X RAY PRODUCTION AND PROPERTIES

DISCOVERY OF X RAY

- Discovered in 1895 by German physicist named Wilhelm Roentgen.
- while studying cathode rays (stream of electrons) in a gas discharge tube.
- He observed that another type of radiation was produced (presumably by the interaction of electrons with the glass walls of the tube) that could be detected outside the tube.
- This radiation could penetrate opaque substances, produce fluorescence, blacken a photographic plate, and ionize a gas.
- He named his discovery “x rays” because “x” stands for an unknown.

PROPERTIES OF X-RAY

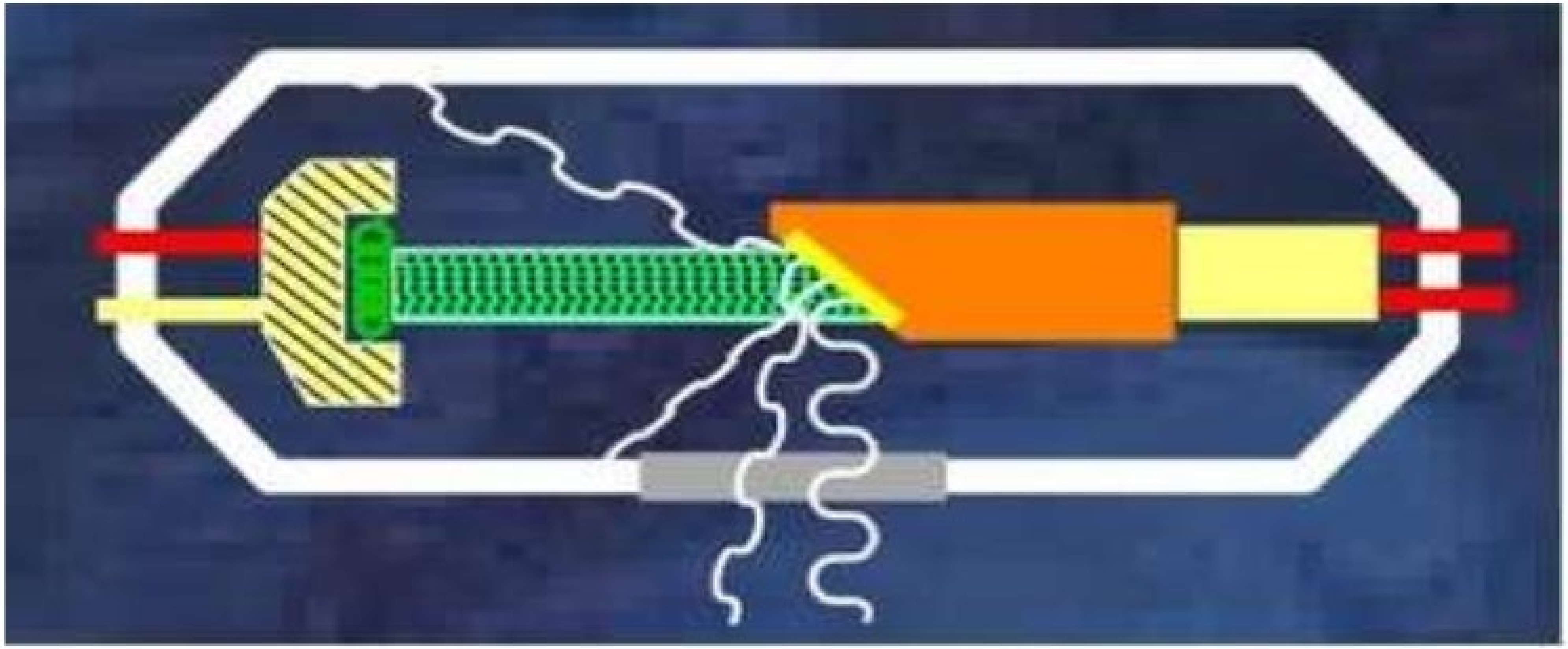
- X-rays are invisible.
- X-rays have no mass.
- X-rays travel at the speed of light in a vacuum
- X-rays travel in straight lines.
- They have a very short wavelength
- They are unaffected by electric and magnetic fields
- They cannot be refracted
- They cause **ionisation** (adding or removing electrons in atoms and molecules)

- ✓ They are transmitted by (pass through) healthy body tissue
- ✓ They affect photographic film in the same way as visible light (turning it black)
- ✓ They are absorbed (stopped) by metal and bone
- ✓ They can cause photoelectric emission
- ✓ They are produced when a beam of high-energy electrons strike a metal target

- **These properties make X-rays very useful for medical diagnosis and treatment.**

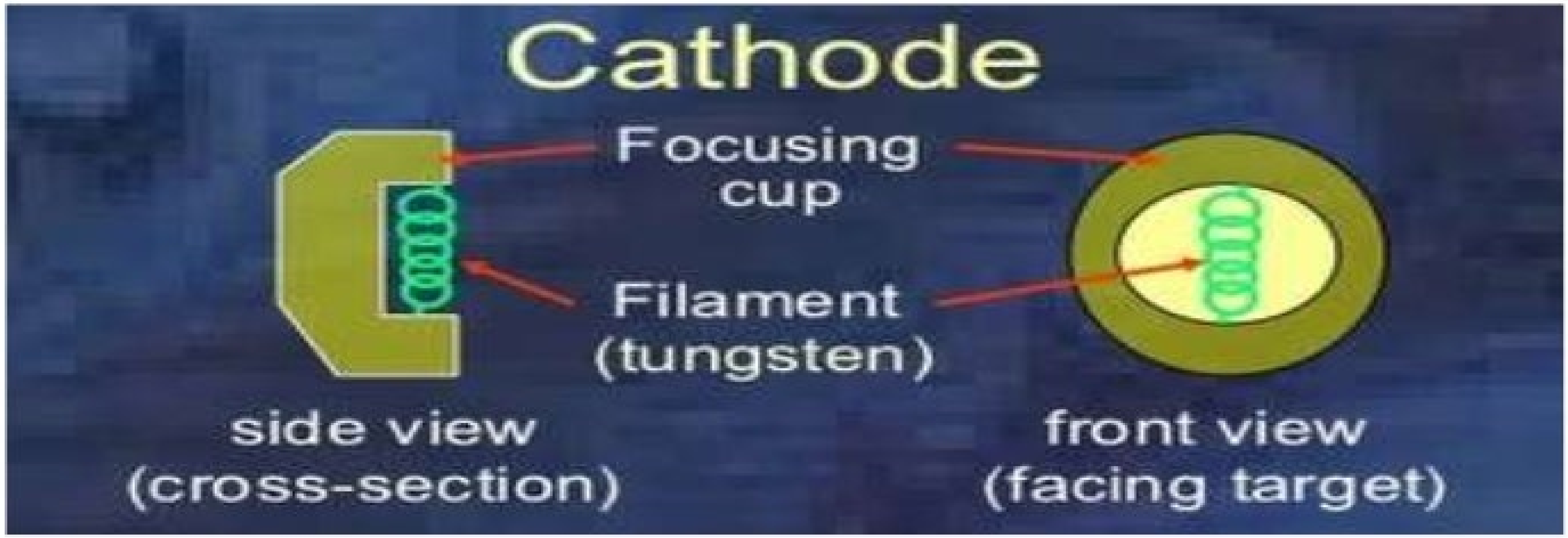
X-RAY TUBE

- X ray are produced in the x-ray tube, which is located in the x-ray tube head.
- X-ray are generated when electrons from the filament cross the tube and interact with the target.
- The two main component of the x-ray tube are the cathode and the anode.



