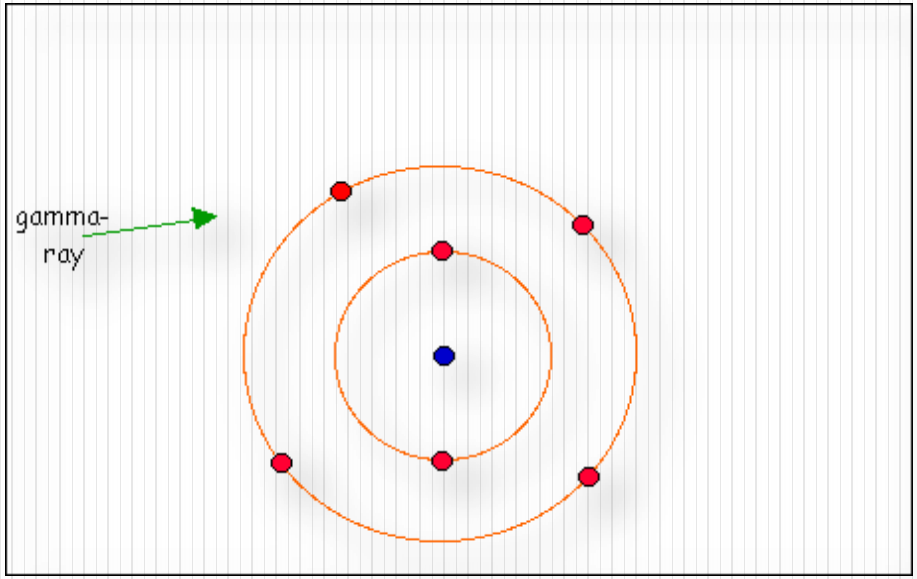
Session 3

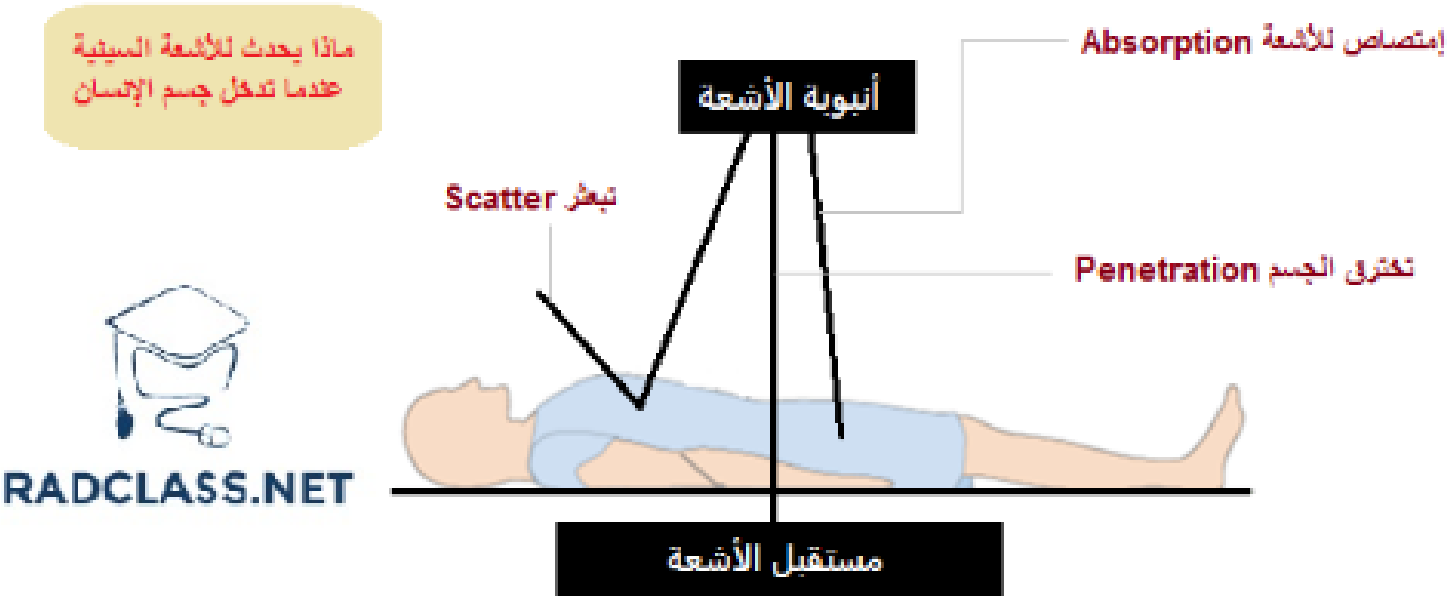
X- Ray Interaction

Medical Imaging Physics Made Easy



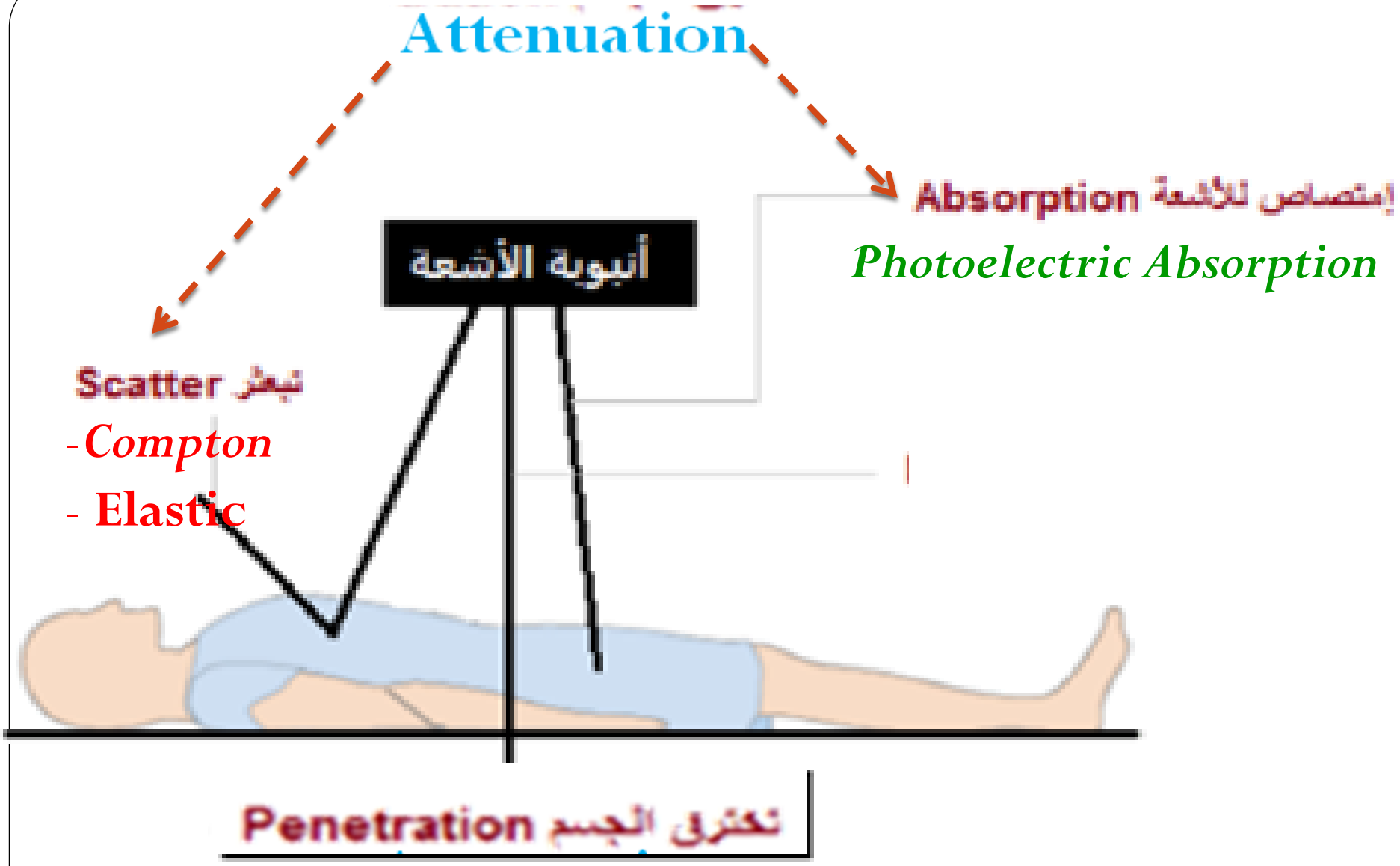
By

Ahmad Mokhtar Abodahab



يعتمد تفاعل الأشعة السينية مع جسم الإنسان على عدة عوامل منها:

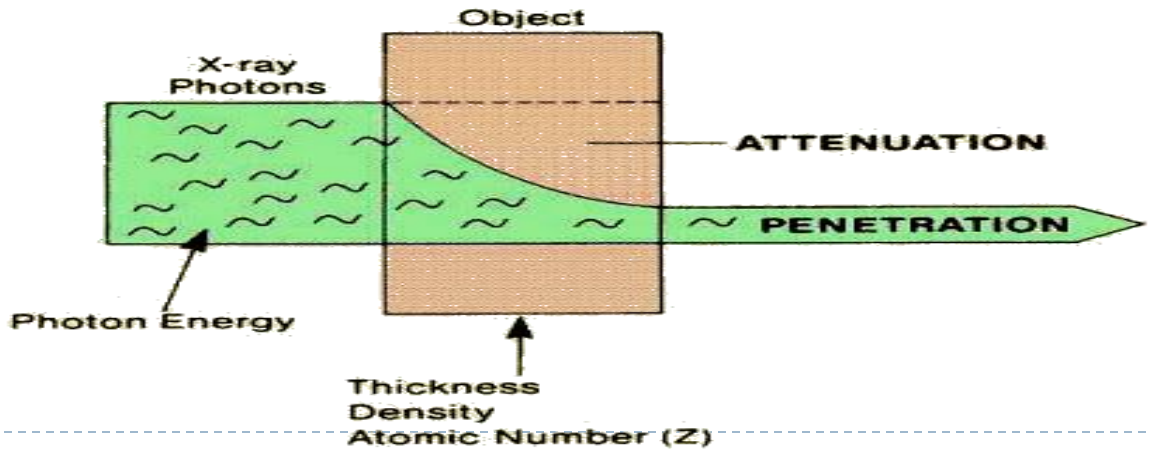
طاقة الأشعة السينية – السماكة – العدد الذري – الكتلة.


Attenuation
Absorption إمتصاص للأشعة
Photoelectric Absorption
أنبوبة الأشعة
Scatter تبعثر
-Compton
- Elastic
Penetration تخترق الجسم

➔ ATTENUATION

- fewer photons are emerging from the beam entering.

- Attenuation = photons that completely absorbed and scattered.



NARROW, MONO-ENERGETIC BEAM OF X-RAYS

- **Monoenergetic beam**, = Beam composed of rays has the same energy.
- it generated by filtering X ray beam ,
- Filter absorb rays of lower energy , & passing higher rays of the same energy.

As **BEAM** penetrates material, → it progressively more homogeneous.

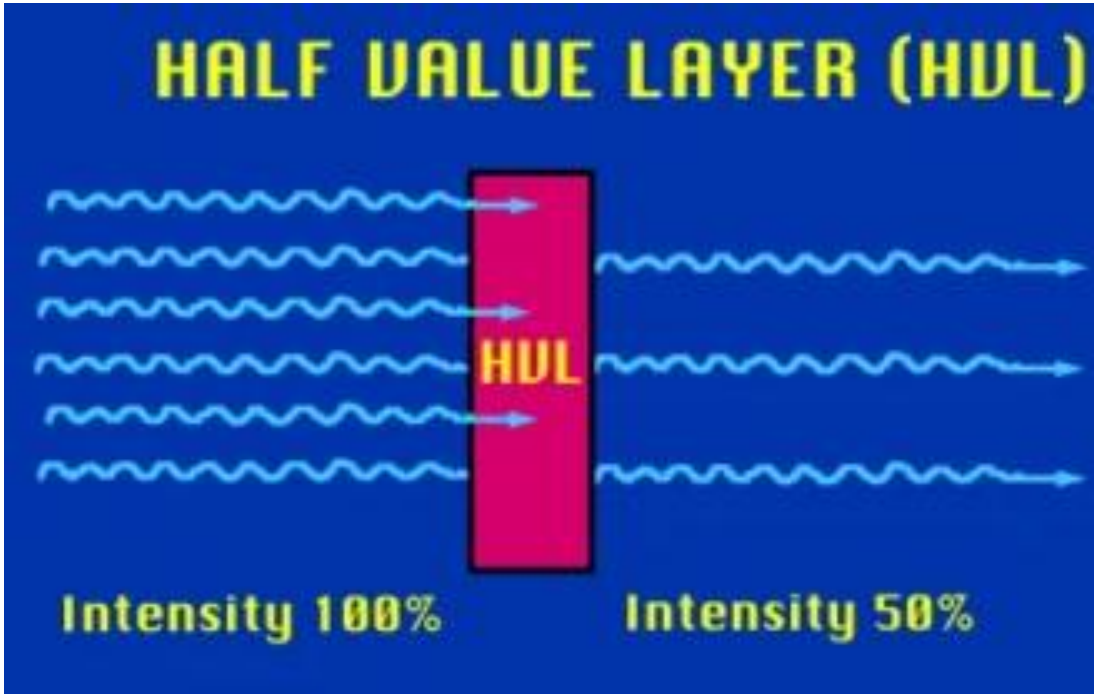
The proportion of higher-energy photons in the beam increases,

This described as **beam hardening**.

HALF-VALUE LAYER (HVL)

- the thickness of material that → reduce the intensity

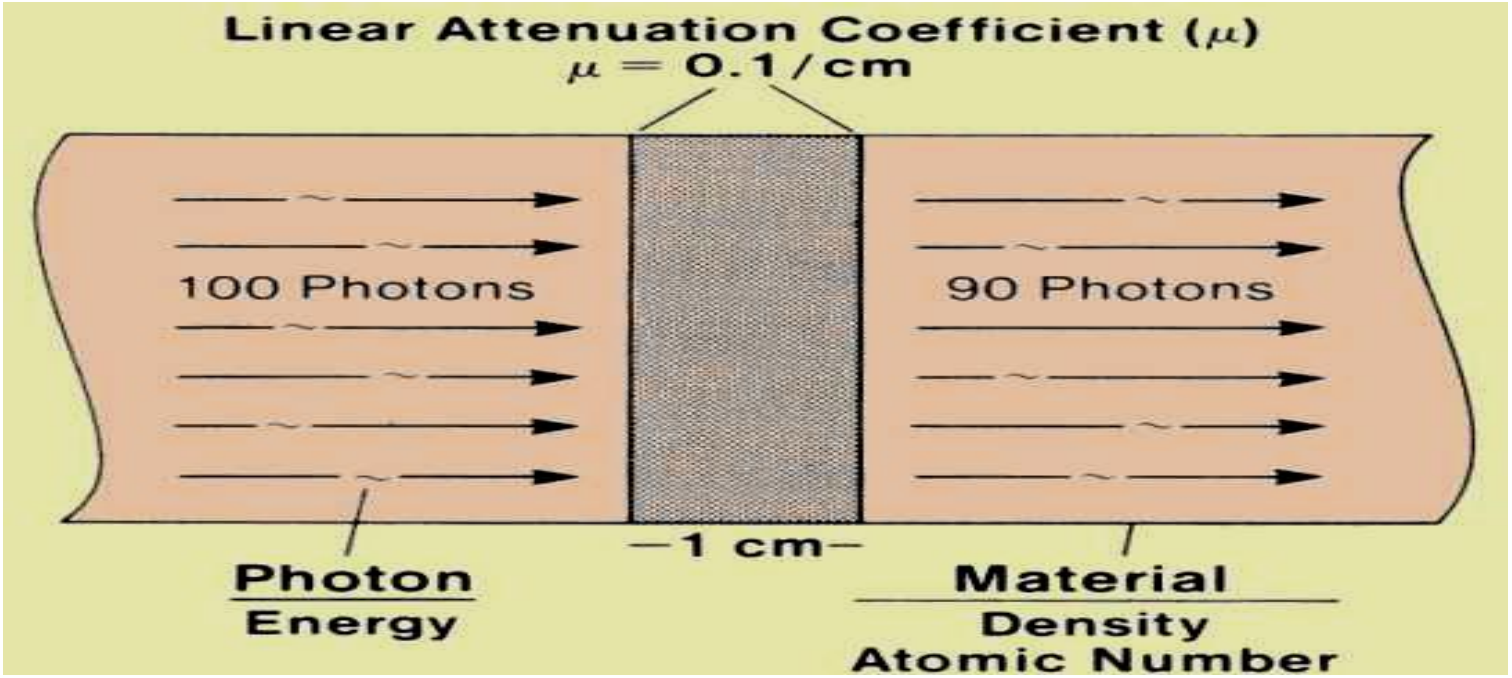
  of a X ray beam → to one-half of its original value.

