

**MD511**

# **Medical Imaging & Processing**

## **L2 – X-ray Imaging & Clinical Application**

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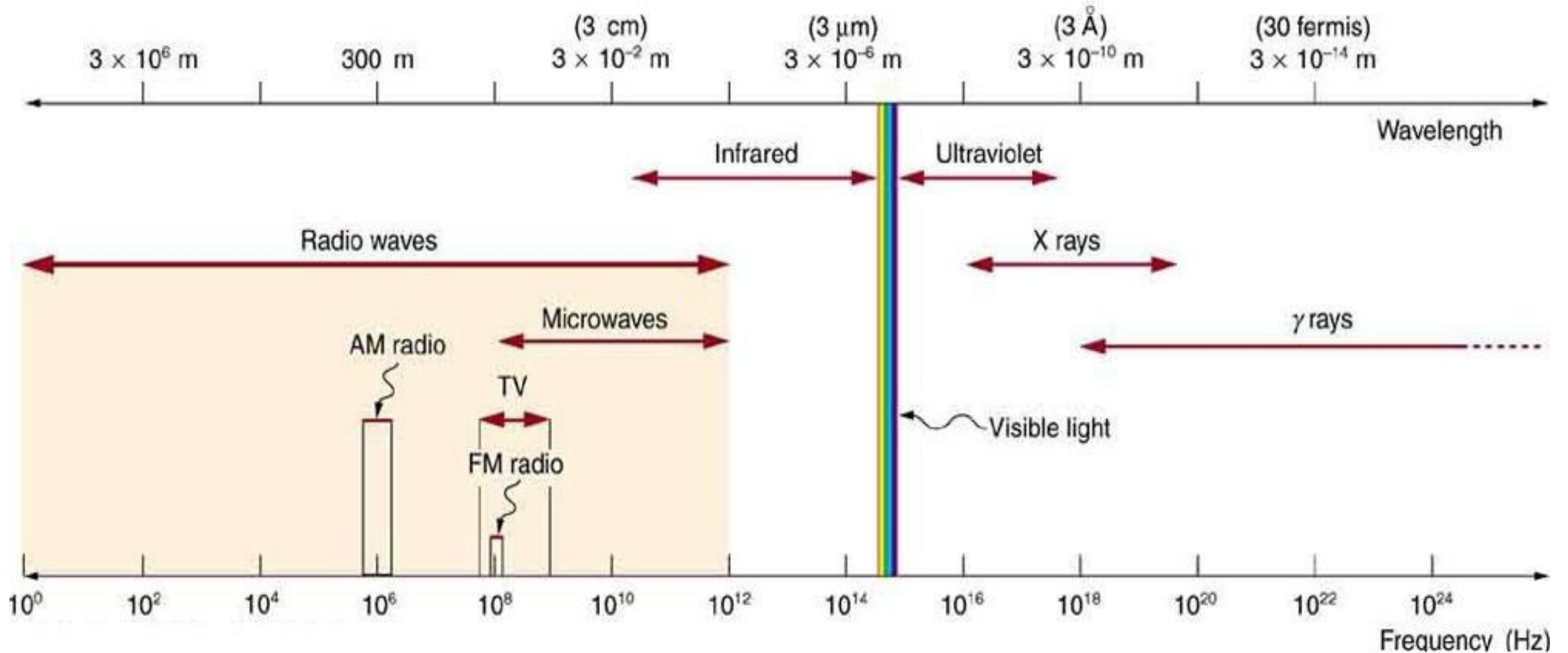
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# Last Lecture: Source of EMR



# Outlines of lecture

- X-Rays Physics
  - History
  - Generation of X-Rays
  - Types of x-rays
  - Spectrum of X-Rays
  - Inverse square Law
- X-Rays Machine
  - Cathode ray tube
- X-Ray Detector
- X-Rays interaction with Body
- X-Rays Safety - Radiation Dose
- X-Rays Clinical Applications
  - Plain Film Radiography
  - Contrast Radiography
- Image Artifacts

# X-Rays History

- Wilhelm Röntgen, discovered x-rays in 1895, while experimenting with Cathode rays.
- These rays were obtained by applying a potential difference across a partially evacuated glass “discharge” tube.
- Röntgen observed the emission of light from crystals of barium platinocyanide some distance away, and he recognized that the fluorescence had to be caused by radiation produced by his experiments.
- He named the radiation “**x rays**” and quickly discovered that the it could penetrate various materials and could be recorded on photographic plates.

*Röntgen, W. Über eine neue Art von Strahlen (vorläufige Mitteilung). Sitzungs-Berichte der Physikalisch-Medicinischen Gesellschaft zu Würzburg 1895;9:132.*

# X-Ray Discovery

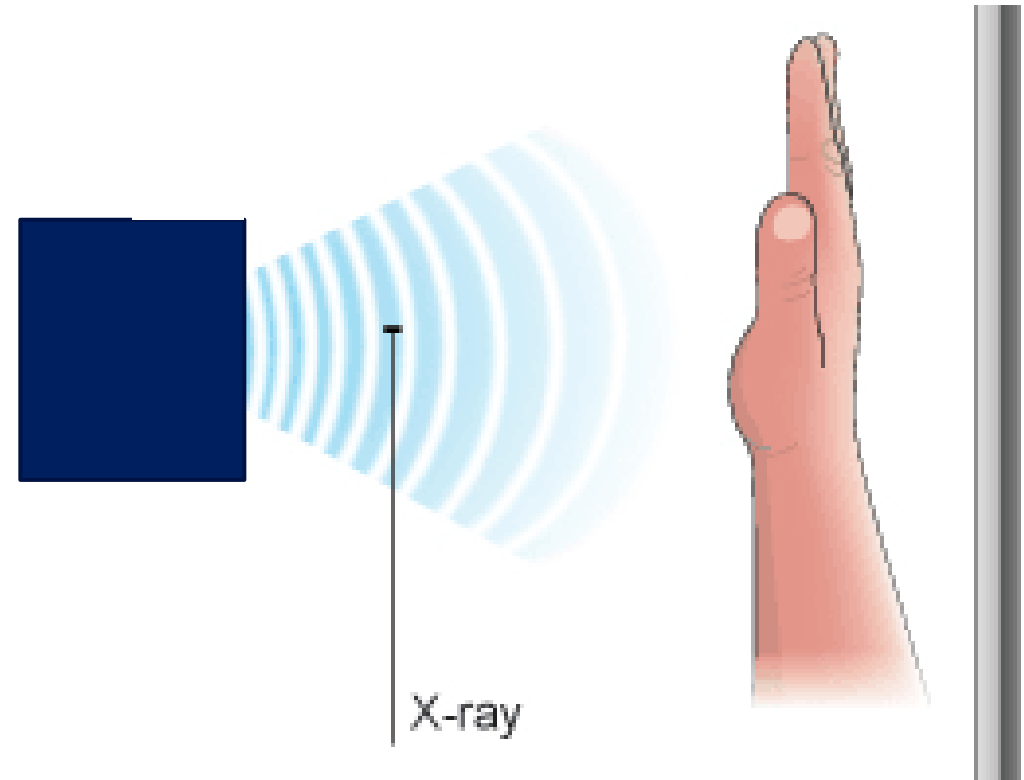
- ❑ Discovered and named by Dr. W. C. Röntgen at University of Würzburg, 1895
- ❑ Awarded first Nobel prize for Physics, 1901
- ❑ Did not patent the invention - Dr. Röntgen felt the discovery was for the benefit of mankind and not his sole property



*Stanton A (23 January 1896). "Wilhelm Conrad Röntgen On a New Kind of Rays: translation of a paper read before the Würzburg Physical and Medical Society, 1895". Nature. 53 (1369): 274–6*

