School of Physics

PHYC20020: Introductory Quantum Mechanics

Experiment 1: Gamma Ray Absorption and Counting Statistics

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1. Abstract

The aim of this experiment was to investigate the interactions between gamma rays and matter, more specifically, lead. Using a photomultiplier and a scintillation counter, gamma rays are detected by the scintillations produced when the phosphorous material is struck by ionising radiation or gamma rays. The photomultiplier detects these scintillations by producing an electric pulse when it detects a flash. During this experiment a number of important interactions are seen between the matter and gamma rays, such as Compton Scattering, the photoelectric effect and pair production. The result recorded in this experiment for the linear absorption coefficient of lead, μ, was $1.118 \pm .0732\ cm^{-1}$. This value was divided by the density of lead, ρ, to yield $.0985 \pm .00645\ cm^2/g$ .These values contain errors, however the true value of both , μ, and μ/ρ, are within the intervals calculated. The uncertainties from the experiment were caused by a lack of number of measurements, along with uneven thickness of the lead plates and systematic errors. The next part of the experiment investigated the number of events of gamma rays observed over a fixed time interval. This data was analysed and compared to a normal distribution.

2. Theory

2.1 Gamma Ray Interactions

In this experiment the scintillations seen come from the interaction between a phosphor and ionising radiation such as a gamma ray. The production of this light causes the particle to lose its energy, so the production of a flash is directly proportional to the loss of energy of a particle [1]. The mechanisms of interaction seen in the experiment such as the photelectric effect, pair production and absorption are combined to cause a loss of intensity, a dispersion in energy and a deflection of certain gamma rays [2]. This corresponds to a loss of energy as mentioned above.

The photoelectric effect can be described as photons in a gamma ray incident to the material (i.e. lead), if high enough in energy cause electrons to leave and thus reducing the intensity, due to annihilation [2]. It is also not possible for a gamma ray to interact with a free electron by means of the photoelectric effect. The law of conservation of energy disputes this interaction as a gamma ray can interact with an electron-positron pair only. This is implied by the conservation of energy as a single gamma ray is not equal to the mass of an electron and so the free electron and gamma ray can't interact alone. The annihilation mentioned above corresponds to a photopeak in an energy level diagram, as seen below,

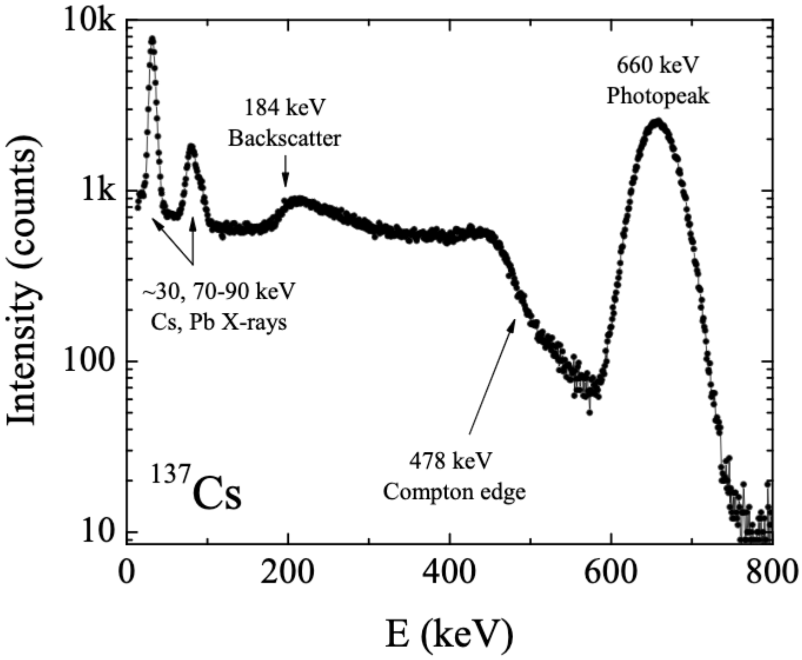

Figure 2.1 Gamma Ray Spectrum for ^{137}Cs [2]

Similarly the Compton Scattering Effect contributes to a loss in intensity, due to an interaction between an electron and an incident photon. The electron is struck by the photon resulting the electron gaining energy in the form of kinetic, and so the photon loses a part of its energy [3]. The incident photon is deflected in a new direction [2]. This corresponds to the formula for Compton Scattering shown below,

$$\lambda_f - \lambda_i = \Delta\lambda = \frac{h}{m_0 c}(1 - \cos\theta) \qquad \text{(Eq. 2.1)[4]}$$

Pair production is another phenomena that occurs during this experiment. When a positron and an electron collide they annihilate each other and produce photons. By the law of conservation of energy, the energy of the two particles combined, is equal to the energy of a photon produced [2]. This process can similarly happen in reverse where a photon can annihilate to produce a positron and an electron. This process is called pair production and similarly like the past gamma ray interactions mentioned, it reduces the intensity of the gamma ray [1]. There is no evidence of pair production in the gamma ray spectrum produced (Fig 2.1) as the energy from our radiation source is too weak. In order for pair production to occur approximately 1.022MeV is needed however our gamma rays from our radiation source produce about 662KeV [1].
These interactions can be seen in the diagram below which describers the key mechanisms of gamma ray interactions,