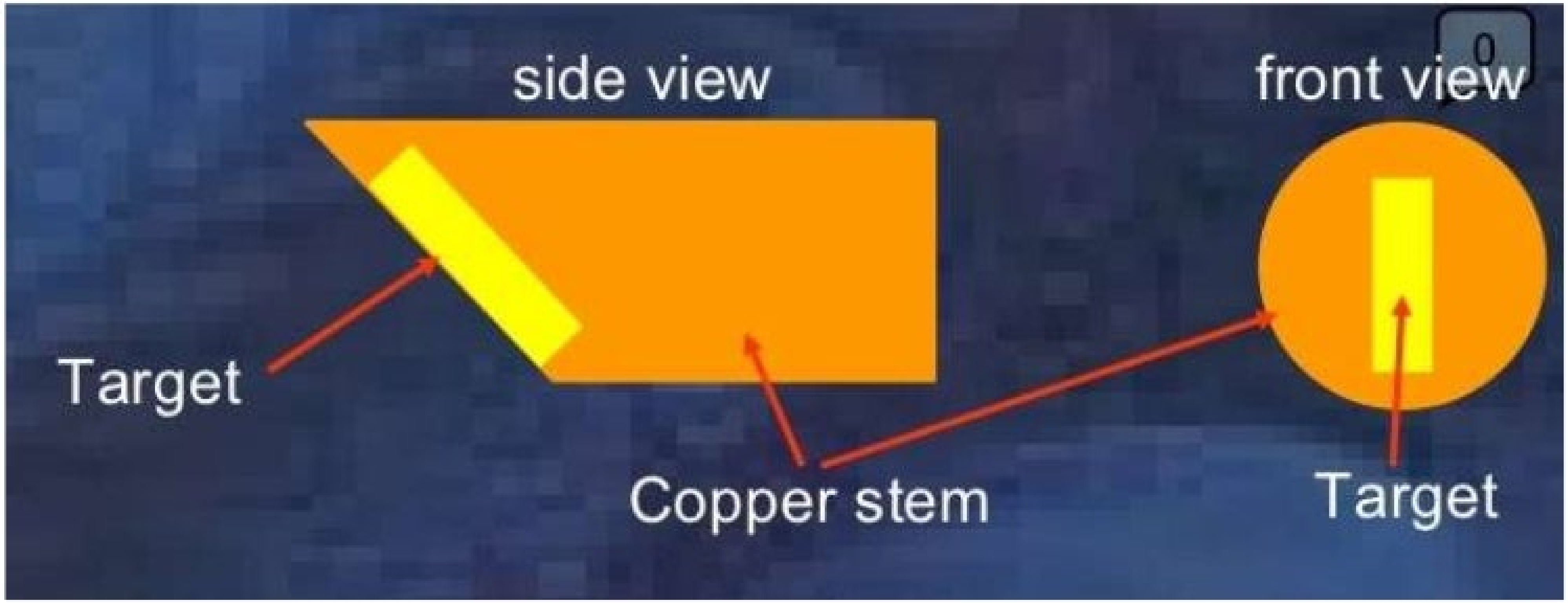
Cathode

- The cathode is composed of tungsten filament which is centered in a focusing cup.
- Electron are produced by the filament and are focused on the target of the anode where the x-ray are produced.
- The focusing cup has a negative charge ,like the electrons and this helps direct the electrons to the target(focuses them ,electrons can be focused-ray cannot)



Anode

- The anode in the X-ray tube is composed of a tungsten target embedded in a copper stem.
- When electrons from the filament enter the target and generate X-rays a lot of heat is produced.
- The copper helps to take some of the heat away from the target so that it doesn't get too hot.



WHY TUNGSTEN?

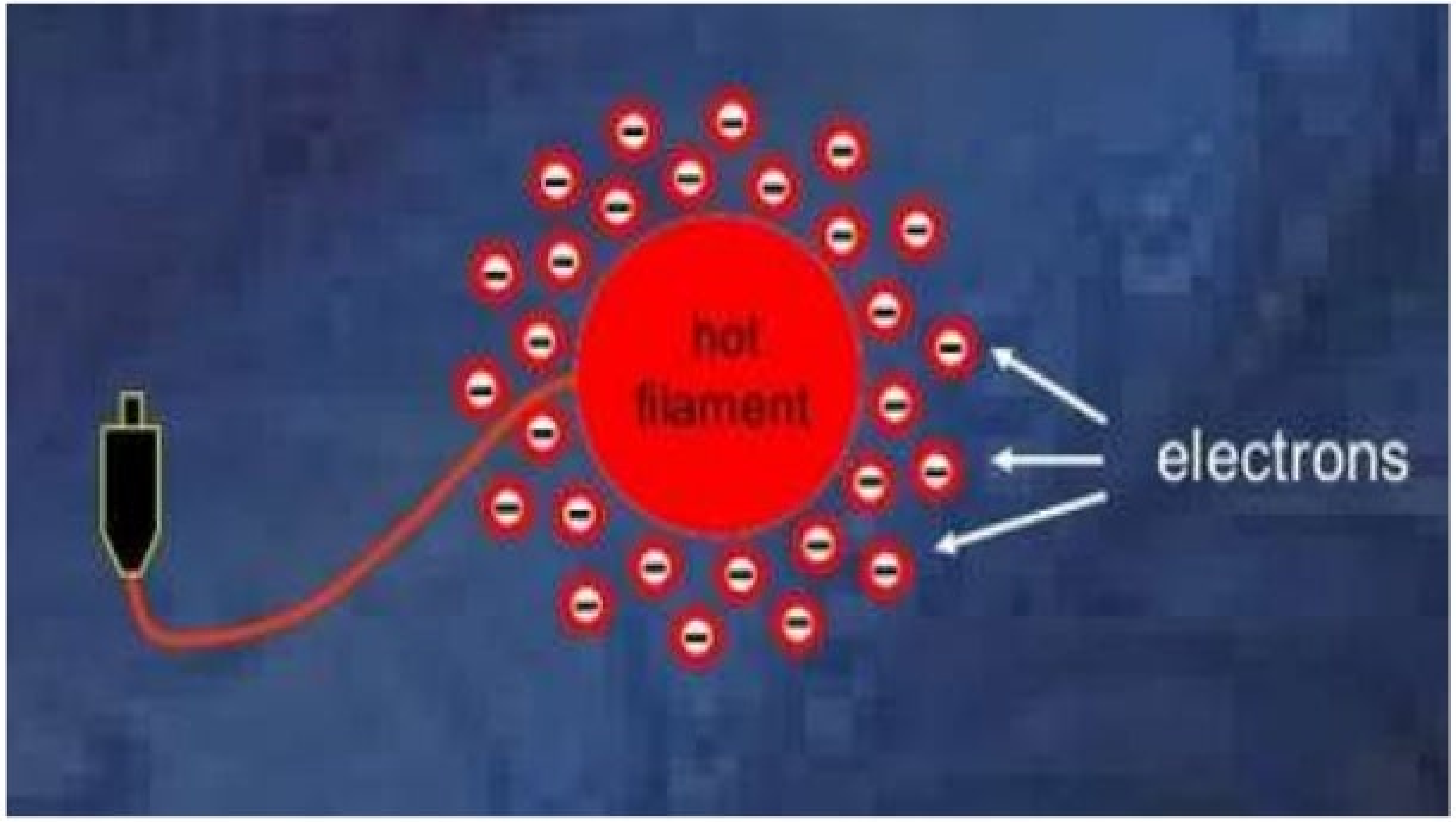
- The choice of tungsten as the target material in conventional x-ray tubes is based on the criteria that the target must have a high atomic number and high melting point.