# X-Rays Imaging

- X-Ray Imaging require
  - X-Ray Source
  - Object
  - Detector



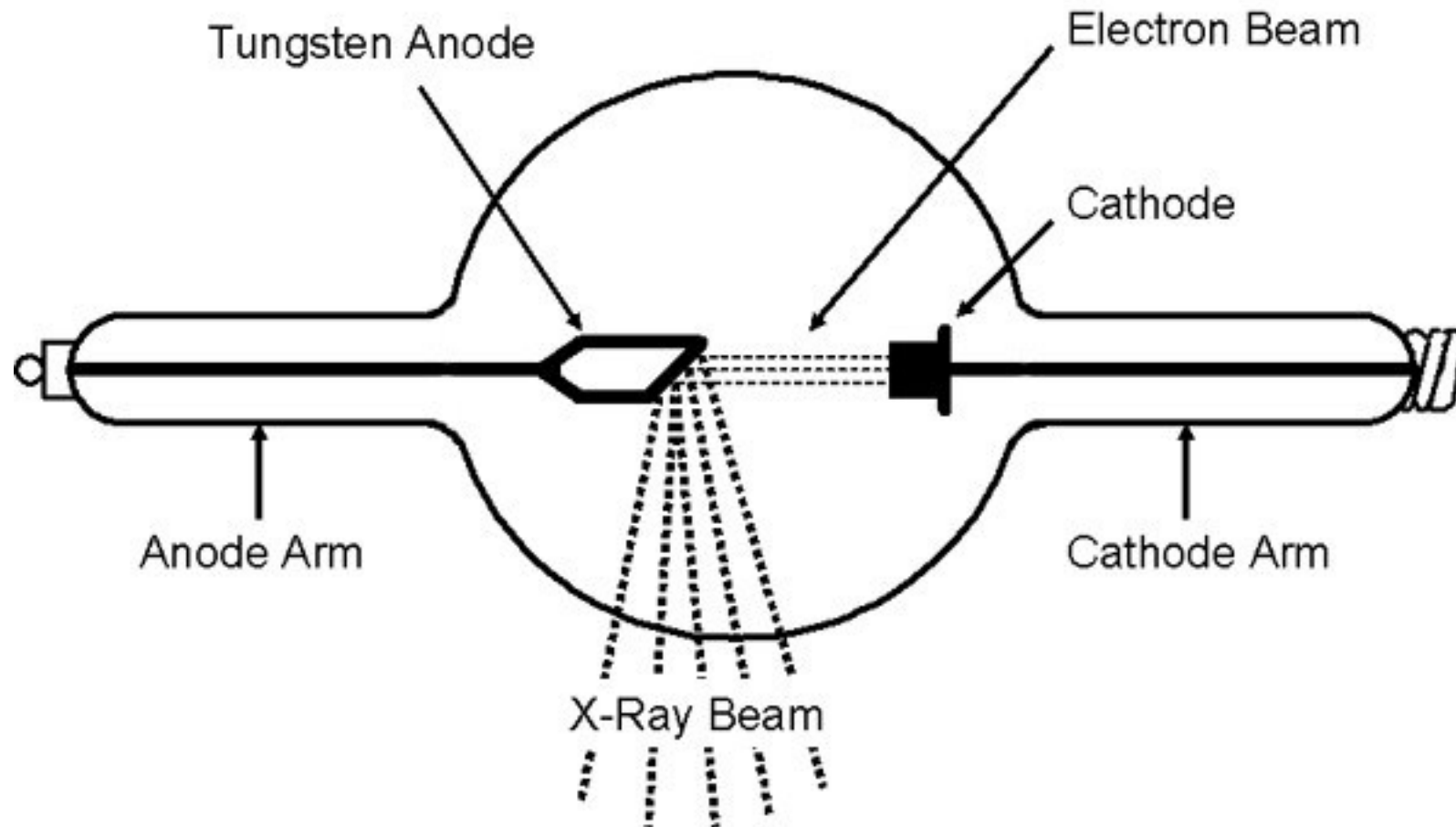
# X-Rays Source

- X-rays source requirements for Medical Images:
  - Produces enough x rays in a short time
  - Allows the user to vary the x-ray energy
  - Provides x rays in a reproducible fashion
  - Meets standards of safety and economy of operation
  
- X-rays are produced by:
  - radioactive isotopes,
  - Nuclear reactions such as fission and fusion,
  - Particle accelerators
  
- Only special-purpose particle accelerators known as **x-ray tubes** meet all the requirements mentioned above

# X-Ray Tube

- Initial X-ray studies were performed with a cathode ray Tube
  - Electrons liberated from residual gas atoms in the tube were accelerated toward a positive electrode (anode).
  - These electrons produced X-rays as they interacted with components of the tube.
  - This was an unreliable and inefficient method of producing X- rays.
- Hot cathode X-ray tubes
  - Heating of wire filament with electric current release electrons
  - Released electrons were repelled by the negative charge of the filament (cathode) and accelerated toward a positive target (the anode).
  - X rays were produced as the electrons struck the target.

# X-Ray Tube (Coolidge tube )



# X-Ray Tube (Coolidge tube )...

- The key advantages of the Coolidge tube are its stability, and the fact that the intensity and energy of the x-rays can be controlled independently.
- Increasing the current to the cathode increases its temperature. This increases the number of electrons emitted by the cathode, and as a result, the intensity of the x-rays.
- Increasing the high voltage potential difference between the anode and the cathode increases the velocity of the electrons striking the anode, and this increases the energy of the emitted x-rays.

<https://www.ornl.gov/PTP/collection/xraytubescoolidge/coolidgeinformation.htm>

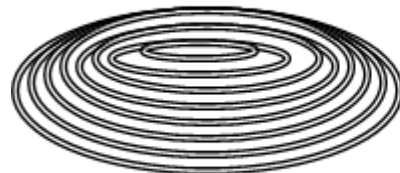
# Electron Source

- ❑ A metal with a high melting point is required for the filament of an X-ray tube.
- ❑ Tungsten filaments (melting point of tungsten  $3370^{\circ}\text{C}$ ) are used in most X-ray tubes.
- ❑ A current of a few amperes heats the filament, and electrons are liberated at a rate that increases with the filament current.
- ❑ The filament is mounted within a negatively charged focusing cup.
- ❑ Collectively, these elements are termed the cathode assembly.

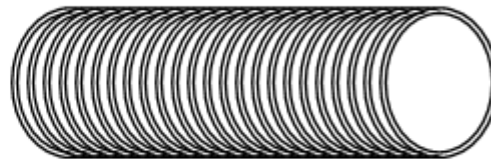
# X-Ray Tube: Cathode

- ❑ The cathode of the Coolidge tube incorporates a wound tungsten filament that emits electrons when heated.
- ❑ There are two general configurations of the filament.
  - spiral tungsten wire takes a circular/conical form (typical of the "Universal" tubes)
  - ilongate coil (the so-called Benson design).

Filament Configurations



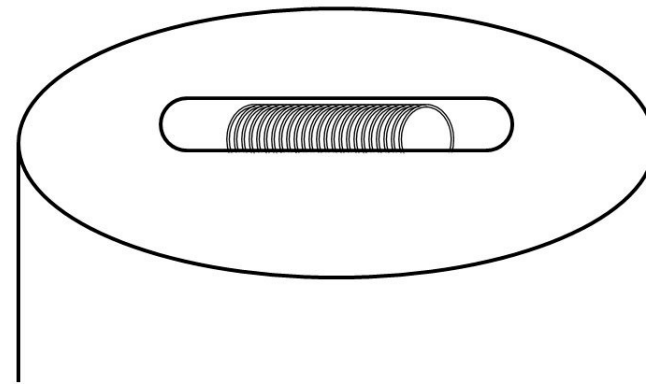
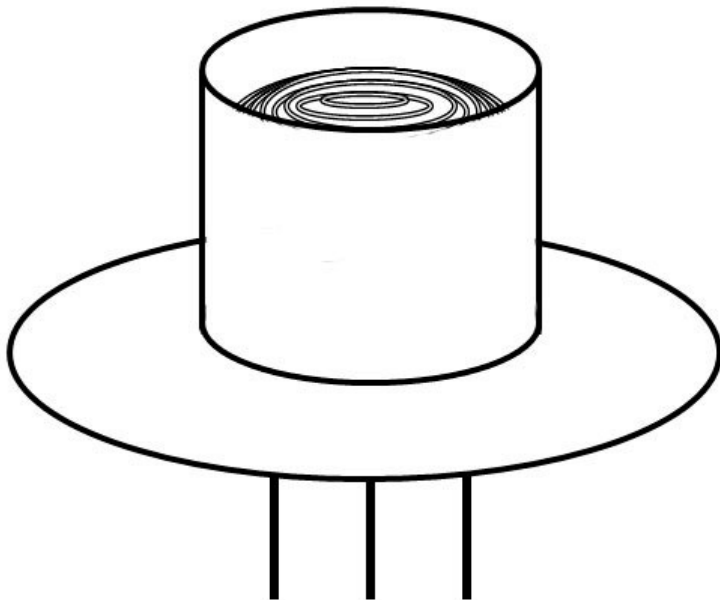
Flat/conical spiral



