**$M_2$: Determination of the linear absorption coefficient and mass absorption coefficient of aluminum (Al) using $^{137}Cs$ radioactive source**

**Theory:**

The elements those exhibits radioactivity are known as radioactive substances. When the nucleus of an atom emits α, β and γ-radiation, the process is known as radioactive decay. One of the most important characteristics of radioactivity is that it decays exponentially with time.

Geiger Müller (G-M) counter is an instrument used for measuring γ-radiations. To find the linear absorption coefficient of a given material for gamma radiation, the radiation intensity received by the G-M counter is recorded. The radiation intensity is related to the thickness of the material placed between the counter window and the radioactive source.

Let $I_o$ be the initial intensity of the $\gamma$-ray beam incident normally on the absorber and I be the intensity of the outgoing $\gamma$-ray beam that has travelled a distance $x$ through the absorber which is shown in Figure-1. If $dI$ represents a further diminution of intensity of the beam as it travels an additional small distance $dx$, then the decresing rate of intensity $-\frac{dI}{dx}$ is proportional to $I$, therefore,

$$-\frac{dI}{dx} = \mu I$$

$$\frac{dI}{I} = -\mu dx \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

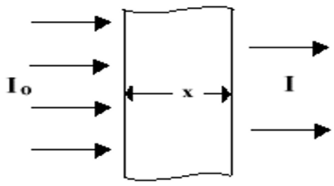

*Figure: 1*

Where, $\mu$ is the proportionality constant and is called the linear absorption coefficient of the absorber material for the $\gamma$-ray of particular energy. This $\mu$ depends on gamma ray energy and absorber material. However, $\mu$ is independent of the thickness $x$ of the absorber.

Now integrating equation (1), we get,

$$\ln I = -\mu x + C \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

To find the constant of integration C, the initial condition can be imposed.

When $x = 0, \quad I = I_o$

Therefore equation (2) becomes

$$C = \ln I_o$$

Substituting the value of C in Equation (2),

$$\ln I = -\mu x + \ln I_o \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Therefore, linear absorption co-efficient



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Updated on UG semester July-2022

$$\mu = \frac{1}{x}\ln\left(\frac{I_0}{I}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Mass absorption co-efficient can be determined as follows,

$$\mu_m = \frac{\mu}{\rho} = \frac{1}{x\rho}\ln\left(\frac{I_0}{I}\right) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Here, $\rho$ is the mass density of the absorber.

If we plot a graph with the thickness of the material ($x$) along the abscissa and the corresponding logarithm of the intensity of outgoing γ-ray beam ($\ln I$) along the ordinate, the graph will be a falling straight line with slope $\mu$ and Y-axis intercept $C = \ln I_0$.

Now equation (3) becomes

$$\ln\frac{I}{I_o} = -\mu x$$

$$or \quad \frac{I}{I_o} = e^{-\mu x}$$

$$or \quad I = I_o e^{-\mu x} \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

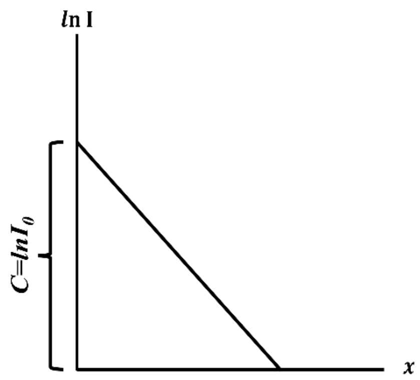


*Figure: 2*

Thus, the absorption of γ-ray phenomenon appears to obey exponential law. As the thickness $x$ of the absorber increases, the γ -ray intensity $I$ decreases exponentially.

