Alpha Spectrum of ^{212}Bi Source Prepared using Electrolysis of Non-Enriched $ThNO_3$ Salt

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Abstract

We present various aspects involved in performing alpha spectroscopy experiments using non-enriched $ThNO_3$ salt. The experimental design is improved in a cyclic fashion to bring forth the importance of thin film preparation of the radioactive source, and creating vacuum in reducing the energy losses due to self-absorption and air scattering respectively. Thin film preparation using electrolysis of $ThNO_3$ aqueous solution has been optimized for current and time to selectively deposit ^{212}Bi. The obtained spectrum had large peaks at 6093 keV and 8753 keV with resolutions of 2.10% and 2.90% and relative percentage errors of 0.59% and 0.35% respectively. These peaks had intensity ratios of 33.2% : 66.8% matching with existing values in Nuclear Data Tables. Then the concentration (ratio of $ThNO_3$:water) has been increased to obtain reasonably large counts within 4 hours so that data can be utilised to obtain half life of ^{212}Bi. The best obtained half life of Bismuth from the counts saved after every 20 minutes has been determined to be 62.77 ± 0.79 minutes which is close to the expected value of 60.55 ± 0.30 minutes.

1 Introduction

UGC guidelines [1] 2015 for B.Sc. Hons in Physics has included a course on Radiation Safety, with 30 lectures, and insists on a set of experiments to be performed using GM counters for radiation detection, Spark counter for alpha detection and Gas Light mantle (source of Thorium) for obtaining gamma spectrum. While this course is one of the skill enhancement courses, the discipline specific elective paper on Nuclear and Particle Physics is loaded with 5 credits and only a Tutorial of 1 credit with no lab work.

There are two major difficulties for proposing a nuclear physics lab at both the UG and PG level: The high cost involved in procuring nuclear instrumentation, and the need for radiation safety.
Realising the need for dissemination of knowledge in experimental nuclear physics and the need to create awareness regarding radiation at the UG/PG level in various colleges, Dr.Ajith has taken initiative under the outreach programme of Inter University Accelerator Centre (IUAC), and along with Er. Satyanarayana, developed an alpha spectrometer [2] with associated software in python, all of which are made as open source.
CSpark Research (India) has adopted their basic hardware design comprising of a pre-amplifier and shaping amplifier and redesigned it with enhanced detector and vacuum solution along with a 1K MCA and a user friendly featured software CN-Spec and made it available in the market at very low cost of less than Rs.50,000/-.
Our PER group at Central University of Himachal Pradesh is working on developing a Nuclear Physics lab based on good practices found through research such as (a) establishing learning goals (b) designing activities, simulations and experiments and accordingly revise the curriculum to achieve the desired learning goals and finally (c) create appropriate rubrics to provide precise assessment.
To realise these objectives, we need to address the disadvantages pertaining to cost and safety. In this paper, we are focusing on using CSpark Research's low cost alpha spectrometer **('AlphaSpec-1K')** [3] to perform experiments with non-enriched $Th(NO_3)$ salt which is available from suppliers of chemicals at a reasonable cost of about Rs.5000/- for 100gm.
In the presentation of this paper, we have chosen to follow closely the advanced lab learning goals suggested by University of Colorado, Boulder in [4]. The goals are classified into the following four categories:

1. Modeling (Physical system, measurement apparatus, predicting outcomes and using statistical analysis for comparison)

2. Design (Apparatus, experiments, and troubleshooting)

3. Communication (Argumentation/ thorough analysis and discussion, oral and poster presentation, writing papers etc)

4. Technical lab skills (Basic test and measurement, computer interfacing, computer aided analysis)

The actual listing is available at [4].
In this paper, we shall be focussing on incorporating learning goals about modelling lab experiments based on the experiment involving alpha spectrum of ^{212}Bi. We shall restrict our scope to suit the learners at the UG level.

