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Department of Biomedical Engineering

Course Code & Name: 19BME301 – Medical Physics

III Year : V Semester

Unit II

INTERACTION OF RADIATION WITH MATTER

Ionizing radiation

- Ionizing radiation is radiation that has sufficient energy to remove electrons from atoms, creating ions.
- Ionizing radiation can be classified into two groups: photons (gamma and X-rays) and particles (alpha, beta, and neutrons)

Basic Concepts Of Interaction of photons with matter

- Three possible occurrences when x or gamma photons in the primary beam pass through matter:
  - No interaction at all
    - Known as transmission
  - Absorption
  - Scatter
    - The latter two are methods of attenuation

Attenuation Of An X-Ray Photon

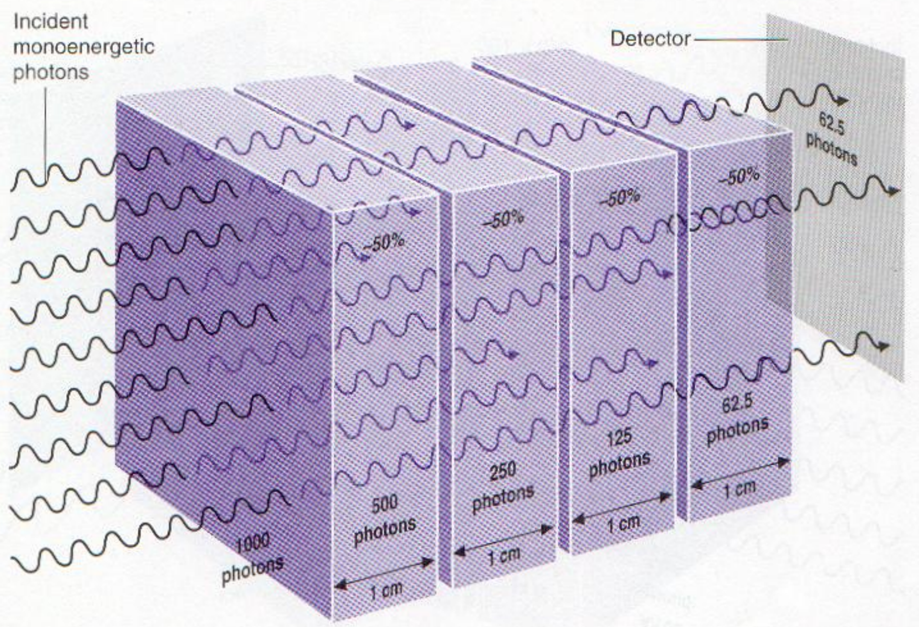


Figure 4–1 Attenuation of a monoenergetic beam.

The Three main Interactions Of X and Gamma Rays With Matter

- Photoelectric effect
  - Very important in diagnostic radiology
- Compton scatter
  - Very important in diagnostic radiology
- Pair production
  - Very important in therapeutic & diagnostic radiology

Photoelectric Effect

- All of the energy of the incoming photon is totally transferred to the atom
  - Following interaction, the photon ceases to exist
- The incoming photon interacts with an orbital electron in an inner shell – usually K
- The orbital electron is dislodged
- To dislodge the electron, the energy of the incoming photon must be equal to, or greater than the electron’s energy

