X-ray Interaction (Part II)

In this lecture

★Differential Attenuation
★Effect on Radiographic Image
★Contrast Examinations
★Exponential Attenuation

Attenuation in Radiography

- At particular photon energies, some or all of the attenuation processes may be competing to remove photons form the X-ray beam
- Consider linear attenuation coefficients for radiological purposes

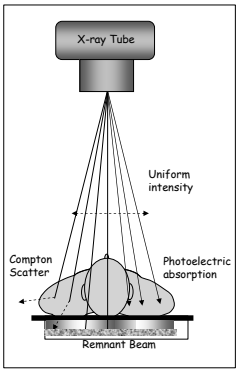
$$I_x = I_o e^{-(\mu)x}$$

or

$$I_x = I_o e^{-(\tau+\sigma+\pi)x}$$

Differential Attenuation

- Of the five interaction processes two are important for diagnostic radiography
- The transmitted x-rays are more important than those which interact

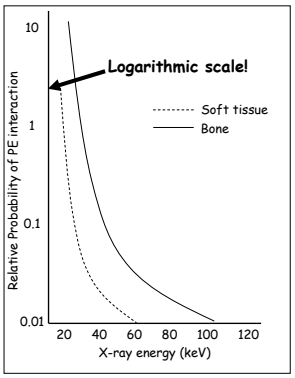


Dependence on Atomic Number, Z

- Example: Extremity examination
- More photons are absorbed photoelectrically in bone than in soft tissue
- Photoelectric absorption is proportional to Z^3
- Probability of PE interaction in bone is 7 times for bone than soft tissue

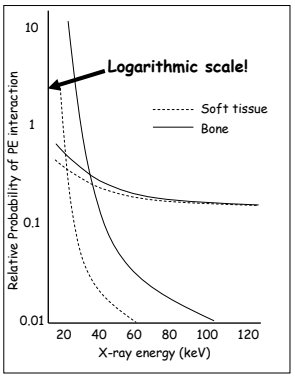
Dependence on Atomic Number, Z

Photoelectric Contribution for bone & soft tissue



Dependence on Atomic Number, Z

Combined Contribution of Photoelectric & Compton scattering for bone & soft tissue



Dependence on Atomic Number, Z

Effective atomic numbers of materials important to diagnostic radiography

Material	Atomic Number (Z)
Human Tissue	
Fat	6.3
Muscle/soft tissue	7.4
Lung	7.4
Bone	13.8
Contrast Agents	
Air	7.6
Barium	53
Iodine	56
Other Materials	
Concrete	17
Molybdenum	42
Tungsten	74
Lead	82

Dependence on Atomic Number, Z

Example:

How much more likely is an x-ray photon to interact with bone than fat?

Material	Atomic Number (Z)
Human Tissue	
Fat	6.3
Muscle/soft tissue	7.4
Lung	7.4
Bone	13.8
Contrast Agents	
Air	7.6
Barium	53
Iodine	56
Other Materials	
Concrete	17
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Dependence on Mass Density

- Intuitively, we could image bone even if differential absorption were not related to Z
  - Bone has a higher Mass density than soft tissue
- Mass density: mass per unit volume (Kg/m^3)
- All interactions are proportional to mass density

Material	Mass Density (Kgm^{-3})
Human Tissue	
Lung	320
Fat	910
Muscle/soft tissue	1000
Bone	1850
Contrast Agents	
Air	1.3
Barium	3500
Iodine	4930
Other Materials	
Calcium	1550
Concrete	2350
Molybdenum	10200
Tungsten	19350
Lead	11350

Dependence on Mass Density

Example:

What is the relative probability that 60 keV X-ray photons will undergo Compton scattering in bone compared to soft tissue?

Material	Mass Density (Kgm^{-3})
Human Tissue	
Lung	320
Fat	910
Muscle/soft tissue	1000
Bone	1850
Contrast Agents	
Air	1.3
Barium	3500
Iodine	4930
Other Materials	
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Molybdenum	10200
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Characteristics of Differential Absorption

As x-ray energy increases	•Fewer Compton interactions •Much fewer photoelectric interactions •More transmission through tissue
As tissue atomic number increases	•No change in Compton interactions •Many more photoelectric interactions •Less transmission through tissue
As tissue mass density increases	•Proportional increase in Compton interactions •Proportional increase in photoelectric interactions •Proportional decrease in transmission through tissue

Example

- Assume that all interactions during mammography are photoelectric. What is the differential absorption of x-rays in microcalcifications relative to fatty tissue?

Contrast Examinations

- Barium & Iodine
- Both have high Z & density than soft tissue
- Example:
  - What is the probability that an x-ray will interact with iodine rather than soft tissue?

Exponential Attenuation

For exponential law to be applied

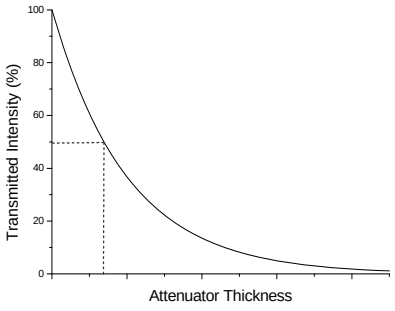
1. Radiation beam must be parallel
2. Radiation must be Monoenergetic
3. Attenuator must be homogeneous

$$I_x = I_o e^{-(\mu)x}$$

or

$$I_x = I_o e^{-(\tau+\sigma+\pi)x}$$

Exponential Attenuation

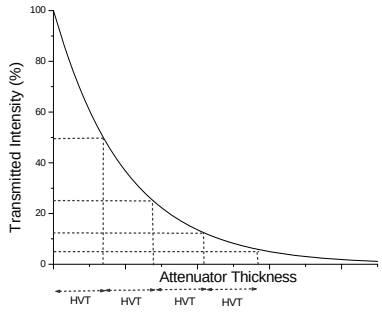


$$I_x = I_o e^{-(\mu)x}$$

or

$$I_x = I_o e^{-(\tau+\sigma+\pi)x}$$

Half-Value-Thickness



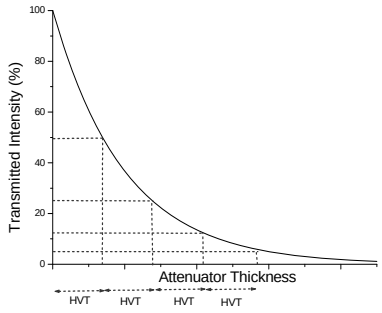
$$I_x = I_o e^{-(\mu)x}$$

or

$$I_x = I_o e^{-(\tau+\sigma+\pi)x}$$

Definition: Thickness of a substance that will transmit one-half of the intensity of radiation incident upon it

Half-Value-Thickness



$$I_x = I_o e^{-(\mu)x}$$

$$\frac{I_o}{2} = I_o e^{-(\mu)HVT}$$

$$\frac{1}{2} = e^{-(\mu)HVT}$$

$$\mu = \frac{0.693}{HVT}$$

Summary

- Differential Attenuation
- Effect on Radiographic Image
- Contrast Examinations
- Exponential Attenuation
- Half-Value-Thickness

X-ray Interaction 2 - Problem Sheet

1. Define Differential Absorption?
2. In a contrast chest x-ray, what is the relative probability that an x-ray photon will interact with lung tissue rather than air?
3. What is the relationship between the atomic number of tissue and differential absorption?
4. In a contrast examination using iodine, what is the relative probability that the x-ray beam will interact with iodine rather than soft tissue?
5. What is the relationship between the atomic number of a tissue and the differential absorption?