Study Effective Atomic Numbers and Attenuation Cross-Section of Caprylic Acid by Using Gamma Ray Sources.

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Abstract. Measured the effective atomic number ($Z_{eff}$), effective electron density ($N_{eff}$), atomic cross-section ($\sigma_t$) and electronic cross-section ($\sigma_e$) depending on the amount of mass attenuation coefficient, the mass attenuation coefficients ($\mu_m$) measured for fatty acid “Caprylic” C₈H₁₆O₂ by using Gamma ray radiation($\gamma$), emitted from sources Co⁵⁷, Ba¹³³, Na²², Cs¹³⁷, Mn⁵⁴, and Co⁶⁰ with energies from 122 to 1330 keV. We used scintillation NaI(Tl) detector with resolution 8.2% (at 662 keV). The attenuation coefficient data were then used to obtain the effective atomic numbers ($Z_{eff}$), and effective electron densities ($N_{eff}$), atomic cross-section ($\sigma_t$) and electronic cross-section ($\sigma_e$) of fatty acids. It was observed that the effective atomic number ($Z_{eff}$) and effective electron densities ($N_{eff}$) initially decrease and tend to be almost constant as a function of gamma-ray energy. $Z_{eff}$ and $N_{eff}$ experimental values showed good agreement with the theoretical. Data on interaction of photons of energy (below 1500 keV) with biological compounds are used in radiation therapy, especially for dose calculations.

Keywords: Fatty acid, NaI (Tl) scintillation detector, effective atomic number ($Z_{eff}$), effective electron density ($N_{eff}$), atomic cross-section ($\sigma_t$) and electronic cross-section ($\sigma_e$).

1. Introduction

Gamma rays are electromagnetic radiation of very short wavelength ($\approx 10^{-3}$ Å to 1 Å) and therefore they have no electric charge and cannot be deflected by electric and magnetic field. The precise measurement of $\gamma$--ray energies is therefore not possible by usual magnetic spectrographs. The absorption of $\gamma$--ray is also different from that charge particles like $\alpha$ and $\beta$-rays since $\gamma$--radiations are much penetrating. The charge particles lose their energies by inelastic collisions so that they slow down and come to rest and absorbed at the end of their definite will define range. On the other hand $\gamma$--rays have no definite range but their intensity decreases exponentially, as they pass through the absorbing material [1].

The nuclear reaction cross-section gives an idea of the probability that bombarding particle will interact with the target nucleus. This probability may be visualized in terms of area presented by the nucleus to the incident particle. The incident particle hitting on this area will interact at target nucleus, while that not hitting this area will escape the interaction. Thus larger is the cross-section, greater is
the probability of nuclear reaction to take place. The nuclear cross-section is not the geometrical area of nucleus, but depends on the nature of interaction process [2].

Although the reaction cross-section bears no direct or simple relationship to the geometrical nuclear cross-section $\pi R^2$ ( $R$ being the nuclear radius ), nevertheless, for most nuclear interactions it agrees with it as far as order of magnitude is concerned, as it generally falls within $10^{-28}$ and $10^{-27} \text{ m}^2$. Due to this small value it has been found convenient to use a unit barn = $10^{-28} \text{ m}^2$ for nuclear cross-section [3].

The magnitude of a nuclear reaction cross-section depends upon (i) kinetic energy and nature of incident particle and (ii) nature of target nucleus. The nuclear reaction cross-section may be defined as

$$\sigma = \frac{\text{number of given type of event per nucleus per second}}{\text{number of incident particles per unit area per second}}$$

When radiation is absorbed in body it causes chemical reactions to occur which can alter the normal function of the body. The effects are considered to be due to ionization of the atoms in the molecules of the chemical constituents of cells. As a result of ionization, some of the molecules of the cell constituents are damaged or broken up and so cannot normally function. If only a relatively few atoms in a cell are ionized, it may recover from damage [4–5].