2 Modeling

In this experiment, designing lab specific learning goals based on modeling framework involves

1. understanding the source, its preparation and characteristics
2. interaction medium, which consists creating a vacuum within the source-detector housing assembly using a rotary vacuum pump
3. measurement process, which has the detection electronics hardware followed by the data acquisition software along with its various features

2.1 Modeling the Source

The source is a non-enriched radioactive sample composed of thorium nitrate ($Th(NO_3).5H_2O$) in powder form which has ^{232}Th and its various daughter products available via alpha and beta emission. Especially, we are focussing on studying:

1. The α spectrum of ^{212}Bi, one of the final daughters in the series, which results from the process of preparation of thin film source required for reducing the alpha energy losses due to self-absorption.
2. The half-life of ^{212}Bi

The learners' goals are to (i) model the radioactive decay of alpha theoretically and (ii) obtain the quantitative predictions of observable phenomenon, in this case, the alpha energies that are emitted by ^{212}Bi and its half-life.

Typically, modeling the alpha decay should have been done using Gamow's theory as presented in various books [[6]-[9]]and notes [[10]-[11]. Here, the focus being ^{212}Bi, which is an odd-odd nuclei, undergoing both α and β decays with significant branching ratios, it is difficult for existing theoretical models as well as phenomenological models such as those using Viola-Seaborg formula [12] to predict its half-life accurately. So, for the sake of making predictions, we resort to already existing experimental data as a basis.

The expected alpha energies of the radioactive decay chain of Thorium-232 are obtained from ENSDF website [13]. These are compiled in Table.1 and labelled from A-G. An alpha-energy is considered only if it has an intensity of atleast 1% or above.

Now, looking specifically at ^{212}Bi, we observe that it has an α-branch with 35.94% and a β-branch with 64.06%. Interestingly, this is the only nuclei among all those appearing in the four naturally occuring radioactive series to be having such a significant branching ratio. Its α-decay proceeds majorly to two closely lying levels in the daughter nucleus ^{208}Tl, with 69.91% and 27.12% towards 6050.78 keV and 6098.88 keV α-energies respectively. If the spectrometer has resolution poorer than 50 keV, it would not be possible to resolve these two peaks and one would obtain a single peak

at the weighted average of the two given by 6061.71keV. 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. In fact, once again, this is the minimum half-life and the maximum energy for any nuclei appearing in all the naturally occuring radioactive series.
The expected half-life for ^{212}Bi taken from Nuclear Wallet Cards [14] is 60.55 ± 0.30 mins. This could be verified from either of the two branches of ^{212}Bi, as the daughter from its β-decay has negligible half-life.
Finally, students should be made aware of safety issues to be followed while handling the radioactive source. Even though it is a non-enriched source, one should not touch the powder with bare hands, and must take care to never ingest any.

2.2 Modeling of Physical System

'AlphaSpec-1K' alpha spectrometer setup (shown in Figure 1) contains the physical system (source-detector housing assembly along with vacuum pump) and the measurement apparatus (detector electronics hardware along with data acquisition via the USB port of a computer, and its associated software 'CNSpec'.
The physical system in the context is the interacting medium. This leads to another learning goal from the lab point of view. That is, students should gain appreciation with regards to the interacting medium by considering the following points:

1. The detector which is also sensitive to light photons needs to be housed inside a chamber, so that only alphas register their energy inside its active volume.

2. Since alpha particles lose energy due to scattering as they pass through air , we need the source also to be placed in an air tight chamber so that vacuum can be created.

Keeping these points in view, the physical system is designed (see Figure-1) to have an air-tight stainless steel chamber(1) for housing the source and detector. The inner dimensions of the chamber allow for variation of source-detector distance upto 25 mm.
In order to create the required vacuum, a 1/5 BHP rotary vane pump (2) in Figure-1, fitted with a pressure gauge (3) and two valves (A and B) are utilised. While closing the vent valve (A) cuts off the atmosphere from the chamber, the series valve (B) connects the vacuum pump to the chamber to evcuate it down to 1 mbar.