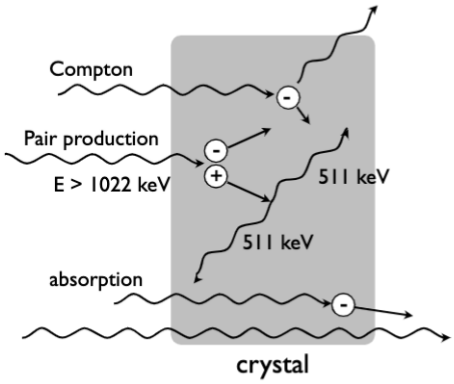

Figure 2.2 Key Interactions Between Gamma Rays and Matter [2]

2.2 Gamma Ray Absorption

Gamma ray absorption is a key interaction in this experiment as by understanding this interaction, the linear absorption coefficient can be calculated. The equation below relates intensity, the path length travelled in the material and the linear absorption coefficient.

$$I = I_0 e^{-\mu x} \qquad \text{(Eq. 2.2)[1]}$$

Where I is the intensity of the beam, I_0 is the original beam intensity, x is the path length travelled in the material and μ the linear absorption coefficient. In order to calculate μ, we take the natural log of both sides and re-arrange to get,

$$\ln(I) = -\mu x + ln(I_0) \qquad \text{(Eq. 2.3)}$$

Which can be compared to,

$$y = mx + c \qquad \text{(Eq. 2.4)}$$

2.3 Gamma Ray Detection Apparatus

For our gamma ray apparatus a radioactive source of ^{137}Cs with a half-life of 30 years which is seen from our energy diagram in Fig. 2.1 [1]. The unstable nuclei isotope lose energy through a variety of emissions which includes incident mono-energetic gamma rays that are of energy 662keV [2]. For the detection of the scintillations, one of the phosphors used was a cylindrical crystal of thallium activated sodium iodide. The gamma rays strongly interact with the material along with having a high gamma ray sensitivity, because of the density of this medium along with the high atomic number [1]. This detector is enclosed in order to have no particles of light interfere with the apparatus during the experiment. This allows the photomultiplier to detect only the scintillations. The photomultiplier is purposefully covered in lead in order to stop background radiation from interfering from the results recorded.

The photomultiplier is a part of the apparatus that converts a photon absorption into an electron. The photomultiplier is exposed to a photon flux from the gamma rays through the photo cathode [5]. From there the electrons are released and are multiplied by the electrodes called the dynodes as seen in Figure 2.3. Once all the electrons have travelled through the tube they meet the anode at the end, where they are collected. The anode converts the electrons into an electronic pulse [5]. This electronic pulse is sent to a computer where it is converted into the data we see. The amplified photomultiplier pulses are digitised and using an analogy to digitally convert the digital pulses into height stored in the computer [1].

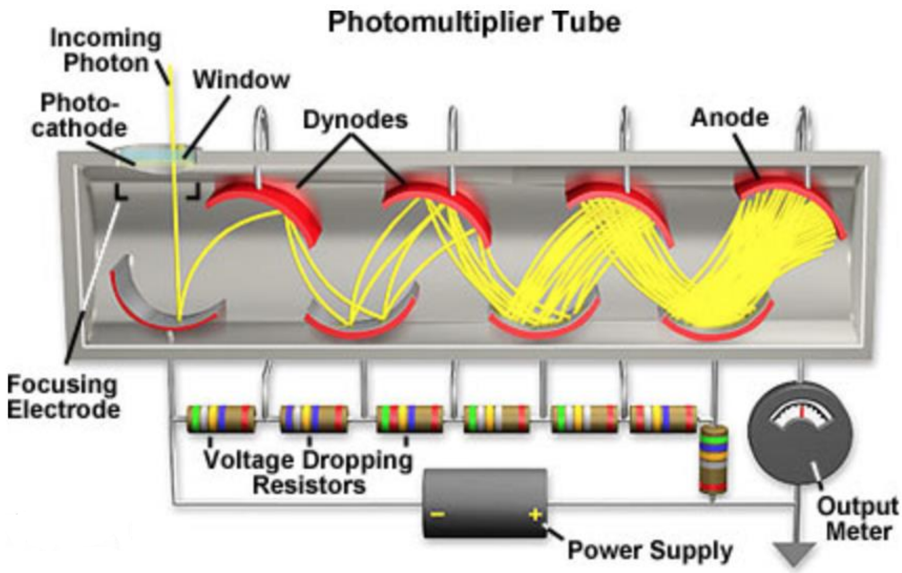

Figure 2.3 Photomultiplier Apparatus [5]

3. Apparatus

3.1 Apparatus Set-up

The apparatus used in this experiment includes a photomultiplier, a radioactive source, a micrometre and a computer. Below the apparatus of the photomultiplier along with the computer is shown below,

Figure 3.1 Apparatus Set-up

The next Figure (Fig. 3.2) shows the micrometre along with the lead plates which were used in the experiment.