Coil (Benson)

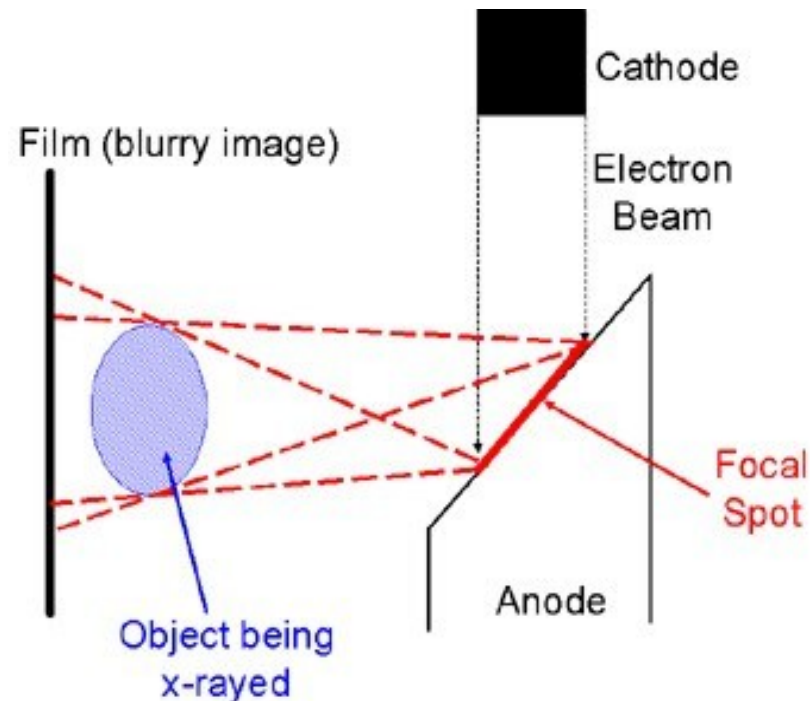
# X-Ray Tube: Cathode...

- ❑ The filament is located in a cylindrical chamber or slot machined into in the cathode.
- ❑ the focal spot is similar in size and shape (either round or elongate) to this opening.



# X-Ray Tube: The Anode

- Tungsten is the most commonly used target material in the anode because
  - it has a high atomic number which increases the intensity of the x-rays,
  - it has a sufficiently high melting point that it can be allowed to become white hot.



# X-Ray Tube: Glass

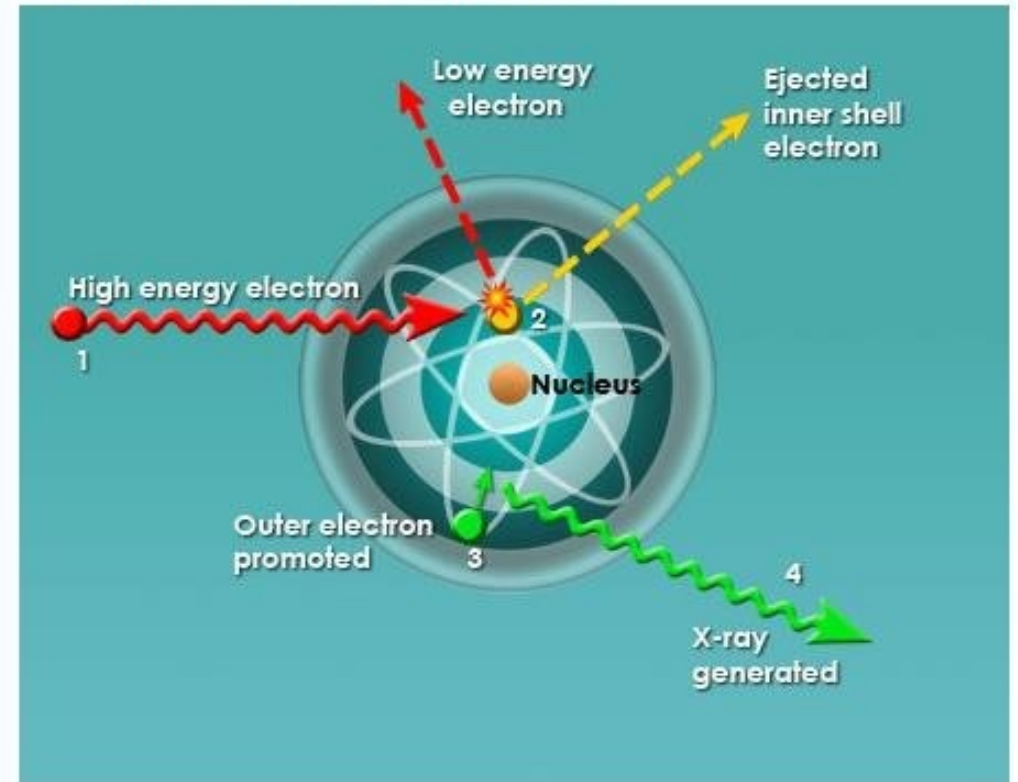
- Glass is more popular because
  - it is a good insulator,
  - it is vacuum tight,
  - it has a relatively high melting point,
  - it does not seriously attenuate the x-rays,
  - it can be fabricated into a wide range of shapes.

# Types of X-Rays

## Characteristic X-rays (related to the anode material)

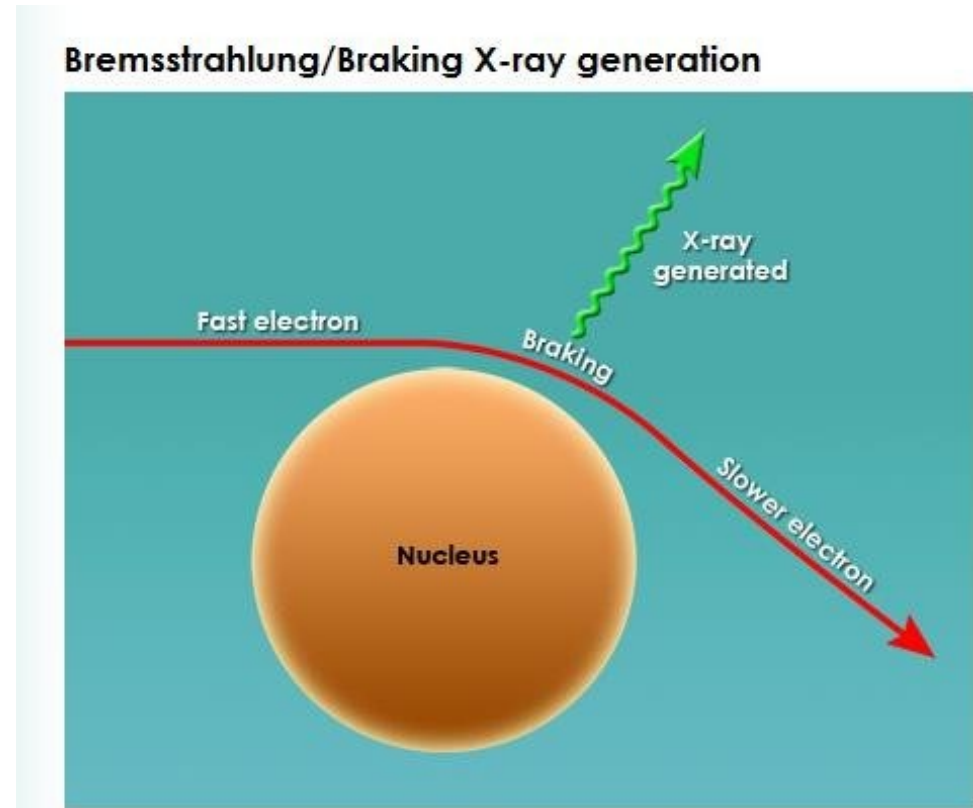
When a high energy electron collides with an inner shell electron both are ejected from the tungsten atom leaving a 'hole' in the inner layer. This is filled by an outer shell electron with a loss of energy emitted as an X-ray photon.

