Interaction of Nuclear Reaction With matter

- Various Particles employed in nuclear Reactions:
- 1) **e. m. radiations**
- 2) **charged particles : further divided into two categories**

- a) Interaction of heavily charged particles like protons, α particles
- b) Interaction of lightly charged particles like electrons, positrons etc.

- **3) neutron radiations**

Bohr's formula for stopping Power

- Processes involved :
- **Excitation**
- **Ionization**

- $-dE/dX = Z^2e^4n/4\pi e^2mv^2 \log (b_{max} / b_{min})$
- Energy loss per unit path length is called specific energy loss

- **Bloch-Bethe Realation**
- $B_{max} = v/\nu$
- $B_{min} = h/2mv$
- Corrected $b_{max} = v/\nu(1-v^2/c^2)^{1/2}$
- Corrected $b_{min} = h/2mv\ (1-v^2/c^2)^{1/2}$
- Exact formula
- $-dE/dx = Z^2e^4NZ/4\pi e^2mv^2 (\log 2mv^2/h\nu - \log (1-v^2/c^2) - v^2/c^2$

Range of Charged Particles

- The distance travelled by a charged particle when it is moving through a medium before it comes to rest is called its range.
- $R = E^2$

- **Bethe Bloch Formula not valid for Electrons**
- Heavily charged particles are mono energetic while in electrons there is a continuous distribution of initial energy.
- Electrons with high energy radiate energy in the form of X rays.
- Collision between identical particles involve energy exchange phenomenon.
- Path of electron is irregular doe to its less mass.

Interactions of light Charged particles with matter

- **Interaction of electrons with matter**
- **Small energy** (eV to keV) - Scattered Elastically
- **Medium energy** : Inelastic scattering by atomic Electrons
- **High Energy** : Inelastic scattering by Nucleus
- **Very High Energy** : Nuclear Excitation

Bremstrahlung

- Means : Braking radiation
- Energy radiated per unit time in the form of e.m radiation when a charged particle is moving with a very high speed.
- Electrons suffer radiative collision with atomic nuclei of the material through which they pass
- e.m radiations of all possible wave-lengths are emitted.
- Rate of loss of energy is proportional to square of atomic number Z of the absorbing material.

Interaction of positron with matter

- Slowing down of positron due to collisions.
- Interaction of positron with an electron.
- Disappearance of two particles.
- Two rays of energy 0.511 MeV are produced and the two photons move in opposite directions.
- Annihilation radiation : Process of disappearing of positron and electron.
- Parallel spins : Three photons at an angle of 120^o
- Anti-Parallel spins : Two photons at an angle of 180^o

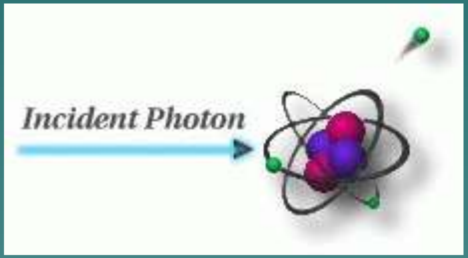
- **Multiple Coulomb scattering**
- Deviation of path due to single scattering.
- Probability of coulomb scattering of charged particle.
- Large number of multiple coulomb scattering.
- Angle of scattering may be large or small.

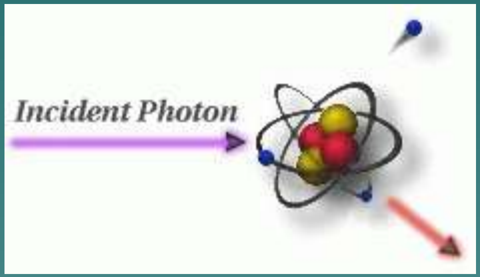
- **Range Straggling**
- Small variation in the range of particles.
- Straggling due to the following facts :
- a) Particle following a zig-zag path
- b) Fluctuations in the energy loss due to the collisions
- c) Absorbing material may be non-uniform
- Difference between R_o and R_{ex} is called straggling parameter