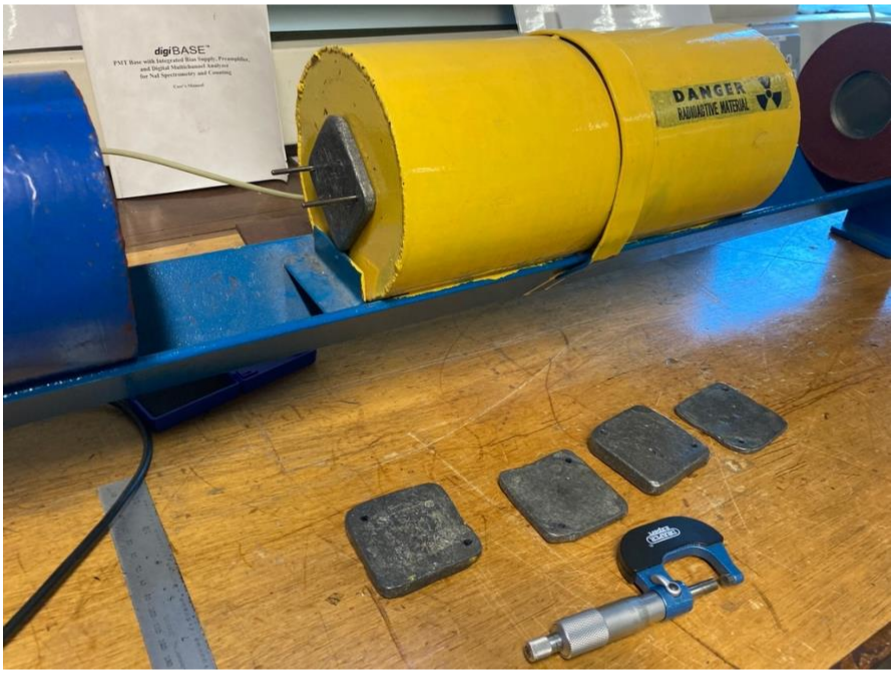

Figure 3.2 Apparatus Set-up of Micrometre and Lead Plates

4. Methodology

4.1 Initial Set-up

First taking any objects, such as lead or iron absorbers between the radiation source in the apparatus. Next setting up the computer program on windows called Maestro [1]. Clicking on 'Acquire', then 'MCB Properties, and the 'High Voltage Tab'. The high voltage tab should be turned on now. The time (integration time) should be set to 30 seconds by clicking 'MCB Properties', then the 'Presets' tab, in order to set the required time [1]. Since the count is configured to be placed in any one of the 1024 channels according to the pulse heights. The smallest pulse E is pre-set an then the width of each channel is about 1KeV. The width of every channel fixes the ΔE within which the pulse must fall in between. The photopeak should occur in between channels 500 and 700 [1]. The next step on the program is marking your peak which as mentioned before should occur within a specific range. Marking the peak by clicking ROI and clicking 'MARK'. After this pressing 'Clear' and 'Run', again in order to run the software and double clicking on the highlighted region in order to get the number of counts and the error associated with it [1].

4.2 Procedure

The first part of the experiment requires the measuring of the thickness of 5 different lead plates and recording the results. Then taking each plate and recording the count rate between the two markers placed and recording the results. Next plotting the natural log of the counts as a function of the absorber thickness, taking into account the error bars of the graph. Comparing eq. 2.3 and eq. 2.4 in order to deduct that m, the slope is equal to $-\mu$. This can be used in order to calculate the linear absorption coefficient. Next computing μ/ρ by diving by ρ, the density of lead which we acquire from Figure 4.1 below,

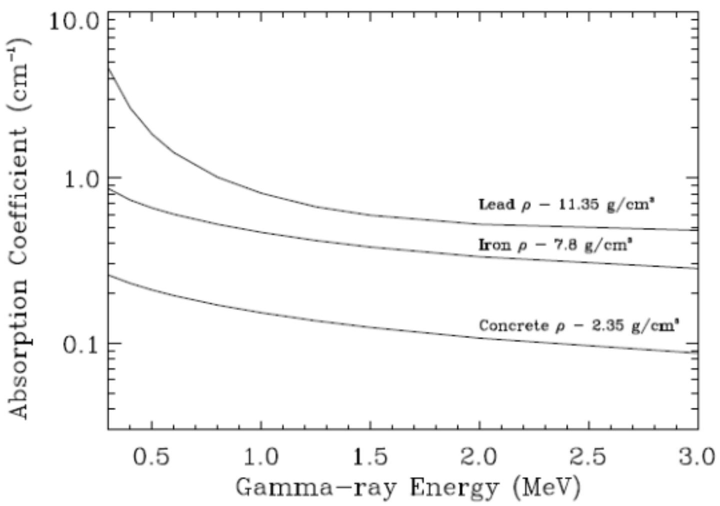

Figure 4.1 Absorption coefficients and density of absorbers [1]

The experimental result can be compared with the theoretical result obtained above from Fig. 4.1. This can be done by taking the energy of our gamma rays (662keV) which is also 0.662MeV and drawing a straight line from the x-axis up to the line for the lead absorber. Next after meeting the line drawing a horizontal straight line to achieve a theoretical.
The next part of the experiment requires finding a suitable combination of lead absorbers until a count rate of approximately 1000 for a period of 30 seconds is achieved in the highlighted region. Running this computer program 50 – 75 times and recording the values [1]. Next calculating the mean of the counts, and the standard deviation. Taking each value, taking the mean away, dividing by the standard deviation and rounding off the values to the second decimal point in order to plot them on a histogram. On the same plot, plotting a normal curve in order to compare the data [1].

