UNIT III

INTERACTION OF RADIATION WITH MATTER LIPIDS

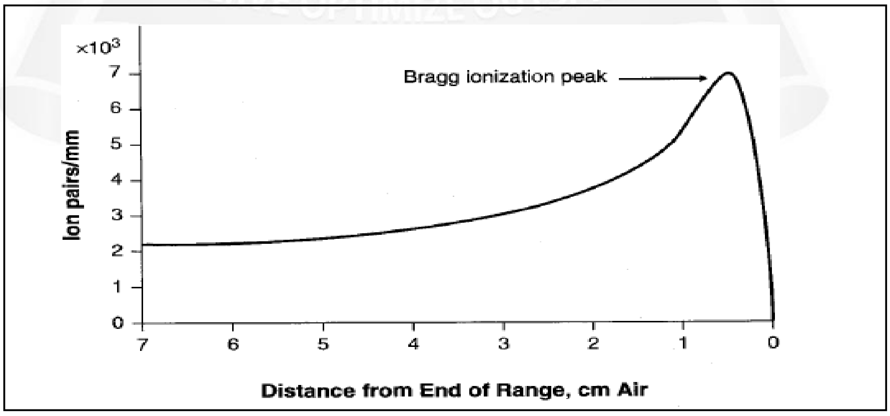
3.1 Interaction of Charged Particles with Matter

- The energetic charged particles such as α-particles, protons, deuterons, and β-particles (electrons) interact with the absorber atoms, while passing through it.
- The interaction occurs primarily with the orbital electrons of the atoms and rarelywith the nucleus.
- During the interaction,both, ionization and excitation as well as the breakdown of the molecule may occur.
- In **excitation**, the charged particle transfers all or part of its energy to the orbital electrons, raising them to higher energy shells.
- In **ionization**, the energy transfer may be sufficient to overcome the binding energy ofthe orbital electrons, ultimately ejecting them from the atom.
- Electrons ejected from the atoms by the incident charged particles are called primary electrons, which may have sufficient kinetic energy to produce further excitation or ionization in the absorber.
- The high-energy secondary electrons from secondary ionizations are referred to as delta (δ-) rays.
- The process of excitation and ionization will continue until the incident particle and all electrons come to rest.
- Both these processes may rupture chemical bonds in the molecules of the absorber, forming various chemical entities.
- In ionization, an average energy of W is required to produce an ion pair in the absorber and varies somewhat with the type of absorber.
- The value of W is about 35 eV in air and less in oxygen and xenon gases but falls in the range of 25–45 eV for most gases.
- The process of ionization, that is, the formation of ion pairs, is often used as a means of the detection of charged particles in ion chambers and Geiger–Müller counters.
- Three important quantities associated with the passage of charged particles through

matter are **specific ionization, linear energy transfer, and range of the particle** in the absorber.

Specific Ionization

- Specific ionization (SI) is the total number of ion pairs produced per unit length of the path of the incident radiation.
- The number of primary and secondary ion pairs produced per unit length of the charged particle's path is called the specific ionization, expressed in ion pairs (IP)/mm.
- The SI values of a-particles are slightly greater than those of protons and deuterons, which in turn are larger than those of electrons.
- Specific ionization increases with decreasing energy of the charged particle because of the increased probability of interaction at low energies.
- Therefore, toward the end of the travel, the charged particle shows a sharp increase in ionization. This peak ionization is called **Bragg ionization**.
- This phenomenon is predominant for heavy charged particles and is negligible for electrons.
- A larger charge produces a greater coulombic field; as the particle loses energy, it slows down, allowing the coulombic field to interact at a given location for a longer period of time.
- The specific ionization of an alpha particle can be as high as ~7,000 IP/mm in air.The specific ionization as a function of the particle's path is shown for a 7.69 MeV alpha particle from polonium-214 in air.



- As the alpha particle slows, the specific ionization increases to a maximum (called the Bragg peak), beyond which it decreases rapidly as the alpha particle picks up electrons and becomes electrically neutral, thus losing its capacity for further ionization.

