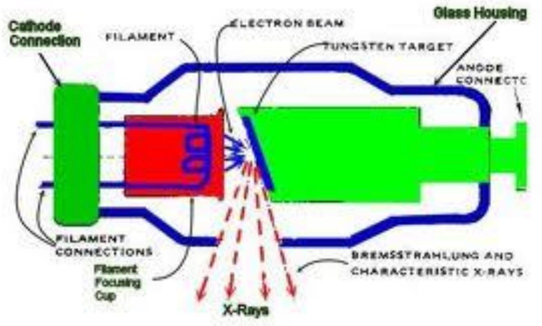
X-ray tube


Cathode Connection
FILAMENT
ELECTRON BEAM
TUNGSTEN TARGET
Glass Housing
ANODE CONNECTC
FILAMENT CONNECTIONS
Filament Focusing Cup
X-Rays
BREMSSTRAHLUNG AND CHARACTERISTIC X-RAYS

The cathode:

- 1- filament ,2-circuit to provide filament current
- 3- negatively charged focusing cup.
- **The function of the cathode cup is to direct the electrons toward the anode so that they strike the target in a well-defined area, the focal spot..**
- **The material of the filament is tungsten which is chosen because of its high melting point.**
-

The anode:

- The material chosen for the anode should satisfy a number of requirements. It should have:
- High conversion efficiency for electrons into X-rays. High atomic numbers are favored since the X-ray intensity is proportional to Z.
- A high melting point so that the large amount of heat released causes minimal damage to the anode.
- High conductivity so that the heat is removed rapidly.
- Low vapor pressure, even at very high temperatures, so that atoms are not boiled off from the anode.
- Suitable mechanical properties for anode construction

The anode:

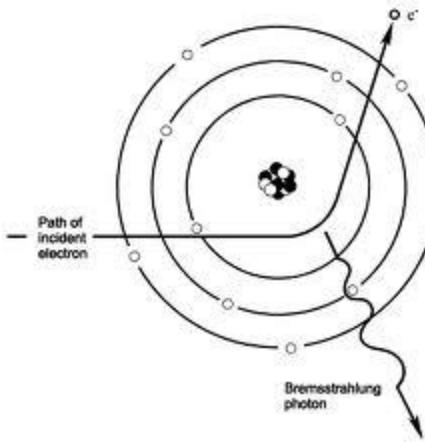
- In stationary anodes the target area is pure tungsten (W) (Z = 74, melting point 3370 °C) set in a metal of higher conductivity such as copper to conduct heat to the outside of the tube where it is cooled by oil, water or air.
- Rotating anodes have also been used in diagnostic X-rays to reduce the temperature of the target at any one spot. The heat generated in the rotating anode is radiated to the oil reservoir surrounding the tube.
- The function of the oil bath surrounding an X-ray tube is to insulate the tube housing from high voltage applied to the tube as well as absorb heat from the anode.

Physics of X–ray production

- **Bremsstrahlung (continuous spectrum):**
- The electron while passing near a nucleus may be deflected from its path by the action of Coulomb forces of attraction and lose energy as Bremsstrahlung.
- As a result, a part or all of its energy is dissociated from it and propagates in space as electromagnetic radiation (X-ray photon.

