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Department of Biomedical Engineering

Course Name: 19BME301 – Medical Physics

III Year : V Semester

Unit II – INTERACTION OF RADIATION WITH MATTER

Interactions 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)

A -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

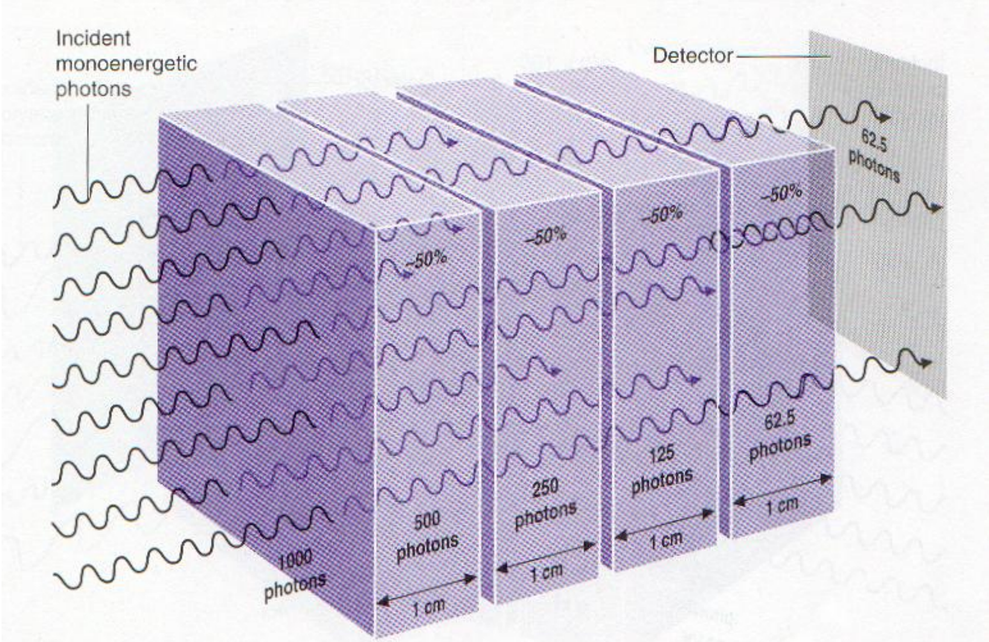


Figure 4–1 Attenuation of a monoenergetic beam.