## Apparatus:

*(i)* G-M counter
*(ii)* $^{137}$Cs radioactive source
*(iii)* Aluminum sheets
*(iv)* Screw gauge

## Procedure:

*(i)* Open the GM counter box, set it on and wait for **5 minutes**.
*(ii)* Measure the thickness of each **Al** sheet (**K, L, M, N, O, P**) using screw gauge.
*(iii)* Press the **"DISPLAY SELECT"** button of the counter, take the pointer at the "**HIGH VOLTAGE"** position and set the operating voltage at **840 volts** using **"UP/DOWN"** buttons.
*(iv)* Press the **"DISPLAY SELECT"** button and take the pointer at **"TIME"** position and set the time at **200 sec** and stay at "**TIME"** position.
*(v)* Press the "**COUNT"** button, wait until **200 sec** is over. Now take the pointer at **"COUNTS"** position by **"DISPLAY SELECT"** button and record the background

count. The background count is recorded without any radioactive source, which is due to the cosmic ray and radioactive substances present in the building material and environment, etc.

*(vi)* Take background counts for **3 (three) times** by repeating the procedure (*v*).

*(vii)* After each background count, press the **"RESET"** button, again take the pointer at "**TIME"** position by using **"DISPLAY SELECT"** button and take next count by pressing "**COUNT"** button.

*(viii)* Place the radioactive source (**$^{137}$Cs**) along the axis of the counter at a suitable distance (At **7$^{th}$** *shelf from the top*). Insert sheets **K, L, M, N, O, P** together from *shelf-1* to *shelf-6* and take counts.

*(ix)* Remove sheet **K** from *shelf-1*, so the thickness of Al will decrease and again take counts, this will give the count for the remaining thickness of Al sheet (**L+M+N+O+P**). Thus, record the count by removing the sheets one by one from the upper *shelf*.

*(x)* Plot a graph with ***ln I*** **(**Absolute value**)** versus thickness of the sheet (***x***). The graphs will be a straight line as shown in *Figure: 2*.

*(xi)* From the graph determine the intercept $C = \ln I_0$ and slope. The slope of the graph, according to Equ. (3), would be the value of the absorption coefficient $\mu$ of the given material (i.e., aluminum) for the radiation of given energy.

**<u>Experimental data:</u>**

Pitch of the screw gauge, $p =$ ..………………

No. of circular scale divisions, $N =$………………

Least count, $\frac{p}{N} =$………………

Instrumental error = ………………

Table 1: Table for the of thickness of lead sheets

| Sheet number | Name of the sheet | Linear scale reading (mm) | No. of circular scale divisions | Value of circular scale divisions (mm) | Thickness of Al sheet (mm) | Mean thickness of ***Al*** sheet (mm) |
|---|---|---|---|---|---|---|
| 1 | K | | | | | |
| 2 | L | | | | | |
| 3 | M | | | | | |
| 4 | N | | | | | |
| 5 | O | | | | | |
| 6 | P | | | | | |

Table 2: Table for background count

| Operating Voltage (Volts) | Background counts for 200sec | Mean counts per min ($I_B$) |
|---|---|---|
| 840 | *(i)*<br>*(ii)*<br>*(iii)* | |

Table 3: Data for net count per minute

Operating voltage = 840 Volts, Source = ………. ($E_\gamma$ = ……. MeV)

| Lead sheet Number | Thickness of *Al* sheet *x* in cm | Count for 200 sec | Mean count per min ($I_M$) | Net count per min ($I = I_M - I_B$) | *ln I* |
|---|---|---|---|---|---|
| K+L+M+N+O+P | | | | | |
| L+M+N+O+P | | | | | |
| M+N+O+P | | | | | |
| N+O+P | | | | | |
| O+P | | | | | |
| P | | | | | |

**Calculations:**

From the graph $\ln I \ vs.\ x$ Intercept, $C = \ln I_0$.

Thus, $I_0 = e^C =$ ………., and slope, μ=…… cm$^{-1}$

$\mu_m = \frac{\mu}{p}$ $[\rho = \text{density of } Al = 2.70\ gm/cm^3]$

**Results:**

Thus, the linear absorption coefficient of *Al* for $E_\gamma$=….........MeV gamma rays (from ……. source) is, $\mu = \ldots\ldots\ldots . cm^{-1}$

Then the mass absorption coefficient of *Al* for $E_\gamma$=….........MeV gamma rays (from …......source) is, $\mu_m$=…………cm$^2$/gm



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Updated on UG semester July-2022