- The efficiency of x-ray production depends on the atomic number, and for that reason, tungsten with $Z = 74$ is a good target material.

- It has a melting point of 3 , 3 70℃, is the element of choice for withstanding intense heat produced in the target by the electronic bombardment.

Thermionic Emission

- When a high voltage is applied between the anode and the cathode, the electrons emitted from the filament are accelerated toward the anode and achieve high velocities before striking the target.



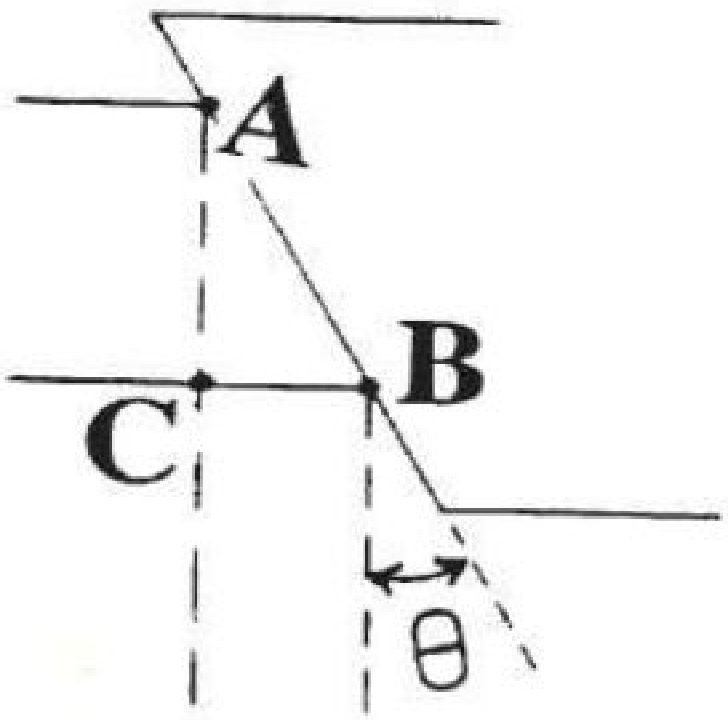
Line Focus Principle

- The area struck by the electron ,called the focal spot of X-ray emission, is heated instantly
- During X-ray production ,a lot of heat is generated.
- If the target is too small, it will overheat and burn up.
- In order to get a small focal spot, while maintaining an adequately large target, the line focus principle is used.

- From line focus principle, provide a wide focal spot with out compromising the resolution.
- In this approach, the face of the target presents an angle of $90+\theta$ with respect to the direction of the incident electron.
- The width of the target struck by the electrons is AB, but when seen from the direction of the useful beam, its apparent width is CB, given by