5. Results

5.1 Linear Absorption Coefficient of Lead

Table 5.1 Table of Count Rate Values with Lead Plate Thickness

Thickness of Lead (mm)	**Count**	**Count Error**
2.66	2921	90
6.765	1665	91
8.73	1462	54
12.94	905	56
7.14	1622	67

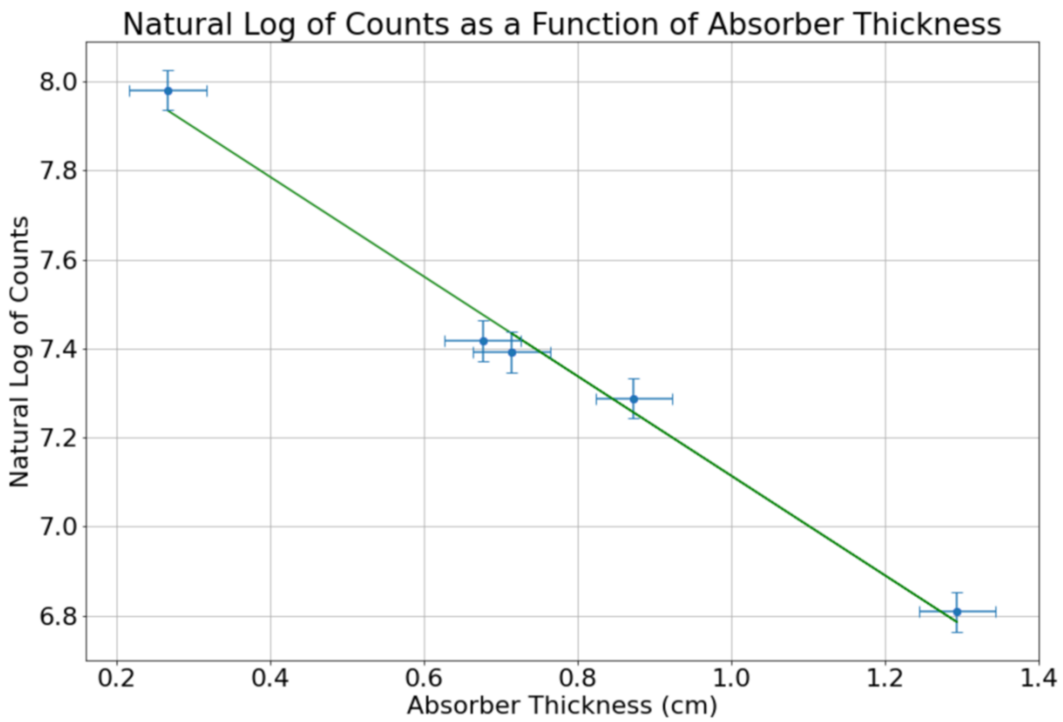

Figure 5.1 Graph of the Relationship Between Natural log of Counts and Absorber Thickness

The linear absorption coefficient, μ, was yielded to be $1.118 \pm .0732\ cm^{-1}$ from Eq. 2.3, and the density of lead was found to be 11.35 g/cm^3 $\pm$ .05 g/cm^3 from Fig. 4.1. μ/ρ was measured to be .0985 $\pm$ .00645 cm^2/g. The error for μ/ρ was calculated as follows [6],

$$\Delta\,(\boldsymbol{\mu}/\,\boldsymbol{\rho})^{\,2} = \left(\frac{\partial(\mu/\,\rho)}{\partial\mu}\right)^2 (\Delta\boldsymbol{\mu})^2 + \left(\frac{\partial(\mu/\,\rho)}{\partial\rho}\right)^2 (\Delta\boldsymbol{\rho})^2$$

$$\Delta(\boldsymbol{\mu}/\,\boldsymbol{\rho}) = \sqrt{\left(\frac{\partial(\mu/\,\rho)}{\partial\mu}\right)^2 (\Delta\boldsymbol{\mu})^2 + \left(\frac{\partial(\mu/\,\rho)}{\partial\rho}\right)^2 (\Delta\boldsymbol{\rho})^2}$$

$$\Delta(\boldsymbol{\mu}/\,\boldsymbol{\rho}) = \sqrt{\left(\frac{1}{\rho}\right)^2 (\Delta\boldsymbol{\mu})^2 + \left(\frac{\partial(\mu/\,\rho)}{\rho}\right)^2 (\Delta\boldsymbol{\rho})^2}$$

$$\Delta(\boldsymbol{\mu}/\,\boldsymbol{\rho}) = \sqrt{\left(\frac{1}{\rho}\right)^2 (\Delta\boldsymbol{\mu})^2 + \left(-\frac{\mu}{\rho^2}\right)^2 (\Delta\boldsymbol{\rho})^2}$$

$$\Delta(\boldsymbol{\mu}/\,\boldsymbol{\rho}) = \sqrt{\left(\frac{1}{11.35}\right)^2 (.\mathbf{073})^2 + \left(-\frac{1.118}{11.35^2}\right)^2 (.\mathbf{05})^2}$$