2. Theory

According to mass attenuation coefficient we determined effective of atomic number $(Z_{eff})$, electron density $(N_{eff})$, atomic cross section $(\sigma_t)$ and electronic cross section $(\sigma_e)$ was the hypothetical formulation for the determine of “Mass Attenuation Coefficient $(\mu_m)$” and other related factors. A photon can be absorbed by an atomic nucleus and knock out a nucleon. This process is called photodisintegration [6].

Gamma rays are electromagnetic radiation and suffer absorption in matter just like light photons [7]. $\gamma$–ray photons are either completely absorbed or are deflected (scattered) from their path, usually at large angles. For both these reasons, the intensity of a collimated beam of $\gamma$–rays is reduced as it passes through matter [5].

The attenuation in their intensity follows a similar exponential law:

$$\Delta I \propto I \Delta x,$$

where $\Delta I$ is the change in intensity in passing through a thickness $\Delta x$. $x$ is measured in terms of the mass per unit area (kilogram per meter square). Then $\mu_m$ has the dimension of $\text{m}^2/\text{kg}$ [8].

The experimental arrangement consists of a source and a detector between which can be placed a thin slab of target of the experimental material. If $I_0$ is the particle intensity reaching the detector in the absence of the absorbing material and $I$ is the value when the target of thickness $d$, containing $n$ atoms per unit volume is present, the total cross-section $\sigma$ can be calculated using the expression:

$$\sigma = \frac{\Delta I}{I} \cdot \frac{1}{nd} \quad (1)$$

Diminution in incident wave intensity

Incident intensity x (target nuclei/cm²)

If $\mu_{ab}$ is the absorption coefficient and $\mu_{sc}$ is the scattering coefficient we can write [2]

$$\mu = \mu_{ab} + \mu_{sc} \quad (2)$$
The corresponding mass absorption and mass scattering coefficients are obtained by dividing \( \mu_{ab} \) and \( \mu_{sc} \) respectively by \( \rho \).

\[
n = \frac{N_0 \rho}{M} (3)
\]

Where \( N_0 \) is the Avogadro number and \( M \) is the atomic weight. If we write

\[
\sigma = \frac{\mu}{n} = \frac{\mu M}{N_0 \rho} (4)
\]

Or,

\[
\mu = \sigma n = \frac{\sigma N_0}{M} \rho (5)
\]

So, \( n \) measure in \( (\text{m}^3) \), \( \sigma \) dimension of an area \( (\text{m}^2) \), \( \sigma \) is the cross-section for attenuation of the gamma rays. It has two parts:

\[
\sigma = \sigma_{ab} + \sigma_{sc} \tag{6}
\]

Where:

\[
\sigma_{ab} = \frac{\mu_{ab}}{n} \quad \text{and} \quad \sigma_{sc} = \frac{\mu_{sc}}{n}.
\]

\( \sigma_{ab} \) is the cross-section for absorption & \( \sigma_{sc} \) is the cross-section for scattering [2].

Experimentally one can measure the attenuation coefficient \( \mu \) by plotting \( \ln I \) as a function of the thickness \( x \) of material traversed. The graph should be a straight line of slope \( -\mu \).

3. Results

By using chemical formula for fatty acid calculated the effective atomic numbers \( (Z_{eff}) \), following table show the atomic numbers. The effective atomic number \( (Z_{eff}) \), effective electron density \( (N_{eff}) \), atomic cross-section \( (\sigma_{a}) \) and electronic cross-section \( (\sigma_{e}) \) calculated from the chemical formulae of fatty acid is displayed in Table 1.

| Fatty acid | Chemical formula | Molar mass (g/mol) | effective atomic number \( (Z_{eff}) \) |
|------------|------------------|--------------------|----------------------------------------|
| Caprylic   | \( \text{C}_8\text{H}_{16}\text{O}_2 \) | 144.2114           | 3.0769                                  |

