Absorption of Gamma Radiation (γ) and the Attenuation Coefficient (μ)

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(DC171) B.Sc in Applied Physics.

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10:00 A.M - 1:00 P.M

1 Introduction:

Discovered by Henri Becquerel in 1896, Radioactivity is described as the spontaneous change an atomic nuclei undergoes in an effort to become a more stable nuclei. There are three types of radiation: Alpha radiation (α), Beta radiation (β) and Gamma radiation (γ). Each of these types of radiation have unique methods for spontaneously changing an atomic nuclei, such as:

(α) **Alpha Radiation:**
The unstable radioactive nucleus emits two protons and two neutrons simultaneously, which is equivilent to a ${}^{4}_{2}He$ nucleus.

(β) **Beta Radiation:**
The unstable radioactive material emits a single electron ${}^{0}_{-1}e$ from each atom.

(γ) **Gamma Radiation:**
Instead of emitting a charged particle, Gamma Radiation emits a high energy photon which is an electromagnetic wave.

A Geiger-Muller tube (MG tube), is a piece of scientific equipment used to detect all three forms of radiation mentioned above. The overall apparatus of a GM tube is two electrodes filled with a gas (typically neon and a gas located in the halogen column of the periodic table) which are kept at a low pressure, this gas becomes ionised as soon as radiation enters the tube. This ionisation generates electrons in the gas which are free to move around, with their negative charge being attracted to the positive electrode in the tube which results in the electrons gaining energy which is used to ionise other atoms. This energy transfer process results in a voltage pulse within the circuit of the tube which can easily and accurately be measured as the number of counts.

Our experiment begins with the equation:

$$I(d) = I_0 e^{-\mu d} \tag{1}$$

Where $I(d)$ is the number of gamma rays passing through the sheet, I_0 is the gamma rays heading towards an absorbing sheet where d is the thickness of the sheet and μ is a constant associate with the material.

We already know that the number of counts C is proportional to the intensity of the gamma rays, since we are familar with the theory behind the GM tube.

$$C(d) = C_0 e^{-\mu d} \tag{2}$$

Where C_0 is the number of counts for zero thickness. We can rewrite this equation, removing $e^{-\mu d}$ and instead just have μd using the inverse of e which is the natural log ln.

$$ln(C(d)) = lnC_0 - \mu d \tag{3}$$

We can see that the final equation is a function which states that the natural logarithm of the counts is relative to the thickness of the sheet, with the constant μ as it's slope, this constant is whats known as the Attenuation Coefficient.

Preliminary Questions:

(a) State the purpose of the aluminium sheet.
Our Aluminium sheet acts as a form of shielding which inhibits the Gamma Rays ability to travel from the radioactive source directly to the Geiger-Muller tube. Shielding is an important safety procedure when working with radioactivity as it reduces the Gamma rays ability to cause harm to humans.

(b) What is the effect on the counts of:

(i) increasing the distance to the source
The radioactive sources intensity is governed by the inverse square law when considering distance. The inverse square law is mathematically described as:

$$I_1{D_1}^2 = I_2{D_2}^2 \tag{4}$$

This relationship implies that as the distance between the person and the source is increased, the intensity of the radioactive source decreases by a square factor. So if the distance between the person and the source is doubled, the radioactive source has $\frac{1}{4}$ the intensity.
(ii) increasing the thickness of the aluminium sheet
As previously mentioned the aluminium acts as a form of shielding, inhibiting the Gamma Rays, an increase in thickness will result in the shielding affect being increased also.
(iii) taking out the aluminium sheet.
Removing the aluminium sheet will end this shielding affect and the Gamma Rays will freely be able to move from the radioactive source to the GM tube, it's intensity only subdued by the distance between the two.

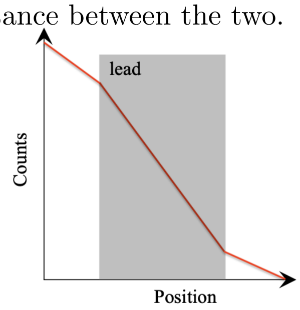

Figure 1.1: Counts vs Position

Source: The graph starts with the counts being high due to the position from the source being low, before decreasing due to the inverse square law.
Lead: Once the rays reach the lead shielding the number of counts is diminished while still being affected by the inverse square law as the position continues increasing.
Final: After it leaves the lead shielding the counts continue to decrease slower, solely due to the inverse square law.

