X-RAY ATTENUATION AND X-RAY INTERACTIONS

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Fundamental of Radio Physics

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Outline

X-ray attenuation and x-ray interaction

- The linear x-ray attenuation coefficient.
- Interaction x-ray with matter processes
- Unmodified scatter

Objectives

The student should be able to do the followings;

- Explain the linear x-ray attenuation coefficient.
- Mention Interaction x-ray with matter processes
- Explain Unmodified scatter

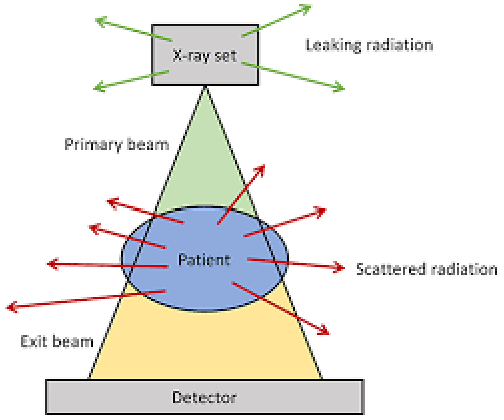
Attenuation of X-Ray

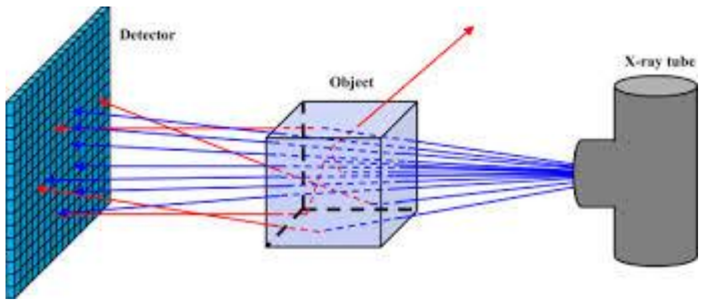
When an x-ray impinges upon a material, there are three possible outcomes.

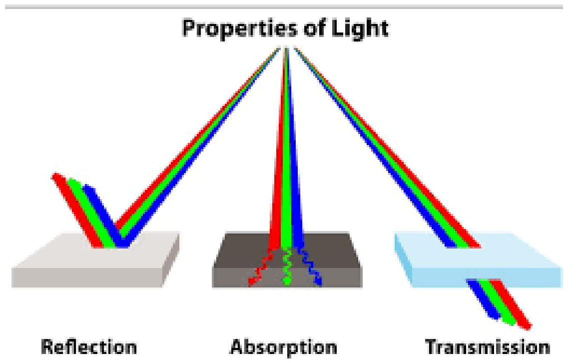
(1) Absorption (transfer its energy to atoms of the target material during one or more interactions)

(2) Scattering

(3) Traversing the material without interaction







Attenuation of X-Ray

The attenuation process is

1- The **photoelectric effect** at lower energies: the photon is completely absorbed by an inner-shell electron, which is then ejected from the atom.

2- **Compton scattering** at higher energies: the x-ray photon interacts with a free or loosely bound outer-shell electron, causing the photon to scatter in a different direction with reduced energy.

* High Z materials have a greater probability of participating in interactions that absorb and remove photons from the beam.

Attenuation of X-Ray

The number of photons penetrating a medium I :

$$I = I_{\circ} \times e^{-\mu . x}$$

where μ is the attenuation coefficient of the medium for the photons

$I_{\circ}$ the initial number of photons in the beam before interacting the matter.

The number of photons attenuated I_{at}

$$I_{at} = I_{\circ} - I$$

Attenuation of X-Ray

- The **total linear attenuation coefficient :**

$$\mu = \tau + \sigma$$

- The coefficients $\boldsymbol{\tau}$ *, and* $\boldsymbol{\sigma}$ represent attenuation by the processes of photoelectric absorption (τ), Compton scattering (σ).

- **attenuation coefficients** vary with 1- the energy of the x rays 2- the atomic number of the absorber.

- **Linear attenuation coefficients** depend on the density of the absorber.

$$\mu_m = \frac{\mu}{\rho}\ (m^2/kg)$$

Question: What is the total mass attenuation coefficient (μ_m) of a copper slab has a density of 8.9×10^3 kg/m^3, a linear attenuation coefficient of 69.3 m^{-1}.