Characteristic X-ray generation



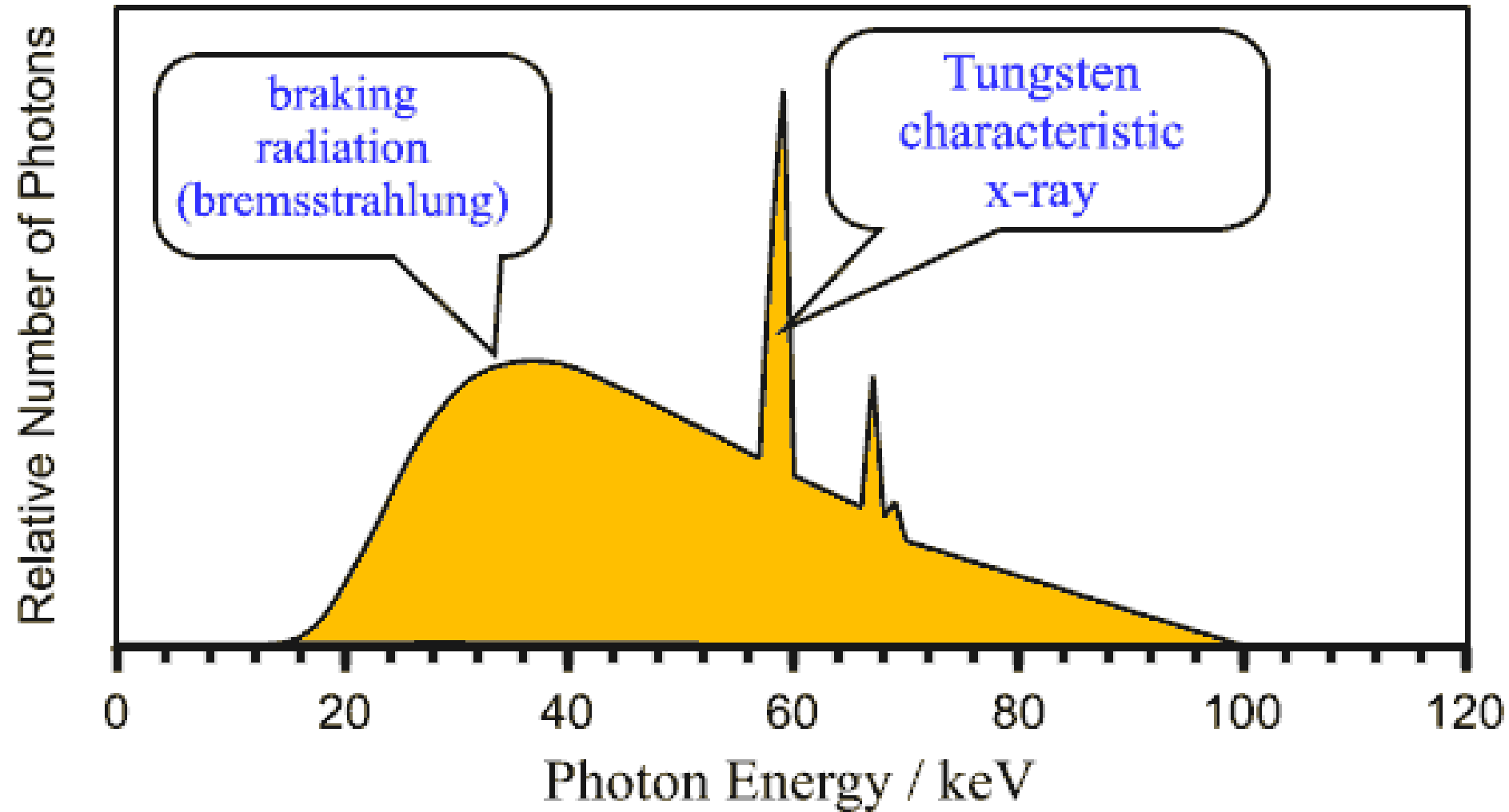
# Types of X-Rays...

- ❑ **Bremsstrahlung/Braking X-ray:**  
When an electron passes near the nucleus it is slowed and its path is deflected.
- ❑ Energy lost is emitted as a bremsstrahlung X-ray photon.



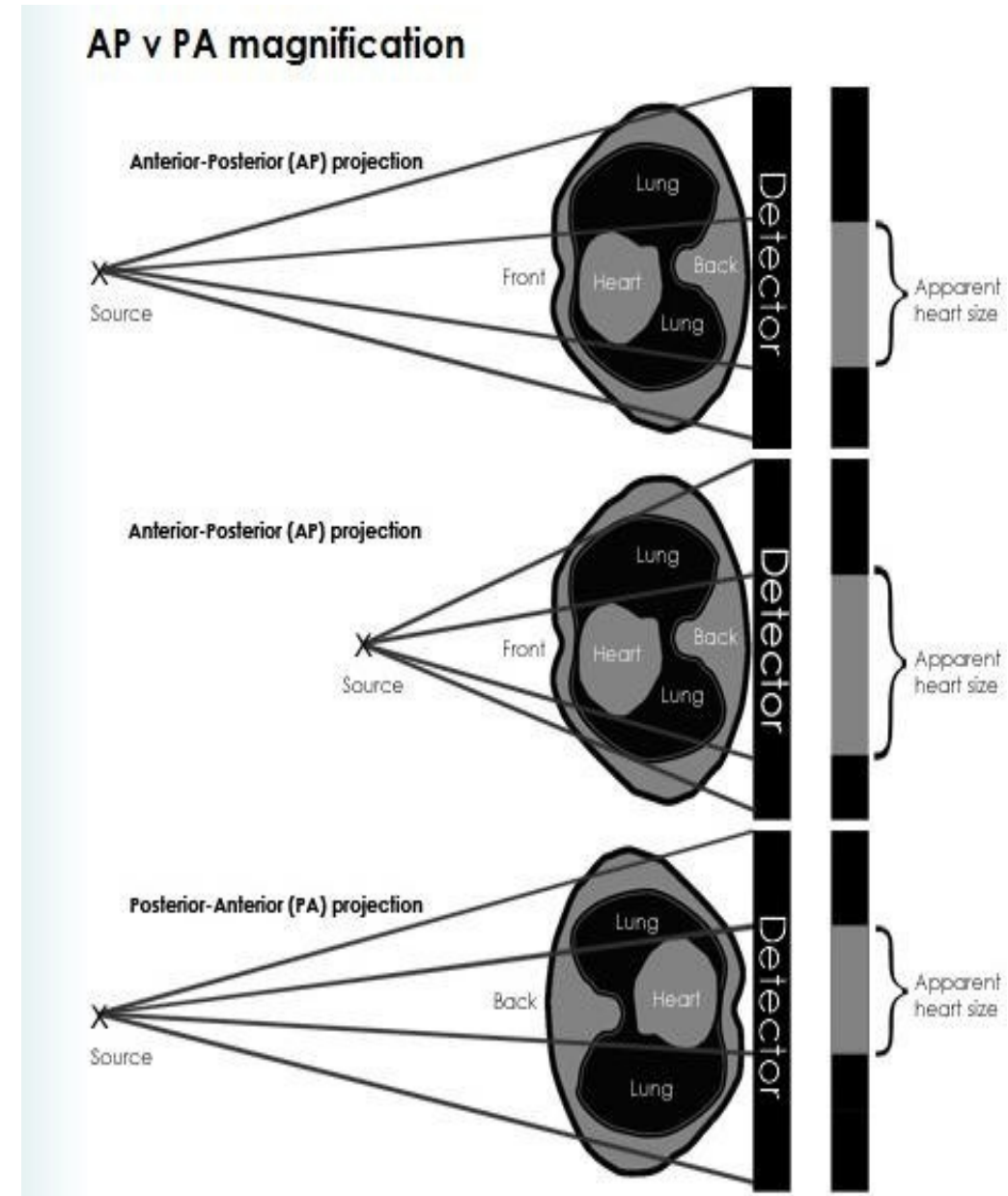
# X-Ray Spectrum

Calculated X-ray Spectrum 100kV, Tungsten target  $13^\circ$  angle



# The X-ray beam

- ❑ X-rays travel in straight lines and a beam of X-rays diverges from its source.
- ❑ Structures the beam hits first will be magnified in relation to those which are nearer the detector.
- ❑ To reduce magnification the X-ray source can be moved further away from the subject.
- ❑ Structures that need to be measured accurately should be placed closer to the detector.