2 Experimental Setup:

Explain the setup, and indicate what safety precautions were taken
The Experimental Setup consisted of a radioactive source which was introduced as 'Radium-226', a box full of sheets made of varying materials of varying thicknesses, a Geiger-Muller (GM) tube, connected to a timer \ scalar box, and a stop watch. We are using the timer \scalar box to visually display the number of voltage pulses which the GM tube is designed to detect.

Radiation has many dangers associated with it, as a result of that- when carrying out this experiment there was many safety precautions that were undertaken in the name of reducing these dangers. This included:

Wearing gloves at all times during the experiment, especially whenever making contact with the radioactive source.

Ensuring that the bench was clear of any unnecessary equipment or objects that could affect our ability to carry out the experiment in a safe manner, keeping our workspace clear of clutter.

When setting the radioactive source into its holder facing the GM tube, the entire apparatus was orientated away from areas of high population and instead was facing towards a wall in the name of safety.

3 Results and Analysis:

background count per minute: 0.261 x 10^3

Table 1: Lead Count

Surface Density (g/cm^2)	d (cm)	d (m)	t (min)	Counts	Counts/m (min^{-1})	C (counts/min) - background
1.78	0.157	0.002	3	6.97 x 10^3	2.3233 x 10^3	2.0623 x 10^3
6.87	0.606	0.006	3	1.839 x 10^3	0.613 x 10^3	0.352 x 10^3
13.7	1.208	0.012	3	1.255 x 10^3	0.4183 x 10^3	0.1573 x 10^3
13.73	1.211	0.0121	3	1.254 x 10^3	0.418 x 10^3	0.157 x 10^3

Density of lead: 11.34 g cm^{-3}

$\frac{1.78}{11.34} = 0.157\,cm$ $\frac{6.87}{11.34} = 0.606\,cm$ $\frac{13.7}{11.34} = 1.208\,cm$ $\frac{13.73}{11.34} = 1.211\,cm$

$\frac{0.157}{100} = 0.002\,m$ $\frac{0.606}{100} = 0.006\,m$ $\frac{1.208}{100} = 0.012\,m$ $\frac{1.211}{100} = 0.0121\,m$