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

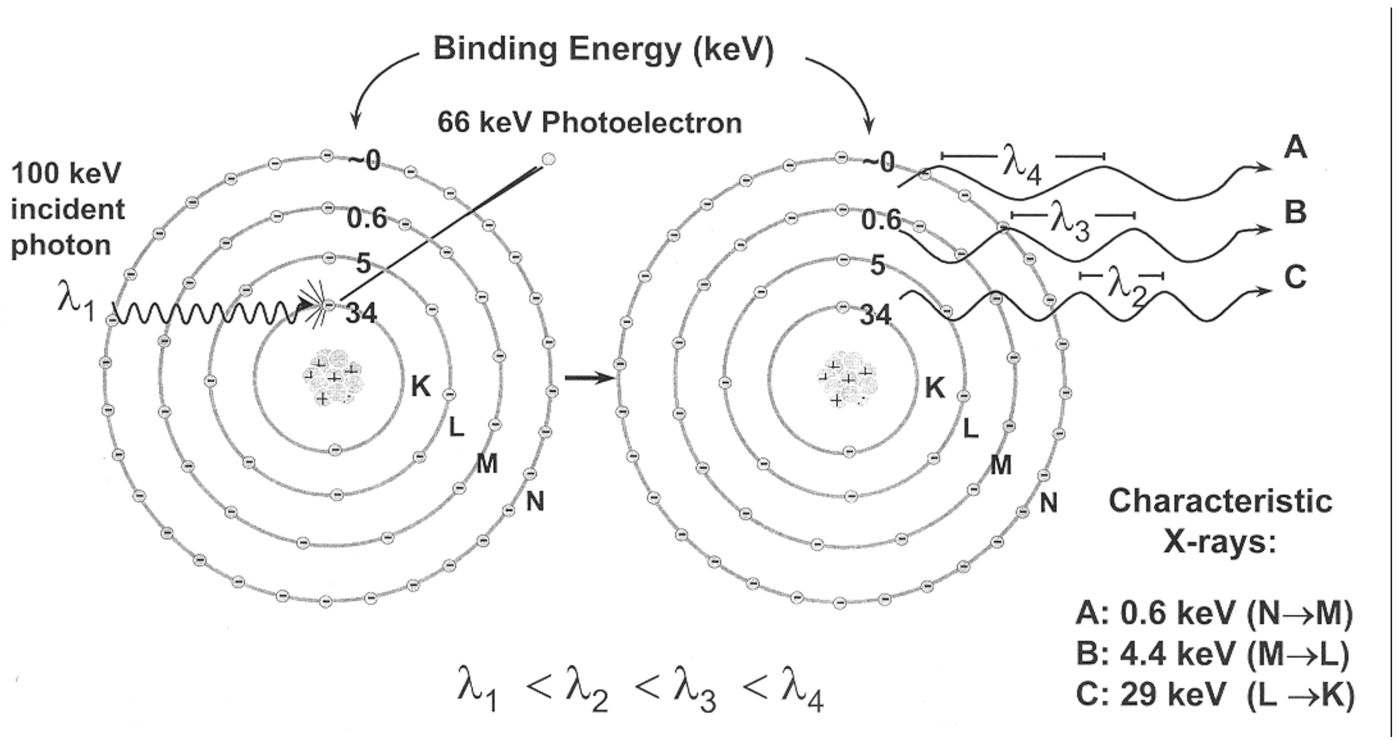
Photoelectric Effect

- 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)



The Byproducts of the Photoelectric Effect

- Photoelectrons
- Characteristic photons

The Probability of Occurrence

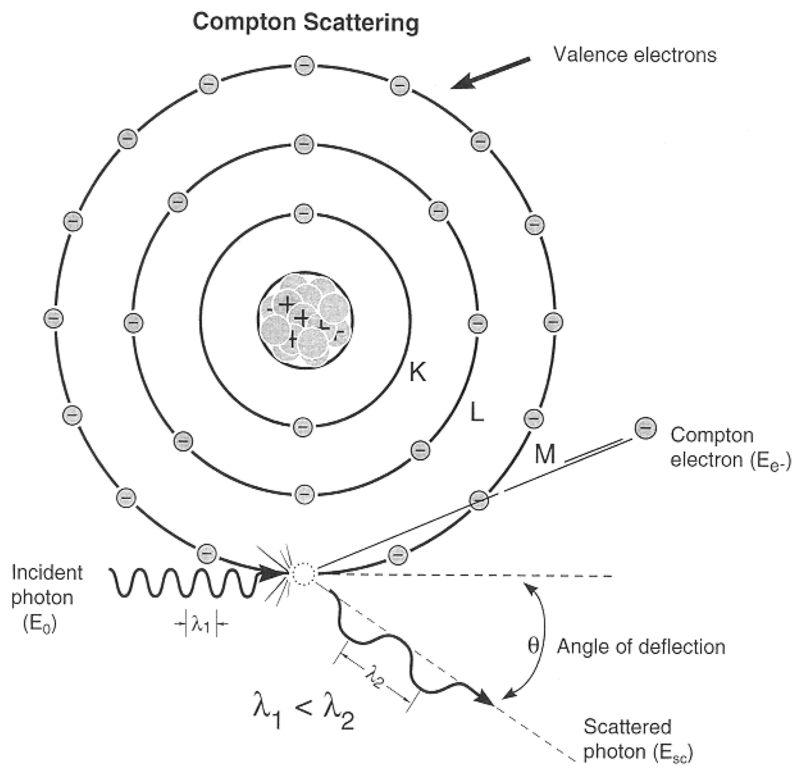
- Depends on the following:
  - The energy of the incident photon(E)
  - The atomic number of the irradiated object(Z)
  - It increases as the photon energy decreases, and the atomic number of the irradiated object increases
  - The probability of photoelectric absorption, is roughly proportional to (Z/E)3
  - This type of interaction is prevalent in the diagnostic keV range – 30 - 150