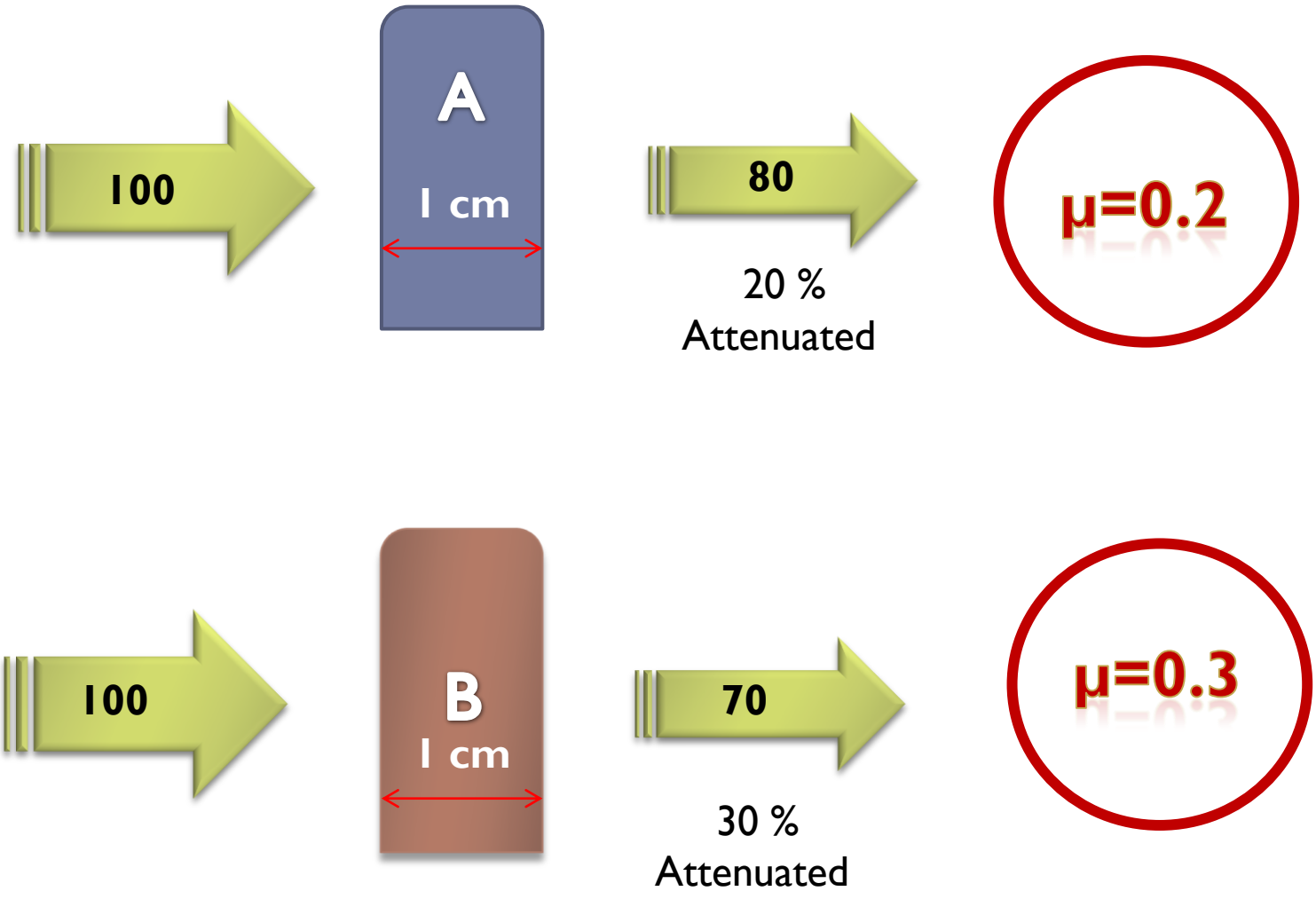


LINEAR ATTENUATION COEFFICIENT (μ)

- **Linear attenuation coefficient (μ)**

is a constant that describes the fraction of **attenuated** photons in a monoenergetic beam per unit thickness of a material.




100
A
1 cm
80
20 %
Attenuated
μ=0.2
100
B
1 cm
70
30 %
Attenuated
μ=0.3

X RAY IN THE MATTER

What's occur ?

2 Scatter & 1 Absorption

INTERACTION PROCESSES

- **Three processes** of interaction between X-rays and matter :

✓ ● 1- ***Compton effect***

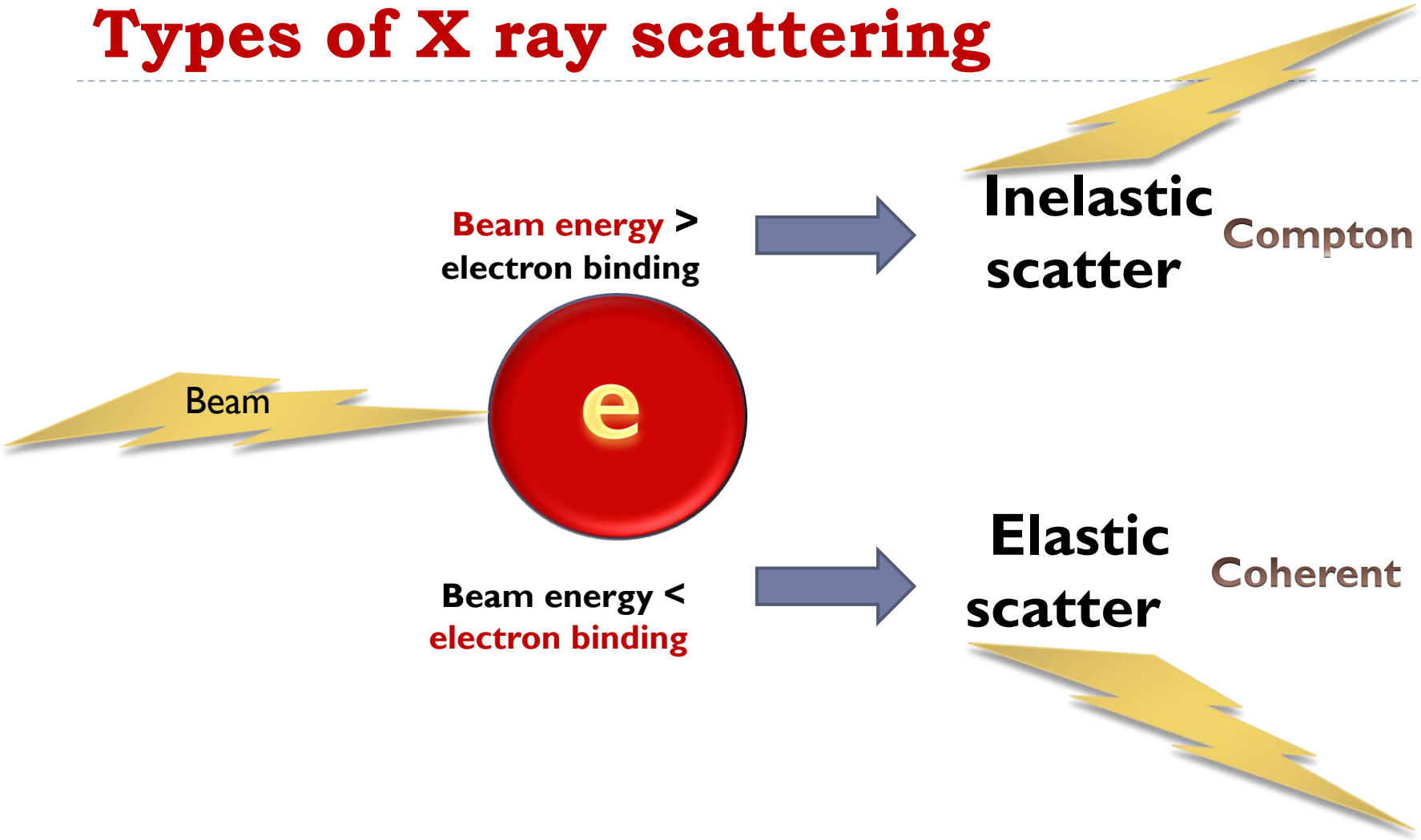
- Beam interaction with **loosely bound** or **free electron**
- Also described as **inelastic** or **non-coherent scattering**

✓ ● 2- ***Photoelectric absorption***

- Beam interaction with inner shell or 'bound' electron
- the **photon is totally absorbed** &, less importantly,