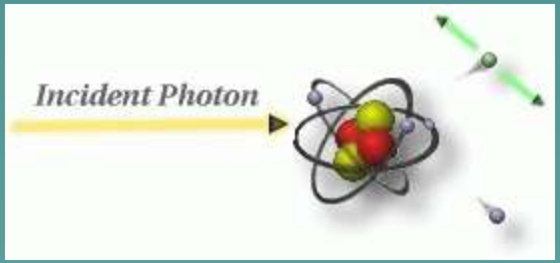
Interaction of gamma rays with matter

- 1) **Photoelectric effect**: Gamma rays striking are absorbed and an electron is liberated.
- 2) **Compton scattering**: An electron and a photon is liberated after absorption.
- 3) **Pair production**: After absorption of gamma ray an electron and a positron of energy 0.511MeV each is liberated in opposite directions.

- **Absorption of gamma rays**
- Decrease in Intensity when they are passed through matter.
- Decrease due to three previously described absorption methods.
- Decrease in intensity proportional to the thickness of the layer.
- Decrease in intensity proportional to the original intensity.


Incident Photon


Incident Photon

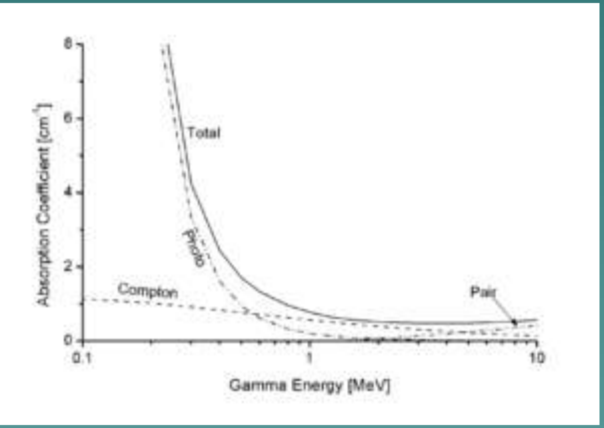

Incident Photon

- **Linear absorption Coefficient**
- Reciprocal of the thickness of the medium required to decrease the intensity of gamma ray beam to 1/e times the original intensity.
- It has units of cm^{-1} or m^{-1}
- Intensity decreases exponentially with the thickness 'x' of the medium.

- **Mass absorption Coefficient**
- Ratio of linear absorption coefficient to the density
- Unit : m^2kg^{-1}
- Independent of the physical state of matter
- Dependent on its nature
- Mass absorption coefficient of water-vapour, water and ice is the same.