2.3 Modeling of Measurement Apparatus

The next important learning goal is to model the measurement process so that it does not merely remain a black box for the students, and that instead they understand the principles of operation, key model parameters, and limitations on the ideal functioning of the apparatus [4]. The detailed modeling

Table 1: The radioactive decay chain of ^{232}Th with alpha energies and their respective intensities are complied from ENSDF [13] and labelled from A to G. Only those alphas which have more than 1% intensity are considered. Beta emissions are also shown, but only for the sake of clarity and completeness.

Radioactive Decay Chain of Thorium-232					
Parent Nuclei	**Decay Mode**	**Half Life (a=year)**	**Energy Released (keV)**	**Intensity of α-decay branch(%)**	**Daughter Nuclei**
^{232}Th	**α**	1.405×10^{10} a	**3974.2 (A1)** **4012.3 (A2)**	21.7 78.2	^{228}Ra
^{228}Ra	β^-	5.75 a	-	-	^{228}Ac
^{228}Ac	β^-	6.25 h	-	-	^{228}Th
^{228}Th	**α**	1.9116 a	**5340.36 (B1)** **5423.15 (B2)**	26 73.4	^{224}Ra
^{224}Ra	**α**	3.6319 d	**5448.6 (C1)** **5685.37 (C2)**	5.06 94.92	^{220}Rn
^{220}Rn	**α**	55.6 s	**6288.08 (D)**	99.886	^{216}Po
^{216}Po	**α**	0.145 s	**6778.3 (E)**	99.99	^{212}Pb
^{212}Pb	β^-	10.64 h	-	-	^{212}Bi
^{212}Bi	β^- 64.06% **α 35.94%**	60.55 min	- **6050.78 (F1)** **6089.88 (F2)**	- 69.91 27.12	^{212}Po ^{208}Tl
^{212}Po	**α**	299 ns	**8784.86 (G)**	100	^{208}Pb

of the apparatus is discussed in a seprate paper by us [15] (to be submitted) to keep this paper from becoming lengthy and also to retain focus on experimentation. Here, we only give a very brief description of the hardware and software specifications.

The Silicon PN junction detector is reverse biased with 9 Volts, and electronic circuits of Pre-amplifier, Shaping amplifier, Peak detector and ADC followed by 1K MCA are integrated at the top part(Figure 1:1(T)) of the chamber to avoid signal losses. The output of the 1K MCA is acquired via USB and is displayed by **'CNSpec'** software provided freely along with the spectrometer.

Hardware Specifications: The design of the electronics is such that the detection system is capable of measuring alpha energies upto 10 MeV with a resolution of 80 KeV for 5.485 MeV energy. The various stages of signal processing electronics are shown as an inset in Figure 1.

At the lower end of the spectrum, spurious events are recorded due to the noise fluctuations in the absence of a signal. In order to reject this, the first 100 channels are not considered while acquiring spectra. **Software Features:** The instrument is factory calibrated using ^{241}Am which is a monoenergetic alpha source. For our instrument, the peak energy of 5485 keV was recorded to be at a centroid value of 495.6 channel. Using this, we can apply a single point calibration. For e.g., the threshold energy corresponding to channel no. 100 using this calibration would be around 800 keV.

The following analytical features are included in the software :

- Curve fitting against standard gaussian function for obtaining the centroid of the peaks. This includes an optional low-energy tail which follows a Lorentzian distribution.
- Summation of counts in a chosen interval to estimate total events from a source which may be spread across a range of adjacent channels due to various reasons such as scattering, noise etc.
- Multi-point calibration with several known peak values.

3 Experimental Design

The design aspect involves varying a particular input parameter, while controlling the rest of the parameters to study the impact on the output obtained. The various aspects involved in the design of the experiment being performed will be based on our understanding of the interactions present. Since, the detection system is already fine tuned by the manufacturer to obtain well resolved spectra, we need to focus only on understanding the source characteristics and interaction of emitted alphas with the environment before reaching the detector.