# The X-ray beam...

- The number of photons passing per unit area perpendicular to the direction of motion of the photons is called the fluence,  $F$  .
- The fluence in a vacuum decreases following the inverse square law, given by

$$\Phi(r) = \Phi(1) \cdot \frac{1}{r^2}$$

- where  $r$  is the distance from the point source and  $\Phi(1)$  is the fluence at  $r=1$  (relative units).
- Beam Hardening
  - Filtering
  - Removing x-rays of low energy by placing some filter

# X-Ray Detectors

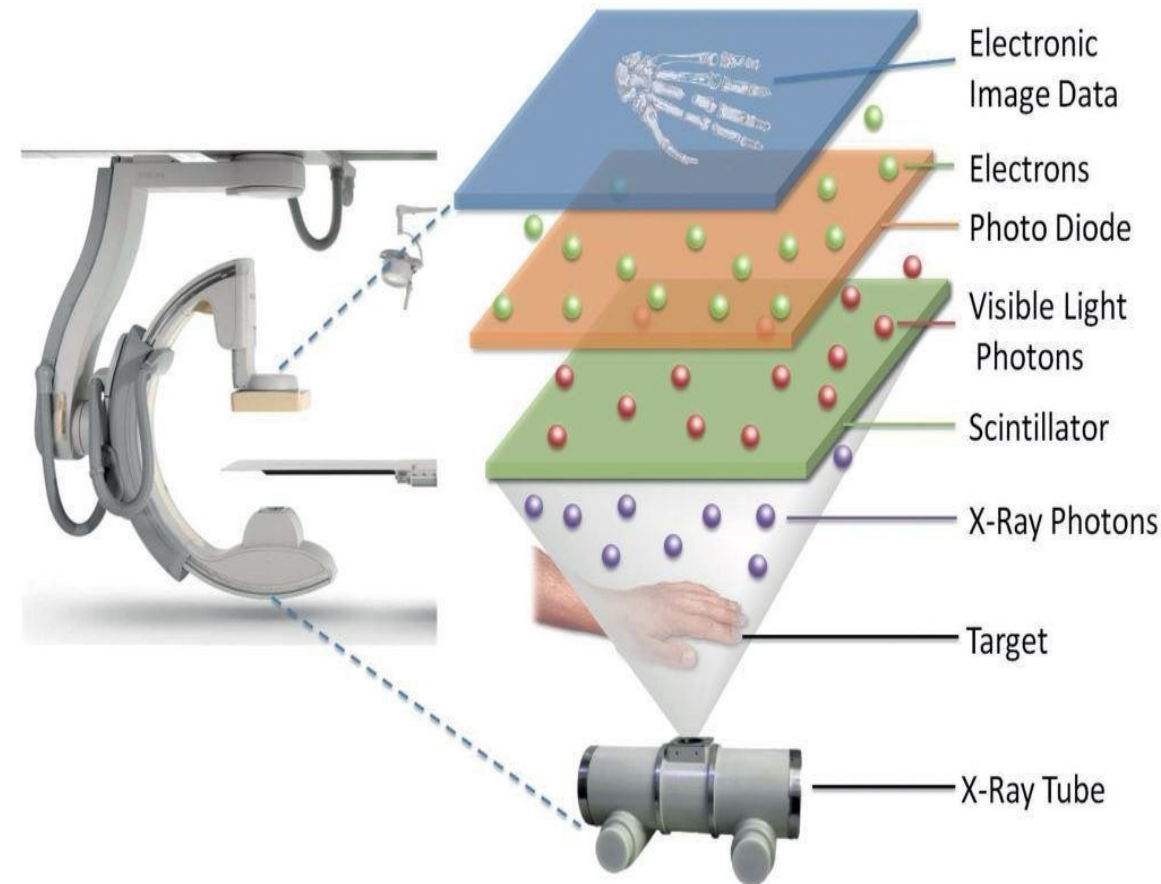
- Three categories
  - Photographic plates / films
  - Scintillation
  - Digital flat panel detectors
  
- Photographic plates: Plastic film coated with gelatin emulsion containing silver halide crystal. It is sensitive to X-rays.
  - X-rays are partially blocked ("attenuated") by dense tissues such as bone, and pass more easily through soft tissues. Areas where the X-rays strike darken when developed, causing bones to appear lighter than the surrounding soft tissue.

# X-Ray Detectors

- ❑ Scintillation: the property of luminescence when excited by ionizing radiation.
  - Detecting the light with a photomultiplier tube or a photodiode. Eg. thallium-activated sodium iodide [NaI(Tl)]; single crystals of sodium-activated cesium iodide [CsI(Na)]
- ❑ Digital Detectors: Semiconductors (Si(Li) or Ge(Li))
  - X-Ray photon is converted to electron-hole pairs-> producing current proportional to X-Ray energy
- ❑ Scintillator + Semiconductordetectors
- ❑ Gaseous ionization detectors: X-Ray will ionize gas -> current proportional to X-Ray energy.

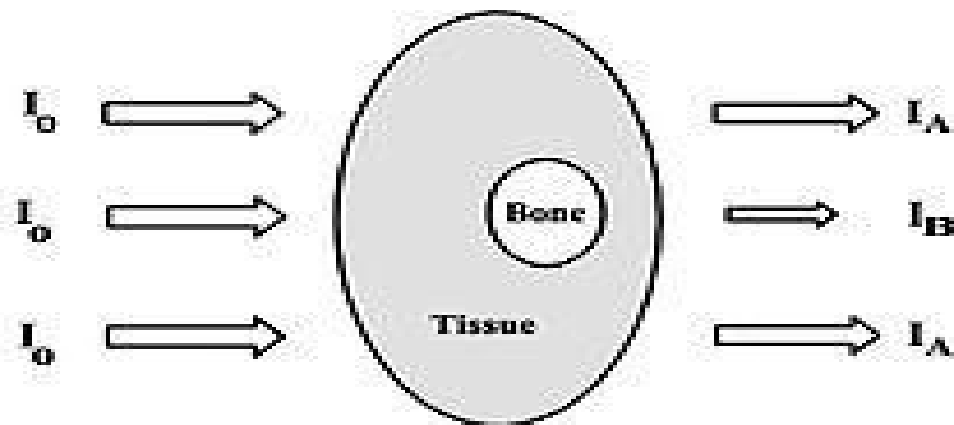
# X-Ray Detectors

- X-rays, a form of high-energy radiation, pass through the target being imaged
- The scintillator interact with X-Ray and emits visible light photons, which is directed to the photodiode.
- The photodiode converts the light photons into electrical signals. The amount of current produced is proportional to the intensity of the light.
- These electrical signals are then amplified and processed and used to create an image, where brighter areas correspond to regions where more X-rays were absorbed and more light was emitted.