$$\Delta(\boldsymbol{\mu}/\,\boldsymbol{\rho}) = \mathbf{0.00644\ cm^2/g}$$

5.2 Counting Statistics

Table 5.2 Table of Count Rate Values Recorded

Run	**R**	**R-R̄**	**(R-R̄)/ σ**	**(R-R̄)/ σ (Rounded Off)**
1	1003	-0.033	-0.0011	0
2	1112	108.967	3.441	3.4
3	1073	69.967	2.209	2.2
4	1084	80.967	2.557	2.6
5	981	-22.033	-0.696	-0.7
6	1019	15.967	0.504	0.5
7	1021	17.967	0.567	0.6
8	1014	10.967	0.346	0.3
9	1052	48.967	1.546	1.5
10	970	-33.033	-1.043	-1.0
11	1066	62.967	1.988	2.0

12	1120	116.967	3.693	3.7
13	904	-99.033	-3.127	-3.1
14	1055	51.967	1.641	1.6
15	983	-20.033	-6.326	-0.6
16	943	-60.033	-1.896	-1.9
17	1110	106.967	3.377	3.4
18	904	-99.033	-3.127	-3.1
19	957	-46.033	-1.453	-1.5
20	979	-24.033	-0.759	-0.8
21	1087	83.967	2.651	2.7
22	1006	2.967	0.094	0.1
23	1010	6.967	0.220	0.2
24	938	-65.033	-2.053	-2.1
25	1003	-0.0033	-0.0011	0
26	1084	80.967	2.557	2.6
27	1008	4.967	0.157	0.2
28	1045	41.967	1.325	1.3
29	790	-213.033	-6.727	-6.7
30	1007	3.967	0.125	0.1
31	910	-93.033	-2.938	-2.9
32	1052	48.967	1.546	1.5
33	1026	22.967	0.725	0.7
34	1073	69.967	2.209	2.2
35	1075	71.967	2.272	2.3
36	1036	32.967	1.041	1
37	1065	61.967	1.957	2
38	1017	13.967	0.441	0.4
39	796	-207.033	-6.537	-6.5
40	1006	2.967	0.0937	0.1
41	968	-35.033	-1.106	-1.1
42	1000	-3.033	-0.0958	-0.1
43	980	-23.033	-0.727	-0.7
44	1045	41.967	1.325	1.3
45	871	-132.033	-4.169	-4.2
46	1015	11.967	0.378	0.4
47	1077	73.967	2.335	2.3
48	850	-153.033	-4.832	-4.8
49	1083	79.967	2.525	2.5
50	989	-14.033	-0.443	-0.4
51	1033	29.967	0.946	0.9
52	865	-138.033	-4.358	-4.4
53	873	-130.033	-4.106	-4.1

54	1026	22.967	0.725	0.7
55	977	-26.033	-0.822	-0.8
56	1008	4.967	0.157	0.2
57	1012	8.967	0.283	0.3
58	1051	47.967	1.515	1.5
59	1075	71.967	2.272	2.3
60	1000	-3.033	-0.096	-0.1