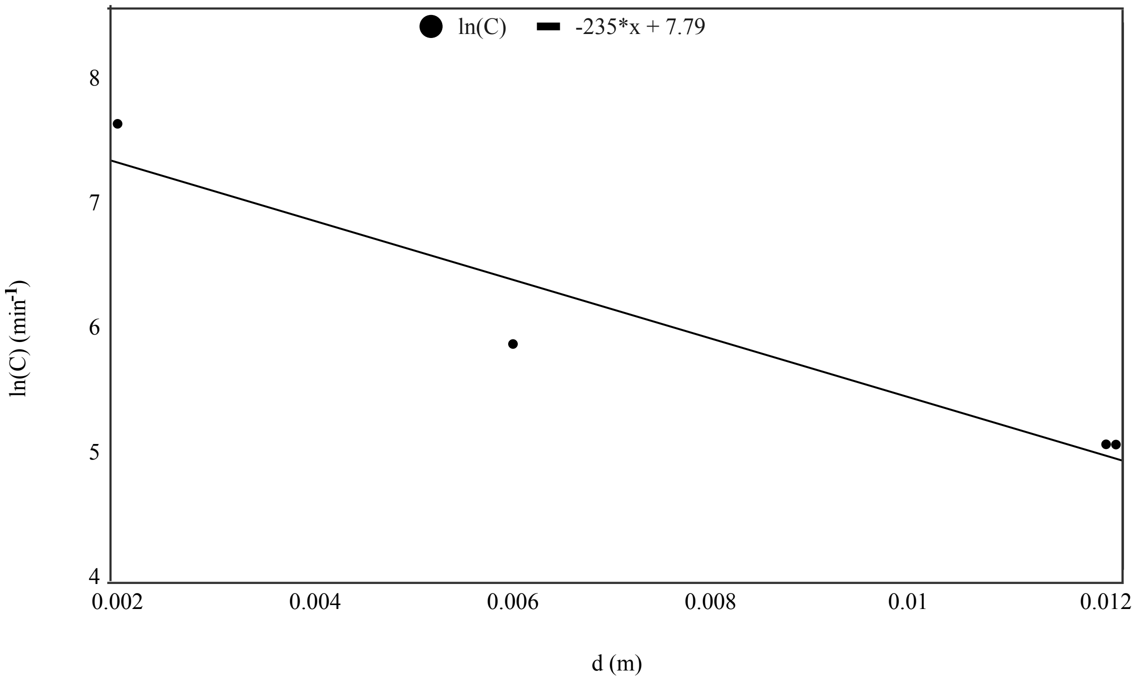

Figure 3.1: Counts (C) vs Thickness (d) [Lead]

From our graph we can determine that our slope is -235, with a y-intercept of 7.79
Using the LINEST function we can determine the slope uncertainty is $\pm$51.32 and the y-intercept uncertainty is $\pm$0.49

Using Eq. 3 we can determine the attenuation coefficient as follows:

$$ln(2.0623 \times 10^3) = ln(0.261 \times 10^3) - \mu(0.002)$$
$$\mu = 1,033.528368$$
for all of our values and we get:
$$\mu_{\text{average}} = 249.794216$$

The reason why we get a negative slope is due to the fact that as our thickness increases (x-axis), the number of counts the GM tube is counting decreases, this verifies that the lead is actually shielding as we expected and that as the thickness of the material increases the shielding affect also increases.

Slope: -235 $\pm$ 51.32
Y-intercept: 7.79 $\pm$0.49
Attenuation Coefficient (μ): 249.79 $\pm$ 51.32

Table 2: Aluminum Count

Surface Density (g/cm^2)	d (cm)	d (m)	t (min)	Counts	Counts/m (min^{-1})	C (counts/min) - background
0.0547	0.02	0.0002	3	36.039 x 10^3	12.013 x 10^3	11.752 x 10^3
0.141	0.052	0.00052	3	17.837 x 10^3	5.946 x 10^3	5.685 x 10^3
0.24	0.08	0.0008	3	11.213 x 10^3	3.738 x 10^3	3.477 x 10^3
0.43	0.159	0.00159	3	6.389 x 10^3	2.130 x 10^3	1.869 x 10^3
0.543	0.201	0.00201	3	4.933 x 10^3	1.644 x 10^3	1.383 x 10^3

Density of aluminium: 2.7 g cm^{-3}

$\frac{0.0547}{2.7} = 0.02\,cm$ $\frac{0.141}{2.7} = 0.052\,cm$ $\frac{0.24}{2.7} = 0.08\,cm$ $\frac{0.43}{2.7} = 0.159\,cm$ $\frac{0.543}{2.7} = 0.201\,cm$

$\frac{0.02}{100} = 0.0002\,m$ $\frac{0.052}{100} = 0.00052\,m$ $\frac{0.08}{100} = 0.0008\,m$ $\frac{0.159}{100} = 0.00159\,m$ $\frac{0.201}{100} = 0.00201\,m$