# X-Ray Beam Interaction with Body

- Intensity of X-Ray beam is reduced as it pass through the body because of X-Ray photons colliding with atoms of the tissue
- Collision results in absorption and scattering of photons
- Absorption process (Photoelectric Effect) - transfer of photon's energy to atoms of the target material
- Scattering process (Compton Effect)



# X-Ray Beam Interaction with Body

## □ Photoelectric Effect (PE):

- In this process, an incoming X-ray photon collides with an electron in an atom, transferring all its energy to the electron.
- The electron is ejected from the atom leaving a hole and called photoelectron.
- To fill these holes electrons cascade from higher to lower energy levels and produce a number of characteristic photon, which are completely absorbed in the surrounding tissue
- $p(PE) \propto Z^3/E^3$  (Z-atomic number, E-photon energy)
- PE → responsible for the contrast in image
  - Bone (Ca) absorb more photons

# X-Ray Beam Interaction with Body

## □ Compton Effect (CE):

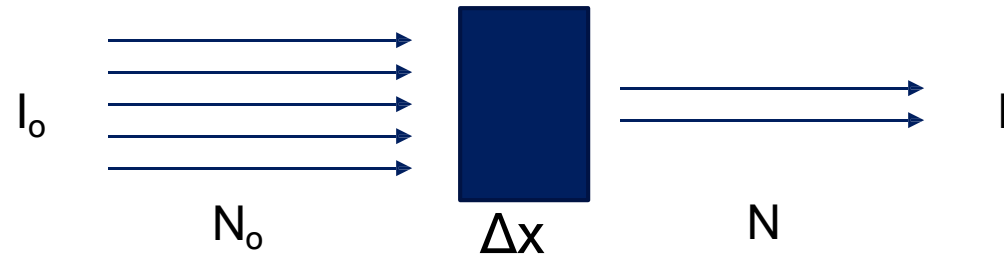
- Incoming X-ray gets scattered by loosely bound outer atomic electrons
- Outer shell electron have essentially low binding energy in atoms with high atomic number (Z);
- Low atomic number (soft tissues) have low binding energy for all atoms
- The photon is scattered (deflected) at an angle, and the electron is also ejected with some of the photon's energy.
- $p(\text{CE})$  is independent of atomic number (Z) and photon energy (E) and contributes to noise in medical images

# X-Ray Beam Interaction with Body

## □ K-edge Effect

- When an incident X-ray has energy equal or slightly greater than the binding energy of the K-shell electron of the atom, a large sudden increase in X-ray attenuation (absorption) is observed.
- Photons with energy equal to or greater than the binding energy of K-shell electrons interact predominantly with K-shell electrons. This energy value is known as K-edge, and the phenomenon is called K-edge effect.
- K-edge value increases with atomic number of the element.
- By using contrast agents with K-edges in the diagnostic X-ray energy range (like iodine- 33.2 keV, barium - 37.4 keV), tissue contrast can be selectively enhanced
- The photoelectric effect and K-edge effect are crucial for creating contrast in X-ray imaging

# X-Ray Attenuation



- $N_0 - N = \mu N \Delta x$
- $\mu \rightarrow$  Linear Attenuation Constant (Characteristic of material)
- $N = N_0 \exp(-\mu x)$  Similarly, Intensity ( $I = N \times \text{Energy}$ )
- $I = I_0 \exp(-\mu x)$ ; called Beer- Lambert Law

# X-Ray Attenuation

- ❑ Tissues have different densities ( $\rho$ ) of attenuating material
- ❑ Mass Attenuation Coefficient,  $\mu_m = \mu / \rho$
- ❑  $\mu_m$  is useful to account for different material phases of an absorber, eg. Water in all three phases have same  $\mu_m$
- ❑ Half Value Layer,  $HLV = \ln 2 / \mu$ 
  - The thickness of absorber to halve the incident beam intensity
  - Useful in radiological protection (Lead plates)



# Radiation Biology

- X-Ray is an ionizing radiation, harmful in excess dose
- X-Ray → ionization of tissue → generation of free radicals
  - → interact with other molecules like DNA to cause mutation
  - → can affect bone marrow, digestive tract to induce cancer
  - → heat can cause thermal damage to tissue
- Cell death occur only above a threshold dose of X-Ray
  - The value of threshold is dependent on tissue type
  - RBC - low radio-sensitive
  - GI tract - high radio-sensitive
  - Ovary & Testicles - Very high radio-sensitive

# X-Ray Dose

- ❑ Unit for measurement for X-Ray dose is millisievert (mSv)
- ❑ Different tissue have varying sensitivity to radiation exposure
- ❑ Effective dose is thus used to refer the radiation risk average over the exposed area
- ❑ Effective dose need to account for Tissue Weighting Factor
  - Bone marrow, Colon, Breast, Stomach - 0.12
  - Gonads - 0.08
  - Bladder, Liver, Thyroid - 0.04
  - Bone, Brain Skin - 0.01
- ❑ Natural / Background radiation exposure
  - 3 mSv/year from natural radioactive matters & cosmic radiations
  - Return flight from NY to LA adds  $\sim 0.03\text{mSv}$

[http://www.radiologyinfo.org/en/safety/?pg=sfty\\_xray](http://www.radiologyinfo.org/en/safety/?pg=sfty_xray)

[http://www.radiologyinfo.org/en/pdf/sfty\\_xray.pdf](http://www.radiologyinfo.org/en/pdf/sfty_xray.pdf)

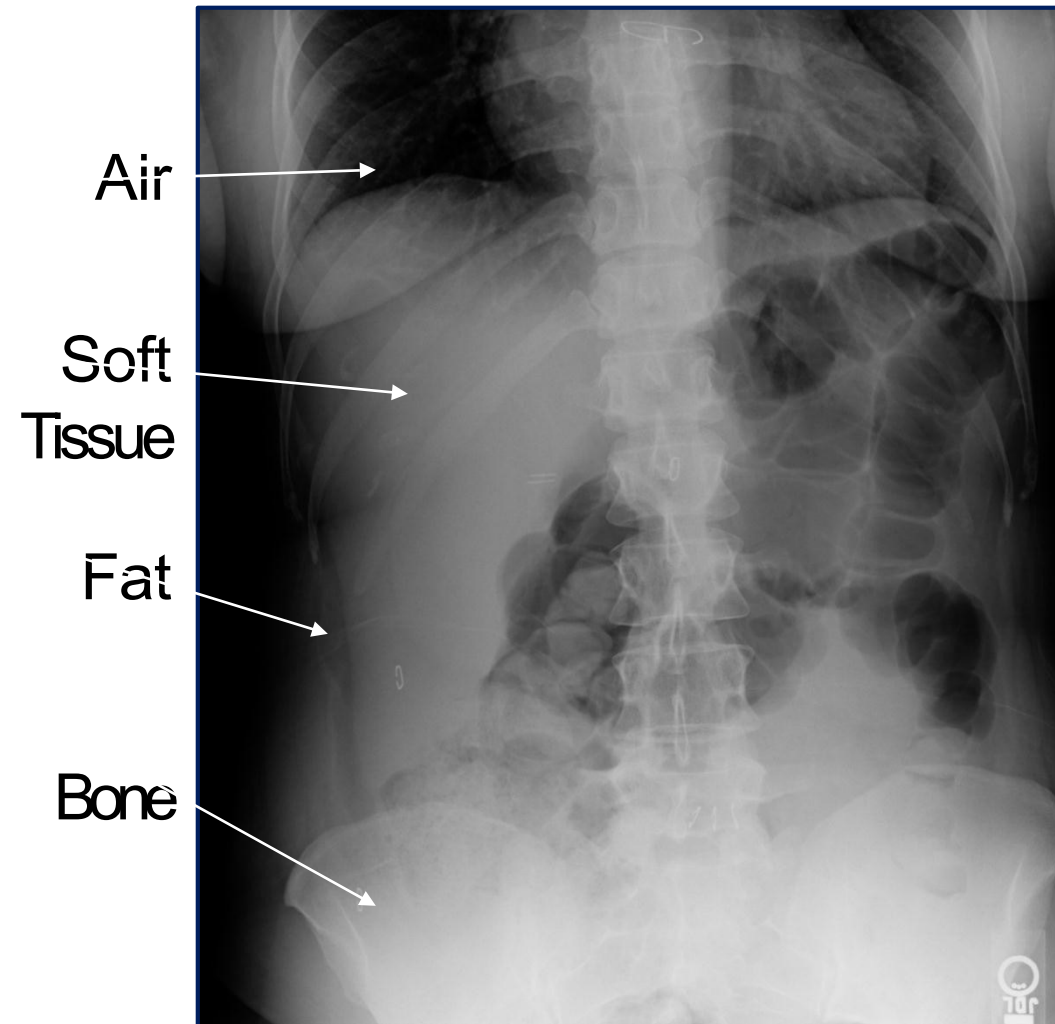
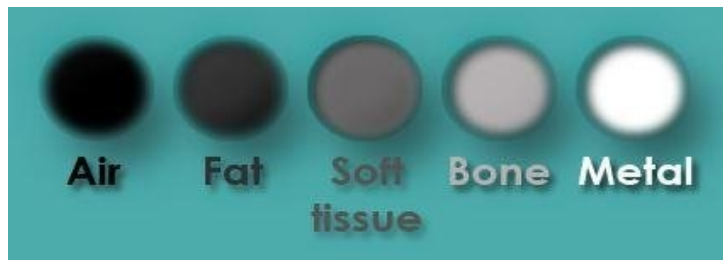
# X-Ray Dose