Bremsstrahlung

Bremsstrahlung X-Ray Production.mp4

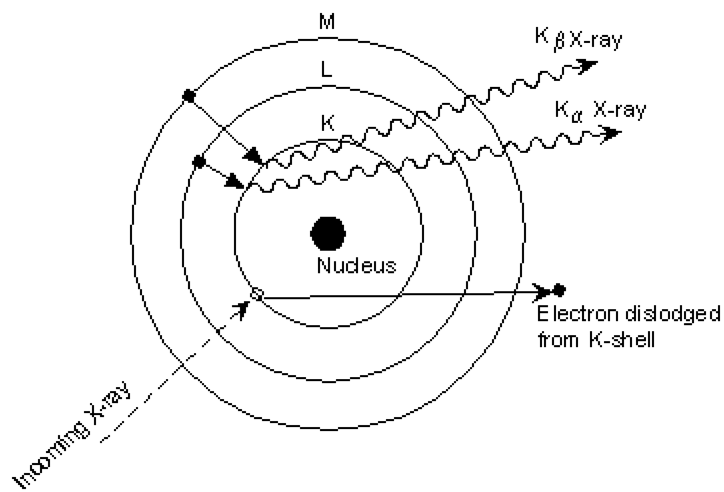


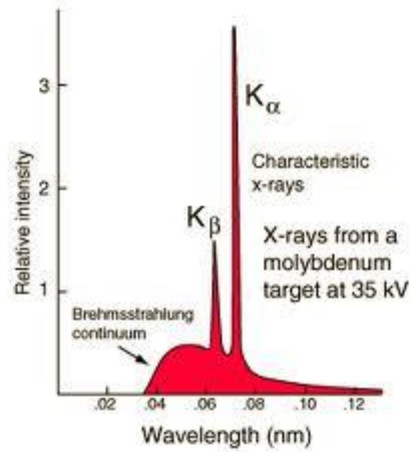
e⁻
Path of
incident
electron
Bremsstrahlung
photon

- The amount of Bremsstrahlung produced for a given number of electrons striking the anode depends upon two factors:
- (1) *the Z no. of the target* (i.e. the more protons in the nucleus, the greater the acceleration of the electrons), and
- (2) *the kilovolt peak* (i.e. the faster the electrons, the more likely they will penetrate into the region of the nucleus).

Characteristic X-rays:

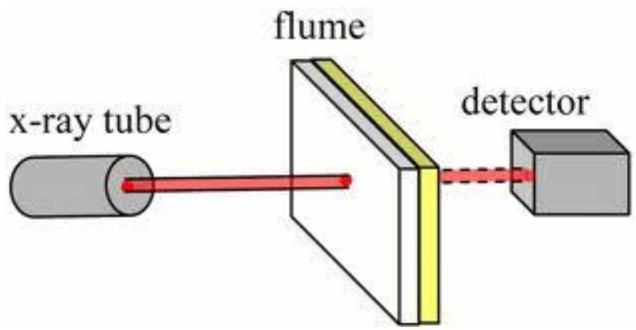
- An electron strikes a K-electron in a target atom and knocks it out of its orbit and free of the atom. The vacancy in the K shell is filled almost immediately when an electron from an outer shell of the atom falls into it, and in the process, a characteristic K X-ray photon is emitted.
- An X-ray photon emitted when an electron falls from the L level to the K-level is called a K_{α} characteristic X-ray, and that emitted when an electron falls from the M shell to the K shell is called a K_{β} X-ray.


M
L
K
Kβ X-ray
Kα X-ray
Nucleus
Electron dislodged from K-shell
Incoming X-ray



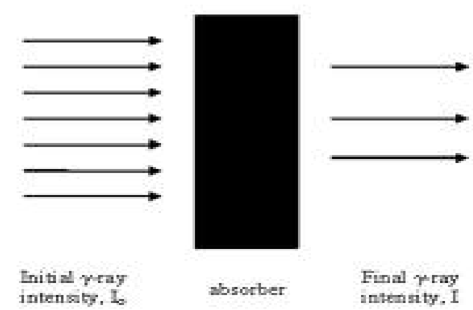
3
2
1
Relative intensity
K_α
Characteristic
x-rays
K_β
X-rays from a
molybdenum
target at 35 kV
Brehmsstrahlung
continuum
.02
.04
.06
.08
.10
.12
Wavelength (nm)

How X – Rays Are Absorbed:



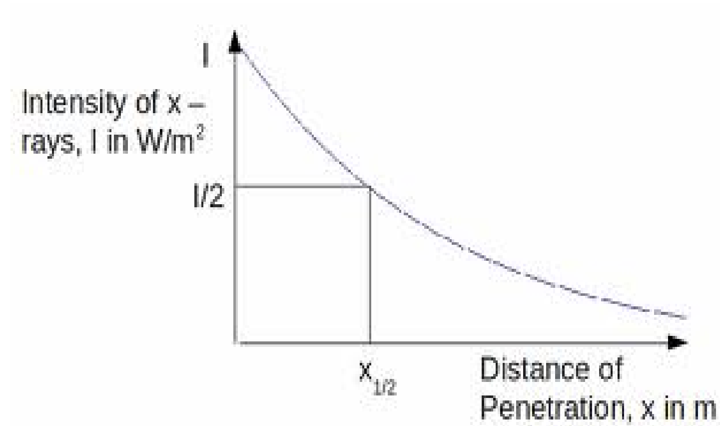
Arrangement for measuring attenuation

The unattenuated beam intensity is I_o. When sheets of aluminum are introduced into the beam; the intensity of the beam (I) decreases approximately exponentially as shown in Figure