Typically the radioactive sources that are bought from manufacturer or those obtained from any agencies such as DAE or BARC, would be packaged in the form of a disc of small size smeared with a small

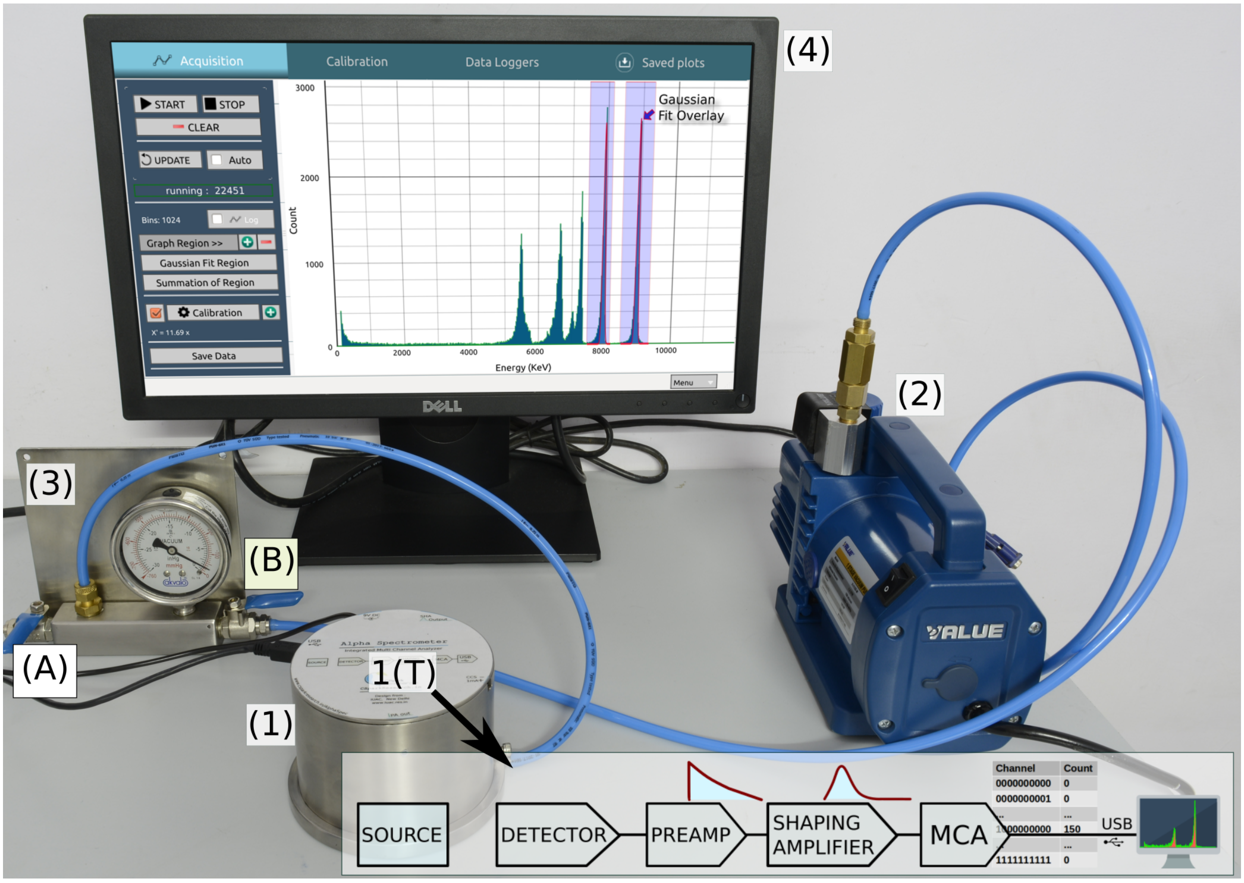

Figure 1: Complete experimental setup for Alpha Spectrometer Alpha-Spec 1K. (1) Chamber for housing source and detector; (1(T)) Detector electronics; Inset shows flow diagram with various stages of signal processing; (2) Rotary Vane pump for creating vacuum; (3) Two way valve with pressure gauge; vent valve (A) to cut of the atmosphere into the chamber and series valve (B) to connect the the vacuum pump to the chamber to create vacuum (4) Typical spectrum obtained in PC using CN-Spec software.

quantity of the isotope. Here, we are using non-enriched $Th(NO_3)$ powder obtained from chemical suppliers.