X-Ray Examination	Dose (mSv)
Skull (AP or PA)	0.03
Skull (lateral)	0.01
Chest (PA)	0.02
Chest (lateral)	0.04 – 0.06
Thoracic spine (AP)	0.4
Thoracic spine (lateral)	0.3
Abdomen	0.6 – 0.7
Pelvis	0.7 – 0.8

[http://hps.org/physicians/documents/Doses from Medical X-Ray Procedures.pdf](http://hps.org/physicians/documents/Doses_from_Medical_X-Ray_Procedures.pdf)

# X-Ray Attenuation and Contrast

- Different tissues in our body absorb X-rays at different extents:
  - Bone - High absorption (appear White)
  - Soft tissue - Somewhere in the middle absorption (appear Grey)
  - Air - Low absorption (appear Black)

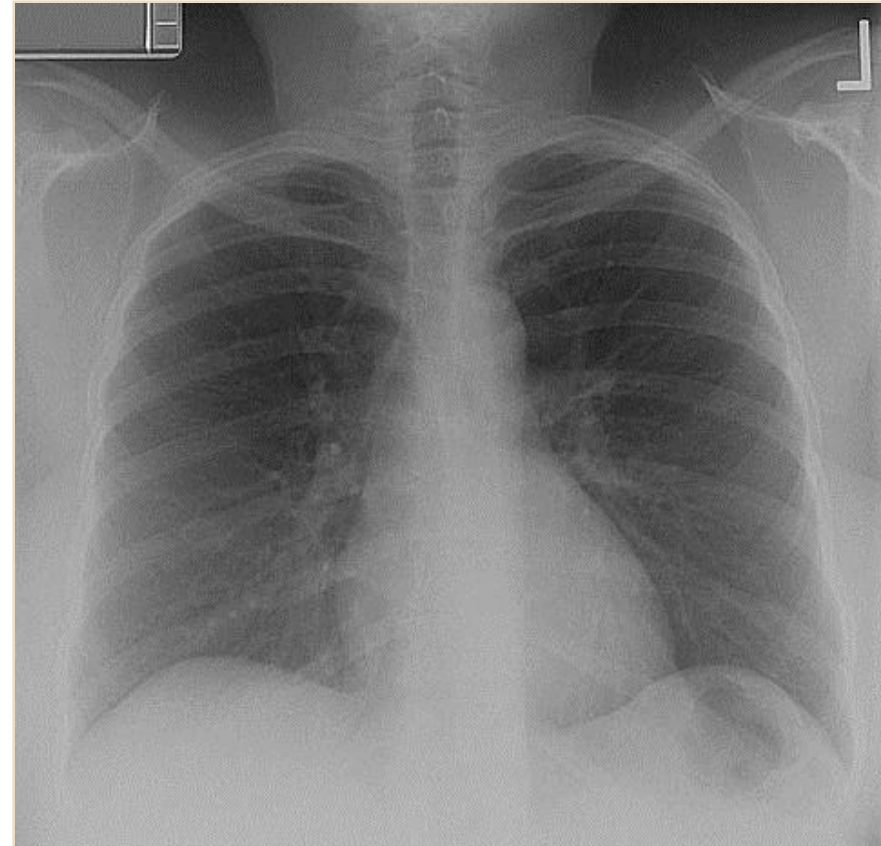


# Role of X-Ray in Clinical Practice

- Separation: Normal vs Abnormal
- Characterization: Describe the abnormality
- Determination: Extent (grade/stage) of disease
- Suggestion: Diagnosis / Differential diagnosis
- Recommendation: Further investigation / Follow-up

# X-Ray or Plain Film Radiography

- ❑ Chest
- ❑ Mammography
- ❑ Abdomen
- ❑ Spine
- ❑ Extremities & Joints
- ❑ Skull

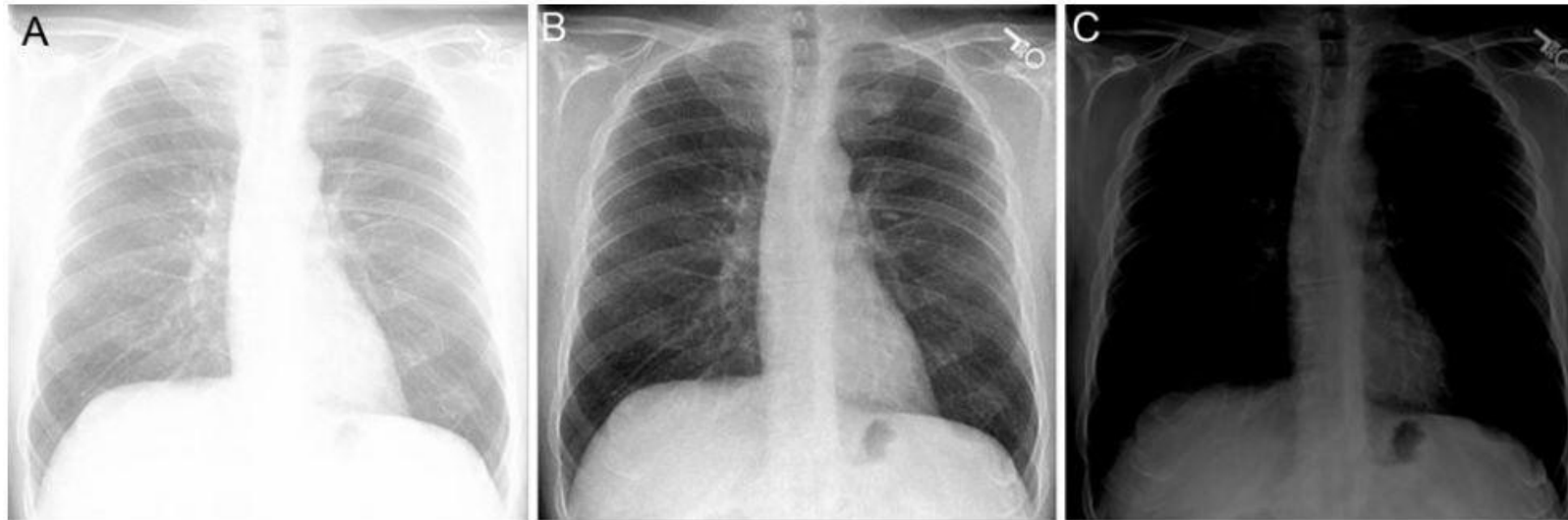


# Chest X-Ray Reading – I view

- Type Xray: PA or Lateral view
  - Posteroanterior refers to the direction of the x-ray traversing the patient from posterior to anterior.
  - This film is taken with the patient
    - upright
    - in full inspiration (breathed in all the way)
    - the x-ray beam radiating horizontally 6 feet (1.8 m) away from the film
- AP view is acquired x-ray traversing the patient from anterior to posterior, usually obtained with a portable x-ray machine from very sick patients, those unable to stand, and infants.