Photon beam attenuation and half value layer

The intensity of a monoenergetic X-ray beam would decrease exponentially as shown by the dashed line in Figure The exponential equation describing the attenuation curve for a monoenergetic X-ray beam is



$$I = I_o e^{-\mu x}$$

The half-value layer (HVL) for an X-ray beam

- **Is the thickness of a given material that will reduce the beam intensity by one-half.** The **Half-value layer is related to the linear attenuation coefficient by:**
- $$\mathrm{HVL} = \frac{0.693}{\mu} \qquad (2\text{-}2)$$

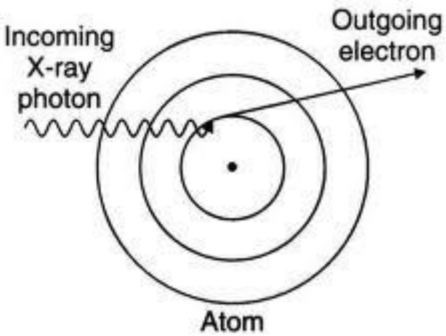
The mass attenuation coefficient μ_m

- **is used to remove the effect of density when comparing attenuation in several materials. The mass attenuation coefficient of a material is equal to the linear attenuation coefficient μ divided by the density ρof the material.**

[B] Interactions of photons with matter

- **Photoelectric effect:**
- **It occurs when the incoming X-ray photon transfers all of its energy to an electron which then escapes from the atom.**
- **The photoelectrons use some of its energy (the binding energy) to get away from the positive nucleus and spends the remainder ionizing surrounding atoms.**

Photoelectric effect



Photoelectric effect

- **The photoelectric effect is more noticeable to occur near the nucleus than in the outer levels of the atom and also in high Z materials.**
- **For a given electron to be liberated its binding energy must be lower than the energy of the X-ray.**

