
EDENBROOK COLLEGE

Primary Beam

- High-speed electrons hit a positively
- As the electrons interact with the atom
- X-ray photons have a broad range o
- Emerging x-ray photon beam is refer

Primary Beam

- Two types of interactions in the anode can produce x-ray photons
  - Characteristic
    - Narrow range of energies
  - Bremsstraulung
    - Most x-ray interactions in diagnostic range

Characteristic Radiation

- Characteristic x-rays are produced after ionization of a K-shell electron.
- When an outer-shell electron fills the vacancy in the K shell, an x-ray is emitted.

Bremsstrahlung Radiation

- Results from the interaction between a projectile electron and a target nucleus.
- Electron is slowed and its direction is changed.

Technical Factors

- Selection of optimal technical factors is critical in minimizing patient dose while producing high quality x-ray imaging.

- It is our job to understand how radiation interacts with matter so that we can select optimal techniques.

Peak Kilovoltage (kVp)

- Highest energy level of photons in the x-ray beam
- kVp controls the quality or penetrating power, of the photons in the beam
- Low kVp won't make it out of the body
- High kVp will go straight through and provide no information
- Determining the optimum kVp for the patient size and body part will reduce the patient dose

Milliampere-Seconds (mAs)

- Product of electron tube current and time (in seconds) when the x-ray tube is activated
- mAs is the main determinant of how much radiation is directed toward a patient
- mAs controls the quantity of photons

Distance

- Distance
  - Most effective means of protection from ionizing radiation
  - More distance, less radiation intensity
    - Spreads out like a flashlight beam
  - Source to Image Distance (SID) affects the density on an image
  - Beam divergence and radiation intensity varies at different distances
  - ISL states beam intensity is inversely proportional to square of the distance

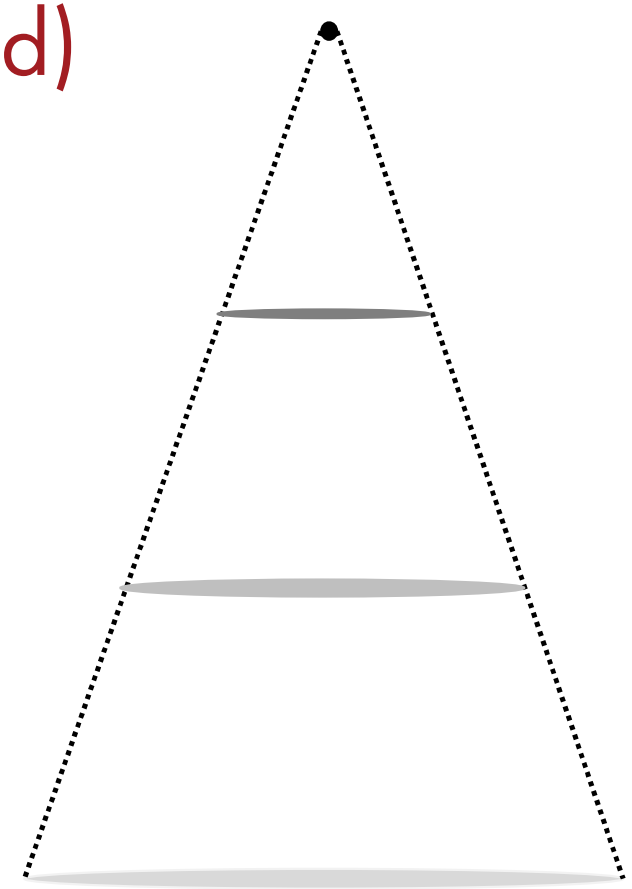
Inverse Square Law (cont'd)

$$\frac{I_1}{I_2} = \frac{(d_2)^2}{(d_1)^2}$$

- I_1 = Exposure (intensity) at original distance
- I_2 = Exposure (intensity) at new distance
- d_1 = Original distance from source of radiation
- d_2 = New distance from source of radiation

Inverse Square Law (cont'd)

- SID and Radiation Intensity
  - 2 x SID = 1/4th of radiation intensity
  - 3 x SID = 1/9th of radiation intensity
  - 4 x SID = 1/16th of radiation intensity



What Happens in the Patient ?