# Chest X-Ray Reading – II quality

- ❑ Exposure: Overexposed films look darker; Underexposed films look whiter
- ❑ Motion: Blurring of the region
- ❑ Rotation: Patient is rotated, causes distortion of the organs



Underexposed

Correct exposed

Overexposed

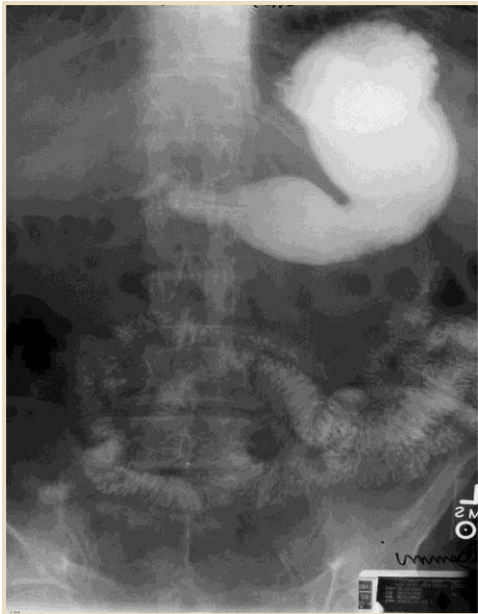
# Chest X-Ray Reading – Ill disease

- Airway:
  - airway is patent & midline trachea; air shadow in both lungs
- Bones: fractures, mineralization, lytic lesions
- In joints: joint space (narrow/widen), calcification, air in joint
- Cardiac silhouette
- Diaphragms: flat (emphysema) or raised diaphragm (pneumonia)
- Edges of heart/ Soft tissue: lymph node, mass
- Field of lungs: mass, fluid, vascularity
- Gastric bubble:

# Contrast Radiography

- ❑ Injection, ingestion or other placement of opaque materials within the body
- ❑ Improve visualization and tissue separation
- ❑ Can demonstrate functional anatomy and pathology

**Upper GI – Barium meal –  
stomach barium contrast**



**Without contrast-plain  
X-Ray Abdomen**



**Lower GI - Barium enema -  
rectal barium contrast**



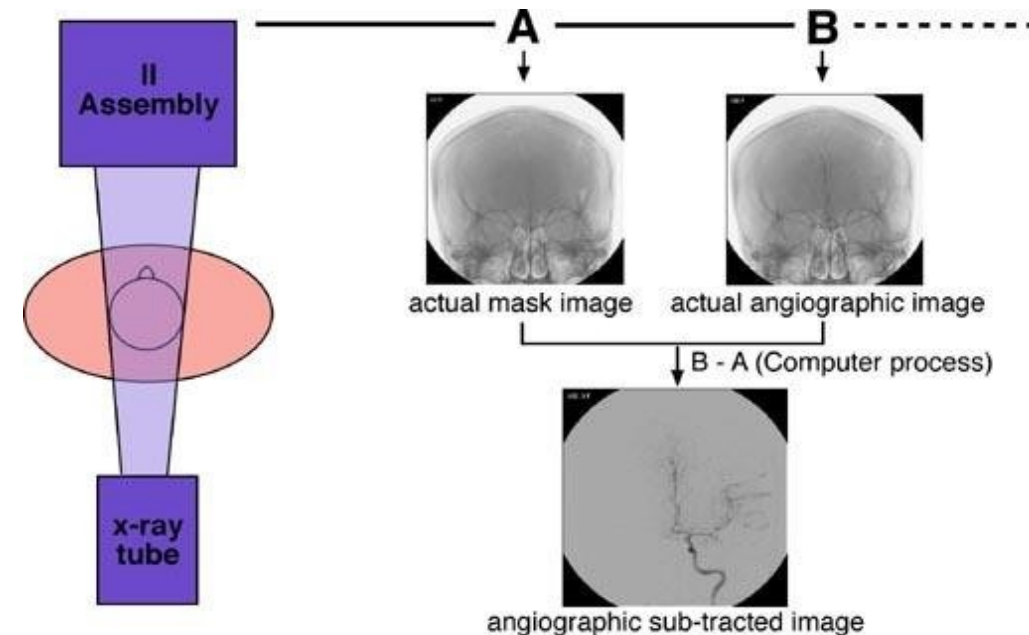
# Contrast Radiography – DSA

## □ Digital Subtraction Angiography (DSA)

- Fluoroscopy technique – obtain real-time moving image of internal organ
- Interventional radiology
- Used to visualize blood vessels

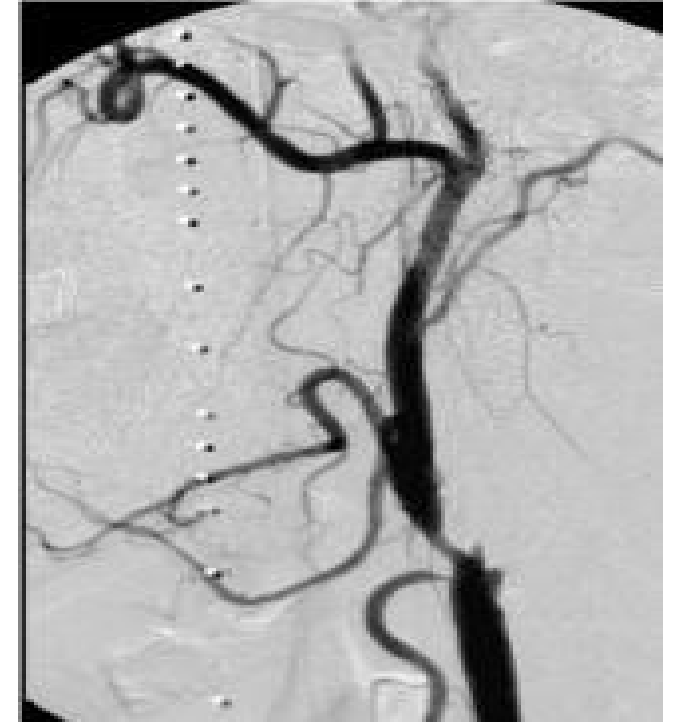
## □ Procedure:

- Inject contrast agent (Iodine chelate) into the artery / vein
- Acquire pre- and post contrast image
- Subtraction of Post-image – Pre-image



# Contrast Radiography – DSA

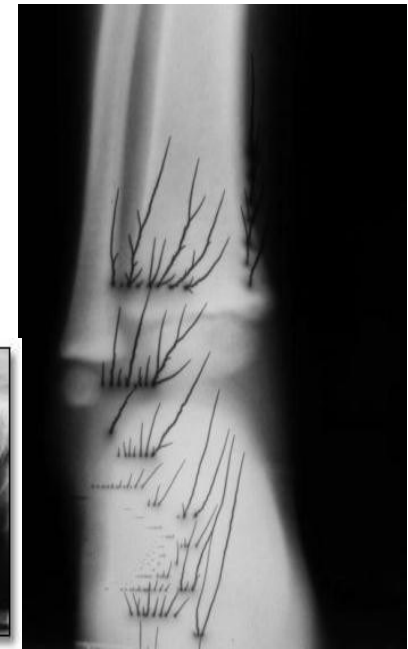
- Clinical Application:
  - Arterial and venous occlusion
    - Carotid stenosis
    - Pulmonary embolism
  - Renal Artery Stenosis (Gold Standard is DSA)
  - Cerebral Aneurysm
  - Arterio-Venous Malformation (AVM)



Left Common Carotid Artery Stenosis

# X-Ray Artifacts

- ❑ Artifacts are abnormal shadow on the radiograph that degrade image quality for diagnostic purposes
- ❑ Motion artifact – blurring
- ❑ Radio-opaque object (necklaces, button)
- ❑ Static electricity - black “lightning” marks resulting from films forcibly unwrapped or excessive flexing of film
- ❑ Crescent-shaped white lines - due to cracked intensifying screen
- ❑ Black film - due to complete exposure to light
- ❑ Over or Under exposure X-Ray
- ❑ Ghosting



# References

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