INTRODUCTION

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CHAPTER I

INTRODUCTION

Gamma rays are electromagnetic radiations of very high frequencies. When gamma rays pass through matter, their intensity is attenuated according to the exponential law. This means that a beam of radiation of a definite energy $E_\gamma$ having intensity $I_0$, passing through an absorber of thickness $x$ will have a transmitted intensity given by [1]

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

.............................. (1.1)

where $\mu$ is a constant characterizing the medium for that gamma energy. It is called the linear attenuation coefficient. If $x$ is in cm, $\mu$ will be expressed in units of cm$^{-1}$. The mass attenuation coefficient is expressed as $\mu/\rho$ where $\rho$ is the density of the medium. It is more common to express the thickness of the absorber as $t = x\rho$ and the mass attenuation coefficient is then given in units of cm$^2$/g. The absorption law can be rewritten as

$$I(t) = I_0 e^{-\mu t}$$

.............................. (1.2)

The linear absorption coefficient $\mu$ depends on the gamma ray energy $E_\gamma$, the atomic number $Z$, and the density $\rho$ of the absorber medium. On the other hand, the mass attenuation coefficient $\mu/\rho$ is independent of the absorber density. For a mixture or a compound of different elements, the mixture rule [2] applies. According to this, the mass attenuation coefficient is given by the equation
\[
\frac{\mu}{\rho} = \sum f_i (\mu / \rho)_i \tag{1.3}
\]

where \( f_i \) is the weight fraction of the \( i \)th element with mass absorption coefficient \((\mu / \rho)_i \).

When a \( \gamma \) ray photon interacts with an atom, there is a finite probability that the whole of the photon energy is completely absorbed by the atomic electrons. Part of this energy may be used to overcome the binding of the electrons to the atom and the remaining energy will be converted into the kinetic energy of the electron. It can be represented by the simple equation

\[ E_e = E_\gamma - B \tag{1.4} \]

where \( B \) is the binding energy of the electron in the atom. This process is known as the photoelectric effect. It will not take place with a free electron, as it would not be possible to conserve energy and momentum. The cross section for photoelectric absorption in the K shell of an atom with atomic number \( Z \) is proportional to \( Z^5 / E_\gamma^{7/2} \). Thus the process is more predominant at lower energies (up to 500 keV) and for heavy elements.

Pair production involves the complete absorption of gamma ray photon in the field of nucleus of an atom or an electron. During this absorption a pair of electron and positron will be produced. The condition for pair production is that the energy of the photon must be greater than \( 2m_e c^2 \) (1.02MeV), the total rest mass energy of the pair. The pair production cross-section increases with the atomic number of the absorber as \( Z^2 \).
When the energy of the incident gamma ray photon exceeds the separation energy of proton or neutron, photonuclear absorption takes place. It is also called nuclear photo effect. This process is negligible if the photon energy is less than about 10 MeV. If the energy of the incident photon is greater than 150 MeV, then the process of photo meson production will start. But the cross sections are extremely small.

The other mode of interaction of gamma ray photons with matter is scattering. There are two types of scattering (a) elastic scattering (b) inelastic scattering. In the case of elastic scattering, both momentum and kinetic energy of the particles are conserved. Hence the energy of elastically scattered gamma ray photon is nearly same as the incident energy. There are four types of elastic scattering. The scattering from bound atomic electrons is called Raleigh scattering. This process is predominant in the region around and below 1 MeV and is more effective at small scattering angles. Coherent scattering from the nucleus as a whole is called Thomson scattering. When a beam of photons passes near an electron, this electron is momentarily accelerated by the electric field of the wave and so radiates energy. It is independent of energy and is proportional to $Z^4$.

In the case of nuclear resonance scattering the nucleus of an atom is excited due to the incident photon energy. Subsequently there will be re emission of the excitation energy when the excited nucleus decays to the ground state. The scattering cross section varies as $Z^2$. This process is more predominant in the regions of narrow resonance maxima at low energies and broad maxima in the range of 10-30 MeV.
When the gamma ray photon interacts with the coulomb field of the nucleus another type of scattering process can take place. This process is called Delbrück scattering.

Inelastic scattering of gamma ray photons by a free electron is called the Compton scattering. In this process some energy is scattered and some is transferred to kinetic energy of the struck electron. This process dominates in the energy region of around 1 MeV. It decreases as energy increases. For very low energy photons, the Compton scattering cross section is same as that of Thomson scattering cross section. The cross section varies as Z.

When a beam of gamma rays passes through an absorber, the gamma ray photons interact with the atoms individually and are either absorbed (via photoelectric effect and pair production) or scattered away from the beam. The intensity of the transmitted beam is consequently attenuated. The total cross section for attenuation of the incident beam of γ-rays is the sum of the cross sections per atom for all the three processes. Therefore, the total cross section is given by

\[ \sigma = \sigma_{\text{ph}} + Z \sigma_c + \sigma_{\text{pair}} \]  \hspace{1cm} (1.4)

If \( N \) is the number of atoms per unit volume of the absorber, the linear absorption coefficient

\[ \mu = \sigma N \]  \hspace{1cm} (1.5)
The total attenuation coefficient can be measured experimentally by simple absorption measurements. In order to find the value of $\mu$ we have to know the initial intensity of the incident $\gamma$-ray photon. The absorption of $\gamma$-rays depends strongly upon its energy and the atomic number of the absorber. The exponential absorption law (equation 1.1) is difficult to observe experimentally because of the detection of the gamma rays scattered from the absorber and other surroundings along with the transmitted beam. The $X$-rays emitted from the absorber also affect the measurements. In order to reduce the above mentioned problem we have to use a narrow beam geometry set up [2]. This arrangement reduces the solid angle subtended by the detector at the center of the target by use of suitable shielding and collimation. It prevents the coherently and incoherently scattered photons from reaching the detector. Hence only the radiation coming out from the target without any interaction will reach the detector.

Photon attenuation and photoelectric effect data are very essential in many fields of research areas. It is very relevant in studies of radiation transport and shielding. The photoelectric absorption cross section close to the absorption edge is very important in radiation physics and it has lot of application in medical field.

The main intention of the present studies has been to determine the total attenuation coefficients of various rare earth elements using 59.54 keV gamma rays from Amrecium-241 source. This gamma energy is quite interesting since it comes in between the K-edge energies of the rare earth elements from Ce to Yb. Also, another equally important purpose has been the determination of the photoelectric cross sections of the
rare earth compounds by using Americium-241. By using the same experimental setup and the detector, the water content of fresh and dried wood and leaf samples were also investigated. With the help of $^{241}$Am source, the effect of the grain size of various soil samples of the beaches of Calicut and Neendakara were investigated. The present thesis gives the details, results and discussions of the experimental investigations.

In the following, various gamma ray interactions with matter are reviewed in detail in Chapter II. Some previous experimental and theoretical studies on gamma ray attenuation and photoelectric effect are described in Chapter III. In the subsequent chapters IV and V, the present experimental studies on attenuation and photoelectric absorption have been described in detail. Investigations have been carried out using oxides of some rare earth elements. For the attenuation studies, both aqueous solutions and pellets have been used as absorbers. For the photoelectric measurements, the pellet targets have been used. Chapter VI presents the experimental details and the important results obtained from the gamma attenuation studies on fresh and dried leaf and wood samples. In Chapter VII a detailed discussion of the results of the present investigations on absorbers with various particle sizes, is provided along with conclusions drawn there from.
REFERENCES