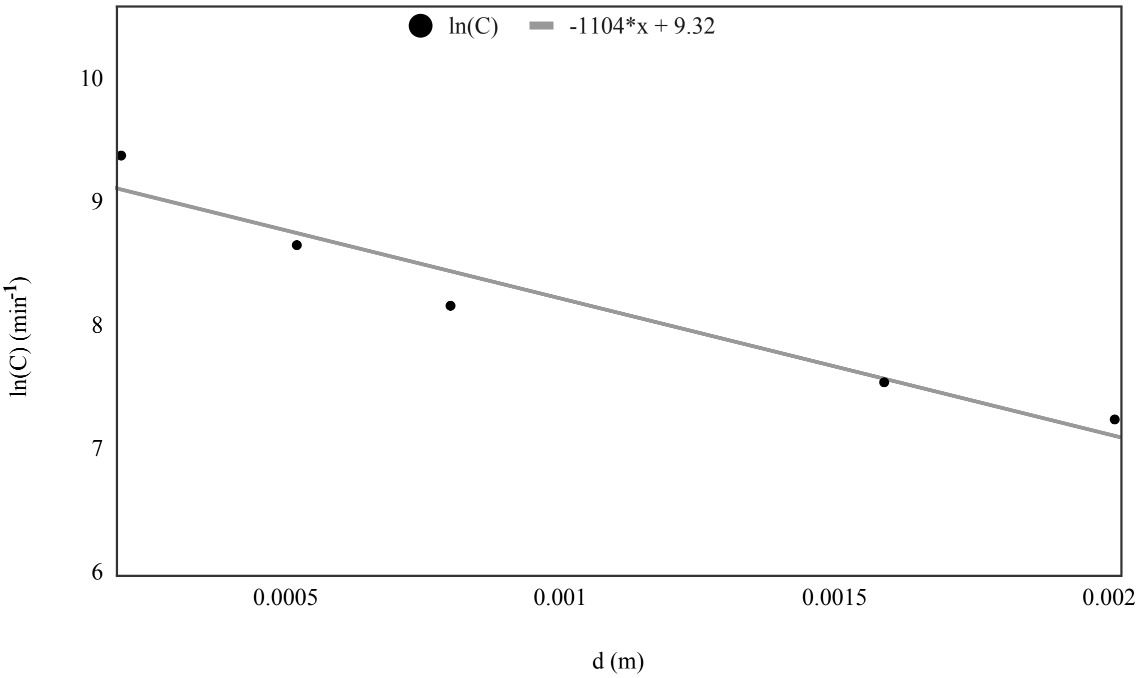

Figure 3.2: Counts (C) vs Thickness (d) [Aluminium]

From our graph we can determine that our slope is -1104, with a y-intercept of 9.32 Using the LINEST function we can determine the slope uncertainty is ± 163.51 and the y-intercept uncertainty is ± 0.20

Using Eq. 3 we can determine the attenuation coefficient as follows:

$$ln(11.752 \times 10^3) = ln(0.261 \times 10^3) - \mu(0.0002)$$

$$\mu = 19036.29$$

for all of our values and we get:

$$\mu_{\text{average}} = 6,053.18 \pm 163.51$$

Table 3: Steel Count

Surface Density (g/cm^2)	d (cm)	d (m)	t (min)	Counts	Counts/m (min^{-1})	C (counts/min) - background
3.904	0.494	0.00494	3	2.426 x 10^3	0.809 x 10^3	0.548 x 10^3
7.81	0.989	0.00989	3	2.055 x 10^3	0.685 x 10^3	0.424 x 10^3
11.712	1.483	0.01483	3	1.898 x 10^3	0.633 x 10^3	0.372 x 10^3
15.616	1.977	0.01977	3	1.548 x 10^3	0.516 x 10^3	0.255 x 10^3
19.52	2.471	0.02471	3	1.366 x 10^3	0.455 x 10^3	0.194 x 10^3

Density of steel: 7.9 g cm^{-3}

$\frac{3.904}{7.9} = 0.494\,cm$ $\frac{7.81}{7.9} = 0.989\,cm$ $\frac{11.712}{7.9} = 1.483\,cm$ $\frac{15.616}{7.9} = 1.977\,cm$ $\frac{19.52}{7.9} = 2.471\,cm$

$\frac{0.494}{100} = 0.00494\,m$ $\frac{0.989}{100} = 0.00989\,m$ $\frac{1.483}{100} = 0.01483\,m$ $\frac{1.977}{100} = 0.01977\,m$ $\frac{2.471}{100} = 0.02471\,m$

