{\Delta t}$), we can rewrite eqn (4) as

$$\Delta I(t) = [\Delta t A(0)]e^{-\lambda t} = I(0)e^{-\lambda t} \quad (6)$$

where $\Delta I(t) = I(t+20) - I(t)$ is the counts obtained in particular twenty minutes interval.

The counts data is obtained for the two peaks as P1 (6062 keV) and P2 (8785 keV) and their sum as Sum (P1+P2). The plots of $\log(\Delta I)$ vs t fitted with linear regression are shown in Figure 17(a).

The decay constants given by the slopes of the respective lines are shown in Table 2. The observation that the three fitted lines are almost parallel reflects the fact that the decay constant should remain the same through both the α and β - branches. The obtained decay constants are used to fit the actual data with exponential functions. This approach is followed because students can easily get confused by looking at the seemingly different exponential decay plots.

Uncertainty in Half-life

The half-life is given by $t_{1/2} = \frac{0.693}{\lambda}$. Hence, its uncertainty is $\delta t_{1/2} = \frac{0.693 \cdot \delta \lambda}{\lambda^2}$. $\delta \lambda$ is obtained by determining the standard deviation in the slope of the regression data, given by:

$$\sqrt{\frac{\frac{1}{n-2} \sum_{i=1}^n (y_i - \hat{y}_i)^2}{\sum_{i=1}^n (x_i - \bar{x})^2}} \quad (7)$$

The obtained standard deviation for three regression data are tabulated in Table 2. The half-life and its uncertainty for each of the data is determined and presented in Table 2. The

best value for half-life is found to be 62.77 Min with an uncertainty of 0.79 Min from the data, corresponding to that of P2, and this is because the peak is well defined with no adjacent peaks as compared to P1 which has combination from overlap of other Thorium daughters. The overall half-life is slightly greater than the expected value of 60.5 min with an error of 3.66%. This is because the thin film source contains small quantities of parent products of 212-Bismuth resulting from the 232-Thorium series, which would to some extent replenish Bismuth nuclei within the sample over time.

Since the peak formed around 6081keV may also contain contributions from various trace isotopes from the Thorium-232 series, we used the higher energy peak formed around 8685keV for half-life calculations.

The activity was obtained by determining total counts under the 8685 keV peak in 12 minute intervals. The log of the activity has been plotted as a function of time in [Figure 17](#). The slope of the regression line determines the decay constant λ (shown in inset of [Figure 17](#)) using which the half-life is determined to be 60.3 minutes with an uncertainty of 2.4 minutes. It agrees with the expected value of 60.55 ± 0.30 minutes to an accuracy of 0.33%.

References

- [1] Swapna Gora, Jithin B.P, V. Satyanarayana, O. Sastri, and B. Ajith, “Alpha Spectrum of ^{212}Bi Source Prepared using Electrolysis of Non-Enriched ThNO_3 Salt,” 2019.
- [2] Jithin B.P, V. V. V. Satyanarayana, S. Gora, O. S.K. S. Sastri, and B. P. Ajith, “Measurement Model of an Alpha Spectrometer for Advanced Undergraduate Laboratories,” 2019.