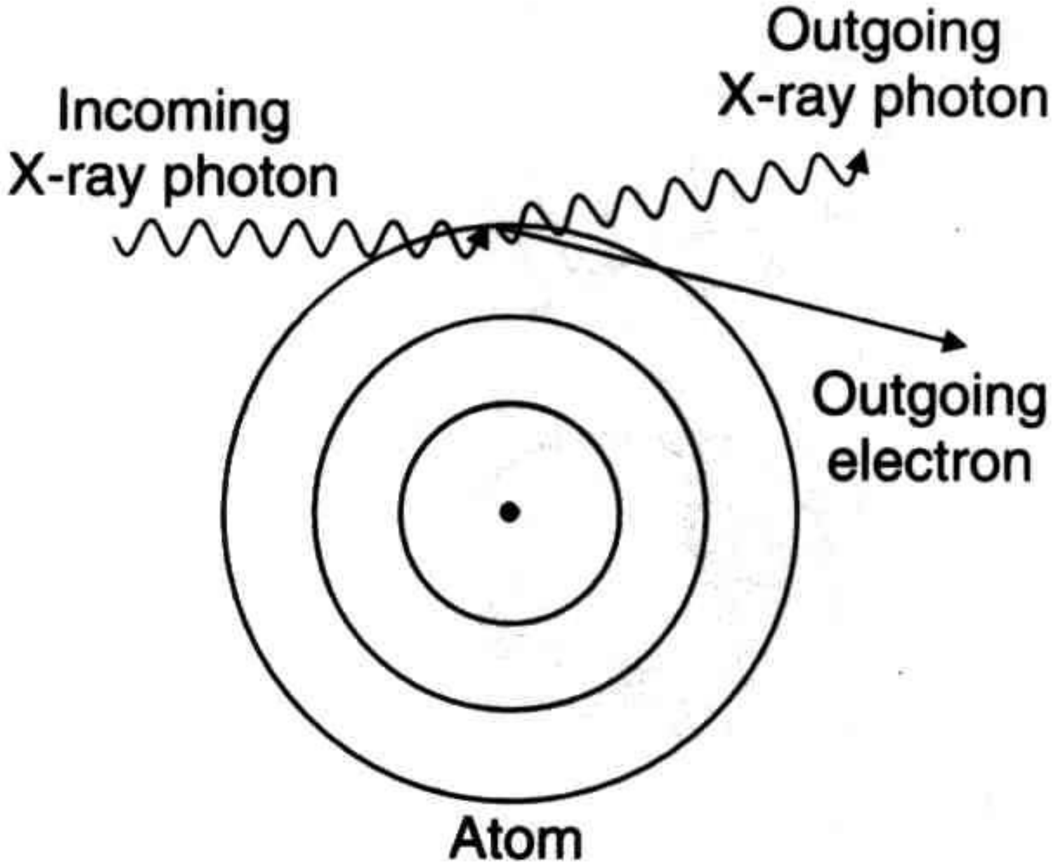
Compton scattering

- X-ray photon can collide with a loosely bound electron much like a billiard ball collides with another billiard ball.
- At the collision, the electron receives part of the energy and the remainder is given to a Compton (scattered) photon, which then travels in a direction different from that of the original X-ray.

Compton scattering

- **The energy transferred to the electron can be calculated** $E=mc^2$
- ***m is the effective mass of the X-ray***
- **the energy equivalent of the electron mass is 511 keV**
- **the Compton effect is most likely to occur when the X-ray has this energy**

Compton



Outgoing
X-ray photon
Incoming
X-ray photon
Outgoing
electron
Atom

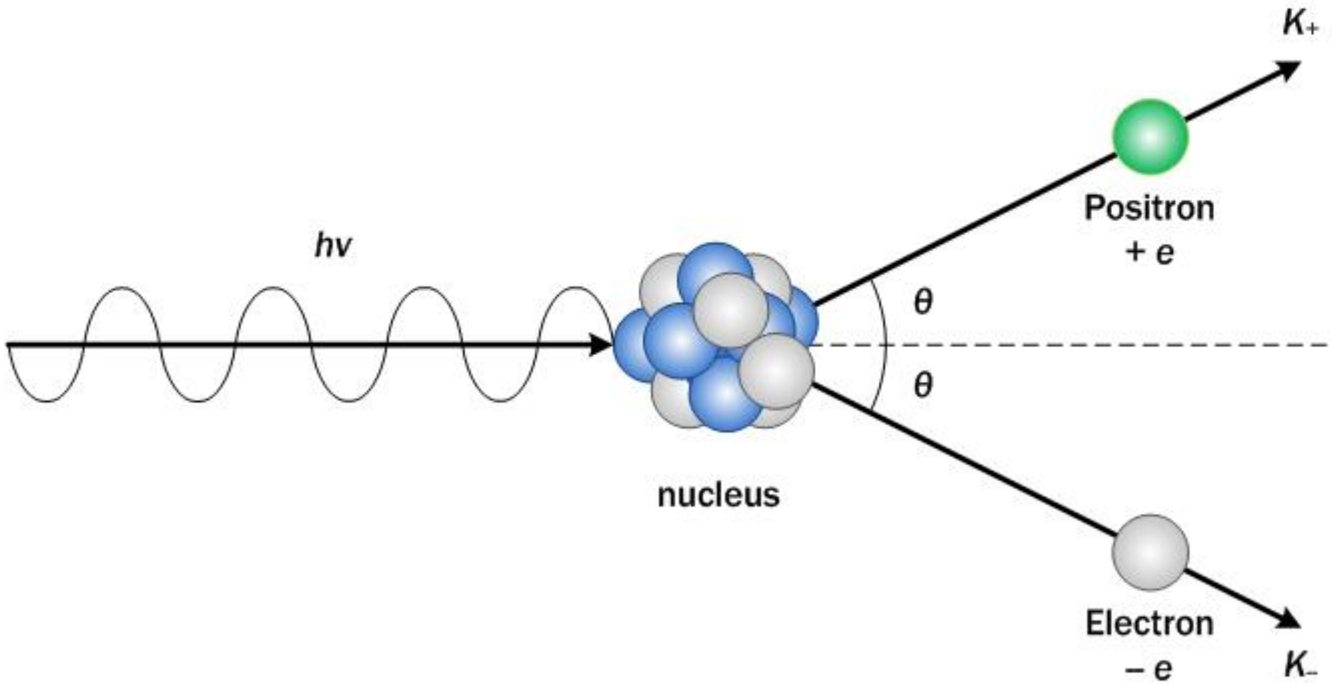
- **Since the photoelectric effect is more apparent to occur in high Z materials the fraction of X-rays that lose energy by the Compton Effect is greater in low Z elements.**

