



Fundamentals of Radio-physics

First Semester

Practical Part

Week2 : X-Ray Interaction with Matter

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➤ X-Ray Beam Interacts With Anatomic Tissues

When a primary diagnostic x-ray beam interacts with anatomical tissue, **three processes occur**:

- Absorption - complete loss of photon energy
- Scattering - deflection of the photon with a loss of some energy
- Transmission - the photon passes unchanged

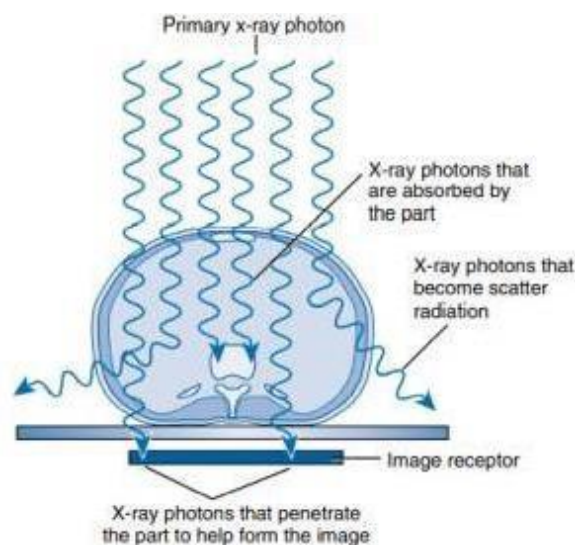
X-rays interact with matter in the following five ways:

1. Coherent scattering
2. Compton scattering
3. Photoelectric effect
4. Pair production

5. **Photodisintegration**

Only **Compton scattering and the photoelectric effect** are important factors in producing an x-ray image. The conditions governing these two interactions control differential absorption, which determines the degree of **contrast of the x-ray image**.

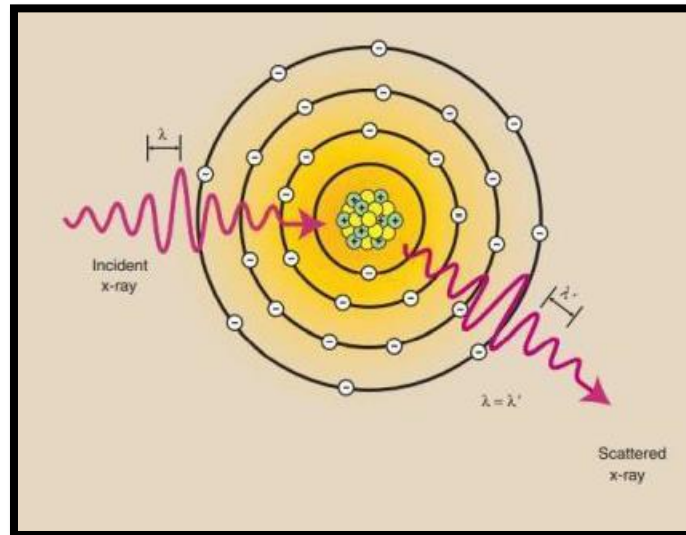
During attenuation of the x-ray beam, the photoelectric effect is responsible for the total absorption of the incident x-ray photon.



1.Coherent Scattering

The direction of the scattered x-ray is different from that of the incident x-ray.

- The result of coherent scattering is a change in direction of the x-ray without a change in its energy.
- There is **no energy** transfer and therefore **no ionization**.




- Coherent scattering contributes **little to the medical image**.
- The wavelength of the incident x-ray is **equal** to the wavelength of the scattered x-ray

Coherent Scattering

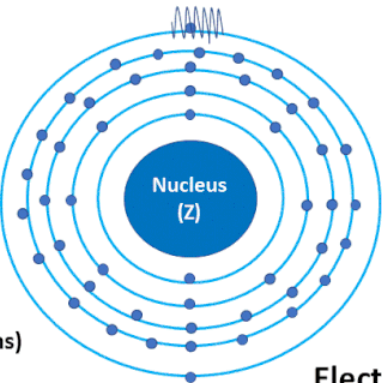
(aka elastic scattering, Rayleigh scattering)

X-Ray Photon



Scattered X-ray
Same Energy

Occurs for x-rays
less than 10keV



Nucleus (Z)