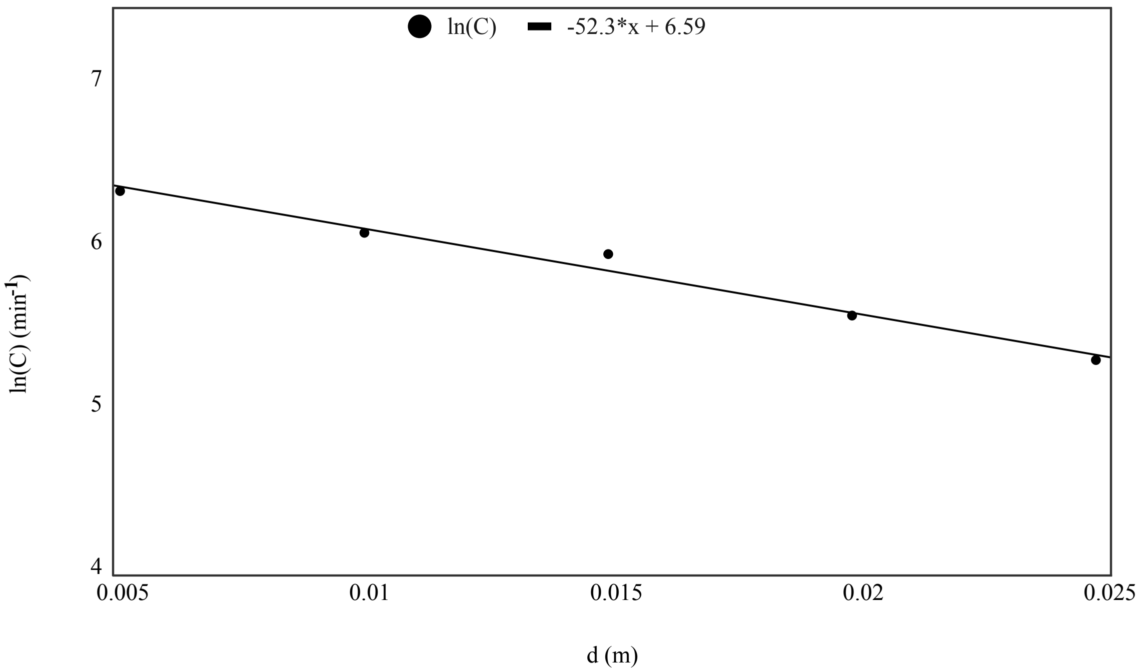

Figure 3.3: Counts (C) vs Thickness (d) [Steel]

From our graph we can determine that our slope is -52.3, with a y-intercept of 6.59
Using the LINEST function we can determine the slope uncertainty is ± 4.24 and the y-intercept uncertainty is ± 0.07

Using Eq. 3 we can determine the attenuation coefficient as follows:

$$ln(0.548 \times 10^3) = ln(0.261 \times 10^3) - \mu(0.00494)$$

$$\mu = 150.15$$

for all of our values and we get:

$$\mu_{\text{average}} = 41.98 \pm 4.24$$

Table 4: Copper Count

Surface Density (g/cm^2)	d (cm)	d (m)	t (min)	Counts	Counts/m (min^{-1})	C (counts/min) - background
5.86	0.654	0.00654	3	17.159 x 10^3	5.720 x 10^3	5.459 x 10^3
11.72	1.308	0.01308	3	10.646 x 10^3	3.549 x 10^3	3.288 x 10^3
17.58	1.962	0.01962	3	3.066 x 10^3	1.022 x 10^3	0.761 x 10^3
23.44	2.616	0.02616	3	1.513 x 10^3	0.504 x 10^3	0.243 x 10^3
29.30	3.270	0.03270	3	0.949 x 10^3	0.316 x 10^3	0.055 x 10^3

Density of Copper: 8.96 g cm^{-3}

$\frac{5.86}{8.96} = 0.654\,cm \quad \frac{11.72}{8.96} = 1.308\,cm \quad \frac{17.58}{8.96} = 1.962\,cm \quad \frac{23.44}{8.96} = 2.616\,cm \quad \frac{29.30}{8.96} = 3.270\,cm$

$\frac{0.654}{100} = 0.00654\,m \quad \frac{1.308}{100} = 0.01308\,m \quad \frac{1.962}{100} = 0.01962\,m \quad \frac{2.616}{100} = 0.02616\,m \quad \frac{3.270}{100} = 0.03270\,m$

