

γ -ray Absorbption

Jeffrey Sharkey, Spring 2006
Phys. 2033: Quantum Lab

1 Purpose

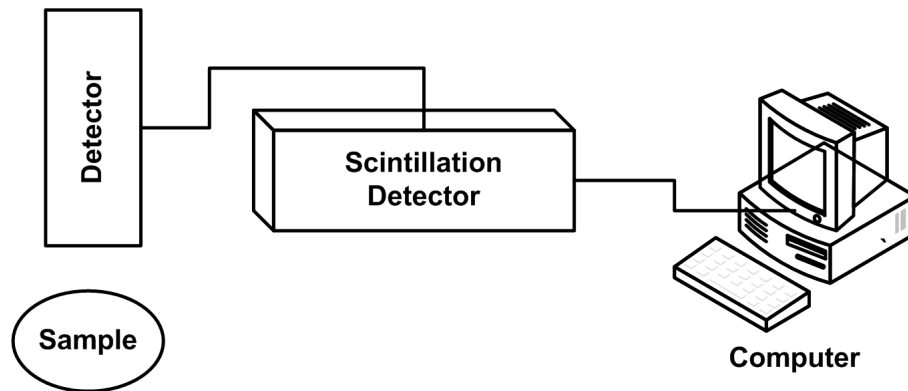
To observe and measure the absorbption coefficient of lead.

2 Methodology

We calibrated the equipment by finding a slope and intercept as shown below. Then we made nine sets of measurements of a ^{22}Na source, each with varying thicknesses of lead over the sample.

2.1 Equipment Used

We used a scintillation detector connected to a computer. The system detected γ rays, and sorted them into various bins based on energy.



The detector controlled by an applied voltage of $900V$ and a gain of roughly 23.

2.2 Physics Demonstrated

Similar to the Geiger-Müller detector lab, as released γ rays pass through the detector chamber, they trigger a cascade that causes a voltage short across the chamber. These shorts are then sorted into bins based on voltage and sent to the computer for counting. Also, the computer software in this lab compensated for any dead time.

We also know that the decay of γ rays follows the equation below, where μ is the decay constant of the material and x is the thickness of that material.

$$I(x) = I_0 e^{-\mu x} \quad (1)$$

3 Collected Data

Below we list all data collected as we progressed through the lab.

Source	Max Bin (n)	Count (n)	Known eV
^{137}Cs	40	61567	31
	665	21598	662
^{22}Na	528	3137	511
	1228	319	1275
Unknown	670	2995	
	41	8736	
^{60}Co	1139	467	
	1282	345	

Table 1: For four samples, the bins of two maximums found after collecting for 5 minutes. For the first two samples we list the expected (known) KeV of those two maximums.

Depth (cm)	I_1 (n)	I_2 (n)
0	442	49
0.3175	257	41
0.635	161	35
0.9525	111	28
1.27	73	25
1.5875	46	21
1.905	32	18
2.2225	19	13
2.54	20	15

Table 2: For a sample of ^{22}Na , the I values for the two maximums found when the depth of lead is placed between sample and detector.

4 Analysis and Results

4.1 Energy Calibration

Because the detector only has 2048 bins to store count data, we use the gain control to select the energy spectrum recorded into these bins. By measuring the maximum bins for two samples where the energy is known, we can use linear regression to find an equation that describes the relationship between bins and actual energy for a given gain value.

The maximum measurable energy of this calibrated system would be 1.9KeV as shown above. To measure larger energy levels we would need to adjust the gain control.