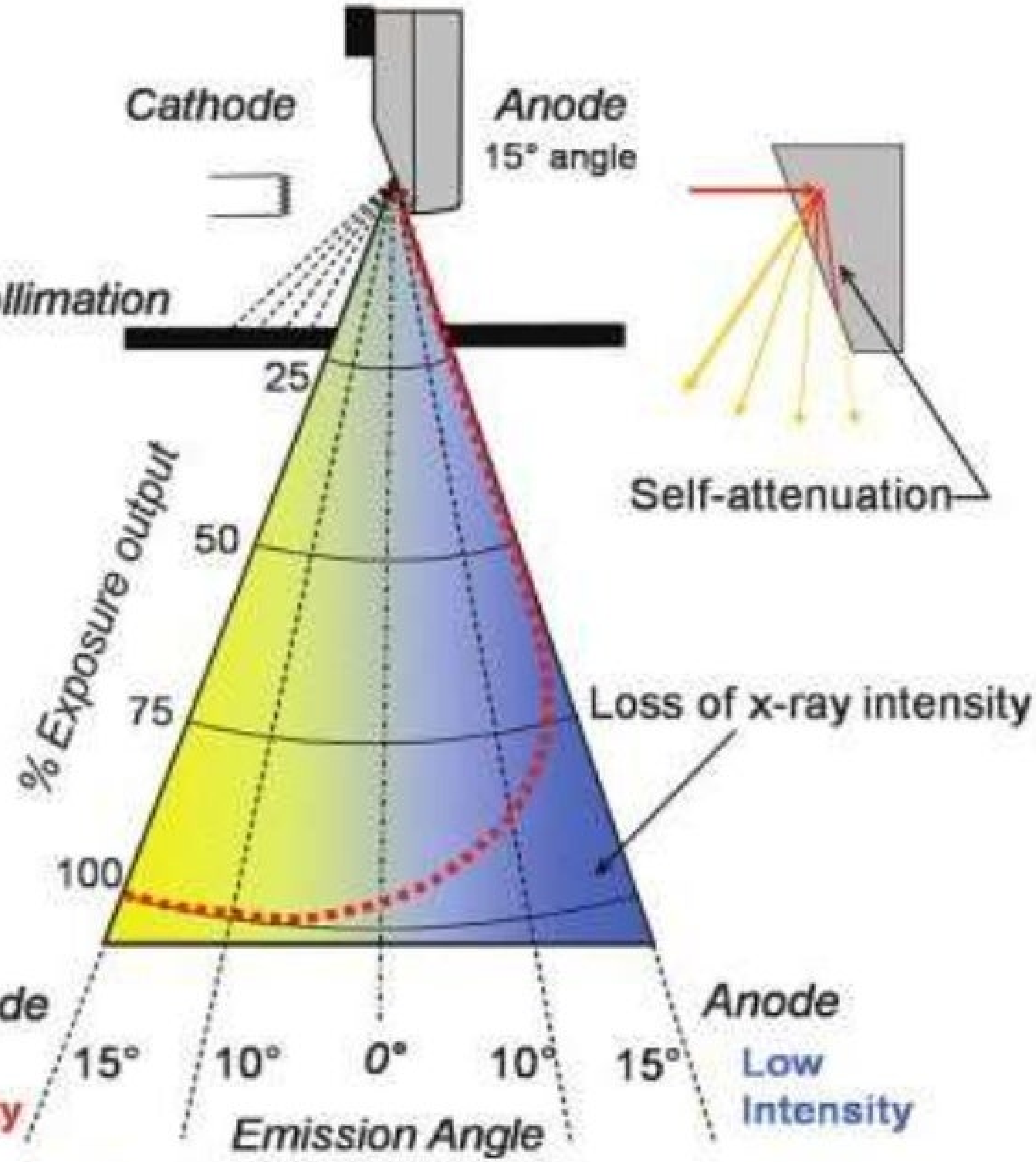
$$CB=AB\sin\theta$$

The Smaller the angle θ,
the smaller the size of the
apparent focal spot.



Heel Effect

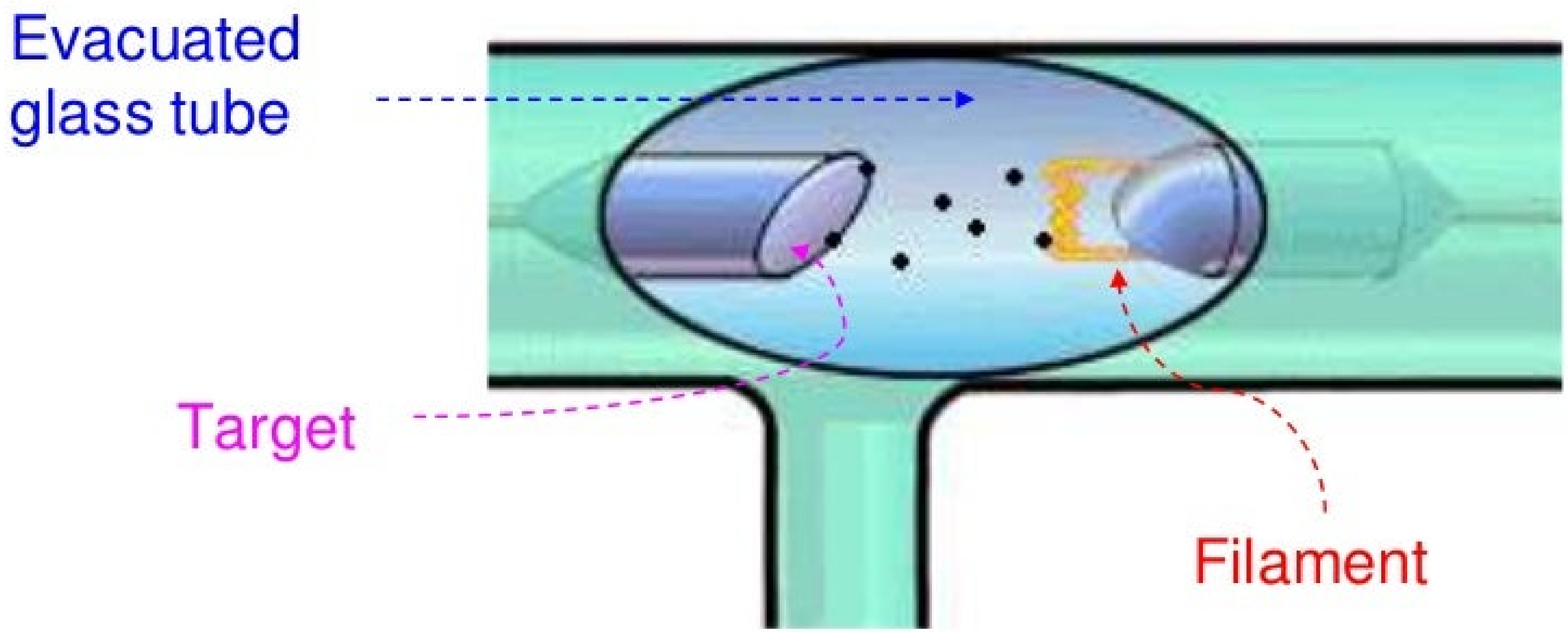
- The x-rays are produced at various depths in the target, they suffer varying amounts of attenuation in the target.
- There is greater attenuation for x-rays coming from greater depths than those from near the surface of the target.
- The intensity of the x-ray beam decreases from the cathode to the anode direction of the beam.
- This variation across the x-ray beam is called the heel effect.
- The effect is particularly pronounced in diagnostic tubes because of the low x-ray energy and steep target angles.
- The problem can be minimized by using a compensating filter to provide differential attenuation across the beam in order to compensate for the heel effect and improve the uniformity of the beam.



■ FIGURE 6-17 The heel effect is a loss of intensity on the anode side of the x-ray field of view. It is caused by attenuation of the x-ray beam by the anode. Upper right is an expanded view that shows electrons interacting at depth within the anode and the resultant "self attenuation" of produced x-rays that have a trajectory towards the anode side of the field.

Production of X-rays

- X-rays are produced when rapidly moving electrons that have been accelerated through a potential difference of order 1 kV to 1 MV strikes a metal target.