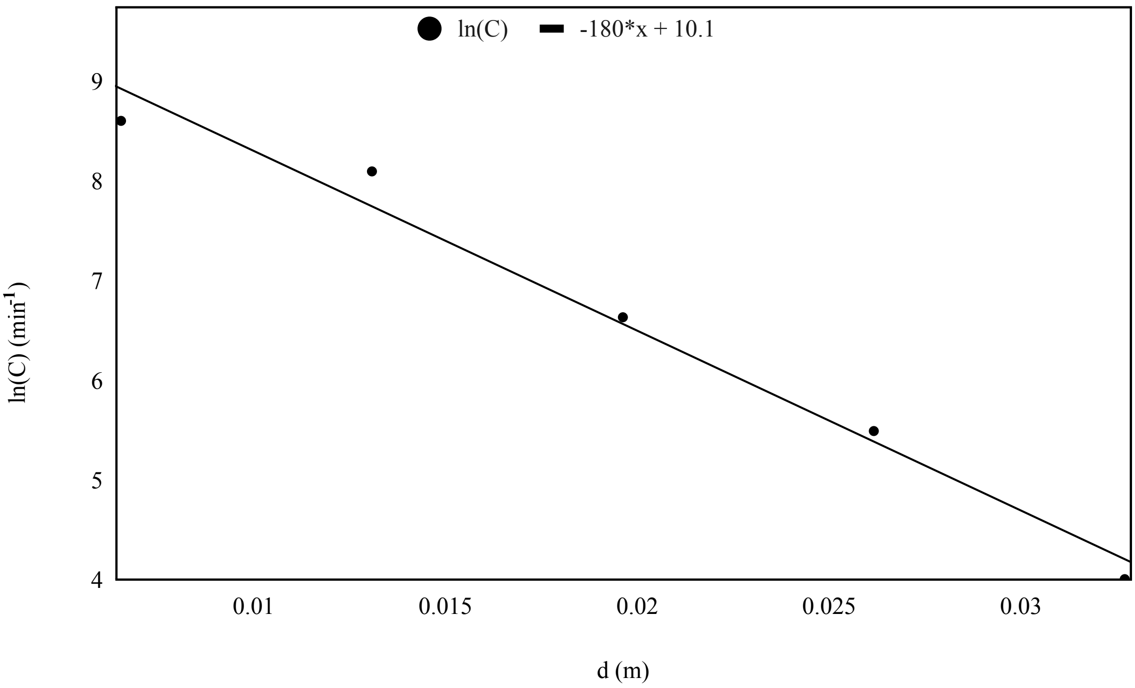

Figure 3.4: Counts (C) vs Thickness (d) [Steel]

From our graph we can determine that our slope is -180, with a y-intercept of 10.1 Using the LINEST function we can determine the slope uncertainty is ± 14.84 and the y-intercept uncertainty is ± 0.32

Using Eq. 3 we can determine the attenuation coefficient as follows:

$$ln(5.459 \times 10^3) = ln(0.261 \times 10^3) - \mu(0.00654)$$
$$\mu = 464.91$$
for all of our values and we get:
$$\mu_{\text{average}} = 132.61 \pm 14.84$$

4 Conclusion:

We were able to find values for the attenuation coefficient that were within a: 5.92%, 81.76%, 24.58% and 35.74% margin of error respectively. 3 out of 4 of the values existed outside the expected margin of error, with aluminium being extremely inaccurate. This 81.76% margin of error could have been due to many things such as the aluminium sheets being the only form of shielding that wouldn't sit flush against each other when stacked, leaving gaps in between them.

5 Appendix:

Answer the following problem: For photons of 6 MeV, the lead attenuation coefficient is 0.057 mm . You have a source of gamma radiation of that energy which gives 1 million counts per minute, and the safety officer wants this reduced by 95%. How thick does your lead shield have to be to achieve this?

Using Eq. 3:

$$ln(C(d)) = lnC_0 - \mu d$$

Where, (C(d)) = 5%(1,000,000), C_0 = 1,000,000, μ = 0.057 mm Therefore:

$$\frac{ln(50{,}000) - ln(1{,}000{,}000)}{0.057} = -d$$

$$d = 52.56\,mm$$