UNIT III

INTERACTION OF RADIATION WITH MATTER LIPID

3.3 Interaction of Gamma radiation with matter

Mechanism of Interaction of gamma radiations

- When penetrating g-rays pass through matter, they lose energy by interaction with the orbital electrons or the nucleus of the absorber atom.
- The g-ray photons may lose all of their energy, or a fraction of it, in a singleencounter.
- The specific ionization of g-rays is one-tenth to one-hundredth of that caused by a non-penetrating electron of the same energy.
- There is no quantity equivalent to a range of particles for g-rays, but they travel a longpath in the absorber before losing all energy.
- The average energy loss per ion pair produced by the photons is the same as for electrons, that is, 35keV in air.
- There are four mechanisms by which x-rays and gamma-rays interact with absorber atoms during their passage through matter, Rayleigh scattering, Photoelectric effect, Compton scattering and pair production.

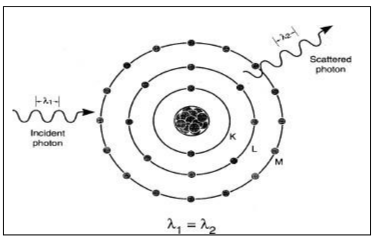
Rayleigh Scattering

- In Rayleigh scattering, the incident photon interacts with and excites the total atom.
- This interaction occurs mainly with very low energy diagnostic x-rays, as used in mammography (15 to 30 keV).
- During the Rayleigh scattering event, the electric field of the incident photon's electromagnetic wave expends energy, causing all of the electrons in the scattering atom to oscillate in phase.
- The atom's electron cloud immediately radiates this energy, emitting a photon of the same energy but in a slightly different direction.

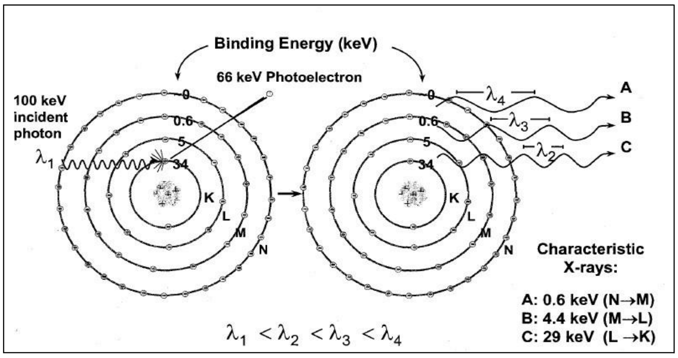
- In this interaction, electrons are not ejected and thus ionization does not occur. In general, the scattering angle increases as the x-ray energy decreases.
- In medical imaging, detection of the scattered x-ray will have a deleterious effect on image quality.
- This type of interaction has low probability of occurrence in the diagnostic range.
- In soft tissue, Rayleigh scattering accounts for less than 5% of x-ray interactions above 70 keV and at most only accounts for 12% of interactions at approximately 30 keV.
- Rayleigh interactions are also referred to as **"coherent" or "classical" scattering**.

Photoelectric Effect

- In the photoelectric effect, the incident γ -ray transfers all its energy to an orbital electron of the absorber atom whereby the electron, called the photoelectron, is ejected with kinetic energy equal to $E\gamma - E\beta$, where $E\gamma$ and $E\beta$ are the energy of the γ -ray and the binding energy of the electron, respectively.
- The photoelectron loses its energy by ionization and excitation in the absorber.
- The photoelectric effect occurs primarily in the low-energy range and decreases sharply with increasing photon energy. It also increases very rapidly with increasing atomic number Z of the absorber atom.
- Roughly, the photoelectric effect is proportional to Z^5/E^3_γ. The photoelectric contribution from the 0.15-MeV γ -rays in aluminum (Z = 13) is about the same (~5%) as that from the 4.7-MeV g -rays in lead (Z = 82).



· The photoelectric effect occurs primarily with the K-shell electrons, with about20% contribution from the L-shell electrons and even less from higher shells.