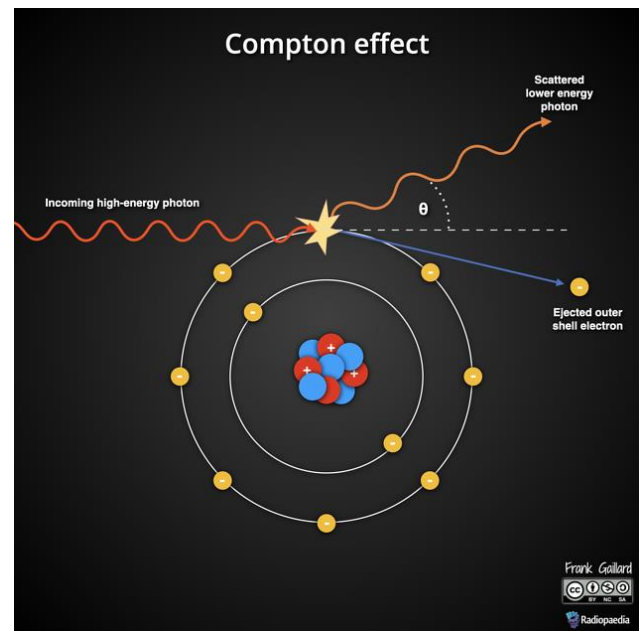
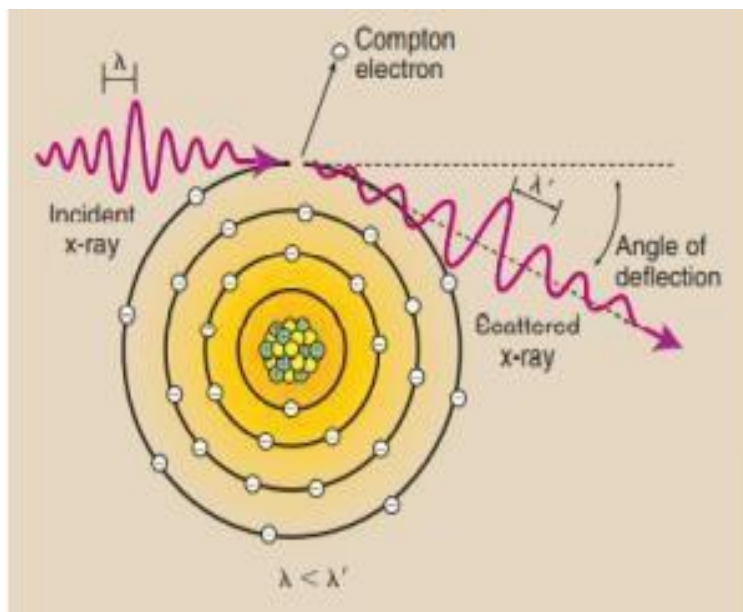
Electron Cloud

Likelihood $\sim \frac{Z}{E^2}$ (# protons / (photon energy)²)

2-. Compton Scattering - The dominant interaction in soft tissue

In Compton scattering, incident X-rays interact with an outer-shell electron and eject it from the atom, ionizing it.

The ejected electron is called a Compton electron



Mathematically, this energy transfer is represented as follows:

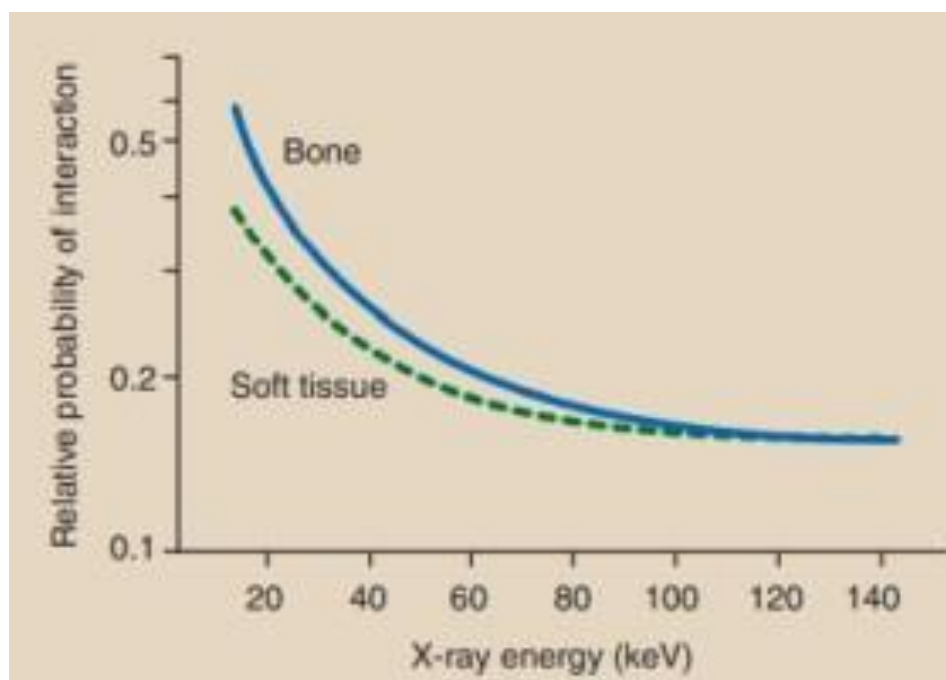
$$E_i = E_s + (E_b + E_{KE})$$

where E_i is energy of the incident x-ray, E_s is energy of the scattered x-ray, E_b is electron binding energy, and E_{KE} is kinetic energy of the electron

(H.W) A 30-keV x-ray ionizes an atom of barium by ejecting an O-shell electron with 12 keV of kinetic energy. The binding energy of an O-shell electron of barium is 0.04 keV. What is the energy of the scattered x-ray?

Features of Compton Scattering

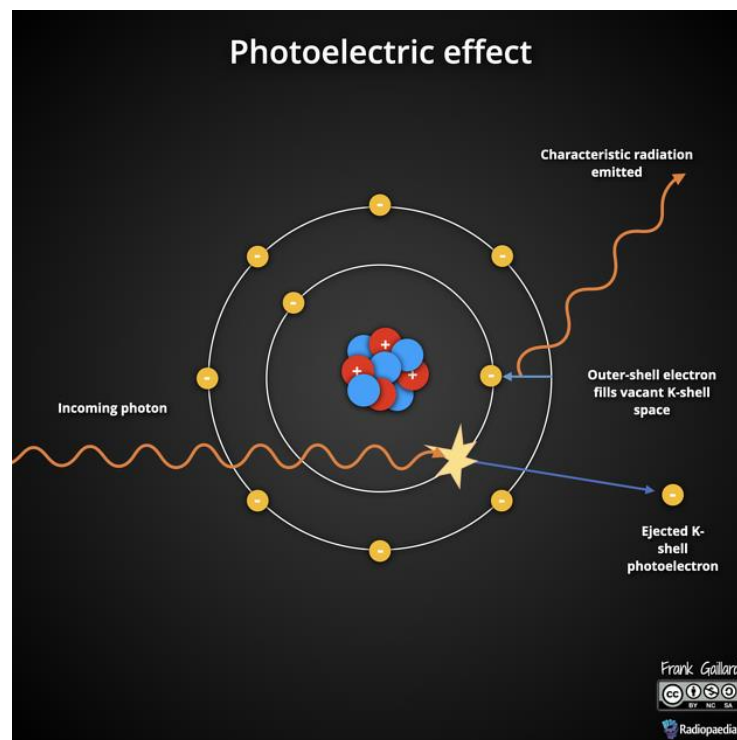
- The probability of Compton scattering is inversely proportional to x-ray energy ($1/E$)
- The probability of Compton scattering does not depend on the atomic number of the atom
- As mass density of absorber increases Proportional increase in Compton scattering
- Compton scattering is a predominant interaction in the diagnostic energy range with soft tissue (100 keV-10 MeV).
- Scattered X-rays provide no useful information, reduces image contrast, create radiation hazards in radiography (reducing image contrast and causing noise)