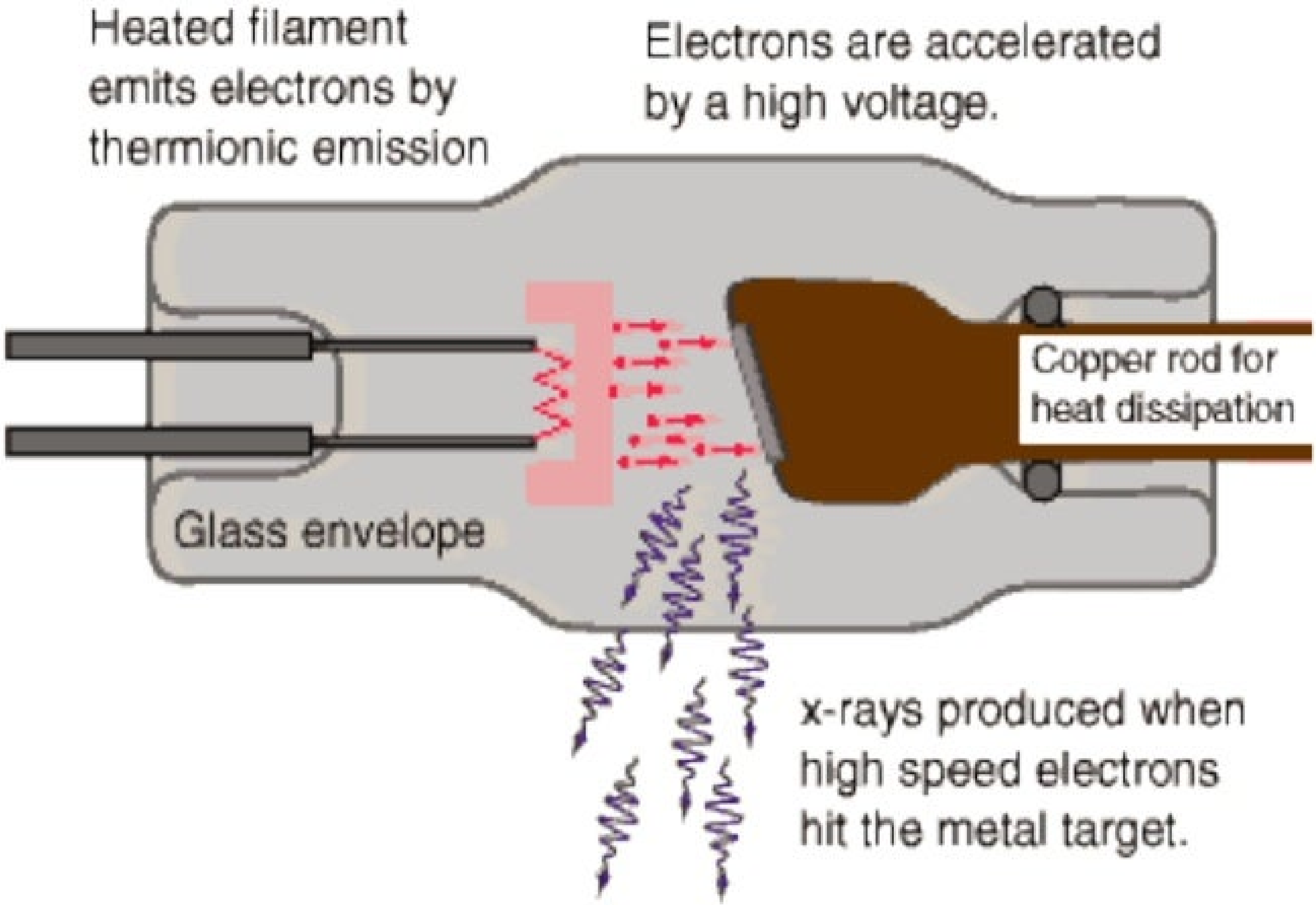
Production of X-rays

- Electrons from a hot element are accelerated onto a target anode.

- The source of electrons is the cathode, or negative electrode. Electrons are stopped or decelerated by the anode, or positive electrode. Electrons move between the cathode and the anode because there is a potential difference in charge between the electrodes.

- When the electrons are suddenly decelerated on impact, some of the kinetic energy is converted into EM energy, as X-rays.

- Less than 1 % of the energy supplied is converted into X-radiation during this process. The rest is converted into the internal energy of the target.

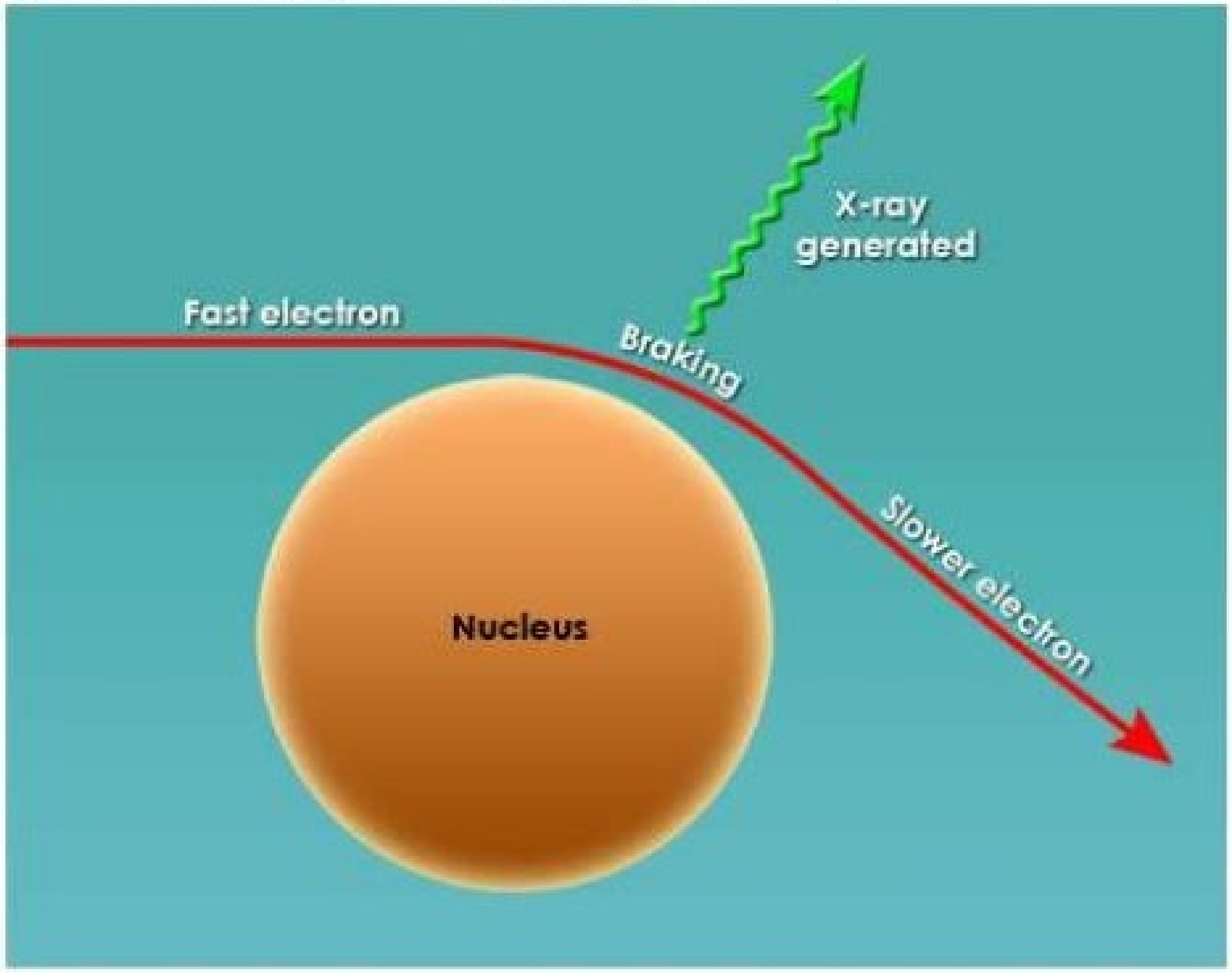

Heated filament emits electrons by thermionic emission
Electrons are accelerated by a high voltage.
Copper rod for heat dissipation
Glass envelope
x-rays produced when high speed electrons hit the metal target.