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})

Byproducts Of Compton Scatter

- Compton scattered electron
  - Possesses kinetic energy and is capable of ionizing atoms
  - Finally recombines with an atom that has an electron deficiency
- Scattered x-ray photon with lower energy
  - Continues on its way, but in a different direction
  - It can interact with other atoms, either by photoelectric or Compton scattering
  - It may emerge from the patient as scatter

Probability Of Compton Scatter Occurring

- Increases as the incoming photon energy increases up to certain limit then decreases as the photon energy increases.
- Independent on Z of the absorber.
- The Compton process is most important for energy absorption for soft tissues in the range from 100 keV to 2MeV.

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

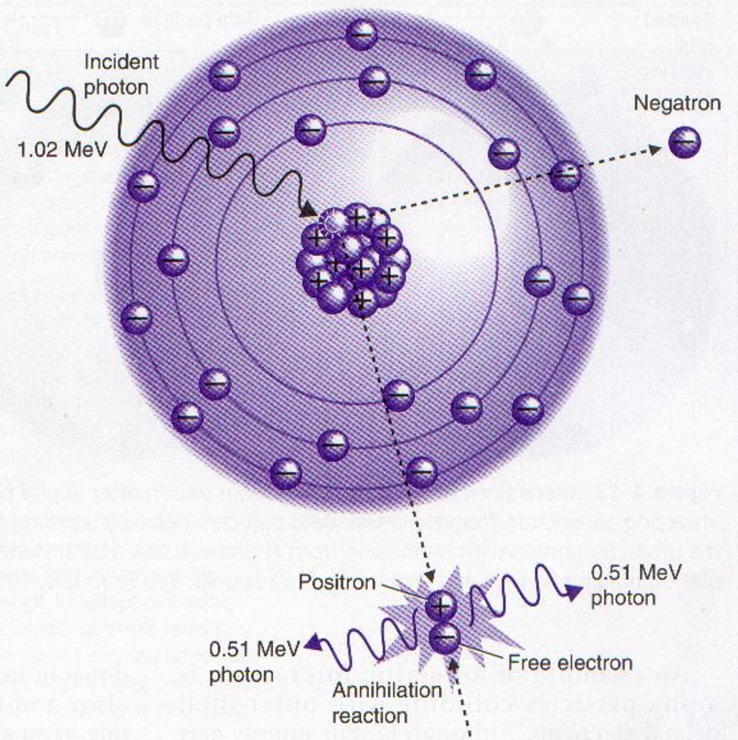


Figure 4–10 Pair production.

Positrons

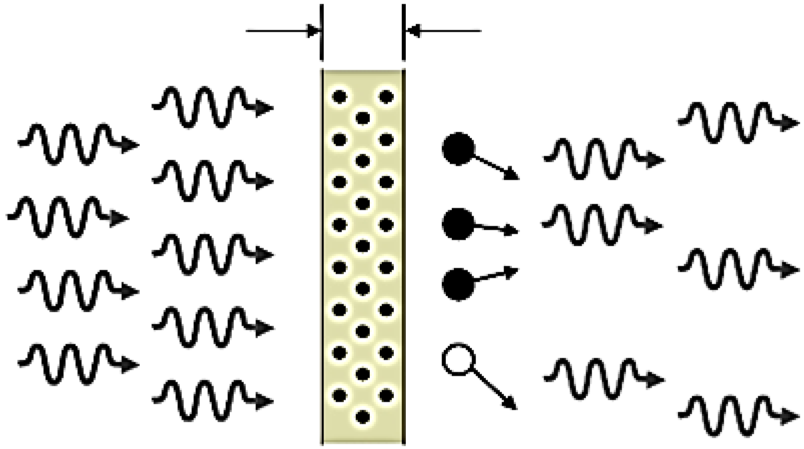
- Considered antimatter
- Do not exist freely in nature
- Cannot exist near matter
- Will interact with the first electron they encounter
- An electron and the positron destroy each other during interaction
  - Known as the annihilation reaction
- This converts matter back into energy
- Both the positron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

