PAM1014
Introduction to Radiation Physics

"X-ray Interaction"

In this lecture

★Attenuation
★Possible Interactions
★X-ray Matter Interactions

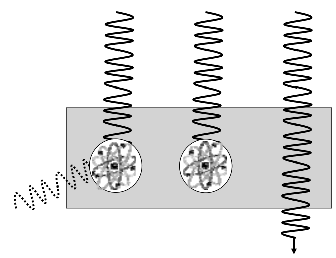
Attenuation

- What is attenuation
- Absorption
- Scattering

Possible Interactions

- Three types of interaction

1. Scattering
   - Interaction with an atom
   - Deflected
   - May or may not loss of energy



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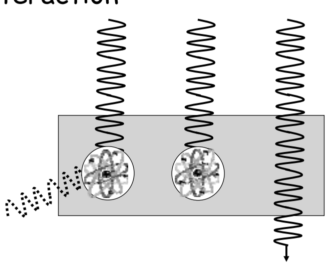
Possible Interactions

- Three types of interaction

1. Scattering
2. Absorption
   - Interaction with an atom
   - Loses all of it energy to the atom



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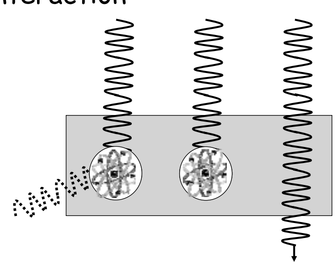
Possible Interactions

- Three types of interaction

1. Scattering
2. Absorption
3. No Interaction
   - Passes through material without interacting ANY atoms



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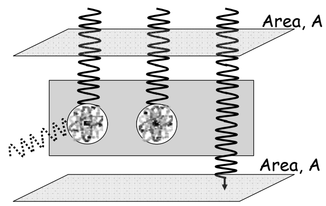
Possible Interactions

- Compare radiation intensity before and after interaction with medium
- Lower intensity after passing through medium
- Beam has been attenuated by processes of scattering & absorption



Attenuation Processes

Five x-ray attenuation processes:

1. Coherent (or Elastic) Scattering
2. Photoelectric Effect
3. Compton Scattering
4. Pair Production
5. Photodisintegration

Coherent Scatter

- If the energy of a photon is considerably less than binding energies of orbiting electrons of an atom the photon may be deflected from it's path with NO loss in energy
- Also called *Classical* or *Rayleigh Scattering*

Coherent Scatter

- The photon interacts with an electron, raise it's energy.
- Not sufficient to become excited or ionized
- Returns to original energy level and emits photon with same energy as the incident photon
- Different direction: Therefore scattered

Coherent Scatter

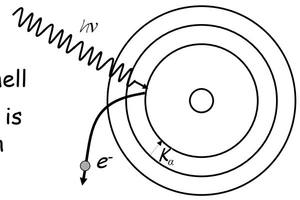
- Predominantly forward scatter
- Elastic scatter can not occur if recoil experienced by atom is sufficient to cause excitation or ionization
- No absorption:
  - I.e. No energy has been permanently transferred to material

Photoelectric Effect

- X-ray photon involved in an inelastic collision with an orbiting electron
- Photon gives up ALL of its energy and therefore disappears (absorbed)
- Electron is ejected from atom
- Can only take place if photon energy is equal to or greater than electron binding energy

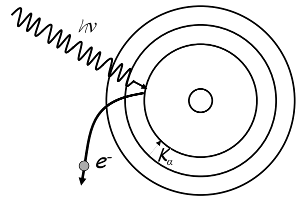
Photoelectric Effect

- X-ray photon of energy $h\nu$
- Electron ejected from K-shell
- Some of the photon energy is used in overcoming electron binding energy, B
- Remaining energy is given to electron as kinetic energy
- Electron Kinetic Energy = ($h\nu$ – B)



Photoelectric Effect

- Vacancy created in K-shell will be filled by electron from the L-shell
- Quantum 'jumps' producing characteristic radiation
- Energy of characteristic photon is equal to energy difference between shells
- For tissue, energy difference is very small
  - ($1.2 - 1.8 \times 10^{-2}$ eV) => Infrared



Photoelectric Effect

- Probability related to the atomic number of the absorber (Z) and the photon energy (E)
- Approximated by:

$$\propto \frac{Z^3}{E^3}$$

- Applies to E up to 200 keV.
- At higher energies E^3 term approximates to E^2 & eventually E

Photoelectric Effect

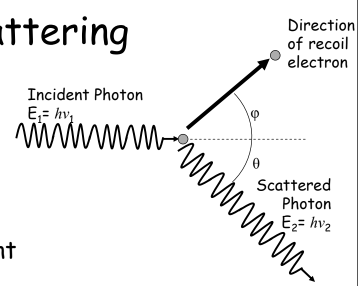
- Photoelectric Effect causes both *attenuation* and *absorption,* BUT NOT *scattering*
- Individual photons are removed form beam
  - *Attenuation*
- Energy is imparted to the absorbing medium
  - *Absorption*
- Energy absorbed
  - Kinetic energy of ejected electron
  - Energy of recoil of absorbing atom
  - Energy of characteristic radiation