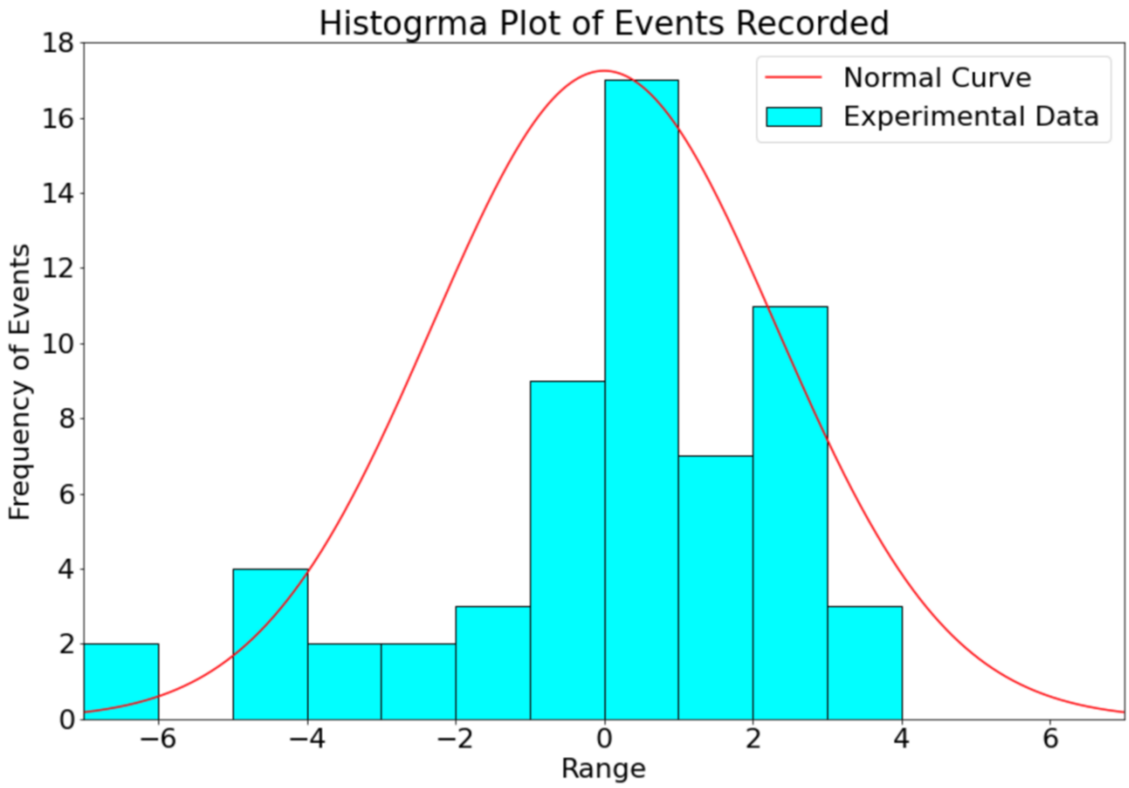

Figure 5.2 Histogram Plotted for Frequency of Events Distribution

6. Data Analysis

6.1 Linear Absorption Coefficient of Lead

The values collected in Table 5.1 show the thickness of each plate and the associated count. These values were plotted as shown in Fig. 5.1. A clear negative linear relationship can be seen between the natural log of counts and the thickness of lead. This negative line arises from the fact that as the thickness of lead increases the count decreases, and thus the natural log of the count decreases. The line of best fit was plotted using python and the slope of this line was found to be $1.118 \pm .0732\ cm^{-1}$. This value is close to our expected value of around $1.15\ cm^{-1}$, found by looking at Fig. 4.1 and using the fact that the energy of the gamma rays emitted in this experiment had an energy of approximately 662keV [1]. This theoretical value of $\boldsymbol{\mu}$, falls within the range of error for the measured value of $\boldsymbol{\mu}$. The slight errors within the data can originate from the varying thickness of each lead plate, as they are not evenly thick as can be observed in Fig 3.2 [1]. Due to this varying thickness the count can be slightly skewed. Other sources of error can emerge from the low energy gamma rays of the radioactive source, and too few readings. These mono-energetic gamma rays can cause a fewer amount of readings within the channels marked for the photopeak and thus combined with few readings taken, this can lead to errors in the data collected.

6.2 Counting Statistics

The second part of the experiment looks at comparing the rounded off events against rounded off values as a histogram. This distribution is compared to an ideal normal distribution curve [1]. The values collected in Table 5.2 show the counts collected for the plotting of the histogram in Fig 5.2. These count values were collected for a lead plate combination of one lead plate of thickness 6.73 mm combined with another plate of thickness 2.66 mm. The first reading achieved with this configuration of plates was 1003 counts with an error of 63 counts. This value was approximately 1000 counts so the results were collected with this specific combination of lead plates. Observing Fig. 5.2, the histogram plotted looks approximately like a normal distribution, however there is a skew to the right side. This skew to the right side could result from a number of errors such as particularly uneven lead plates, lack of measurements taken and systematic errors from the apparatus.

7. Conclusion

This experiment determines the linear absorption coefficient of lead, along with investigating the interactions between gamma rays and matter. The first part of the experiment consisted of measuring the thickness of different plates of lead, and measuring the counts for each plate. The natural log of the counts was plotted against the thickness of the lead plates in order to obtain the linear absorption coefficient, $\boldsymbol{\mu}$ from the slope [1]. This was found to be $1.118 \pm .0732\ cm^{-1}$, which contains our best measured value of $\boldsymbol{\mu}$, 1.15 cm^{-1} found from Fig. 4.1. To measure a value closer to the expected value one would increase the amount of measurements made, repeat the experiment with a set up lead plates with evenly distributed thickness and repeating the experiment with a different source of radiation, more preferably with incident mono-energetic gamma rays of larger energy. One could and with a second set of apparatus in order to eliminate any systematic errors that could have been present during the experiment as well as this. The second part of the experiment focused on comparing the rounded off events against rounded off values as a histogram, and comparing the histogram to a normal distribution curve [1]. The histogram showed a weak resemblance to a normal distribution due to errors in the experiment. The histogram is skewed to the right which could emanate from too little measurements made along with systematic errors.

8. References

[1] Exp 1 Gamma Radiation and Counting Stats - PHYC20020-Introductory Quantum Mechanics-2021/22 Autumn. (2021). Brightspace.ucd.ie. https://brightspace.ucd.ie/d2l/le/content/158311/viewContent/1473424/View

[2] Leclair, P. (2010). Gamma Ray Attenuation. http://pleclair.ua.edu//PH255/templates/formal/formal.pdf

[3] Kuroda, R. (2014). Inverse Compton Scattering Sources. Comprehensive Biomedical Physics, 35–41. https://doi.org/10.1016/b978-0-444-53632-7.00603-1

[4] Wikipedia Contributors. (2021, November 6). Compton scattering. Wikipedia; Wikimedia Foundation. https://en.wikipedia.org/wiki/Compton_scattering

[5] Molecular Expressions Microscopy Primer: Digital Imaging in Optical Microscopy - Concepts in Digital Imaging - Photomultiplier Tubes. (2021). Fsu.edu. https://micro.magnet.fsu.edu/primer/digitalimaging/concepts/photomultipliers.html