To begin with, let us choose the simplest setup with the chamber kept at atmospheric pressure. That is, the vacuum pump is switched off, and the vent valve is open.

3.1 Spectra of $Th(NO_3)$ 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

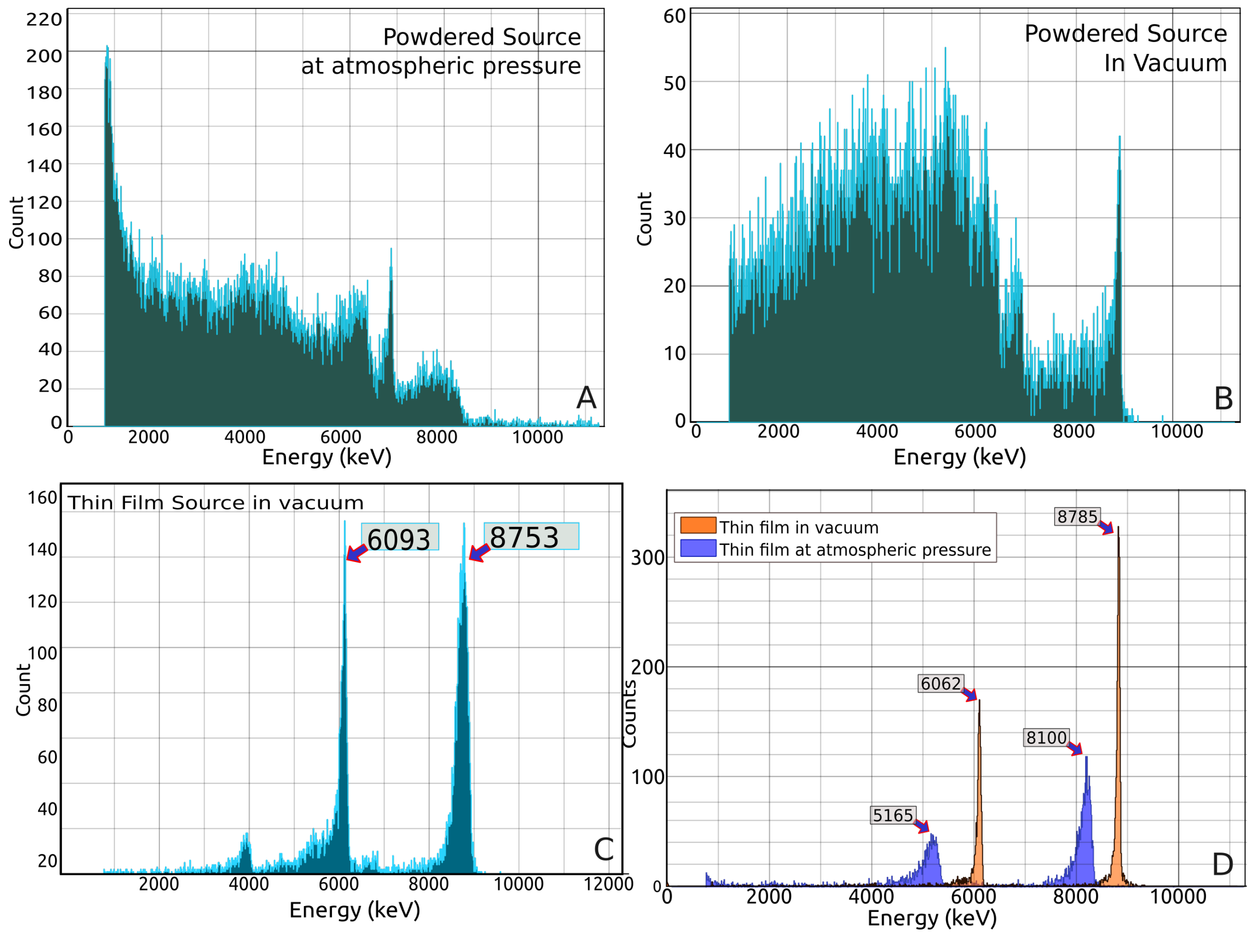

Figure 2: Radioactive sources under various attenuating factors; a) Alpha spectrum of Thorium nitrate salt; b) The same salt studied under vacuum; c) Thin film of ^{212}Bi under vacuum; d) Comparison of ^{212}Bi spectrum in 1 mbar vacuum and under attenuation due to 1 Bar atmospheric pressure.

the obtained spectrum is calibrated using manufacturer's data and is shown in Figure2(a). The energy spectrum does not show well resolved peaks as expected from ^{232}Th given in Table-1, 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.