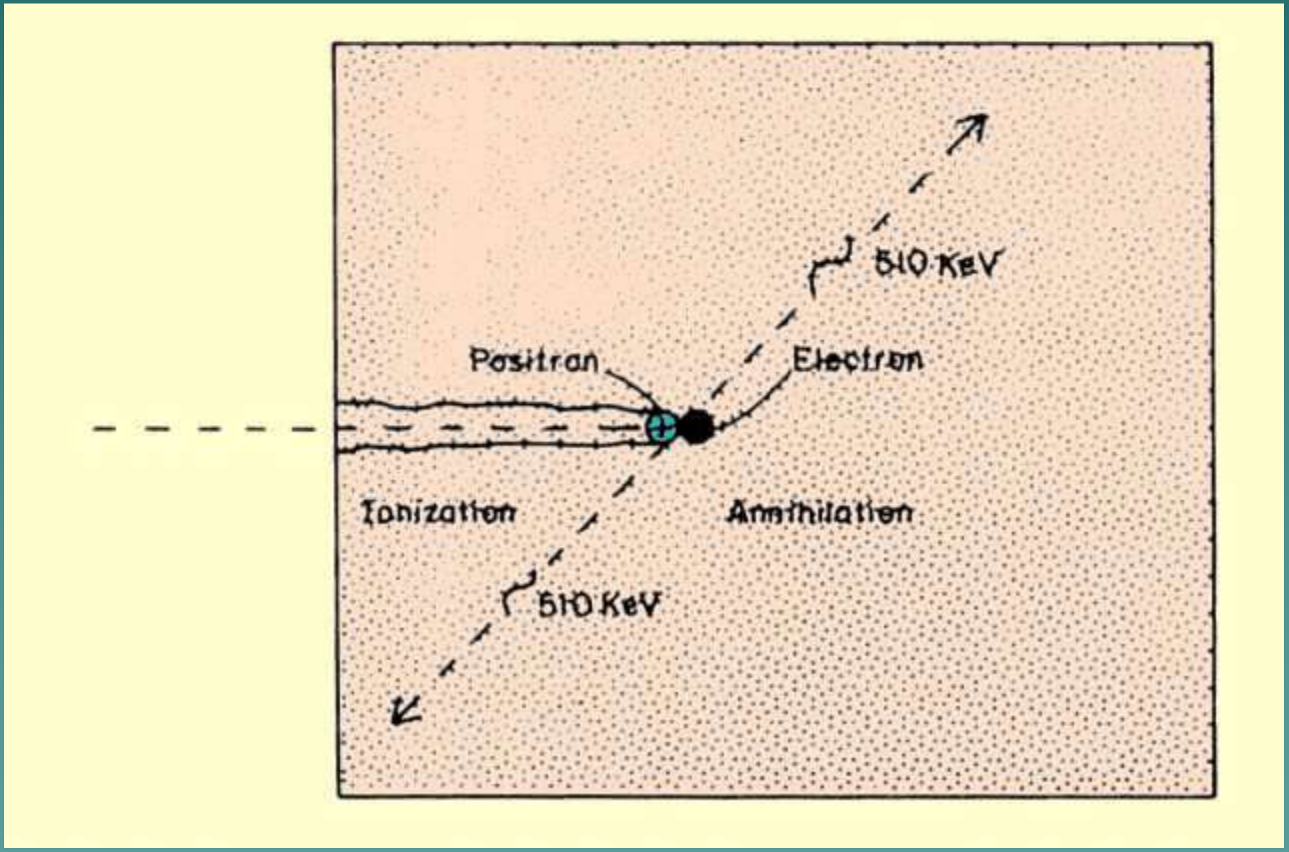
- **Half - Life Thickness**
- $I = I_o e^{-\mu x}$
- Thickness of the material required to decrease the intensity of incident gamma ray to half the original value.
- Denoted by $x_{1/2}$
- $x_{1/2} = 0.693/\mu$

- **Contribution of all the three effects**
- At Low energies - Photoelectric effect dominates
- At Medium energies- Compton scattering dominates
- At high energies more than 1.02 MeV- Pair production dominates
- Photoelectric effect is the best out of the three as in the other two processes, either scattered photon or annihilation radiations are emitted.


Absorption Coefficient [cm⁻¹]
Gamma Energy [MeV]
Total
Photo
Compton
Pair
0
2
4
6
8
0.1
1
10

Pair Production

- Occurs at energy more than 1.02 MeV.
- Pair of positron and electron is produced.
- Move in opposite direction at an angle of 180^o.
- Explained from Dirac's wave equation.
- Transitions from negative to positive energy states are possible when sufficient energy more than $2m_oc^2$ is supplied .
- An electron disappears and a positive energy hole appears corresponding to a positron.



510 KeV
Positron
Electron
Ionization
Annihilation
510 KeV

Distinction between γ rays and X-rays

- γ-rays are produced by radioactive emission, while X-rays are produced when a transition takes place from higher to lower energy level.
- γ-rays is a nuclei process, while X-rays is an atomic process.
- Wavelength of γ ray is less then X-ray.
- Penetrating Power of γ-ray is higher then X-ray.
- γ-rays are monochromatic while X-rays are hard, medium and soft.
- X-rays produce photoelectric effect and Compton scattering, while γ-rays produce photoelectric, Compton and pair production.