When radiation enters matter it can be:

1. Attenuated - interact with atoms in the patient
2. Transmitted – pass through without interaction

- Factors affecting photon interactions include:
  - Incident photon energy
  - Density, thickness and atomic number of the matter, tissue or organ in which it interacts

X-ray Photons

- Absorption and scatter both contribute to attenuation

- May be absorbed and transfer their energy to the tissue
- May be scattered, change direction and possibly lose energy

Radiation Protection

- Absorption: patient dose

- Scatter: technologist dose

Interactions that Attenuate the Primary Beam

- Photoelectric absorption
- Compton scattering
- Coherent, Classical, Elastic and Unmodified scattering (all the same)
- Pair Production
- Photodisintegration

Two most important to us are photoelectric absorption and Compton scattering

Compton and Photoelectric Interactions

- In these interactions incident photons either:
  - Interact and are absorbed by the atom (Photoelectric Interaction)
  - Interact and change direction, called “Scattering” (Compton Interaction)

Photoelectric Absorption

- Photoelectric absorption or effect
- Responsible for patient dose and image contrast
- Results when a photon interacts with a k-shell electron
- Total absorption of the incident photon
- Occurs if the energy is equal to or slightly greater than the binding energy of the atom

Photoelectron

- Negative ion
- Quickly absorbed, micrometres in tissue
- Photoelectron's kinetic energy is equal to the energy of the incident photon, less the binding energy of the electron shell
- May interact with other atoms until all the energy is gone

Reaction in the Atom

- Atom is ionized, unstable energy
- Electron will drop from an outer shell to fill the void left by the photoelectron
- Radiation is produced when an electron from the "L" shell jumps into the "K" shell and releases energy
- Radiation given off is "characteristic radiation" with energy equal to the difference in binding energy

Photoelectric Effect Facts

- Increase probability of PE effect :
  - Decrease of energy of incident photon
  - Higher atomic number of irradiated tissue

- Good for image quality, increased contrast

Patient dose factors

- Lower kVp = more photoelectric interaction
- Higher atomic number = more PE absorption

Low kVp and high atomic numbers = increase patient dose

Products of the Photoelectric Effect Interaction in the Body

1. Photoelectron

2. Positive Ion

3. Characteristic Radiation

Three Rules of PE Interaction

1. Incident photon energy must be greater than the binding energy of the inner shell electron.

2. More likely when the photon energy and electron binding energy are close.

3. More likely to occur with an electron more tightly bound in its orbit.

PE conclusion

- Increased photoelectric effect provides increased contrast

- Increased photoelectric effect increases patient dose

Compton Interaction

- Compton scattering is also known as:
  - Incoherent scattering
  - Inelastic scattering
  - Modified scattering

- Responsible for most of the scattered radiation during radiographic procedures

Compton Interaction

- Interaction between incident photon and loosely-bound outer shell electron
- Incident photon ejects the electron from its shell, giving up some of its energy and resulting in ionization of the atom
- Incident photon is scattered in a different direction
- Ejected electron can be called a Compton or secondary scatter or recoil electron

Characteristics of Compton

- Energy and direction of scatter depends on energy of incident photon
- As mass density of tissue being irradiated increases, so does the increase of Compton Scatter
- Not always totally absorbed and can leave the body, causing less patient dose
- Image quality is decreased if it hits the IR, adds no useful information

Characteristics of Compton

- Scatter provides the biggest safety hazard for us!
- Increased Compton scattering relative to photoelectric effect as x-ray energy increases
- Free electrons from Compton scatters can cause biological damage
- Scattered radiation in a diagnostic exam consists mainly of the Compton effect

Energy Dispersion

- After collision, the energy of the incident photon is distributed between energy of scattered photon and ejected electron that may be capable of ionizing other atoms
- Incident photon will lose energy
- The Compton Electron may recombine with an atom needing an electron
- Two factors determine the energy the photon retains:
  - Initial energy of the incoming photon
  - Angle of deflection

Products of Compton Interaction in the Body

1. Scattered photon

2. Compton/secondary/recoil electron

3. Positive ion (remaining atom)

Principle factors of Compton scatter

1. kVp

2.Mass density of irradiated material

Coherent, Classical, Elastic and Unmodified Scatters

- All mean the same thing
- Interaction that occurs between very low energy photons and whole atom
- Occurs with photons at 10 keV or less
- Photon changes direction less than 20° with **no change in energy**
- **Insignificant in diagnostic imaging**

Pair Production

- Interaction between a very high energy incident photon (1.02 MeV) and the nucleus
- Photon gives up all its energy
- Does not occur in the diagnostic range
- Two particles are formed:
  - Negatron
  - Positron
- Annihilation—mass totally disappears

Photodisintegration

- Interaction is between extremely high energy photon (10 MeV) and the nucleus
- All energy of the photon is absorbed by nucleus, exciting the nucleus
- Excited nucleus emits a nuclear fragment
- Part of the nucleus ejected may be in the form of a neutron, proton or alpha particles

Attenuation

- Attenuation will be greater with:
  - Decreased average energy of the beam
  - Increased thickness of the body part
  - Higher atomic number of the matter
  - Increased tissue density

Human Body

- Variable thickness and density throughout the body
- Air, fat, muscle and bone all have different atomic numbers and densities

Matter	Effective Atomic #	Mass Density
Lung	7.4	320 kg/m³
Fat	6.3	910 kg/m³
Muscle	7.4	1000 kg/m³
Bone	13.8	1850 kg/m³

Bushong, 2013, pp. 152, 157; Statkiewicz Sherer, et al., 2013, pp. 50–51

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