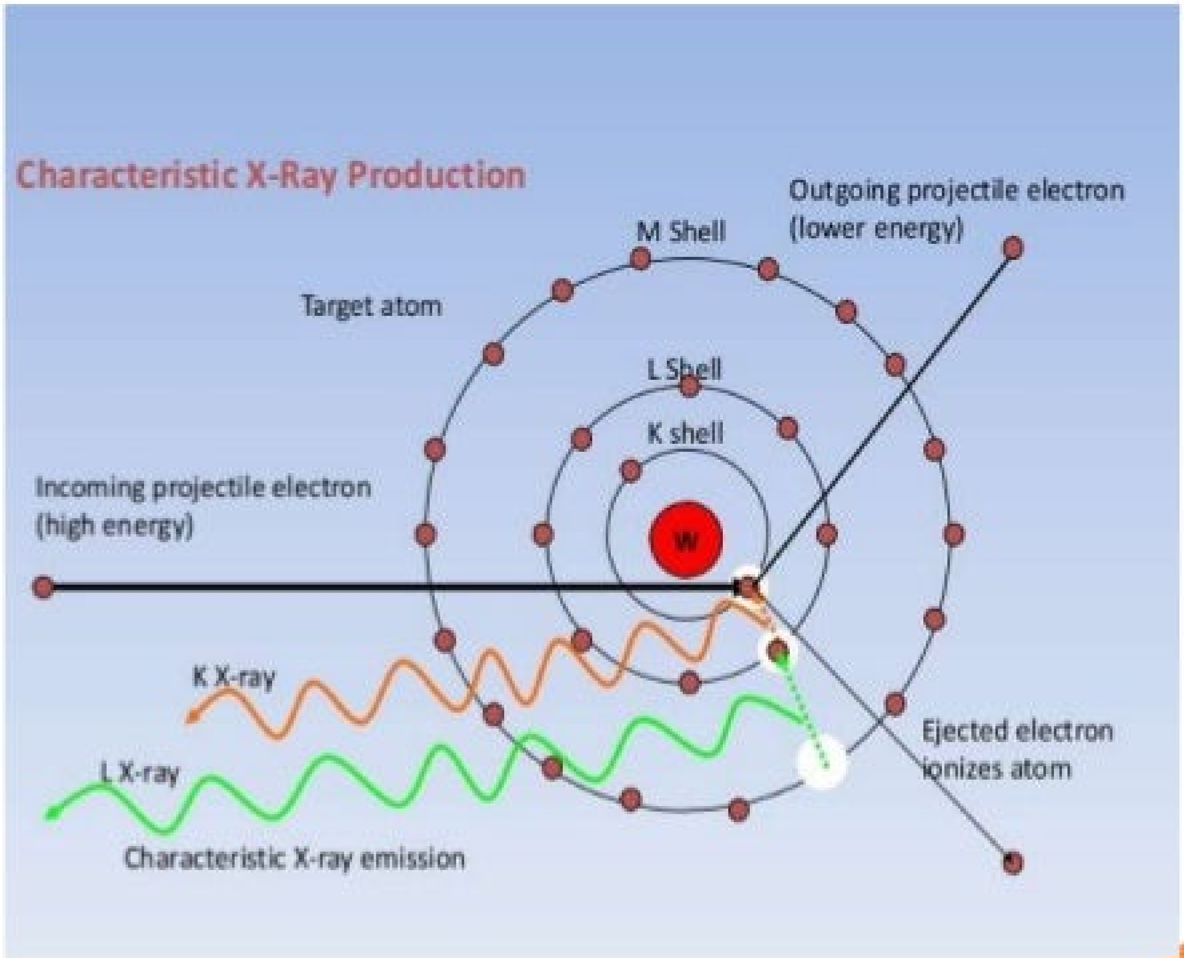
Physics of X ray Production

Bremsstrahlung x-rays

Characteristics x-rays

Bremsstrahlung/Braking X-ray generation





Bremsstrahlung X-rays

If an incoming free electron gets close to the nucleus of a target atom, the strong electric field of the nucleus will attract the electron, thus changing direction and speed of the electron.

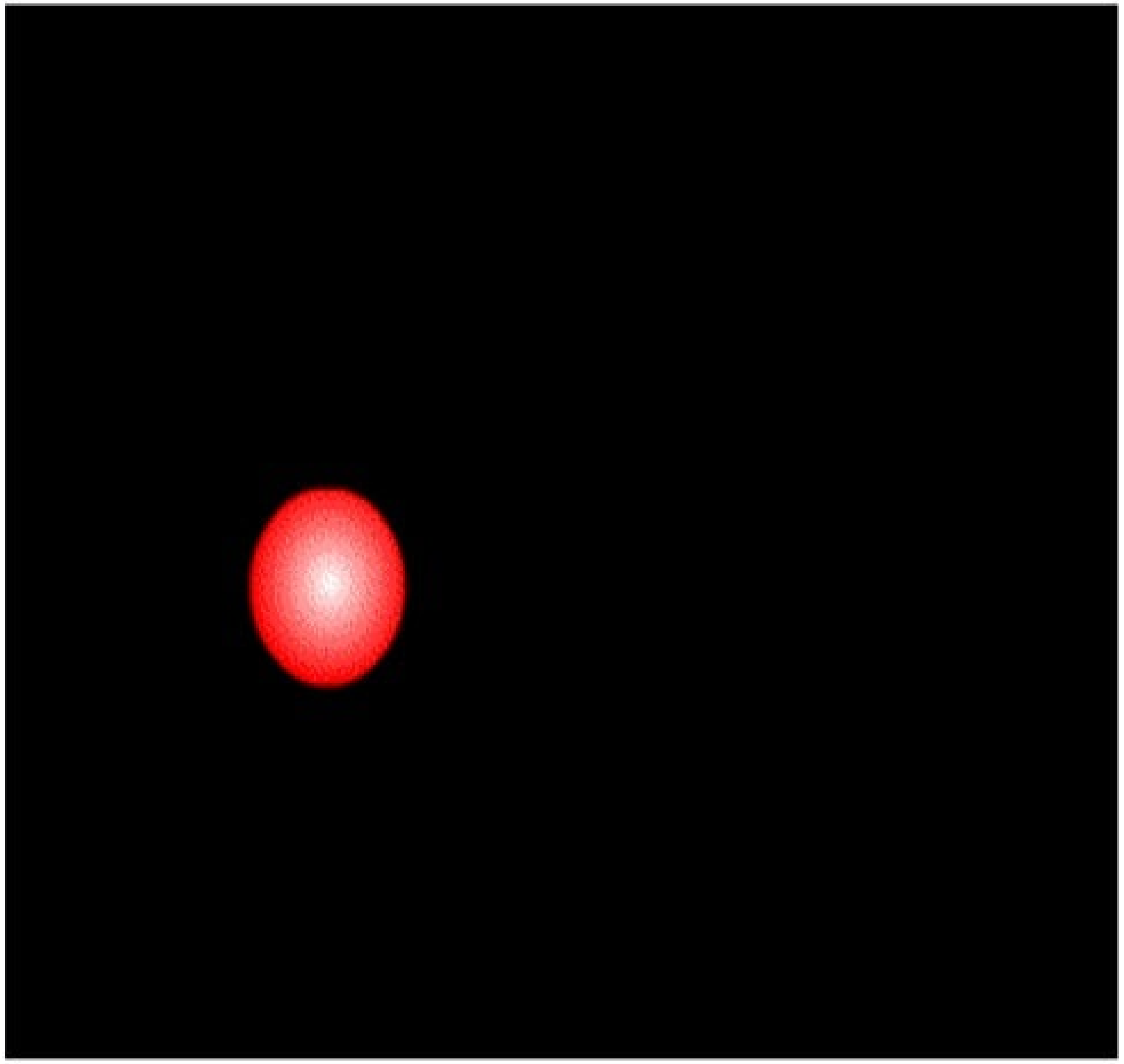
The Electron looses energy which will be emitted as an X-ray photon.