[6] SecondYearErrors - PHYC20020-Introductory Quantum Mechanics-2021/22 Autumn. (2021). Brightspace.ucd.ie. https://brightspace.ucd.ie/d2l/le/content/158311/viewContent/1473432/View

9. Appendix

9.1 Additional Diagrams

Figure 9.1 Apparatus Set-up

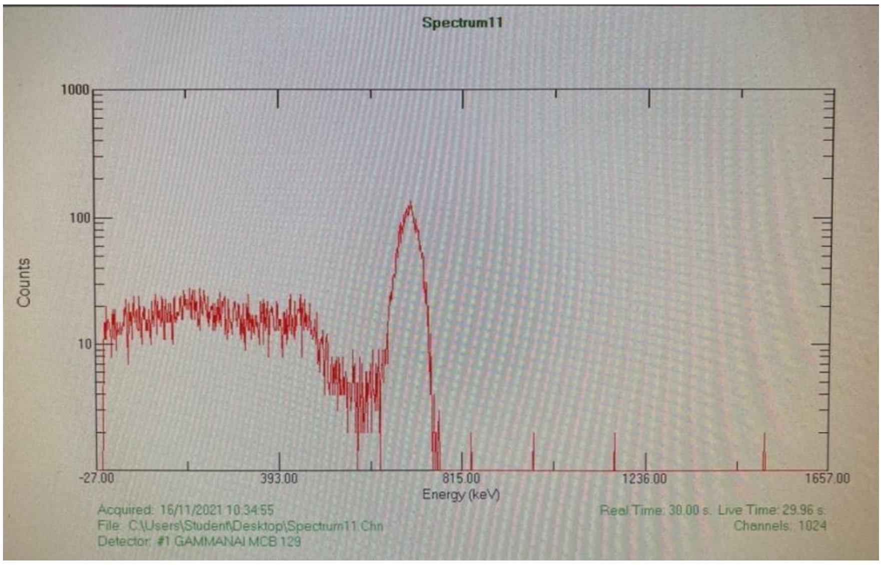

Figure 9.2 Gamma Ray Spectrum for ^{137}Cs as Measured in this Experiment

9.2 Python Code Used for Graphs and Calculations

The python code here calculates and graphs for the first part of the experiment.

```
In [69]: import numpy as np
         import matplotlib.pyplot as plt
         from scipy import integrate
         from scipy.optimize import curve_fit
         import scipy.stats as stats
         %matplotlib inline

         # The below commands make the font and image size bigger
         plt.rcParams.update({'font.size': 22})
         plt.rcParams["figure.figsize"] = (15,10)
```

```
In [52]: ycount=np.array([1003,1112,1073,1084,981,1019,1021,1014,1052,970,1066,1120,904,1055,983,943,1110,904,957,979,1087,1006,
         bins=np.arange(0,9,1)
```

```
In [46]: ycounterr=np.array([63,57,50,42,68,50,63,68,63,73,50,43,78,57,78,73,43,82,68,68,57,56,57,73,63,57,74,50,90,56,73,50,69,
```

```
In [47]: xabs=np.array([.266,.676,.873,1.294,.714])
         xabserr=np.array([.05,.05,.05,.05,.05])
```

```
In [87]: yln=np.log(np.array([2924,1665,1462,905,1622]))
         yerrcalc = (np.log(2924+90)-np.log(2924-90))/2+(np.log(1665+91)-np.log(1665-91))/2+(np.log(1462+54)-np.log(1462-54))/2+
         meanyerr= yerrcalc/5
         ylnerr=meanyerr
         print(ylnerr)

         #np.array([(np.log(2924+90)-np.log(2924-90))/2,(np.log(1665+91)-np.log(1665-91))/2,(np.log(1462+54)-np.log(1462-54))/2,

         0.045147864849126765
```

```
In [85]: def fitfunc(x,m,c):
             return m*x+c
```

```
In [52]: ycount=np.array([1003,1112,1073,1084,981,1019,1021,1014,1052,970,1066,1120,904,1055,983,943,1110,904,957,979,1087,1006,
         bins=np.arange(0,9,1)

In [46]: ,56,57,73,63,57,74,50,90,56,73,50,69,50,69,63,57,63,94,56,56,74,56,42,78,68,57,87,50,73,74,78,82,63,68,63,83,50,50,68])

In [47]: xabs=np.array([.266,.676,.873,1.294,.714])
         xabserr=np.array([.05,.05,.05,.05,.05])

In [87]:
1665-91))/2+(np.log(1462+54)-np.log(1462-54))/2+(np.log(905+56)-np.log(905-56))/2+(np.log(1622+67)-np.log(1622-67))/2


1665-91))/2,(np.log(1462+54)-np.log(1462-54))/2,(np.log(905+56)-np.log(905-56))/2,(np.log(1622+67)-np.log(1622-67))/2])

         0.045147864849126765

In [85]: def fitfunc(x,m,c):
             return m*x+c


In [107]: plt.plot(xabs,yln,'bo')
          pars, cov = curve_fit(fitfunc,xabs,yln)
          plt.plot(xabs,fitfunc(xabs,*pars),'g-')
          plt.errorbar(xabs,yln,ylnerr,xabserr, fmt='o',capsize=5)

          plt.title("Natural Log of Counts as a Function of Absorber Thickness")
          plt.xlabel('Absorber Thickness (cm)')
          plt.ylabel('Natural Log of Counts')
          plt.grid(True)

In [82]: print(pars)

         [-1.11844174  8.23220037]

In [83]: print(cov)

         [[ 0.00536309 -0.00410062]
          [-0.00410062  0.00372638]]

In [ ]:

In [ ]: ycount=np.array([1003,1112,1073,1084,981,1019,1021,1014,1052,970,1066,1120,904,1055,983,943,1110,904,957,979,1087,1006,

In [113]: np.max(ycount)

Out[113]: 1120

In [56]: mean=np.mean(ycount)
         print(mean)

         1003.0333333333333
```

The python code here calculates and graphs for the second part of the experiment.