✓ ● 3- ***Elastic scatter*** with a **bound electron** =

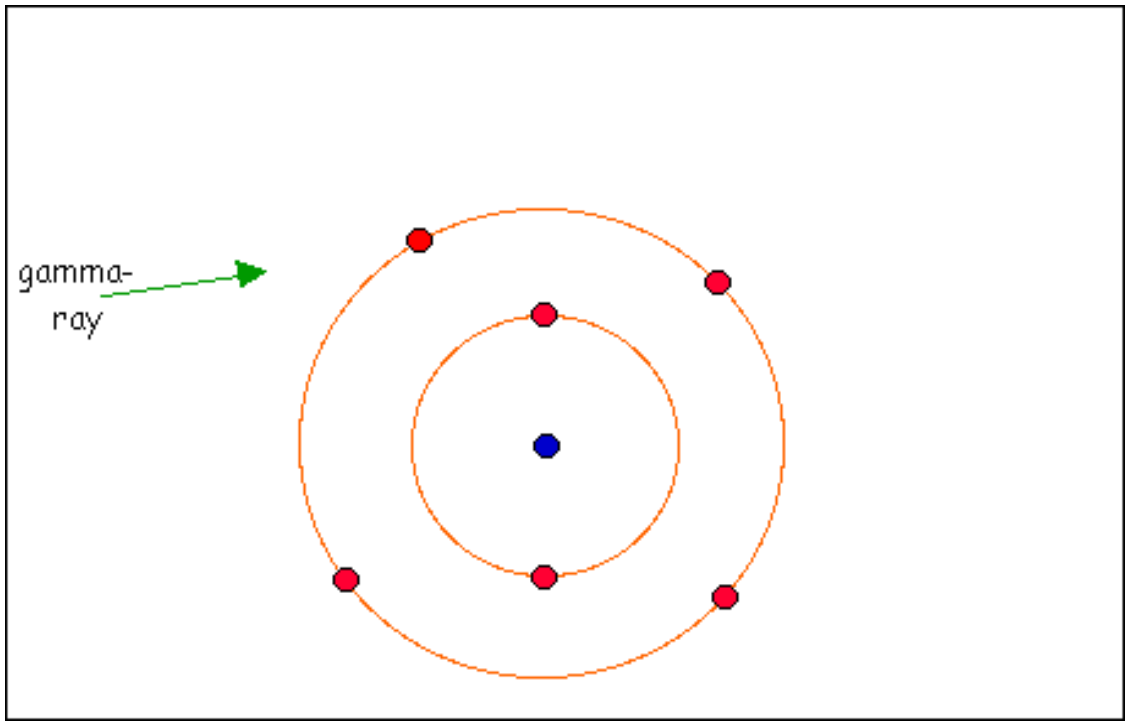
Types of X ray scattering

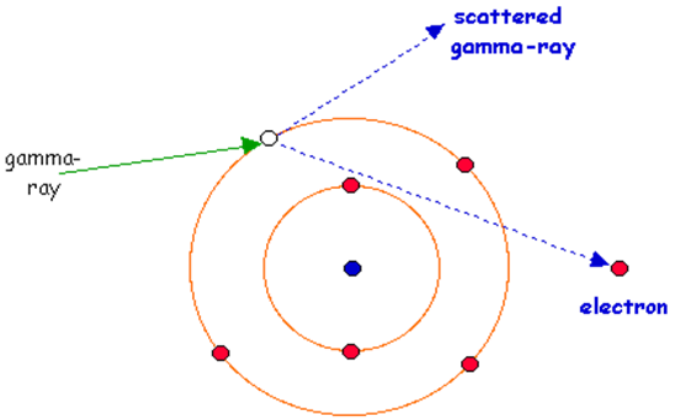


1- COMPTON EFFECT

- X ray **photon** → passing through material → liberate **free electron**→ takes away some of photon energy as <u>kinetic energy</u>.

→ & **photon** is <u>scattered</u>, & diverted in a new direction, with <u>reduced energy</u>.

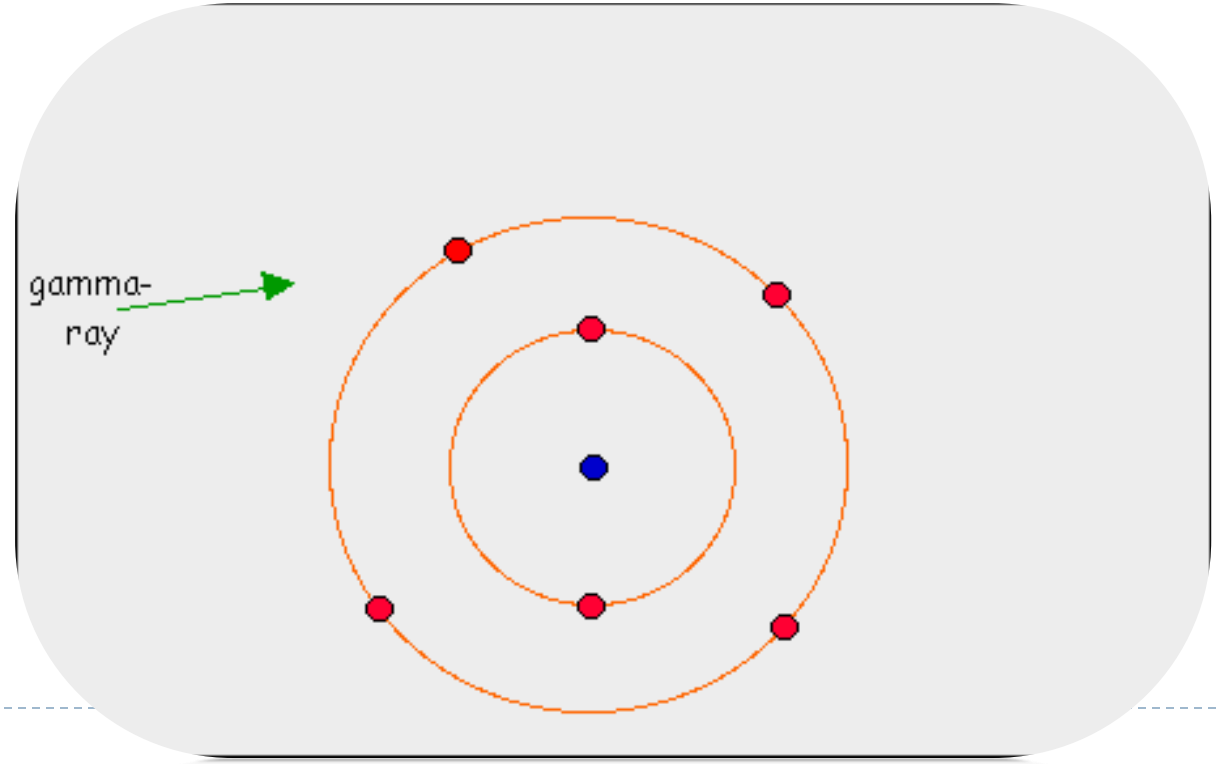




Angle of scatter θ

is the angle between the scattered ray and the incident ray.

- Photons may be scattered in all directions. (Back – Side – Forward)
- The electrons are projected only in sideways and forwards directions.