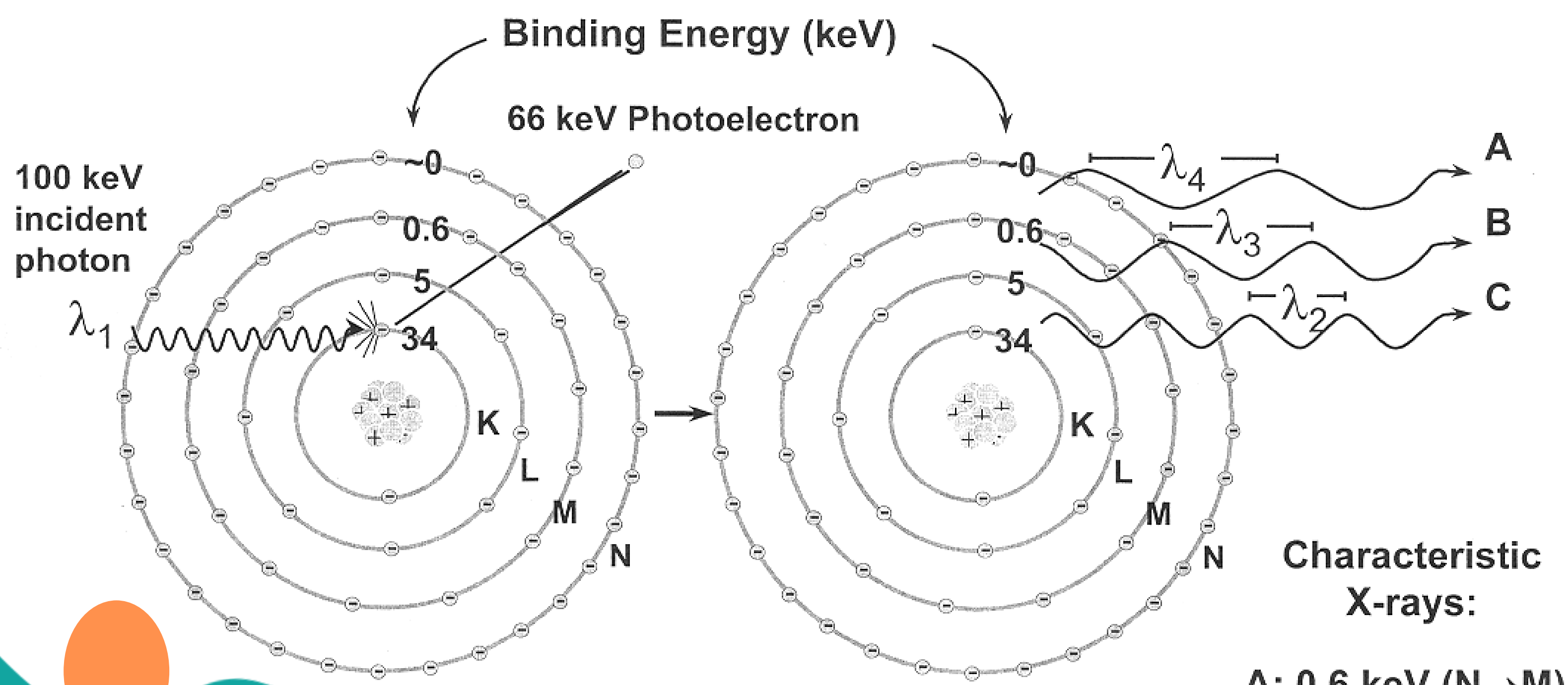
Photoelectric Effect

- The incoming photon gives up all its energy, and ceases to exist
- The ejected electron is now a photoelectron
- This photoelectron now contains the energy of the incoming photon minus the binding energy of the electron shell
- This photoelectron can interact with other atoms until all its energy is spent

Photoelectric Effect

- A vacancy now exists in the inner shell
- To fill this gap, an electron from an outer shell drops down to fill the gap
- Once the gap is filled, the electron releases its energy in the form of a characteristic photon
- This process continues, with each electron emitting characteristic photons, until the atom is stable
- The characteristic photon produces relatively low energies and is generally absorbed in tissue

Photoelectric absorption (I-131)



$\lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$

The Byproducts of the Photoelectric Effect

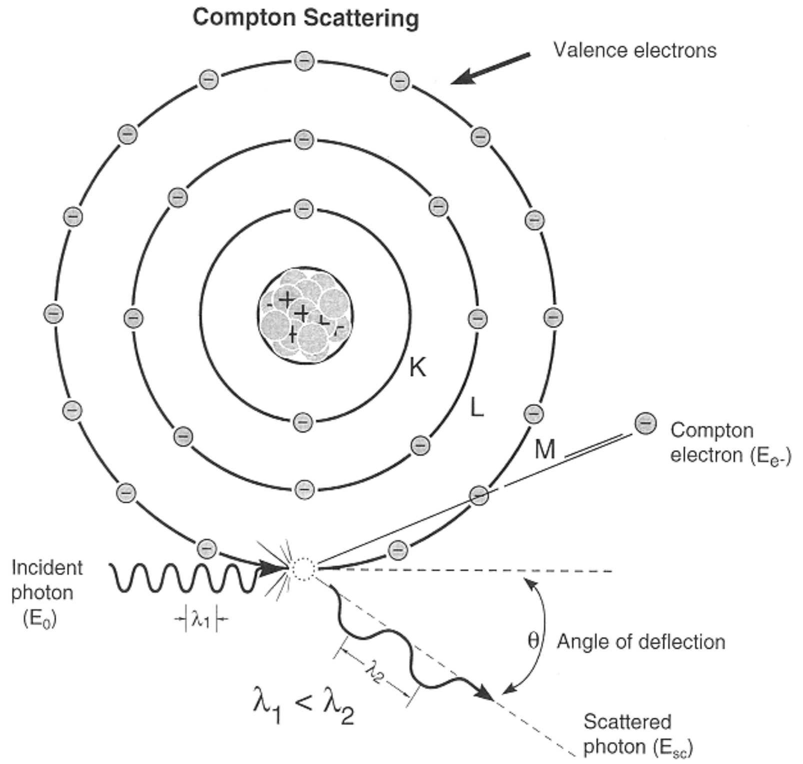
- Photoelectrons
- Characteristic photons