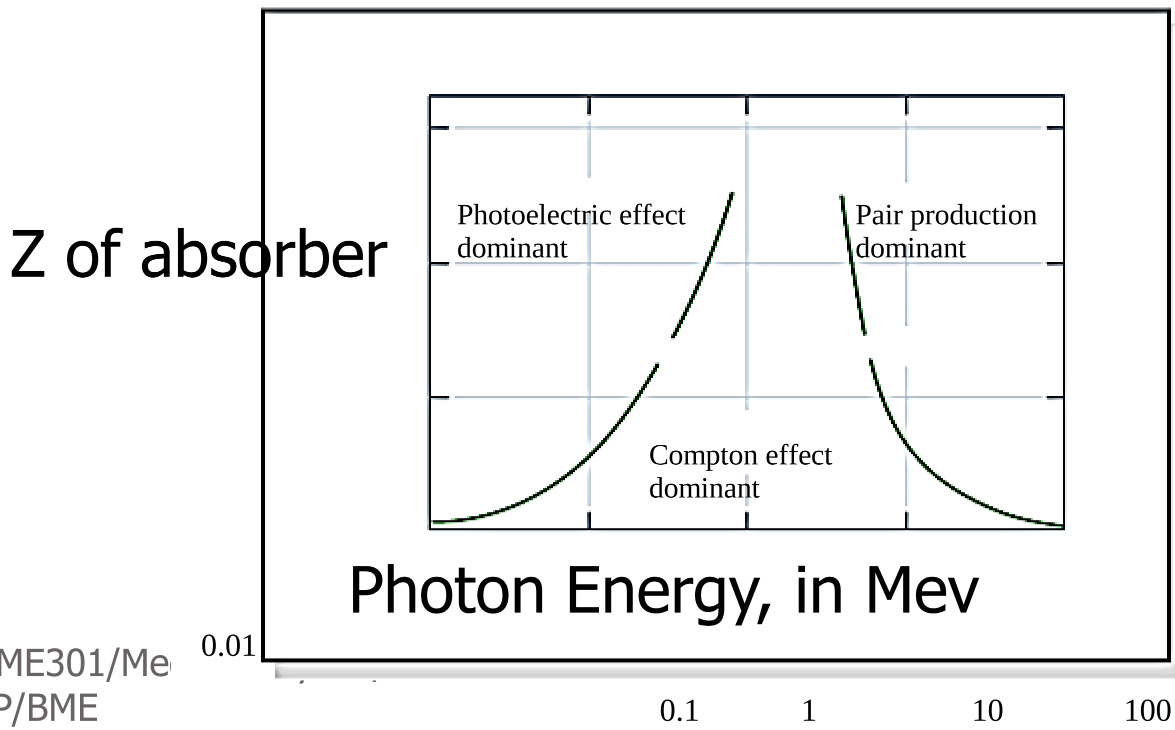
Pair Production

- 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 **Z^2**




Z of absorber
Photoelectric effect dominant
Pair production dominant
Compton effect dominant
Photon Energy, in Mev
0.01
0.1
1
10
100

-Interactions Of Particulate Radiation With Matter

- Alpha particles ionize by attracting an electron from an atom
- Beta particles ionize by repelling an electron from an atom

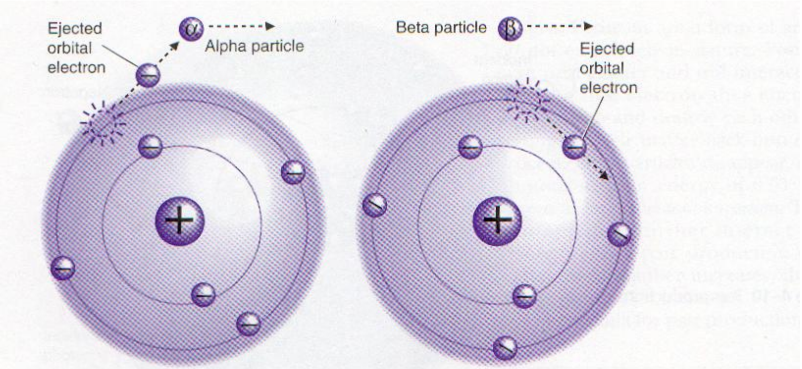


Figure 4–12 Interactions of particulate radiations with matter. Alpha particles ionize by attracting an electron from the atom. Beta particles ionize by repelling an electron away from the atom. (Reprinted with permission from Thompson MA, Hall J, Hattaway P, Dowd S: Principles of Imaging Science and Protection. Philadelphia, WB Saunders, 1994.)