3.2 Spectra of $Th(NO_3)$ obtained at 1 mbar Vacuum:

Again, 2gm of Thorium Nitrate powder is placed inside the chamber at a distance of 2cm from the detector. Following the instruction of the manufacturer, 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 Figure2(b). 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 is still an enigma. 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. 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. 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.

3.3 Spectra of ^{212}Bi Source with 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 such as

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

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 has been taken up in a systematic fashion and the experiments lasted for almost a year. Here, we only present and analyse the results for the spectrum obtained by selective deposition of ^{212}Bi. In the initial trail for obtaining the thin film source, we have dissolved approximately 3 gm of $Th(NO_3).5H_2O$ 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 Figure2(c). Here we have used the single point calibration using the data provided by the manufacturer for Am-241 source (5485 keV energy corresponding to channel number 495.6). We find that there are two peaks, at 6093 keV and 8754 keV respectively. 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 Am-241 peak which was around 80 keV tells us that we must not expect to observe peaks with lesser spacing than this to be resolved.

3.4 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 $Th(NO_3).5H_2O$ 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.

The orange colored histogram in Figure2(d) 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 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.

4 Results, Analysis and Discussion

To build the skills of argumentation, one of the important learning goals in lab work, we need to quantify the results in a representation that allows for comparison with the expected outcomes. In our experiment, firstly, we require to determine the energies of the various peaks obtained in the spectrum along with an uncertainty range so as to be able to compare with the expected values in Table-1.

4.1 Determination of Energies in the Spectrum:

The centroids of these peaks are determined by manually estimating the channel spread based on a Poisson distribution [16].
First, the channel/energy that consists of the highest number of counts, say N, is considered. Then, the standard deviation σ is given by $\sqrt{N}$. All neighbouring channels whose heights lie within $N \pm 2 * \sigma$ are considered to belong to that peak. Their mean gives the centroid 'E' of the peak. The number of counts in the peak corresponding to 'E' is taken as the maximum and then Full Width at Half Maximum (FWHM) 'ΔE' is determined. The resolution of the peak is given by 'ΔE'/E.
Now, consider the peak corresponding to that of Bi. The energy bin 6093 keV has the maximum no. of counts given by 156. Therefore, $\sigma = \sqrt{156}$ which is approximately 12.5 and so, 2σ is 25. Now, all the energy channels consisting of upto 131 counts in the vicinity of 6093 are determined to be varying from 6082 keV to 6104 keV. The energy channel to the left of 6082 keV is 6071 keV and to the right of 6104 keV is 6115 keV. Hence, the centroid is determined as the average of 6071 and 6115, which is 6093 keV. The energies at which the no of counts drops to 78(half the peak values of 156) is 6015 keV on the left and 6148 on the right, whose difference is the FWHM with a value of 133 keV. The resolution for this peak is given by (133keV/6093keV)*100 = 2.1%. Performing a similar analysis for the ^{212}Po peak, we obtain the centroid as 8753 keV and FWHM of 254 keV, with a percentage resolution of 2.9%. The energies of Bi and Po along with the FWHM and % Resolution are tabulated in Table-2. These values are in agreement with the known energies which are 6061.71 kev and 8785 keV respectively, with corresponding relative percentage errors of 0.51% and 0.35%.