- The large Bragg peak associated with heavy charged particles has medical applications in radiation therapy.
- By adjusting the kinetic energy of heavy charged particles, a large radiation dose can be delivered at a particular depth and over a fairly narrow range of tissue containing a lesion.
- On either side of the Bragg peak, the dose to tissue is substantially lower. Heavy particle accelerators are used at some medical facilities to provide this treatment in lieu of surgical excision or conventional radiation therapy.
- Compared to heavy charged particles, the specific ionization of electrons is much lower (in the range of 50 to 100 IP/cm of air)

Linear Energy Transfer

- The linear energy transfer (LET) is the amount of energy deposited per unit length of the path by the radiation.
- From the preceding, it is clear that

$$\mathbf{LET = SI \times W}$$

- The LET is expressed in units of keV/μm and is very useful in concepts of radiation protection.
- Electromagnetic radiations and β -particles interact with matter, losing only little energy per interaction and therefore have low LETs.
- In contrast, heavy particles (α-particles, neutrons, and protons) lose energy very rapidly, producing many ionizations in a short distance, and thus have high LETs.

Range

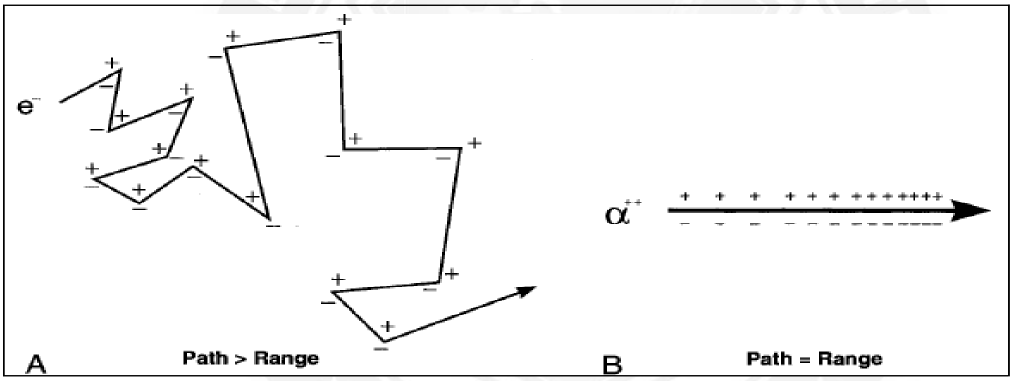
- The **range (R)** of a charged particle in an absorber is the straight-line distance traversed by the particle in the direction of the particle.
- The **path length** of a particle is defined as the actual distance the particle travels.
- The **range** of a particle is defined as the actual depth of penetration of the particle in matter.
- The range of a particle depends on the mass, charge, and kinetic energy of the particle and

also on the density of the absorber.

- The heavier and more highly charged particles have shorter ranges than lighter and lower charged particles. The range of charged particles increases with the energy of the particle.
- Thus, a 10-MeV particle will have a longer range than a 1-MeV particle. The range of the particle depends on the density of the absorber, in that the denser the absorber, the shorter the range.

- The **unit** of range is given in mg/cm2 of the absorber.

· The path length of the electron almost always exceeds its range, whereas the straight ionization track of a heavy charged particle results in the path and range being nearly equal.



- Depending on the type of the charged particle, the entire path of travel may be unidirectional along the initial direction of motion, or tortuous.
- Because the α-particle loses only a small fraction of energy in a single collision with an electron because of its heavier mass and is not appreciably deflected in the collision, the α-particle path is nearly a straight line along its initial direction. Many collisions in a short distance create many ion pairs in a small volume.
- In contrast, β-particles or electrons interact with extranuclear orbital electrons of the same mass and are deflected considerably. This leads to tortuous paths of these particles. In this situation, the true range is less than the total path travelled by the particle.
- It is seen that the ranges of all identical particles in a given absorber are not exactly the same but show a spread of 3% to 4% near the end of their path.
- This phenomenon, referred to as the **straggling of the ranges**, results from the statistical fluctuations in the number of collisions and in the energy loss per collision.

- The range straggling is less prominent with α-particles but is severe with electrons because it is mostly related to the mass of the particle.
- The light mass electrons are considerably deflected during collisions and hence exhibit more straggling.
- If the transmission of a beam of charged particles through absorbers of different thicknesses is measured, the beam intensity will remain constant until the region of range straggling is encountered, where the beam intensity falls sharply from its initial value to zero.
- The absorber thickness that reduces the beam intensity by one half is called the **mean range.**
- The mean range of heavier particles such as α-particles is highly well defined than that of electrons.
- Because β^--particles are emitted with a continuous energy spectrum, their absorption, and hence their ranges, become quite complicated.