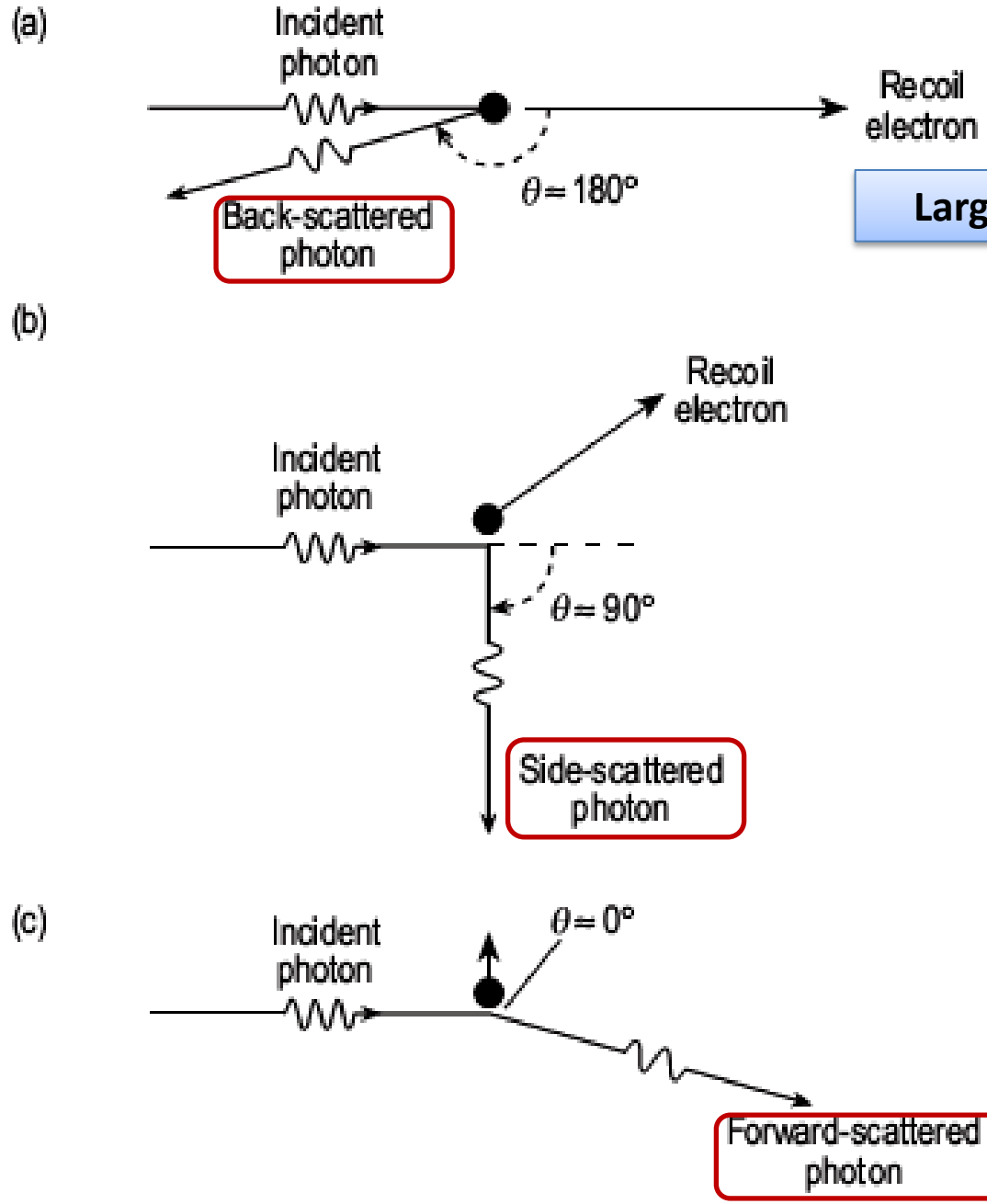
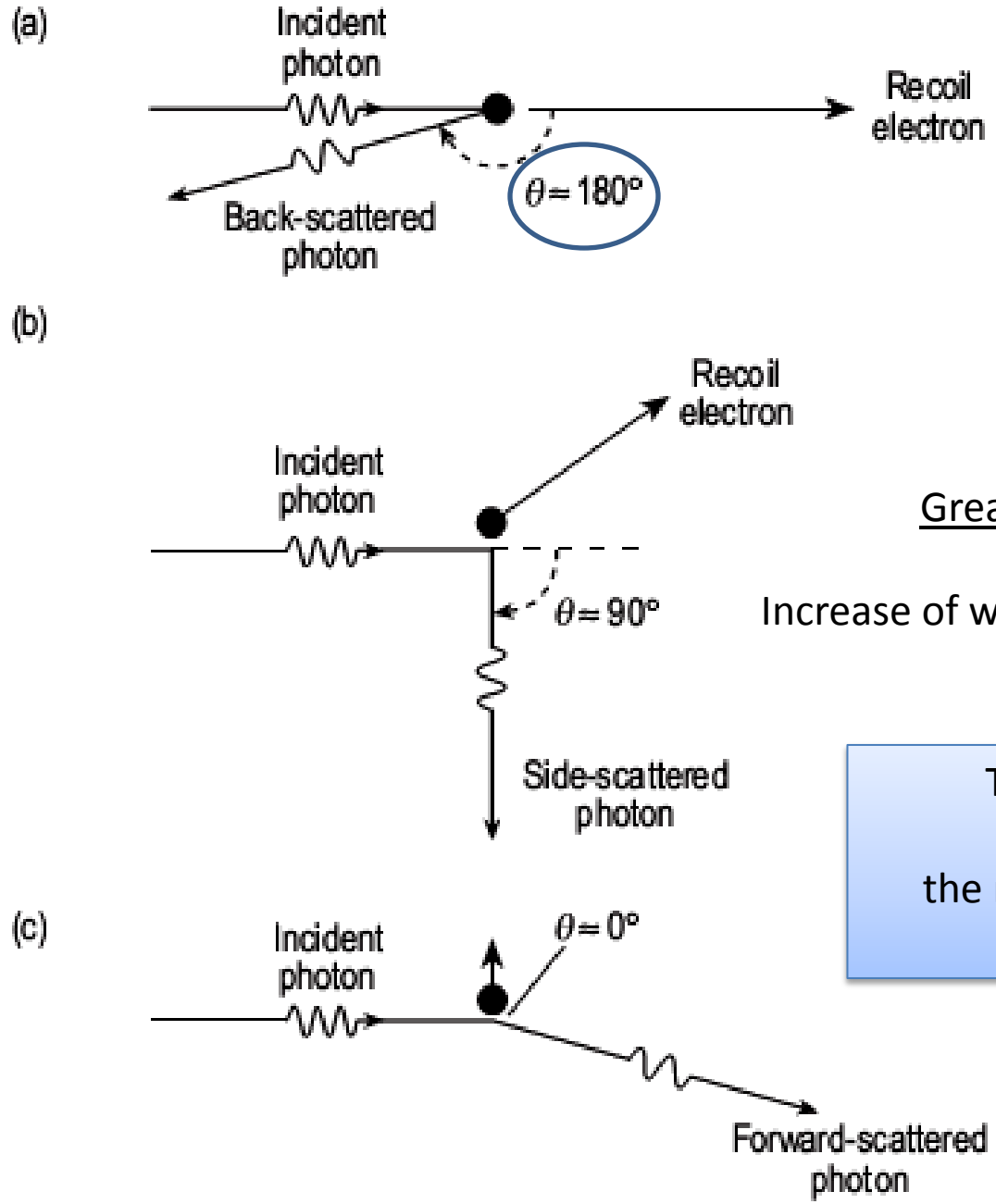


Figure 1.14 Compton scattering by a free electron.

Large angle = lower energy photon

EFFECT OF THE ANGLE OF SCATTERING

Small angle
= Higher energy photon



Greater Angle of Scatter

Greater energy of Recoil electron

Increase of wavelength of the scattered photon

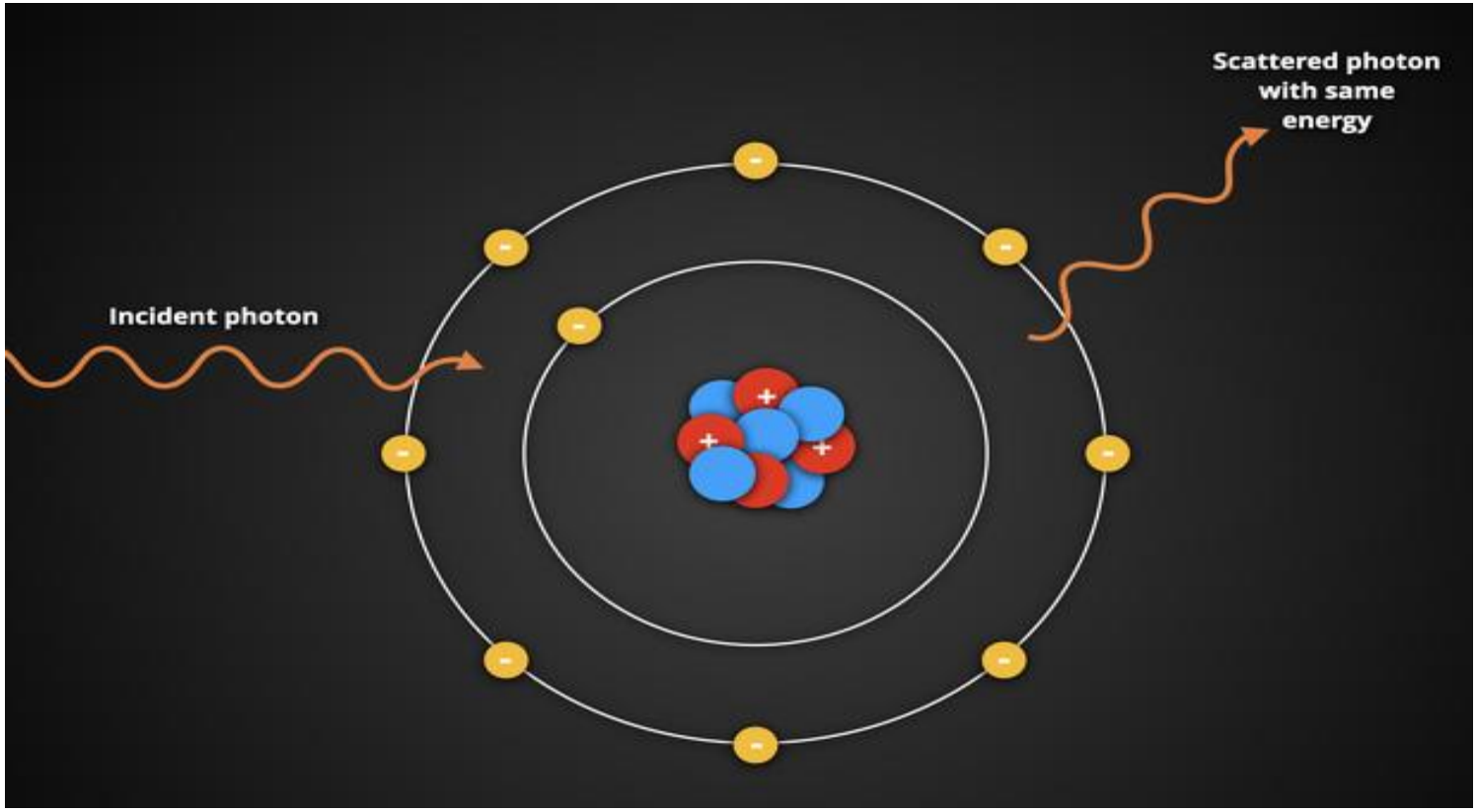
The lengths of the arrows indicate the relative energies of the recoil electrons.