Pair production

- **When a very energetic photon enters the intense electric field of the nucleus, it may be converted into two particles: an electron and a positron (β^+), or positive electron.**
- The **positron** or antielectron is the antiparticle or the antimatter counterpart of the electron. The **positron** has an electric charge of +1 e, a spin of 1/2, and has the same mass as an electron.
- **the mass for the two particles requires a photon with energy of at least 1.022 MeV, and the remainder of the energy over 1.022 MeV is given to the particles as kinetic energy.**

Pair production

- **After it has spent its kinetic energy in ionization it does a death dance with an electron. Both then vanish, and their mass energy usually appears as two photons of 511 KeV each called annihilation radiation**



K+
Positron
+ e
hv
θ
θ
nucleus
Electron
− e
K−

x ray interactions.mp4

The relation between photon interactions with matter and diagnostic radiology:

- Pair production is of no use in diagnostic radiology because of the high energies needed and that the photoelectric effect is more useful than the Compton effect because it permits us to see bones and other heavy materials such as bullets in the body.
- At 30 KeV bone absorbs X-rays about 8 times better than tissue due to the photoelectric effect.

- Radiologists often inject high Z materials, or *contrast media,* into different parts of the body.
- Compounds containing iodine are often injected into the bloodstream to show the arteries.
- Oily mist containing iodine is sometimes sprayed into the lungs to make the airways visible.
- Radiologists give barium compounds orally to see parts of the gastrointestinal tract

Making an X-Ray Image

- **It is relatively easy to make an X-ray image, or roentgenogram, all that is needed is an X-ray source and a film on which to record the image.**

X-ray film

X-ray film

- **Different parts of the body absorb the x-rays in varying degrees. Dense bone absorbs much of the radiation while soft tissue, such as muscle, fat and organs, allow more of the x-rays to pass through them. As a result, bones appear white on the x-ray, soft tissue shows up in shades of gray and air appears black.**
- **Until recently, x-ray images were maintained as hard film copy (much like a photographic negative). Today, most images are digital files that are stored electronically. These stored images are easily accessible and are frequently compared to current x-ray images for diagnosis and disease management.**

Penumbra

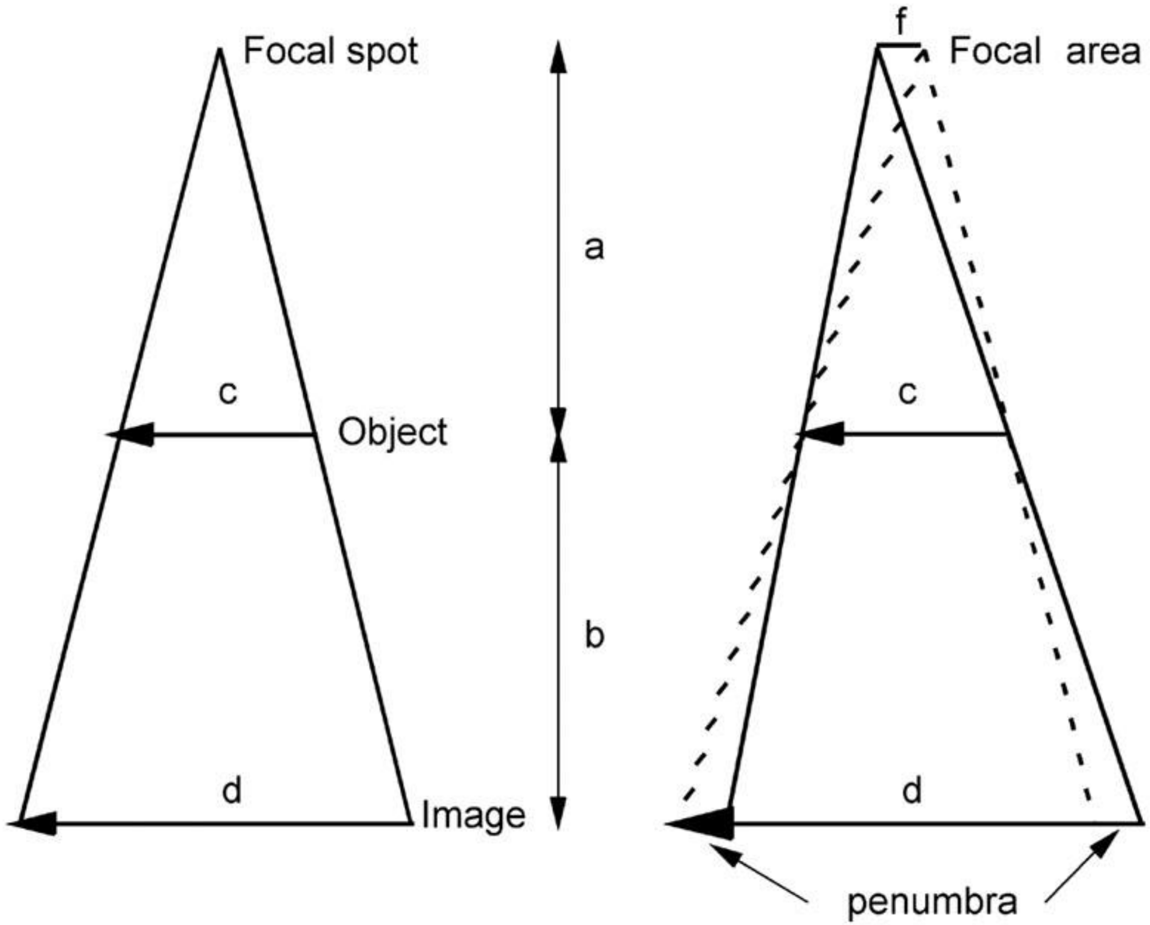
- **The blurred edge of the shadow is called the *penumbra,* which means "next to the shadow".**