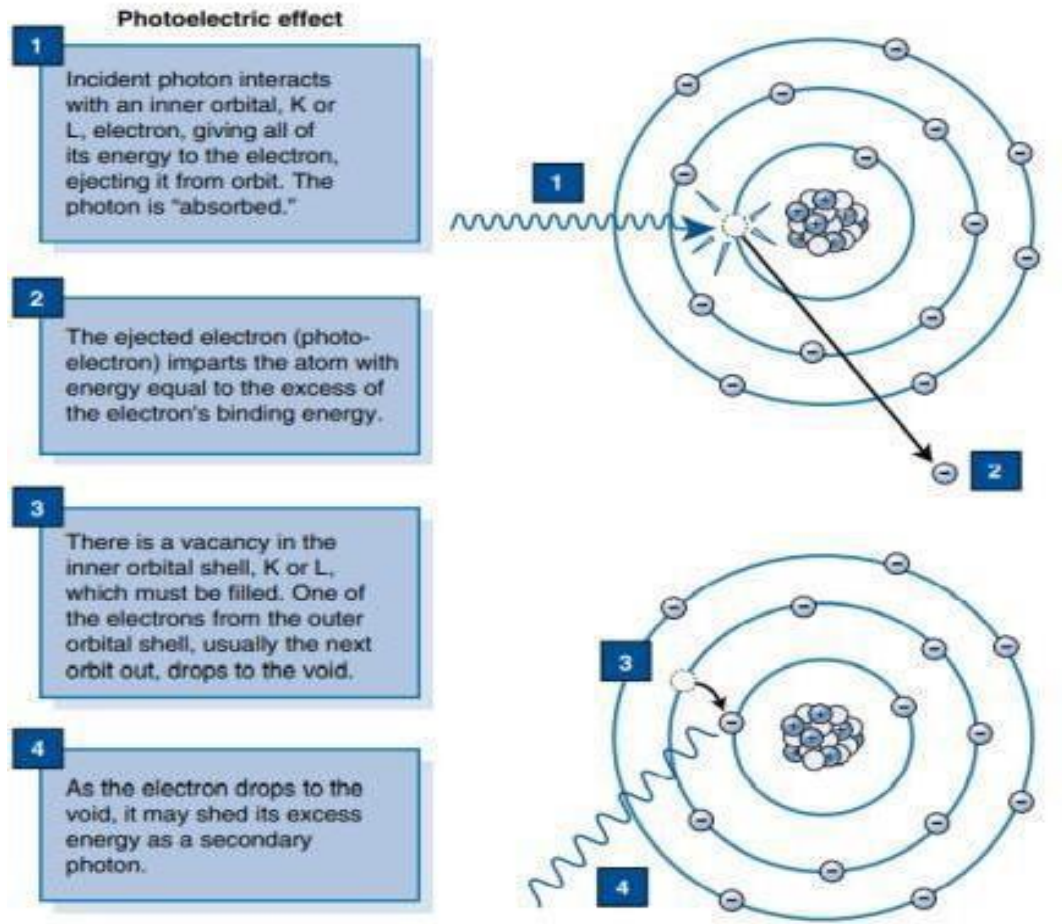


3. Photoelectric Effect

In the photoelectric effect (PE), a photon of energy E collides with an atom and ejects one of the bound electrons from the K or L shells

*The electron removed from the atom, called a photoelectron, escapes with kinetic energy equal to the difference between the energy of the incident x-ray and the binding energy of the electron





The x-ray is not scattered, but it is totally absorbed. Mathematically, this is shown as follows:

$$E_i = E_b + E_{KE}$$

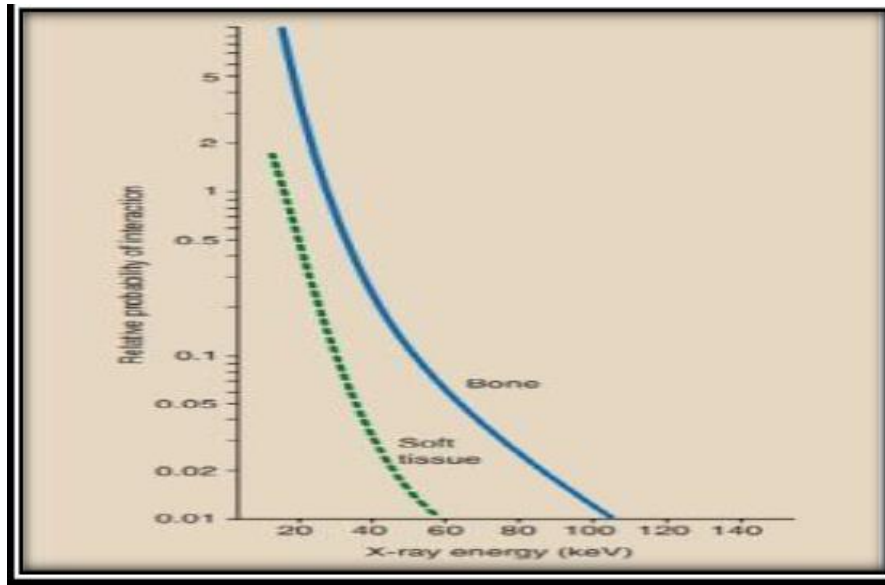
where E_i is the energy of the incident x-ray, E_b is the electron-binding energy, and E_{KE} is the kinetic energy of the electron.

(H.w) A 50-keV x-ray interacts photoelectrically with
 (a) a carbon atom . K-Shell Electron Binding Energy is 0.3 KeV
 (b) a barium atom. K-Shell Electron Binding Energy is 37KeV.

