γ- ray Interaction with matter

When γ- radiation of Intensity I is incident on an absorbing layer of thickness dx the amount of radiation absorbed is given by

$$dI = -\mu I dx$$

where μ = const. of proportionality known as linear absorption coefficient

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

or $\log_e I = -\mu x + \log A$ —(i)

$\log_e A$ = Const. of Integration

when $x = 0$ then $I = I_0$ (Initial Intensity)

∴ $\log_e I_0 = \log A$ Putting in (i)

∴ $\log_e I = -\mu x + \log_e I_0$

or $\log_e \frac{I}{I_0} = -\mu x$ or $I = I_0 e^{-\mu x}$ —(2)

When low energy γ-ray is incident it causes
- (i) Photo electric effect.
- (ii) Compton effect.
- & (iii) Pair production.

Besides the above three effects there are various other effects such as (A) meson production
- (B) Photodisintegration.
- (C) Thomson Scattering
- (d) Delbruck Scattering
- (e) Nuclear resonance scattering etc.

but these effects are minor effects.

Discussion of Important processes:

(1) Photo electric effect: When photon collide

with an atom it delivers its energy to the orbital electron hence if the supplied energy is greater than the work function of the electron, electron will be emitted this phenomenon is known as photo electric effect. According to Einstein Photoelectric equation

$$h\nu = E_B + E_{Kin} \quad \text{--- (3)}$$

where $h\nu$ = Incident photon energy.
E_B = binding energy of the electron.
E_{Kin} = maximum K.E of the ejected electron.

This effect is promient when the energy range is below 0.1 Mev. The most likely interaction occurs between the photon and the most tightly bound electrons (say electrons of k shell) if the incident photon energy is higher. The binding energy depends on Z as well as the orbital electron shell. The binding energy is less for the outermost electron as given by this:

$$E_{B,K} = R(Z-1)^2$$
$$E_{B,L} = \frac{R}{4}(Z-5)^2$$
$$E_{B,M} = \frac{1}{9}R(Z-13)^2$$

where $E_{B,K}$ is the binding energy for K shell & R = Rydberg Constant

The absorption curve as a function of incident energy can be divided into three regions:

(a). Vicinity of the absorption edge (< 0.1 Mev)
(b). away from the edge (> 0.1 Mev)
& (c) Relativistic region ($h\nu > m_e c^2$)

At low energies photo electrons are emitted in a direction perpendicular to the incident beam. At higher γ-ray energies the angular distribution is more in the forward direction i.e the position of the peak shifts to lower angles as energy increases.

The absolute probability of the photoelectric interaction is described by the atomic cross-section $\sigma_{Pe,K}$ for K-electron using non relativistic Born approximation at the intermediate region:

$$\sigma_{Pe,K} = 4\sqrt{2}\left(\frac{m_e c^2}{h\nu}\right)^{7/2} \alpha^4 Z^5 \sigma_T \quad \text{--- (4)}$$

where $\alpha = \frac{1}{137}$ and $\sigma_T = \frac{8}{3} \pi r_0^2$

In the neighbourhood of the absorption edge regions more exact form of electron wave function is needed hence a correction function is applied. While in the relativistic region the exponent 7/2 decreases & the total probability cross-section at very high energy is given by

$$\sigma_{pe,k} = 1.5 \left(\frac{m_e c^2}{h\nu}\right)^{-1} \alpha^4 Z^5 \sigma_T \quad — (5)$$

Thus Z^5 dependence suggest that for a given photon energy this process is important for heavy absorbers.

When an electron is emitted the vacancy created is soon filled up by the jump of electrons from the higher energy state hence this electron transition is accompanied by X-ray emission. This electron is known as Auger electron.

∴ The energy of L Auger electron is $= E_{B,K} - 2E_{B,L}$

The relative probability of Auger emission & X-radiation is measured by:

$$W_K \text{ (for K shell)} = \frac{\text{Number of K quanta}}{\text{Number of K shell vacancies}} \quad — (6)$$

The corresponding K-Auger yield $= 1 - W_K$

∴ total probability = 1

∴ Z dependence by Semi emperical method indicates that for lighter atoms this effect is prominent as given by

$$\frac{W_K}{1-W_K} = \left(-6.4 + 3.4Z - 103 \times 10^{-6} Z^3\right)^4 \times 10^{-8} \quad — (7)$$

Conclusion: For very high energy γ-ray photon direct collision causes the Photoelectric emission for which eq^n (5) holds good. While for lighter atoms

Auger effect is predominent for which Z dependence is given by eqⁿ ⑦.