Figure 1.14 Compton scattering by a free electron.

2- ELASTIC SCATTER

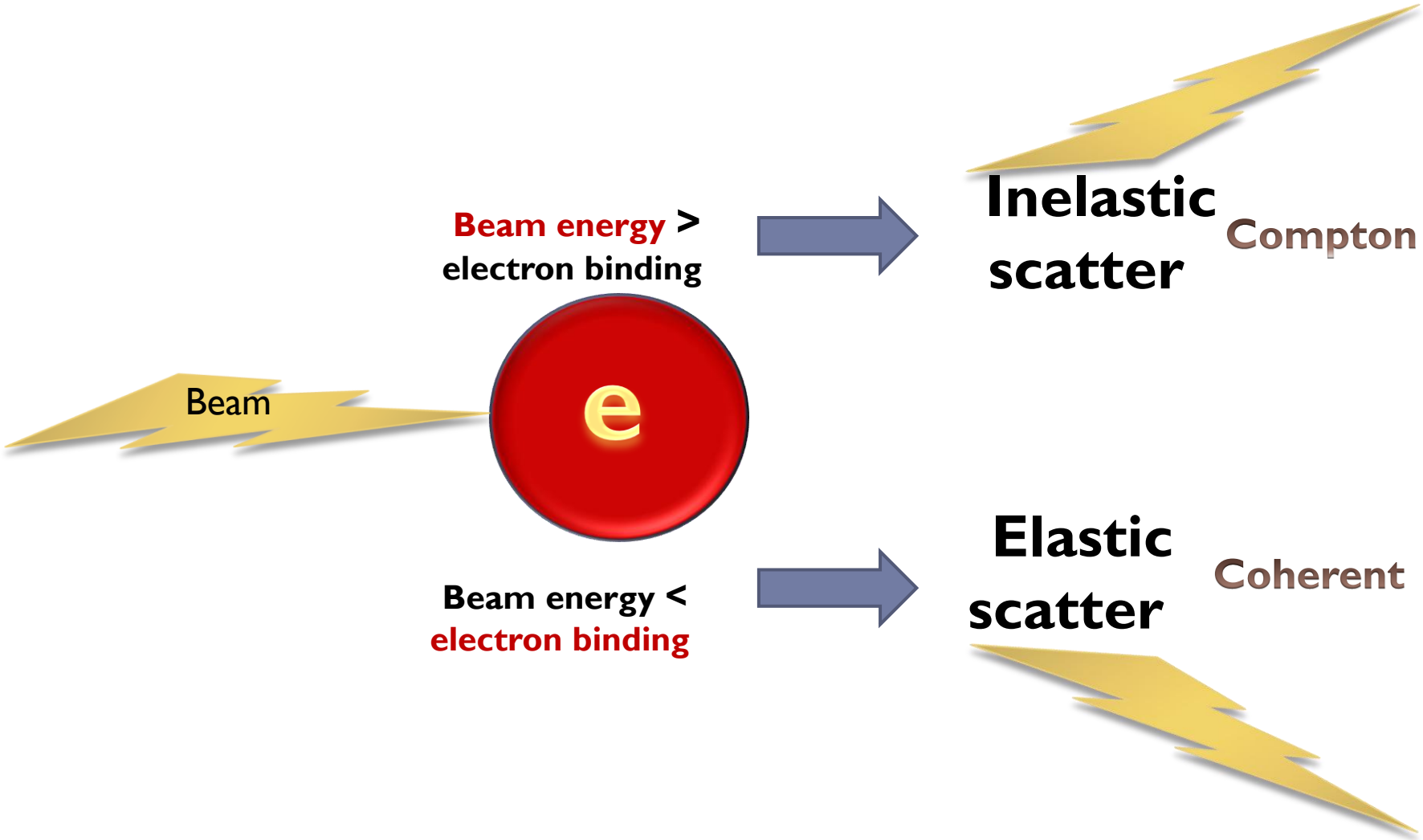
Coherent, **C**lassical, **U**nmodified or **R**ayleigh scattering.

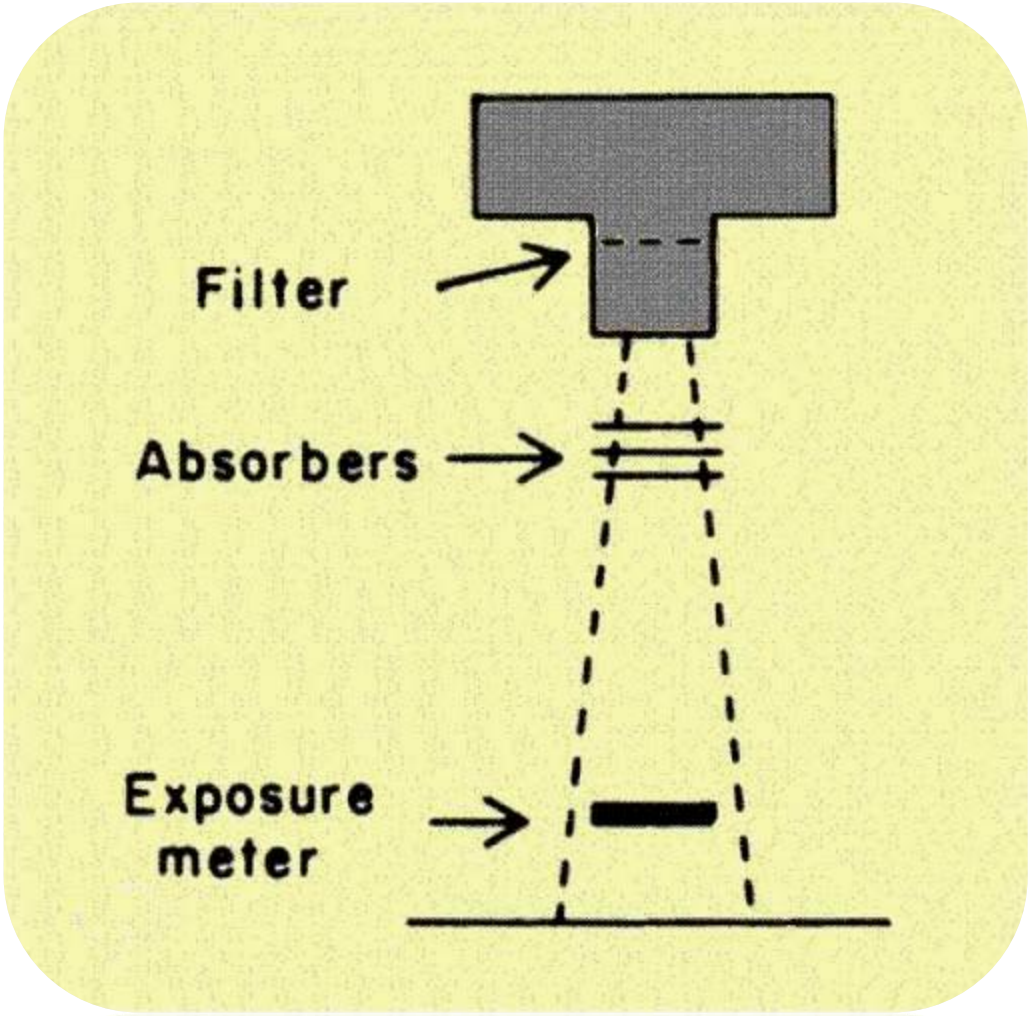
- Third process of X- and gamma rays interact with matter.
- Photon bombard **firmly bound** electron to its atom.
- The photon energy is less than the binding energy of the electron.
- No secondary electron moving and no ionization or other effect is produced.
- → small angles of scatter and little significance in radiology.



- **Elastic Scatter** ……. Photon energy < binding energy → No electron moving

Types of X ray scattering




Filter
Absorbers
Exposure
meter

FILTRATION

- When x ray film is taken, **the lower-energy X-ray** photons

→ mainly absorbed and deposit dose in the patient.