What Does This All Mean?

- Bones are more likely to absorb radiation(Higher Z)
  - This is why they appear white on the film
- Soft tissue allows more radiation to pass through than bone (Lower Z)
  - These structures will appear gray on the film
- Air-containing structures allow more radiation to pass through
  - These structures will appear black on the film

Compton Scattering

- An incoming photon is partially absorbed in an outer shell electron
- The electron absorbs enough energy to break the binding energy, and is ejected
- The ejected electron is now a Compton electron
- Not much energy is needed to eject an electron from an outer shell
- The incoming photon, continues on a different path with less energy as scattered radiation


Compton Scattering
Valence electrons
K
L
M
Compton electron (E_{e-})
Incident photon (E_0)
λ_1
λ_2
$\lambda_1 < \lambda_2$
θ Angle of deflection
Scattered photon (E_{sc})

Pair Production

- Incoming photon must have an energy of at least 1.02 MeV
- This process is a conversion of energy into matter and then matter back into energy
- Two electrons are produced in this interaction

Pair Production

- An incoming photon of 1.02 MeV or greater interacts with the nucleus of an atom
- The incoming photon disappears
- The transformation of energy results in the formation of two particles
- Negatron
  – Possesses negative charge
- Positron
  – Possesses a positive charge

Pair Production

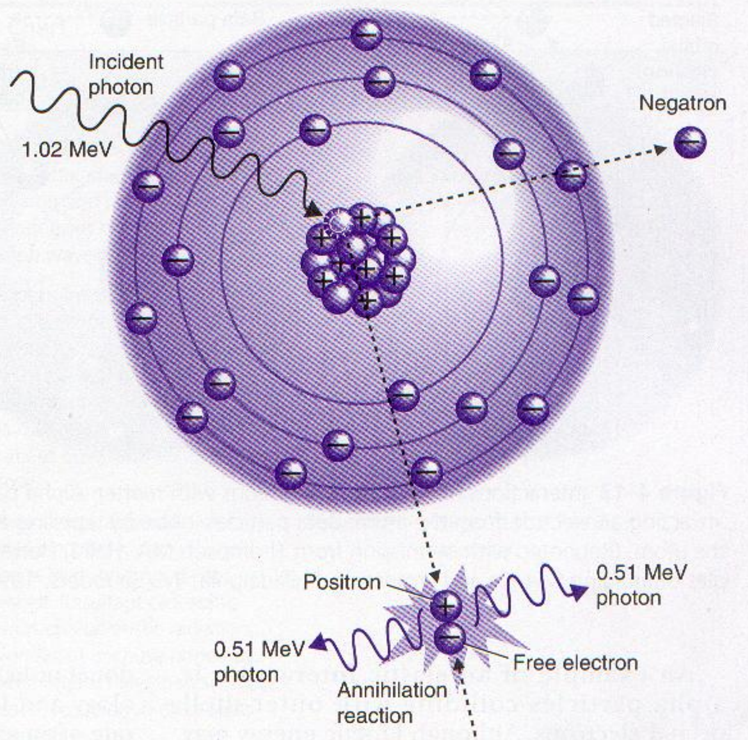


Figure 4–10 Pair production.