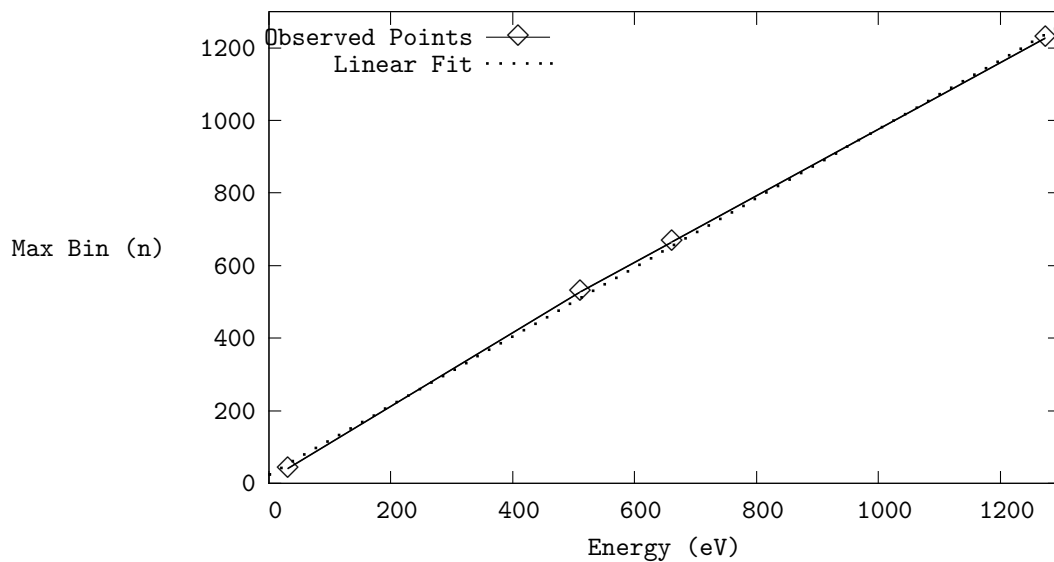


Figure 1: Linear regression plot of the four known energies.

Using the four known values, we found the following relationship, where E is energy and n is the maximum bin.

$$E = 0.952n + 25.2 \quad (2)$$

$$E_{max} = 0.952(2048) + 25.2 = 1974.896\text{eV} \quad (3)$$

When looking at the unknown source and the ^{60}Co source, we can estimate the E values of their two maximums using the equation above to be:

Source	Max Bin (n)	Calculated eV
Unknown	670	663.04
	41	64.232
^{60}Co	1139	1109.528
	1282	1245.664

Table 3: Estimated values of E for the measured maximum bins.

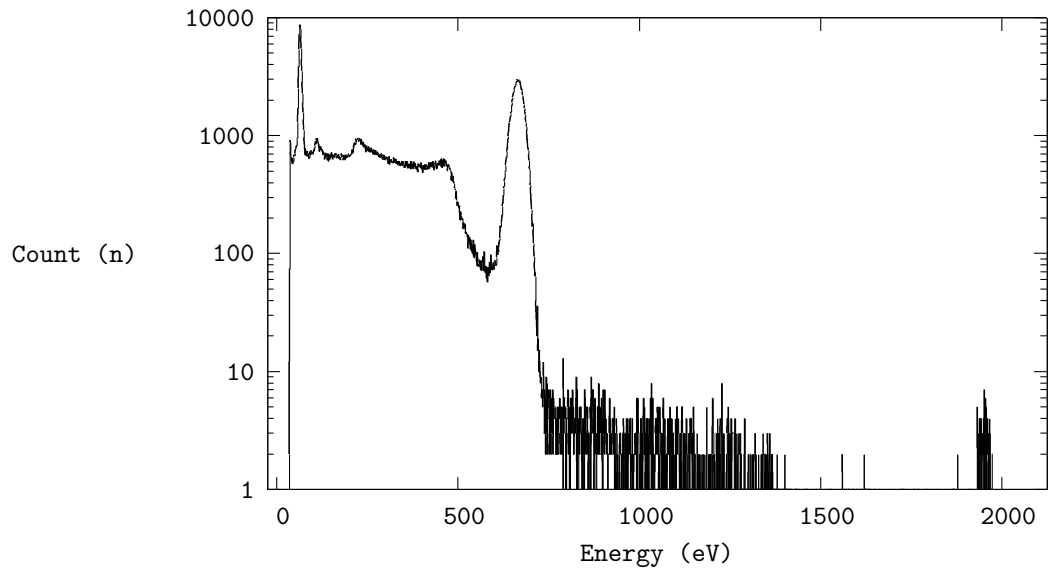


Figure 2: Plot of counts for unknown sample with bin numbers translated into eV space.

4.2 Absorbtion by Lead

We measured the spectrum of a single sample of ^{22}Na while changing the thickness of lead between it and the detector. Below we plot the counts on a logarithmic axis against the thickness.