In [171]:
```
newcount=ycount-mean
print(newcount)
```

```
[-3.33333333e-02  1.08966667e+02  6.99666667e+01  8.09666667e+01
 -2.20333333e+01  1.59666667e+01  1.79666667e+01  1.09666667e+01
  4.89666667e+01 -3.30333333e+01  6.29666667e+01  1.16966667e+02
 -9.90333333e+01  5.19666667e+01 -2.00333333e+01 -6.00333333e+01
  1.06966667e+02 -9.90333333e+01 -4.60333333e+01 -2.40333333e+01
  8.39666667e+01  2.96666667e+00  6.96666667e+00 -6.50333333e+01
 -3.33333333e-02  8.09666667e+01  4.96666667e+00  4.19666667e+01
 -2.13033333e+02  3.96666667e+00 -9.30333333e+01  4.89666667e+01
  2.29666667e+01  6.99666667e+01  7.19666667e+01  3.29666667e+01
  6.19666667e+01  1.39666667e+01 -2.07033333e+02  2.96666667e+00
 -3.50333333e+01 -3.03333333e+00 -2.30333333e+01  4.19666667e+01
 -1.32033333e+02  1.19666667e+01  7.39666667e+01 -1.53033333e+02
  7.99666667e+01 -1.40333333e+01  2.99666667e+01 -1.38033333e+02
 -1.30033333e+02  2.29666667e+01 -2.60333333e+01  4.96666667e+00
  8.96666667e+00  4.79666667e+01  7.19666667e+01 -3.03333333e+00]
```

In [172]:
```
newcount1=newcount/np.sqrt(mean)
print(newcount1)
```

```
[-1.05249747e-03  3.44061424e+00  2.20919220e+00  2.55651636e+00
 -6.95700830e-01  5.04146290e-01  5.67296139e-01  3.46271669e-01
  1.54611879e+00 -1.04302500e+00  1.98816773e+00  3.69321364e+00
 -3.12697000e+00  1.64084356e+00 -6.32550982e-01 -1.89554795e+00
  3.37746439e+00 -3.12697000e+00 -1.45349901e+00 -7.58850679e-01
  2.65124114e+00  9.36722752e-02  2.19971972e-01 -2.05342257e+00
 -1.05249747e-03  2.55651636e+00  1.56822124e-01  1.32509432e+00
 -6.72651136e+00  1.25247199e-01 -2.93752045e+00  1.54611879e+00
  7.25170760e-01  2.20919220e+00  2.27234205e+00  1.04092000e+00
  1.95659280e+00  4.40996442e-01 -6.53706181e+00  9.36722752e-02
 -1.10617485e+00 -9.57772702e-02 -7.27275755e-01  1.32509432e+00
 -4.16894250e+00  3.77846593e-01  2.33549190e+00 -4.83201590e+00
  2.52494144e+00 -4.43101437e-01  9.46195229e-01 -4.35839204e+00
 -4.10579265e+00  7.25170760e-01 -8.22000527e-01  1.56822124e-01
  2.83121821e-01  1.51454387e+00  2.27234205e+00 -9.57772702e-02]
```

In [142]:
```
finalcount=np.around(newcount1, decimals=1, out=None)
print(finalcount)
```

```
[-0.   3.4  2.2  2.6 -0.7  0.5  0.6  0.3  1.5 -1.   2.   3.7 -3.1  1.6
 -0.6 -1.9  3.4 -3.1 -1.5 -0.8  2.7  0.1  0.2 -2.1 -0.   2.6  0.2  1.3
 -6.7  0.1 -2.9  1.5  0.7  2.2  2.3  1.   2.   0.4 -6.5  0.1 -1.1 -0.1
 -0.7  1.3 -4.2  0.4  2.3 -4.8  2.5 -0.4  0.9 -4.4 -4.1  0.7 -0.8  0.2
  0.3  1.5  2.3 -0.1]
```

In [164]:
```
def g(x):
    return 17*np.exp(-((x)**2)/(2*(np.std(finalcount))**2))
```

In [170]:
```
bins=np.arange(-7,7,1)
plt.hist(finalcount,bins,color='cyan', edgecolor='black')
#Title, axes and legend
plt.title('Histogrma Plot of Events Recorded')
plt.xlabel("Range")
plt.ylabel("Frequency of Events")
plt.ylim(0,18)
plt.xlim(-7,7)

x1=np.arange(-7,7,.01)
plt.plot(x1,g(x1),color='red', label='Normal Curve')
plt.legend(['Normal Curve','Experimental Data'])
```