Positrons

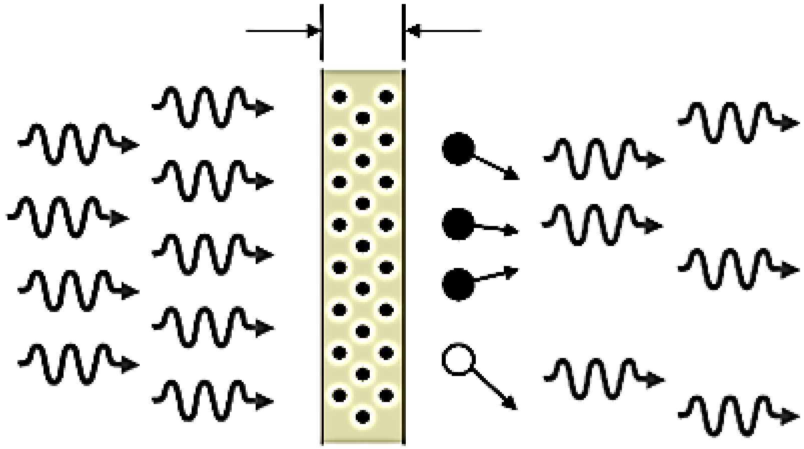
- Considered antimatter
- Do not exist freely in nature
- Cannot exist near matter
- Will interact with the first electron they encounter
- An electron and the positron destroy each other during interaction
  - Known as the annihilation reaction
- This converts matter back into energy
- Both the positron and electron disappear
- Two gamma photons are released with an energy of .51 MeV

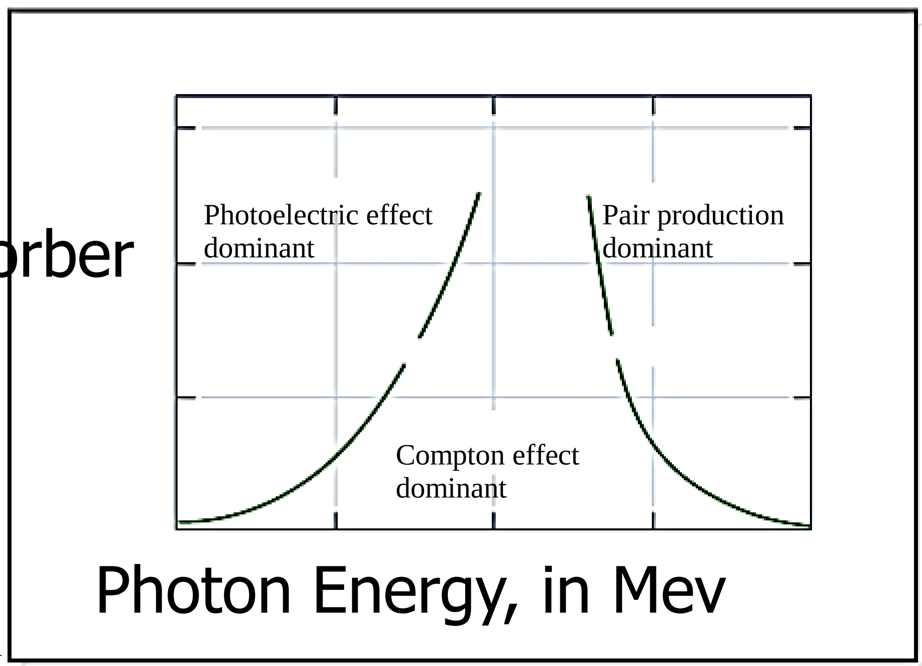
Pair Production

- The produced gamma photons may interact with matter through pair production or Compton scatter
- Pair production is used for positron emission tomography, a nuclear medicine imaging procedure
- It is also used in radiation therapy

Pair production probability

- · Increases with **increasing photon energy**
- · Increases with atomic number approximately as $\mathbf{Z^2}$




Z of absorber
Photoelectric effect dominant
Pair production dominant
Compton effect dominant
Photon Energy, in Mev
1
0.1
1
10
100