4.2 Determination of Intensities of the Peaks:

The intensity of a peak is determined by taking the total number of counts that have contributed to the peak as they are all supposed to be from the same alpha energy emitted by the source. To obtain the total number of counts, we need to choose an interval of energy channels that belong to the peak. This is done by taking twice the stan-

Table 2: The energies, FWHM, Resolution, Intensity and Branching ratio for the two peaks in inset of Figure 4 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)

dard deviation(σ) value which corresponds to 90% of the area under the distribution. For the Bi peak, the energy interval is chosen as [5960,6226] and the summation feature gives us 1811 counts under the peak. Similarly, for the Po peak, we obtain the intensity within an interval of[8504,9012] as 3640 as shown in Figure2. A 3σ spread would have included 99% of the area, however we have only taken 2σ because of the close proximity of other peaks from the thorium spectrum to the peak of ^{212}Bi decaying to ^{212}Tl which will affect the half life estimate if included.

4.3 Determination of Half-life:

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 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. Experimentally, the half life is determined by measuring the activity of the source [17], which is defined as the number of decays per unit time, and is expressed mathematically as,

$$A(t) = \frac{dN_d(t)}{dt} \tag{1}$$

where

$$N_d(t) = N(0) - N(t) \tag{2}$$

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

$$N(t) = N(0)e^{-\lambda t} \tag{3}$$

where λ is the decay constant.
Hence activity can be further expressed as;

$$\begin{aligned} A(t) = \frac{dN_d(t)}{dt} &= -\frac{dN(t)}{dt} = \lambda N(t) \\ &= [\lambda N(0)]e^{-\lambda t} = A(0)e^{-\lambda t} \end{aligned} \tag{4}$$

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 time, whose alphas have been registered by the detector at a

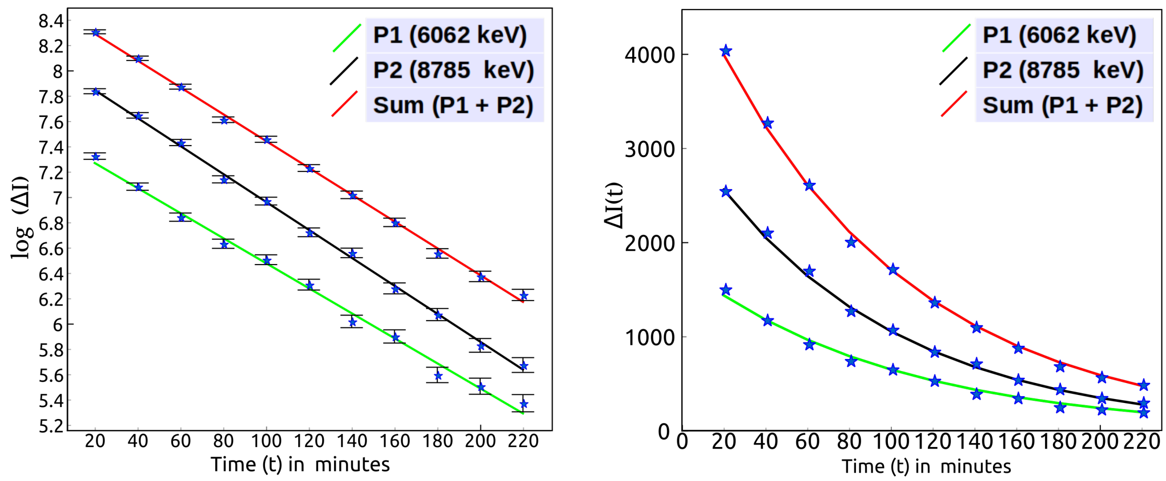

Figure 3: a) Log plots for counts per unit time obtained for both ^{212}Bi peaks as well as their sum in twenty minute intervals. b) Half life calculations for ^{212}Bi spectrum peaks at 6062 keV and 8785 keV using least square fit with a standard exponential decay function.

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 choosen 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

$$\Delta I(t) = [\Delta t A(0)]e^{-\lambda t} = I(0)e^{-\lambda t} \tag{5}$$

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 3(a).

The decay constants given by the slopes of the respective lines are shown in Table 3. 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 $\beta-$ branches [7]. 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.