The empirically measured cross sections of the Caprylic in the range of energy (from 122keV to 1330keV) did it out by using scintillation detector with a collimated narrow beam, are shown in (1-5) tables. Measured mass attenuation coefficients \( (\mu m) \) experimentally are placed in table 1. This is used physical quantity for radiation shielding, applications in field of medical. We can explain by figure-1 changes between mass attenuation coefficients and energy of photon for Caprylic, and it is noted that \( \mu m \) responding inversely with energy of photon and in final the value refer to the control of pair production and Compton scattering. We can say in this process a \( \gamma \)-ray photon interacts with an atom.
of low atomic number in such way that $\gamma$-ray is scattered by one of free electron and as a result the electron is separated from the atom and scattered photon moves with reduced energy in a direction different from one original direction and is thus removed from the incident beam. The Compton scattering per atom is proportional to effective atomic number $Z_{\text{eff}}$. Differences in the calculated values of $\sigma_\theta$ and $\sigma_\phi$ are a like in nature and arranged in tables 2 and 3, one after the other. We plotted in figures 2 and 3 the atomic and electronic cross-sections as a function of energy for $(C_8H_{16}O_2)$ and, it is seen that $\sigma_\theta$ and $\sigma_\phi$ decrease with the interaction photon energy $Z_{\text{eff}}$ as a function of energy is displayed in figure 4.

We found the $Z_{\text{eff}}$ is related with average atomic number, and the values of $N_{\text{eff}}$ tiny with energy as view in figure 5. In table 5 listed value of mass attenuation coefficient ($\mu_m$) with the total electronic cross-section ($\sigma_\phi$) and used to measurement $N_{\text{eff}}$.

4. Conclusion

The experimental study has been under taken to get information on mass attenuation coefficient $\mu_m$ values and related parameters ($Z_{\text{eff}}$, $N_{\text{eff}}$, $6_\theta$ and $6_\phi$) for fatty acid Caprylic sample. It has been found that the $\mu_m$ is useful and sensitive physical quantity to determine the $Z_{\text{eff}}$ and $N_{\text{eff}}$ for Hydrogen, Carbon, and Oxygen based biological compounds. In the interaction of photon with matter, $\mu_m$ values are dependent on the physical and chemical environments of the sample. The mass attenuation coefficient ($\mu_m$) values were found to decrease with increasing photon energies. The variation of $6_\theta$ and $6_\phi$ is identical to $\mu_m$. The $N_{\text{eff}}$ is closely related to the $Z_{\text{eff}}$ and the energy dependence of $Z_{\text{eff}}$ and $N_{\text{eff}}$ is the same. Results of the study help to understand how $\mu_m$ values change with variation of the $Z_{\text{eff}}$ and $N_{\text{eff}}$ values in the case of the H.C and O based biological compounds like fatty acid. It is also worth noting that in the energy region of interest that the $Z_{\text{eff}}$ values of the fatty acid sample used in the present work are related to their respective effective atomic weight.

**Table 2:** Mass attenuation coefficient of Caprylic sample ($\mu$)(cm$^2$/gm)

| Sr.No. | source | Energy keV | $\mu$ (cm$^2$/gm) Theo. | $\mu$ (cm$^2$/gm) Exp. |
|--------|--------|------------|--------------------------|--------------------------|
| 1      | Co$^{57}$ | 122        | 0.159                    | 0.156                    |
| 2      | Ba$^{133}$ | 356        | 0.112                    | 0.111                    |
| 3      | Na$^{22}$ | 511        | 0.095                    | 0.095                    |
| 4      | Cs$^{137}$ | 662        | 0.082                    | 0.085                    |
| 5      | Mn$^{54}$ | 840        | 0.076                    | 0.078                    |
| 6      | Co$^{60}$ | 1170       | 0.065                    | 0.066                    |
| 7      | Na$^{22}$ | 1275       | 0.062                    | 0.061                    |
| 8      | Co$^{60}$ | 1330       | 0.061                    | 0.061                    |