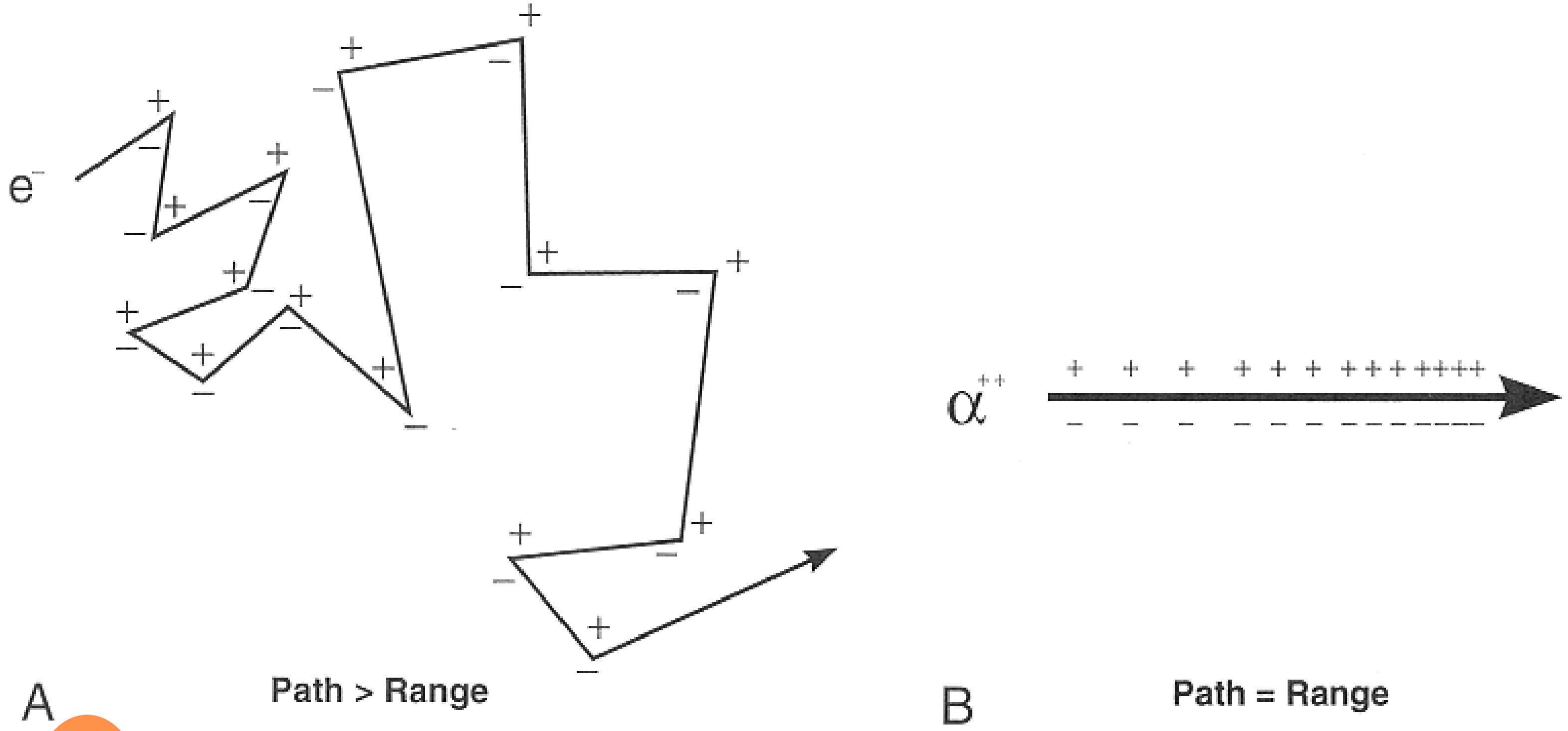
Particle interactions

- Energetic charged particles interact with matter by electrical forces and lose kinetic energy via:
  - Excitation
  - Ionization
  - Radiative losses

Charged Particle Tracks

- Electrons follow tortuous paths in matter as the result of multiple scattering events
  - Ionization track is sparse and nonuniform
- Larger mass of heavy charged particle results in dense and usually linear ionization track
- *Path length* is actual distance particle travels; *range* is actual depth of penetration in matter

Path lengths vs. ranges



Linear Energy Transfer

- Amount of energy deposited per unit path length is called the *linear energy transfer* (LET)
- Expressed in units of eV/cm
- LET of a charged particle is proportional to the square of the charge and inversely proportional to its kinetic energy(velocity)
- High LET radiations (alpha particles, protons, etc.) are more damaging to tissue than low LET radiations (electrons, gamma and x-rays)

Specific Ionization

- Number of primary and secondary ion pairs produced per unit length of charged particle's path is called *specific ionization*
  - Expressed in ion pairs (IP)/mm
- Increases with electrical charge of particle
- Decreases with increase incident particle velocity

Bremsstrahlung(Radiative losses)

- Probability of bremsstrahlung production per atom is proportional to the square of Z of the absorber
- Energy emission via bremsstrahlung varies inversely with the square of the mass of the incident particle $(Z/M)^2$
  - Protons and alpha particles produce less than one-millionth the amount of bremsstrahlung radiation as electrons of the same energy

Thank You