- There are sharp increases (discontinuities) in photoelectric effects at energies exactly equal to binding energies of K-, L- (etc.) shell electrons. These are called **K-, L- (etc.) absorption edges**. The vacancy created by the ejection of an orbital electron is filled in by the transition of an electron from the upper energy shell.
- It is then followed by emission of a characteristic x-ray or **Auger electron**, analogous to the situations in internal conversion or electron capture decay.

Compton Scattering

- In Compton scattering, the g-ray photon transfers only a part of its energy to an electron in the outer shell of the absorber atom, and the electron is ejected.
- The photon, itself with reduced energy, is deflected from its original direction.
- This process is called the Compton **scattering**. The scattered photon of lower energy may then undergo further photoelectric or Compton interaction, and the Compton electron may cause ionization or excitation.
- At low energies, only a small fraction of the photon energy is transferred to the Compton electron, and the photon and the Compton electron are scattered at an angle θ.
- Using the law of conservation of momentum and energy, the scattered photon energy is given by

$$E_{sc} = E_\gamma/[1 + (E_\gamma/0.511)(1 - \cos\theta)]$$

where Eγ and Esc are the energies in MeV of the initial and scattered photons.

- The scattered photon energy varies from a maximum in a collision at 0° (forward) to a minimum at θ = 180° in a backscattering collision.
- Conversely, the Compton electron carries a minimum energy in the forward collision to a maximum energy in the backscattering collision.

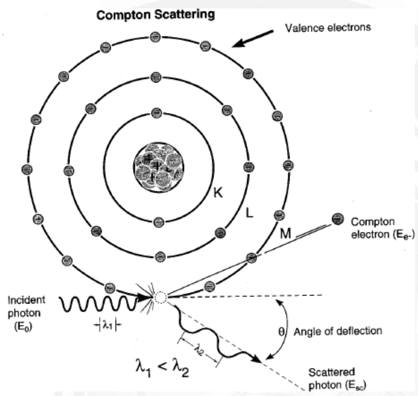
• At higher energies, both the scattered photon and the Compton electron are predominantly scattered in the forward direction.

• If the photon is backscattered, that is, scattered at 180°, then the backscattered photonhas the energy Esc given by the expression (cos 180° = −1):

$$E_{sc} = E_{\gamma}/(1 + E_{\gamma}/0.256)$$

Compton scattering is almost independent of the atomic number Z of the absorber.

• Compton scattering contributes primarily in the energy range of 0.1 to 10MeV, depending on the type of absorber.



Pair Production

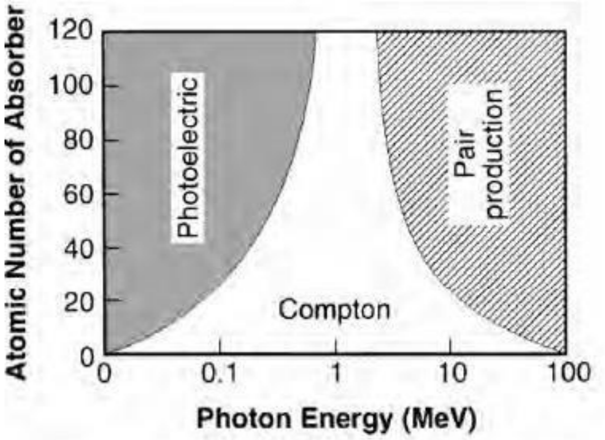
• When the γ-ray photon energy is greater than 1.02MeV, the photon can interact with the nucleus of the absorber atom during its passage through it, and a positive electron and a negative electron are produced at the expense of the photon.

• The energy in excess of 1.02 MeV appears as the kinetic energy of the two particles. This process is called pair production.

• It varies almost linearly with Z^2 of the absorber and increases slowly with the energy of the photon.

• In soft tissue, pair production is insignificant at energies up to 10MeV above 1.02MeV.

• Positive electrons created by pair production are annihilated to produce two 0.511- MeV photons identical to those produced by positrons from radioactive decay.



- It is seen that the photoelectric effect is predominant in high Z absorbers at lower energies (<0.1MeV), whereas the Compton scattering is predominant in inter-mediate Z absorbers at medium energies (~1MeV).
- At higher energies (>10MeV), pair production predominates in all Z absorbers.