Compton Scattering

- If photon energy is much higher than electron binding energy, electron may be considered as a *free electron*
- Interaction between free electron and photon is *Compton Scattering*
- Partial absorption of photon energy

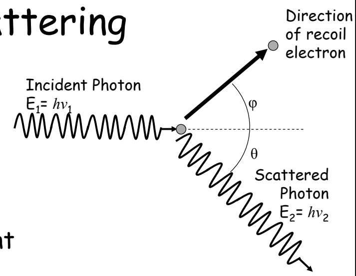
Compton Scattering

- Photon may be scattered in any direction
- Electron can only travel forwards relative to incident photon
- Partial absorption of photon energy



$$\lambda_2 - \lambda_1 = \frac{h(1-\cos\theta)}{mc}$$

Compton Scattering



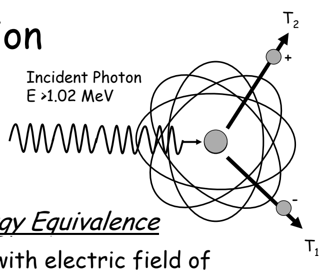
- Photon may be scattered in any direction
- Electron can only travel forwards relative to incident photon
- Partial absorption of photon energy

$$\propto \frac{electron\ density}{E}$$

Pair Production

- Formation of two charged particles from a single high-energy photon
- Can only occur for photon energies greater than 1.02 Mev
  - (Equivalent to twice the rest mass of an electron)
- Produces electron and positron pair

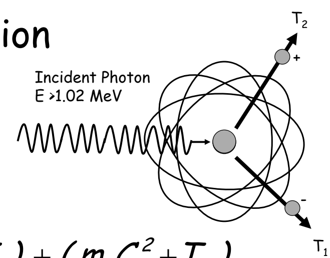
Pair Production



Mass-Energy Equivalence

- Photon interacts with electric field of nucleus
- Photon energy is converted into mass
- Any remaining energy is passed to particles as kinetic energy

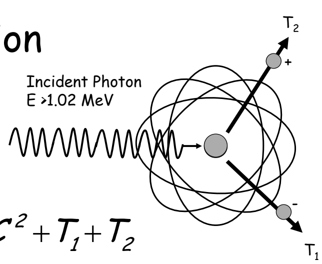
Pair Production



$$E = (m_0C^2 + T_1) + (m_0C^2 + T_2)$$

- E is the photon energy
- m_0 is electron (or positron) rest mass
- c is the speed of light
- T_1 & T_2 are the KE of the electron and positron respectively

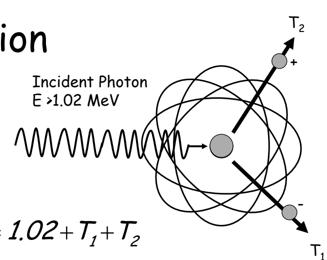
Pair Production



$$E = 2m_0C^2 + T_1 + T_2$$

- E is the photon energy
- m_0 is electron (or positron) rest mass
- c is the speed of light
- T_1 & T_2 are the KE of the electron and positron respectively

Pair Production



$$E(MeV) = 1.02 + T_1 + T_2$$

- E is the photon energy
- m_0 is electron (or positron) rest mass
- c is the speed of light
- T_1 & T_2 are the KE of the electron and positron respectively

Pair Production

- Kinetic Energy of electrons & positrons is *absorbed* by the medium
- Energy absorbed is less than original photon energy
  - (E-1.02) MeV
- Electron will eventually loss all it's energy to medium
- Positron will eventually collide with an electron
  - Positron-electron annihilation
  - Producing two photons each with energy 0.51 MeV

Pair Production

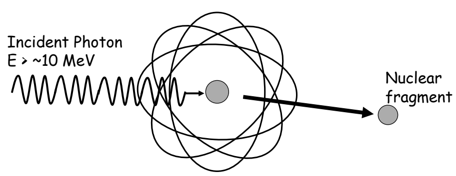
- If the two photons of annihilation radiation are absorbed by the medium, then the total energy absorbed is;

$$\text{Energy Absorbed} = (E - 1.02) + (2 \times 0.51)$$

- I.e. All the original photon energy has been absorbed
- This doesn't always happen!

Photodisintegration

- Very-high-energy photons (>10MeV) can escape interaction with electrons and nuclear electric field.



Summary

- Photoelectric effect dominates at low energies (50-500keV)
- Absorption edges are more pronounced for elements with larger Z
- Compton Scattering dominates over a wider range (50keV – 5MeV)
- Compton attenuation is independent of material (with constant density)
- Pair production is only significant for very high energies (>1.02 MeV) and materials with high atomic number (Z)