Interaction x-ray with matter processes

1- Photoelectric Absorption

During a photoelectric interaction, the total energy of an x-ray is transferred to an inner electron of an atom. The electron is ejected from the atom with kinetic energy $E\kappa$, where $E\kappa$ equals the photon energy $h\nu$ minus the binding energy E_B

$$E\kappa = h\nu - E_B$$

The ejected electron is called a **photoelectron.**

Question: What is the kinetic energy of a photoelectron ejected from the K shell of lead (E_B=88 keV) by photoelectric absorption of a photon of 100 keV?

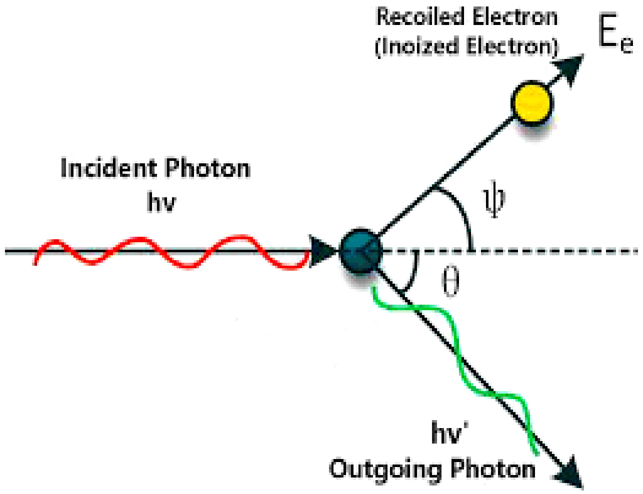
Question: What is the kinetic energy of a photoelectron ejected from the K shell of soft tissue (E_B=0.5 keV) by photoelectric absorption of a photon of 100 keV?

Interaction x-ray with matter processes

2- Compton (Incoherent) Scattering:

- X-rays with energy more than 30 keV interact in soft tissue by Compton scattering. During a Compton interaction, part of the energy of an incident photon is transferred to a loosely bound or "free" electron within the attenuating medium.
- The energy of the Compton electron is $\boldsymbol{E_k = h\nu - h\acute{\nu}}$
- The $\boldsymbol{\nu}$ is the frequency of the incident photon, and $\boldsymbol{\acute{\nu}}$ is the frequency of the incident photon
- The energy of the incident photon $(\boldsymbol{h\nu})$ and the energy of the scattered photon $(\boldsymbol{h\acute{\nu}})$

Question: A 20-keV photon is scattered by a Compton interaction. If the energy of incident photon is 35-keV, find the energy of the recoil electron.



Interaction x-ray with matter processes

3- Pair Production

An x or γ ray with energy ($\boldsymbol{hv}$ ($\boldsymbol{MeV}$)) may interact by pair production while near a nucleus in an attenuating medium. A pair of electrons, one negative and one positive, appears in place of the photon. Because the energy equivalent to the mass of an electron is 0.51 MeV, the creation of two electrons requires 1.02 MeV. Consequently, photons with energy less than 1.02 MeV do not interact by pair production. This energy requirement makes pair production irrelevant to conventional radiographic imaging. During pair production, energy in excess of 1.02 MeV is released as kinetic energy of the two electrons:

$$\boldsymbol{hv\ (MeV) = 1.02 + E_{k_{e-}} + E_{k_{e+}}}$$

Question: A 5-MeV photon near a nucleus interacts by pair production. Residual energy is shared equally between the negative and positive electron. What are the kinetic energies of these particles?

Interaction x-ray with matter processes

4- Unmodified scatter: (or coherent or Rayleigh scattering) : when a photon (like an x-ray) interacts with an atom, causing its tightly bound electrons to vibrate and re-emit the photon without losing significant energy, meaning its wavelength (and frequency) stays the same, only its direction changes.

- This differs from **modified scattering (Compton scattering)** where the photon transfers enough energy to eject an electron, resulting in a lower-energy, longer-wavelength scattered photon.

- Unmodified scatter occurs at lower photon energies and is important in x-ray imaging and diffraction.

-The importance of coherent scattering is further reduced because little energy is deposited in the attenuating medium.

References

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