What is the kinetic energy of each photoelectron

Features of Photoelectric Effect

The probability of the photoelectric effect is inversely proportional to the third power of the x-ray energy $(1/E)^3$



The probability of photoelectric effect is directly proportional to the third power of the atomic number of the absorbing material (Z^3).

Example: What is its relative probability of an 80-keV x-ray interacting with a. Fat? ($Z = 6.3$) b. Barium? ($Z = 56$), compared with soft tissue ($Z = 7.4$)

Answer:

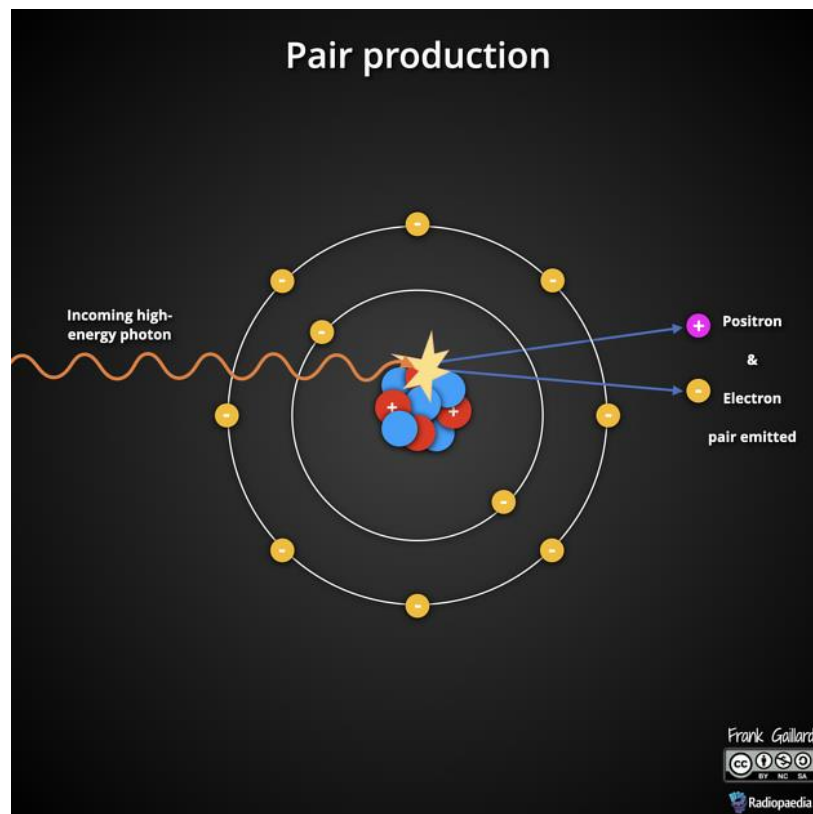
$$\text{a. } \left(\frac{6.3}{7.4} \right)^3 = 0.62$$

$$\text{b. } \left(\frac{56}{7.4} \right)^3 = 433$$

As mass density of absorber increases, Proportional increase in photoelectric absorption

4. Pair production

- When a photon having energy $> 1.02 \text{ MeV}$, it may escape interaction with electrons and come close enough to the nucleus of the atom to be *influenced* by the strong nuclear field
- The interaction between the x-ray and the nuclear field causes the xray to disappear, and in its place, two electrons appear one positively charged (positron) and one negatively charged. This process is an example for the conversion of energy into mass as predicted by Einstein.



□ The positron unites with a free electron, and the mass of both particles is converted to energy in the form of two photons in a process called annihilation radiation.

It is unimportant in x-ray imaging, but it forms the basis for positron emission tomography **imaging (PET Scan) in nuclear medicine.**

5. Photodisintegration

X-rays with energy above approximately **10 MeV** can escape interaction with electrons and the *nuclear field and absorbed directly* by the nucleus

Questions

1- Which of the following interactions is responsible for the contrast in the radiograph?

- a) Compton
- b) Photoelectric
- c) Pair production
- d) Coherent scattering

2-The probability of the photoelectric effect is directly proportional to:

- a) Atomic number Z
- b) The cube of the atomic number Z^3
- c) X-ray energy E
- d) Density only

3-Which interaction dominates in the diagnostic energy range of soft tissue?

- a) Photoelectric
- b) Compton
- c) Coherent scattering
- d) Pair production

4-The probability of Compton scattering increases with increasing:

- a) Atomic number
- b) Mass density
- c) X-ray energy
- d) All of the above