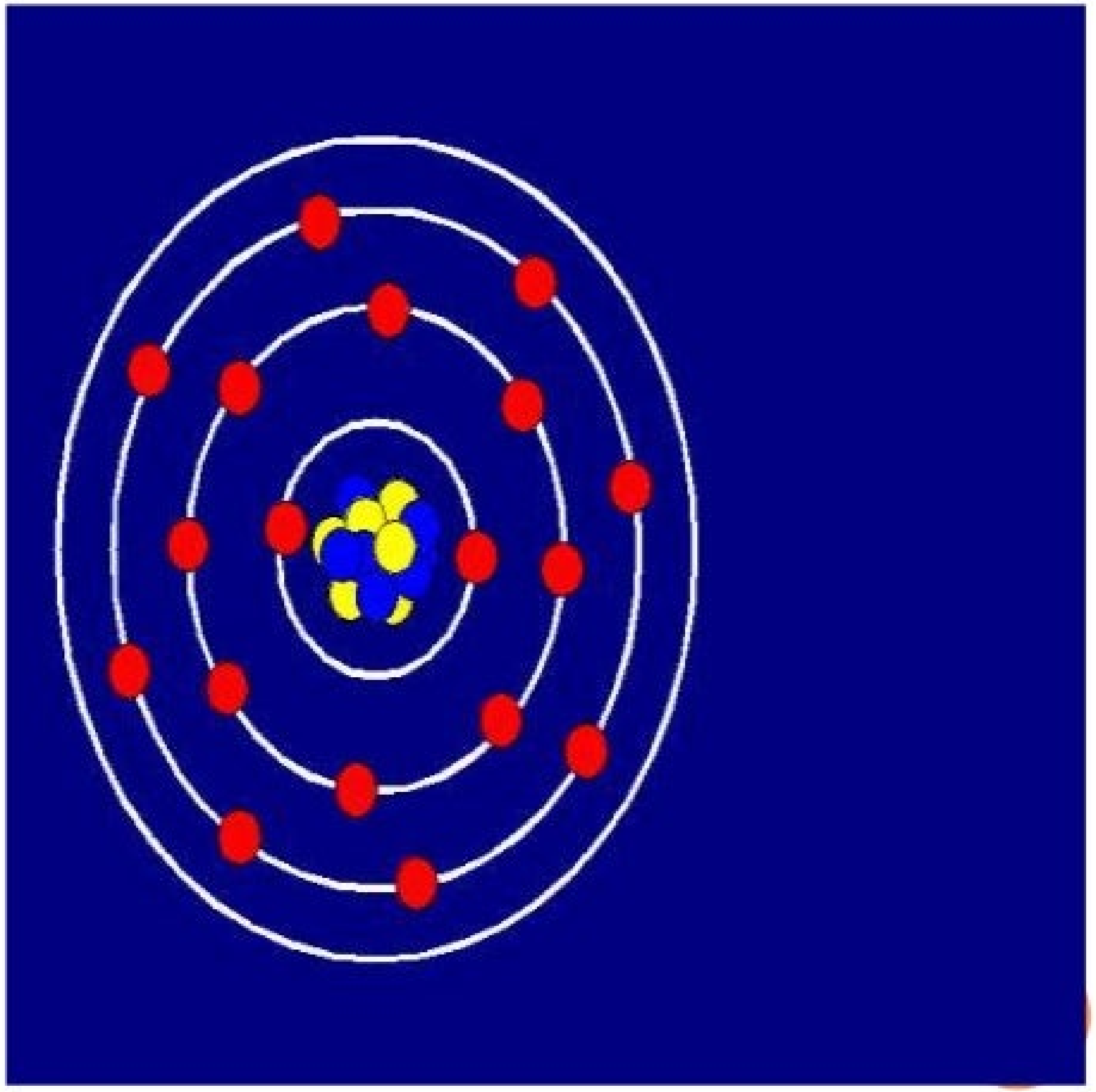
The energy of this photon will depend on the degree of interaction between nucleus and electron, i.e. the passing distance.

Several subsequent interactions between one and the same electron and different nuclei are possible.

X-rays originating from this process are called bremsstrahlung,German word meaning “braking radiation”

- The x-ray energy depends on the interaction distance between the electron and the nucleus; it decreases as the distance increases.





Since an electron may have one or more Bremsstrahlung interactions in the material and an interaction may result in **partial or complete loss** of electron energy, the resulting Bremsstrahlung photon may have any energy up to the initial energy of the electron.

Also, the direction of emission of Bremsstrahlung photons depends on the energy of the incident electrons.

At electron energies below about 100 keV, x-rays are emitted more or less equally in all directions.