→ Only a small fraction reaches film & contributes to image.

- **Filtration** object → remove a large proportion of lower-energy photons before they reach the skin, ……. this lead to

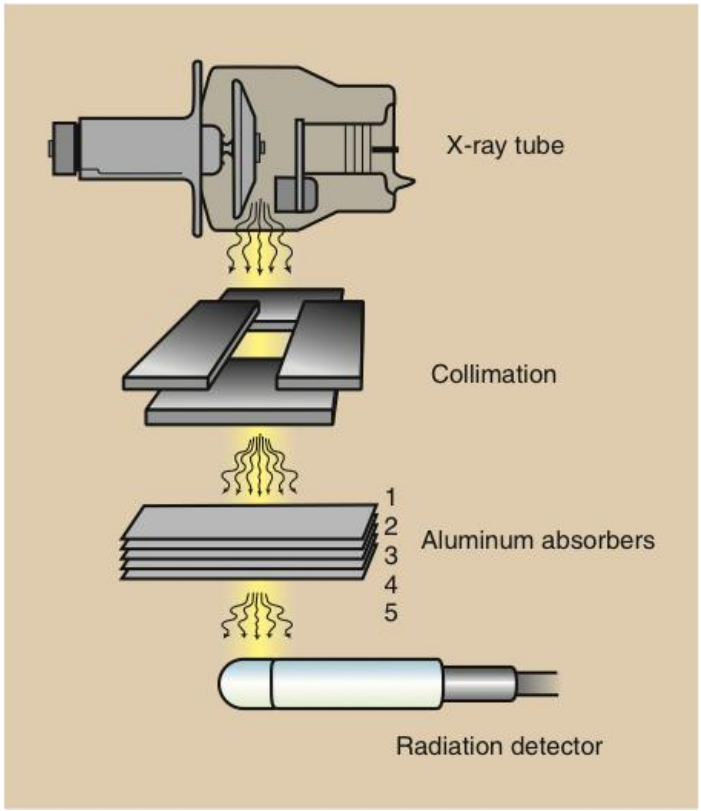
  - → Reduces the dose received by the patient

  - → Hardly affecting the radiation reaching the film, → so improve the resulting image.

How Filtration & Dose reduction Occurs ?

Inherent & Added Filtration

- **Added** or **Additional filtration**:
  - by flat **sheet of metal**
  - between **X-ray tube** and **patient**.
  - **Aluminium**, usually
  - The predominant attenuation process in this filter should be **photoelectric** absorption.



Choice of filter material

- **Atomic number** sufficiently high.
- But not be too high, to eliminate whole beam.
- Attenuating process, **photoelectric absorption** predominate

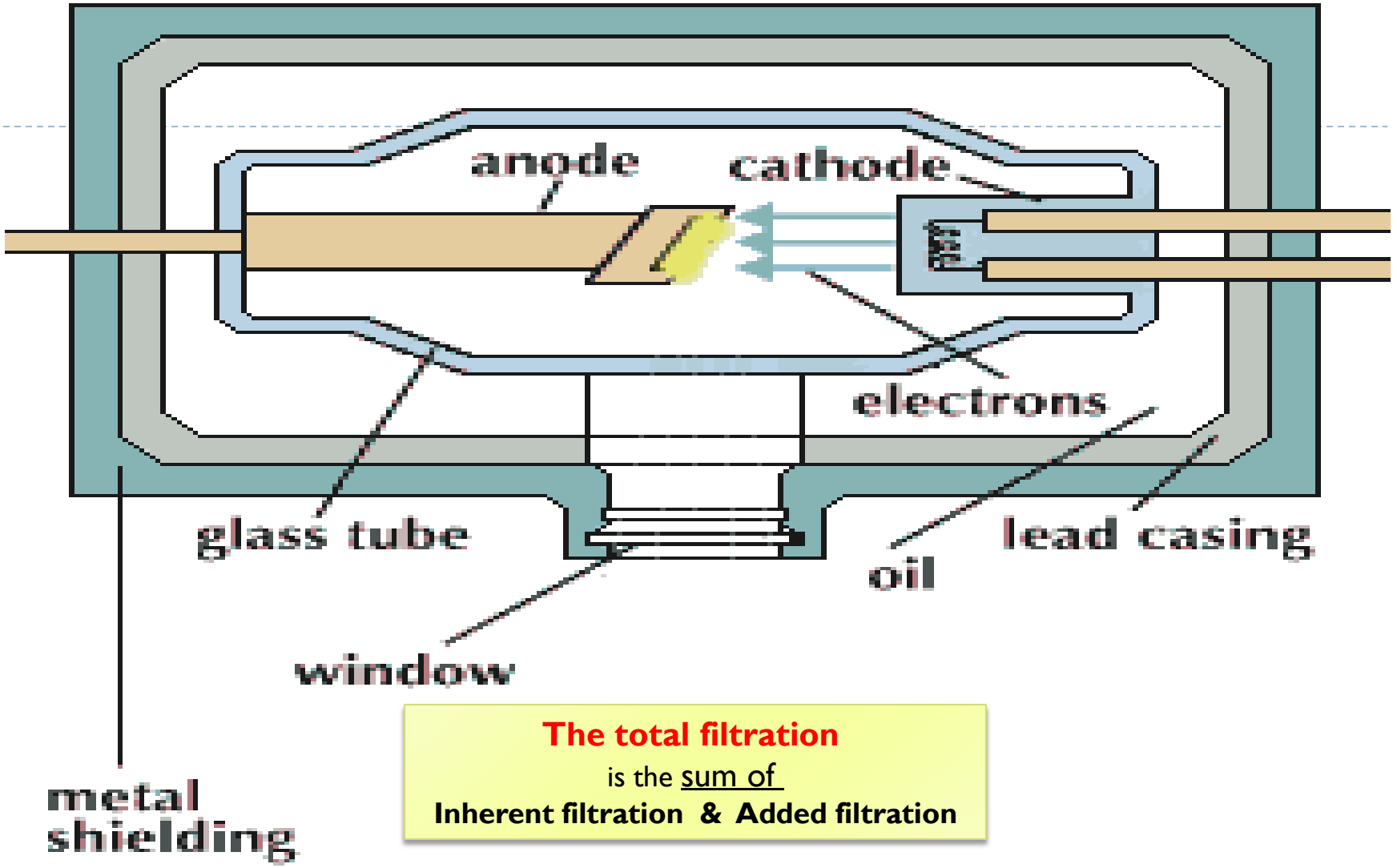
➔ Materials :

- **Aluminium** (Z =13 - EK =1.6 keV)
  - is generally used,
  - it has a sufficiently high atomic number to be suitable for most diagnostic X-ray beams.
- **Copper** (Z 29),
  - The most common alternative.
  - with added filter thicknesses in the range of 0.1–0.3 mm being .
  - more efficient filter, but it emits 9 keV characteristic X-rays.

➔ Inherent filtration

= Filtration with in Tube materials other than filter

- The X-ray photons produced in the target are initially filtered within target itself, because they may be generated below its surface,
- then by the window of the tube housing,
- Insulating oil
- Glass insert.
- The combined effect of these disparate components = inherent filtration & equivalent thickness of aluminium, typically **1 mm Al**,



The total filtration

is the sum of

Inherent filtration & Added filtration

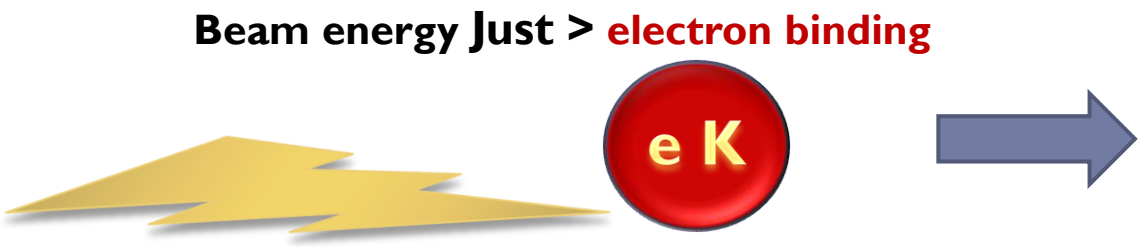
K-absorption edge (K-edge)

- a sudden increase in x-ray absorption occurring when

  the energy of the X-rays is just above the binding energy of

  the innermost electron shell of the atoms interacting with the

  Beam
  photons.