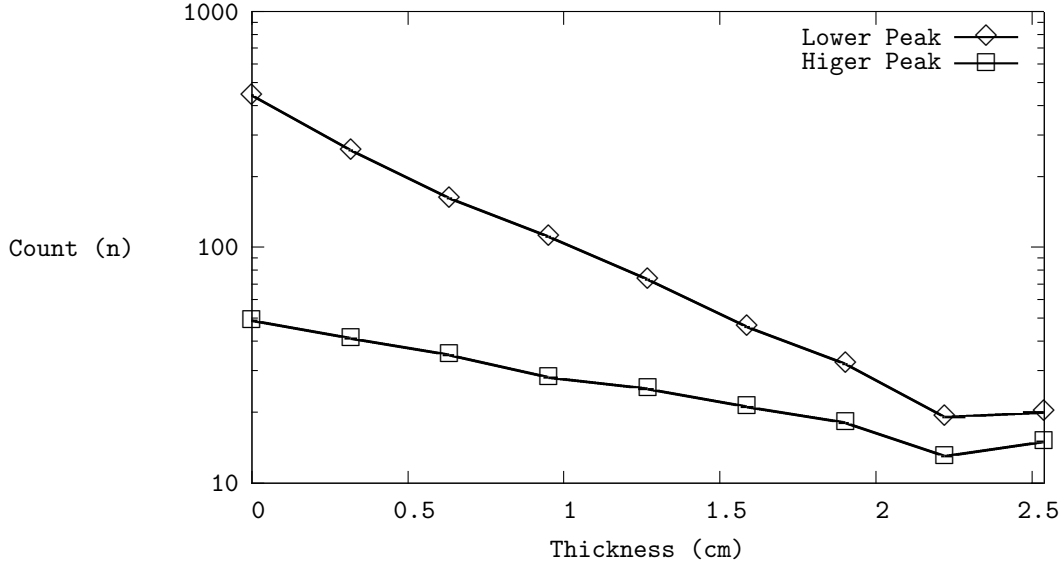


Figure 3: Maximum count of the two highest peaks (log y -axis) plotted against varying thicknesses of lead.

When thinking about the decay relationship below, we know that the plot above would show a straight line because of the logarithmic axis. However, the two lines would have the same slope if μ were the same. Thus, we conclude that the equation is valid, but that μ must be different for varying energies E .

$$I = I_0 e^{-\mu x} \quad (4)$$

$$\mu = \frac{\ln \frac{I_0}{I}}{x} \quad (5)$$

By rearranging the above equation, we find a value is defined for μ for every depth we measured. Below we list the newly calculated values of μ for both of the maximums we examined above.

Depth (<i>cm</i>)	Count (n_1)	Calculated μ_1	Count (n_2)	Calculated μ_2
0	442		49	
0.3175	257	1.708	41	0.561
0.635	161	1.590	35	0.530
0.9525	111	1.451	28	0.588
1.27	73	1.418	25	0.530
1.5875	46	1.425	21	0.534
1.905	32	1.378	18	0.526
2.2225	19	1.416	13	0.597
2.54	20	1.219	15	0.466
Average		1.451		0.541

Figure 4: Calculated values for μ for each measurement of different depth of lead.

We can also think about the half-height, or the thickness required to reduce the exposure by a factor of 2. For the average values of μ above, the half-thickness is given by the equation below.

$$x_{1/2} = x_0 \ln 2 = \frac{1}{\mu} \ln 2 \quad (6)$$

For μ_1 , we need 0.477cm of lead, and for μ_2 we need 1.281cm of lead. There is a significant difference between the estimated μ values. We can attribute this to the energy at the two maximums $\Delta E = 1275\text{eV} - 511\text{eV} = 764\text{eV}$. Fewer photon events occur at the higher energy level, giving us a μ_2 value much lower than expected.

5 Error Analysis

All of the measurements in this lab were conducted by electronic equipment, and very little human involvement was required. In our first lab, we manually compensated for the deadtime of the detector. However, in this lab the computer automatically compensated for deadtime during its readings.

However, a slight error was involved in measuring decay because the slices of lead were not of an exact thickness. We only roughly measured each slice, and used assumed values in our calculations above.

Finally, looking at the expected value $\mu = 1.2$, our values were $\mu_1 = 1.451$ (which is about 20.9% error) and $\mu_2 = 0.541$ (which is about 54.9% error). We discussed above how the large error in the second was introduced by the higher energy level. In addition, the initial I_0 counts for the second maximum were low, and any decayed counts would have been polluted by background radiation.

6 Conclusion

Using two samples, we found an excellent equation to describe the bin-to-energy conversion for the single gain used throughout our measurements:

$$E = 0.952n + 25.2 \tag{7}$$

We then observed the decay introduced by various thicknesses of lead. We confirmed that both maximums in the ^{22}Na spectrum followed a decay given by the equation:

$$I = I_0e^{-\mu x} \tag{8}$$

Where we then calculated $\mu_1 = 1.451$ for the first maximum and $\mu_2 = 0.541$ for the second maximum. The expected value was $\mu = 1.2$, giving our first reading only a 20.9% error. However, μ_2 is significantly different than expected. This is due to the difference in energy levels between the two maximums observed ($\Delta E = 1275eV - 511eV = 764eV$). The photons being counted behave much differently at those varying energy levels.