Blurring can be reduced by:

- Using a small focal spot,
- Positioning the patient as close to the film as possible (and increasing the distance between the X-ray tube and the film as much as possible), and
- Reducing the amount of scattered radiation striking the film as much as possible.
- It is also necessary to avoid motion during the exposure, since motion causes blurring.

Chest radiography

Penumbra



Reducing the penumbra can be achieved by

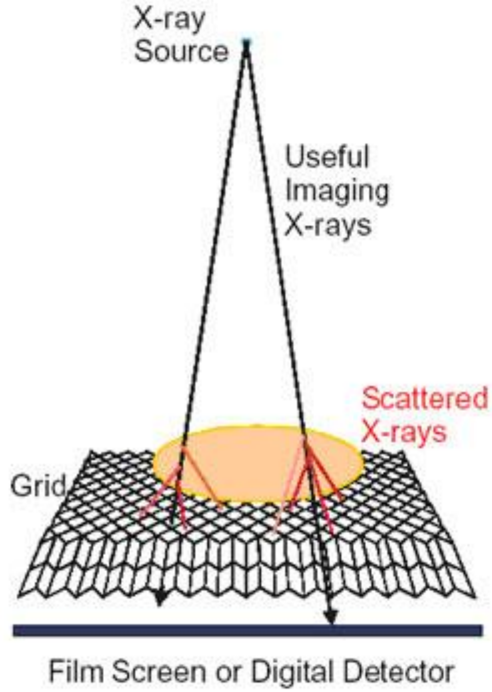
- Placing the patient as close to the film as possible
- increasing the distance from the X-ray tube to the film.
- taking Chest films from a distance of 180 cm

- To obtain a satisfactory X-ray image of thick body parts such as the abdomen,it is necessary to reduce the scattered radiation at the film.
- The amount of scattered radiation at the film depends somewhat on the energy of the x-rays, but the thickness of the tissue that the X-ray beam passes through is the most important factor (*the thicker the tissue, the greater the scatter*). Also, *the larger the beam, the greater the scatter.*

Grids

- **The most significant way of reducing the amount of scattered radiation striking the film is by using a *grid* consisting of a series of lead and plastic strips. The strips are aligned so that unscattered X-rays from the source will go through the plastic strips and strike the film while most of the scattered radiation will strike the lead strips and be absorbed**

GRIDS



X-ray
Source
Useful
Imaging
X-rays
Scattered
X-rays
Grid
Film Screen or Digital Detector