Sudden increase in Absorption

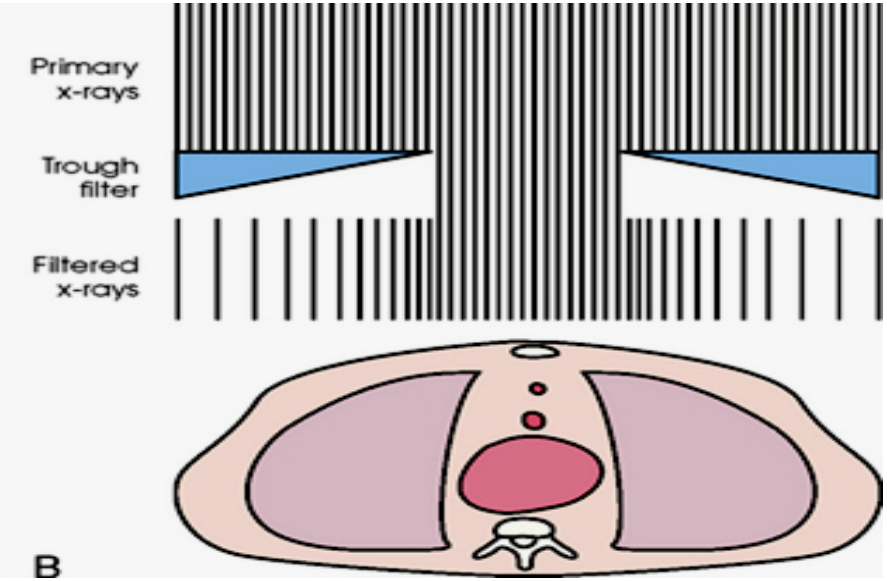
K-edge Uses

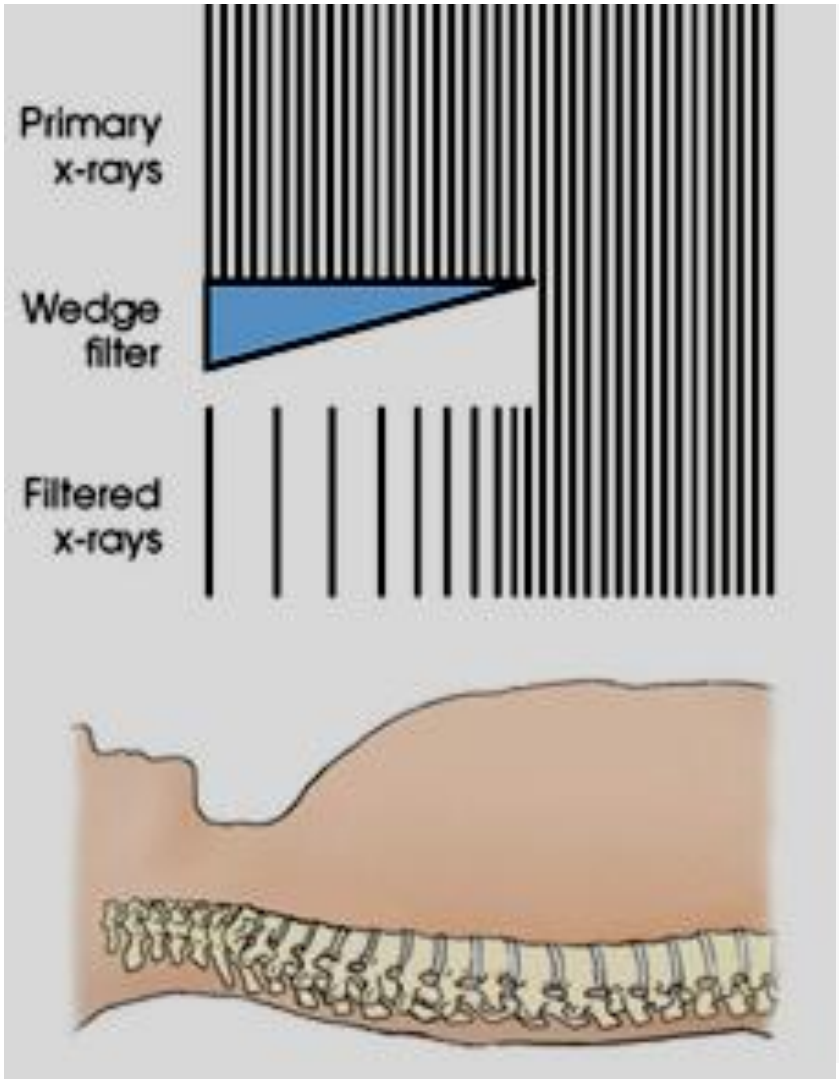
- **Radiocontrast agents** iodine and barium have ideal K-shell binding energies for absorption of X-rays: 33.2 keV and 37.4 keV respectively, which is close to the mean energy of most diagnostic X-ray beams.
- **Filter materials** with K-edges in the higher-energy part of the X-ray spectrum can be used.
- These remove both high- and low-energy X-rays but are relatively transparent to the energies just below the K-edge.
- An example of an 80-kV beam filtered with a 0.1-mm

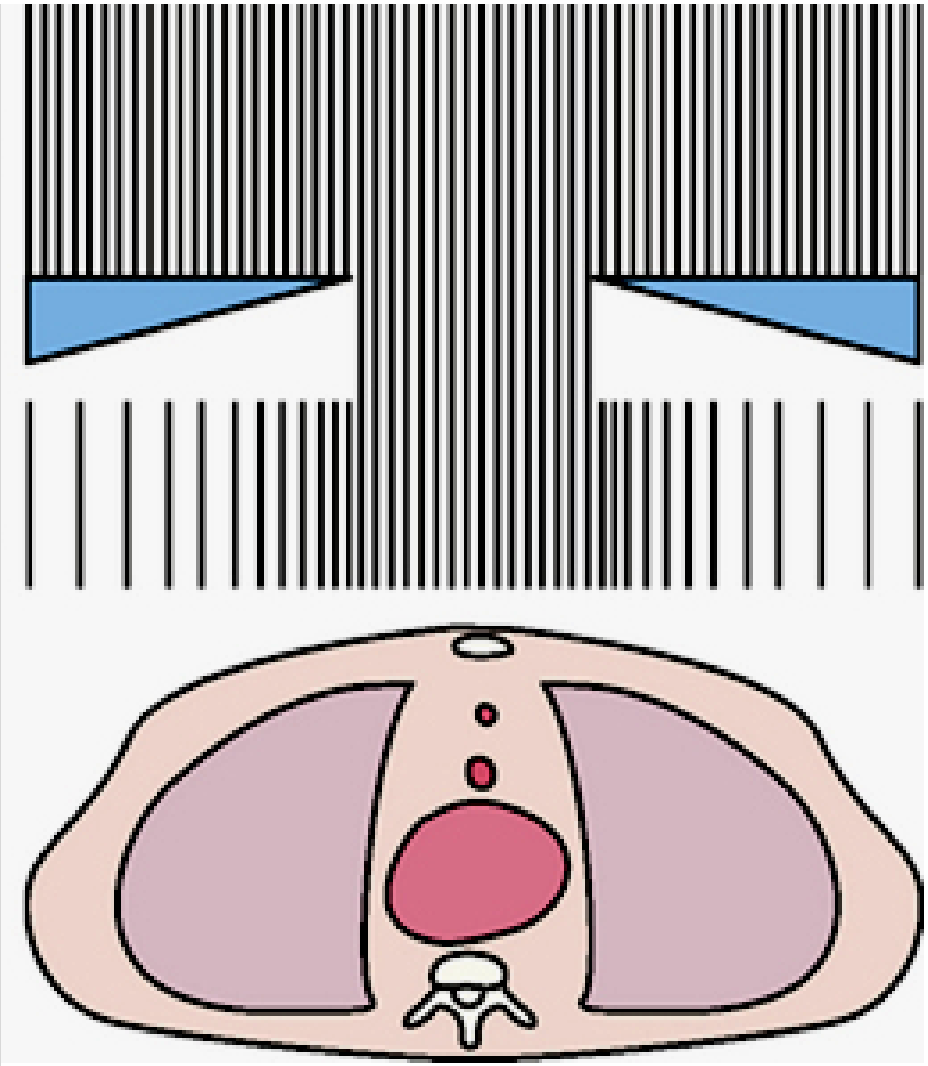
erbium filter (Z = 68, EK = 57 keV) is shown in

* Compensating or wedge filter

- Wedge shaped filter may be attached to the tube → to make the exposure across the film more uniform
- It compensate for the large difference in transmission, *(for example, the upper and lower thorax, neck and shoulder, or foot and ankle).*




Primary
x-rays
Wedge
filter
Filtered
x-rays



Sources & Further reading :

- Farr's , Physics of Medical Imaging
- https://radiopaedia.org/articles/filters
- https://en.wikipedia.org/wiki/X-ray_filter
- https://link.springer.com/article/10.1007/BF02524689
- https://radiologykey.com/quality-of-x-ray-beams-2/
- https://www.science.gov/topicpages/x/x-ray+beam+filtration

- Next ……..

DOSIMETRY

A. M. Abodahab

Oct 2020