4.4 Uncertainty in Half-life

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

$$\sqrt{\frac{\frac{1}{n-2}\Sigma_{i=1}^{n}(y_i - \hat{y}_i)^2}{\Sigma_{i=1}^{n}(x_i - \bar{x})^2}} \tag{6}$$

The obtained standard deviation for three regression data are tabulated in Table 3. The half-life and its uncertainty for each of the data is determined and presented in Table 3. The best value for half-life is found

Table 3: 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

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.

4.5 Low Intensity Peaks in the Spectrum:

To observe the alphas being accumulated from other nuclei in the radiactive series of ^{232}Th, we magnify the counts axis by a factor of 35. The peaks corresponding to those expected from Table 1, are identified with respective letters in brackets, and their energies (determined using Poisson distribution) are indicated in Figure 4. The obtained energy values match with the predicted ones closely.

5 Conclusions

We have used a non-enriched radioactive source $Th(NO)_3$ salt in powder form to prepare a thin film source of ^{212}Bi using electrolysis.

The α spectrum obtained by placing the source inside the airtight chamber at 1mBar vacuum for a period of four hours, has two peaks at 6093 keV and 8753 keV with resolution of 2.1% and 2.9% respectively. They match the expected values for ^{212}Bi and ^{212}Po to an accuracy better than 1% . The half-life of ^{212}Bi is obtained by determining the activity over 20 minute intervals, and the best value obtained from the distinct 8753 keV peak is found to be 62.77 $\pm$ 0.79 minutes, which matches the expected value of 60.55 $\pm$ 0.30 minutes to an accuracy of 3.5%.

The other possibilities such as alpha-spectrum analysis by preparing different thin film sources and study of linear absorption co-efficients of different materials

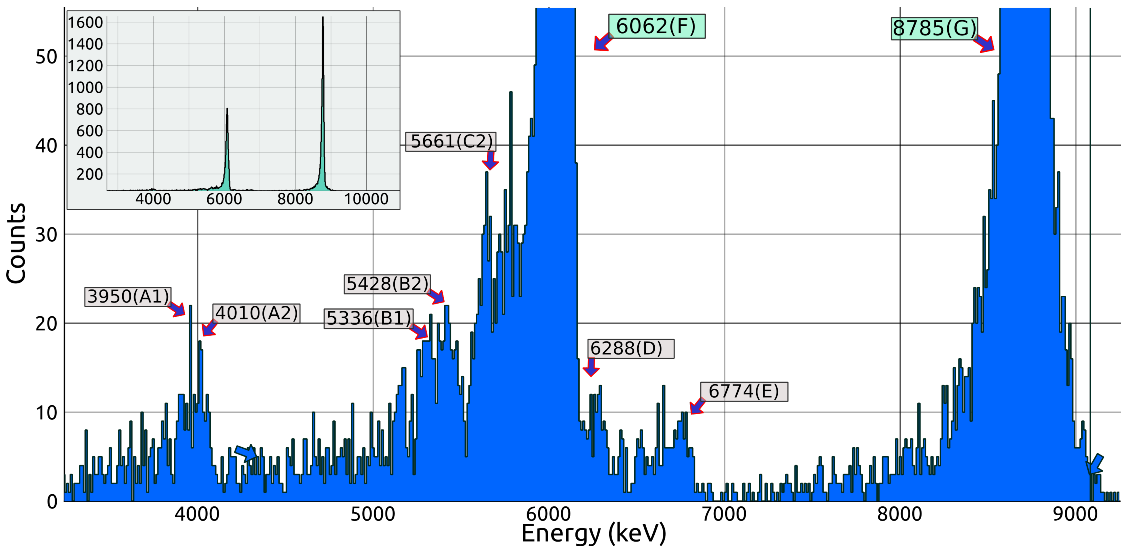

Figure 4: Spectrum obtained over a period of 4 hours from a thin film of ^{232}Th under 1mbar pressure showing prominent peaks for ^{212}Bi, as well as trace amounts of other isotopes. The spectrum has been expanded along the Y axis to exaggerate the small peaks formed by these trace isotopes. The complete spectrum is shown as an inset.

such as aluminium makes for exciting set of experiments for both UG and PG nuclear physics lab.

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