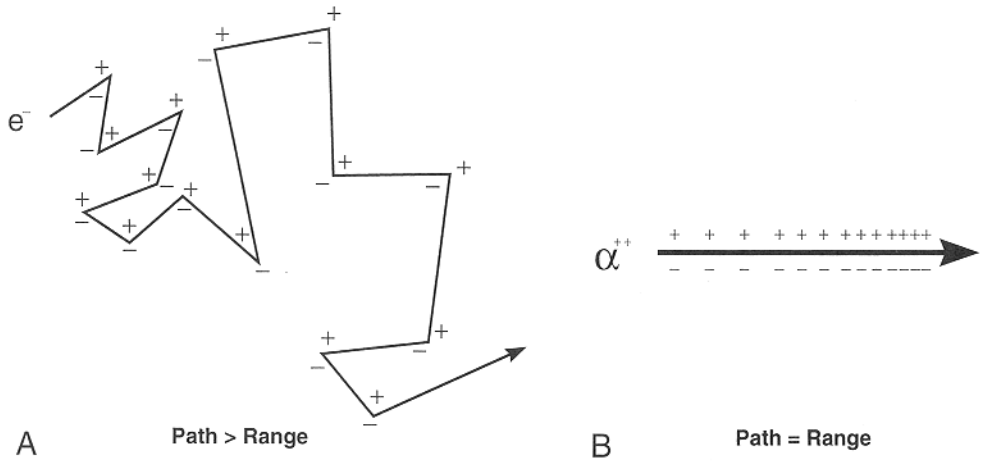
Particle interactions

- 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)

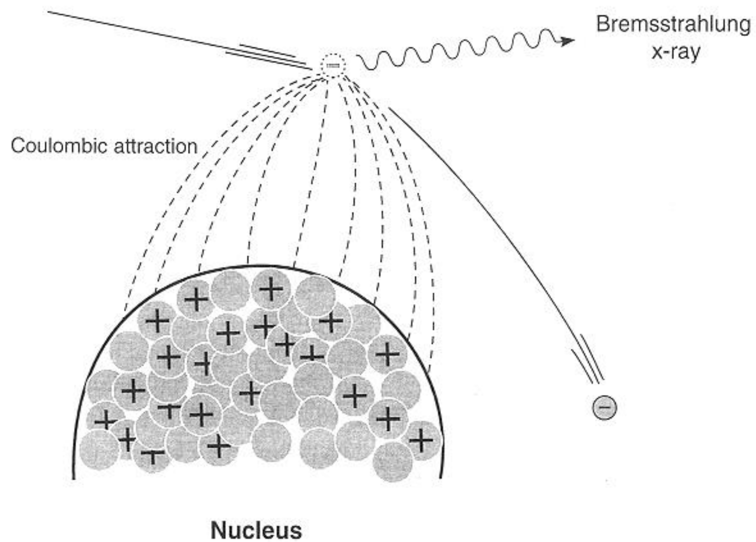
Specific Ionization

- 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

Bremsstrahlung



Question 1

- What are the factors affecting The Probability of Occurrence of :
- Photoelectric effect
- Compton scattering
- Pair production
- Bremsstrahlung

Question 2

- What are the byproducts of :
- Photoelectric effect
- Compton scattering
- Pair production
- Bremsstrahlung

Question 3

- Give the scientific reason for:
- Bones appear more clear than soft tissues in the radiographic film?
- Lead is used for sheading gamma **emitters**?
- Plastic is preferred than lead for sheading Beta emitters?

Thank You