**Table 3:** atomic cross-sections of Caprylic sample ($\sigma$)(barn/atom)

| Sr.No. | source | Energy keV | $\sigma$ b/atom Theo | $\sigma$ b/atom Exp. |
|--------|--------|------------|-----------------------|-----------------------|
| 1      | Co$^{57}$ | 122        | 38.291                | 38.295                |
| 2      | Ba$^{133}$ | 356        | 27.016                | 27.014                |
| 3      | Na$^{22}$ | 511        | 22.967                | 22.962                |
| 4      | Cs$^{137}$ | 662        | 19.817                | 19.813                |
| 5      | Mn$^{54}$ | 840        | 18.378                | 18.374                |
| 6      | Co$^{60}$ | 1170       | 15.717                | 15.711                |
| 7      | Na$^{22}$ | 1275       | 15.011                | 15.007                |
| 8      | Co$^{60}$ | 1330       | 14.649                | 14.653                |
| Table 4: Electronic cross-sections of Caprylic sample ($\sigma_e$) (barn/atom) |
| Sr.No | source | Energy keV | $\sigma_e$ b/atom Theo. | $\sigma_e$ b/atom Exp. |
|-------|--------|------------|------------------------|------------------------|
| 1     | Co$^{57}$ | 122        | 13.290                 | 13.043                 |
| 2     | Ba$^{133}$ | 356        | 9.264                  | 9.181                  |
| 3     | Na$^{22}$ | 511        | 7.844                  | 7.842                  |
| 4     | Cs$^{137}$ | 662        | 6.748                  | 6.991                  |
| 5     | Mn$^{54}$ | 840        | 6.241                  | 6.402                  |
| 6     | Co$^{60}$  | 1170       | 5.317                  | 5.397                  |
| 7     | Na$^{22}$ | 1275       | 5.074                  | 4.967                  |
| 8     | Co$^{60}$  | 1330       | 4.949                  | 4.950                  |

| Table 5: Effective atomic number ($Z_{eff}$) of Caprylic sample |
| Sr.No | source | Energy keV | $Z_{eff}$ |
|-------|--------|------------|-----------|
| 1     | Co$^{57}$ | 122        | 2.881     |
| 2     | Ba$^{133}$ | 356        | 2.916     |
| 3     | Na$^{22}$ | 511        | 2.928     |
| 4     | Cs$^{137}$ | 662        | 2.937     |
| 5     | Mn$^{54}$ | 840        | 2.945     |
| 6     | Co$^{60}$  | 1170       | 2.956     |
| 7     | Na$^{22}$ | 1275       | 2.959     |
| 8     | Co$^{60}$  | 1330       | 2.960     |

| Table 6: Effective electron densities ($N_{eff}$) ($10^{24}$ electron/g) of Caprylic sample |
| Sr. No | source | Energy keV | $N_{eff}$ ($10^{24}$ electrons.g$^{-1}$) |
|-------|--------|------------|----------------------------------------|
| 1     | Co$^{57}$ | 122        | 0.3128                                  |
| 2     | Ba$^{133}$ | 356        | 0.3166                                  |
| 3     | Na$^{22}$ | 511        | 0.3179                                  |
| 4     | Cs$^{137}$ | 662        | 0.3189                                  |
| 5     | Mn$^{54}$ | 840        | 0.3197                                  |
| 6     | Co$^{60}$  | 1170       | 0.3209                                  |
| 7     | Na$^{22}$ | 1275       | 0.3212                                  |
| 8     | Co$^{60}$  | 1330       | 0.3214                                  |
Figure 1: Shows Mass attenuation coefficient of Caprylic sample & Energy from 122 to 1330 keV

Figure 2: Plot atomic cross-sections of Caprylic sample & Energy from 122 to 1330 keV

Figure 3: Shows Mass attenuation coefficient of Caprylic sample & Energy from 122 to 1330 keV

Figure 4: Effective atomic number ($Z_{eff}$) of Caprylic sample & Energy from 122 to 1330 keV
Figure 5: Effective electron densities ($N_{\text{eff}}$) ($10^{24}$ electron/g) of Caprylic sample & Energy from 122 to 1330 keV

5. References

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