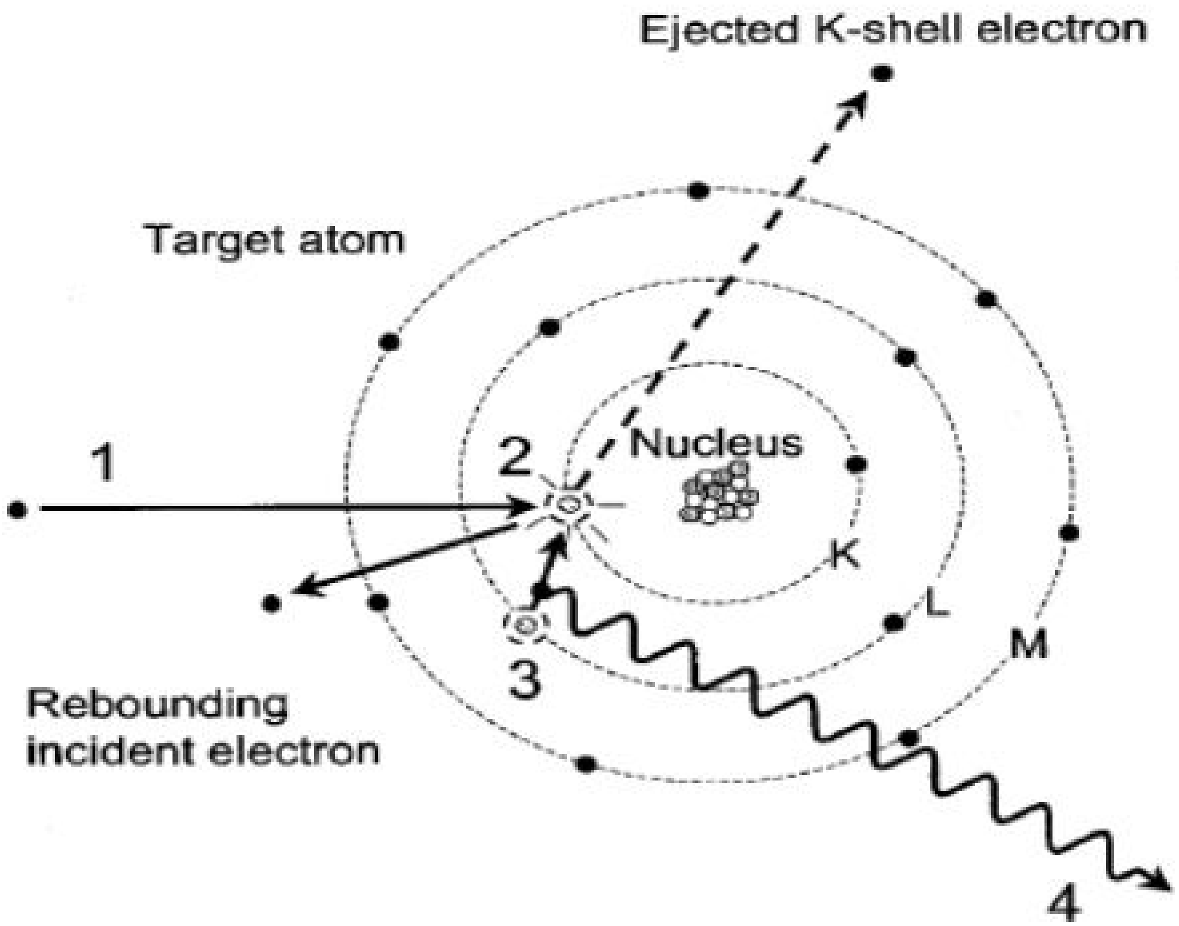
As the kinetic energy of the electrons increases, the direction of x-ray emission becomes increases forward.

Therefore, transmission-type targets are used in megavoltage x-ray tubes (accelerators) in which the electrons bombard the target from one side and the x-ray beam is obtained on the other side.

In the low-voltage x-ray tubes, it is technically advantageous to obtain the x-ray beam on the same side of the target (i.e., at 90 degrees with respect to the electron beam direction).

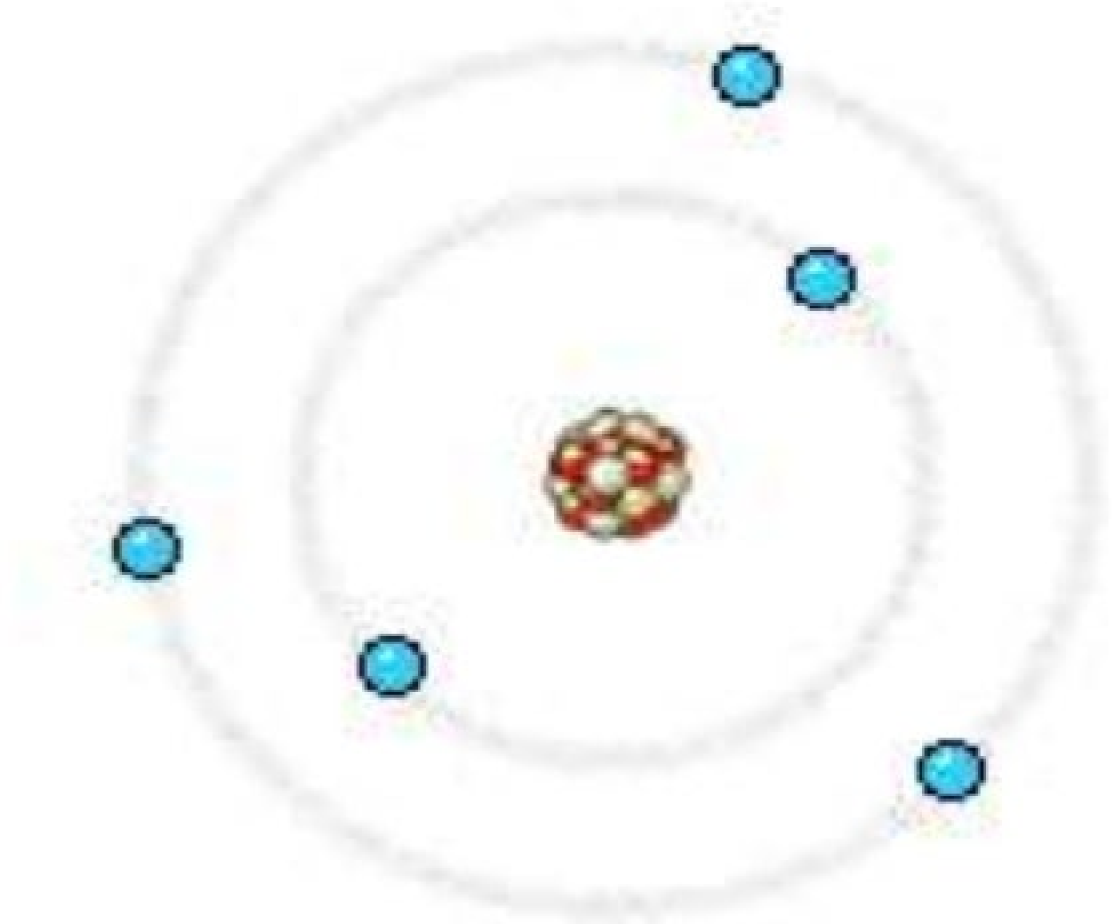
Characteristics X-ray

- When the energy of an electron incident on the target exceeds the binding energy of an electron of a target atom, it is energetically possible for a collision interaction to eject the electron and ionize the atom.
- The unfilled shell is energetically unstable, and an outer shell electron with less binding energy will fill the vacancy.



CHARACTERISTICS X-RAY

- As this electron transitions to a lower energy state, the excess energy can be released as a characteristic x-ray photon with an energy equal to the difference between the binding energies of the electron shells
- With higher-atomic-number targets and the transitions involving inner shells such as K, L, M, and N.

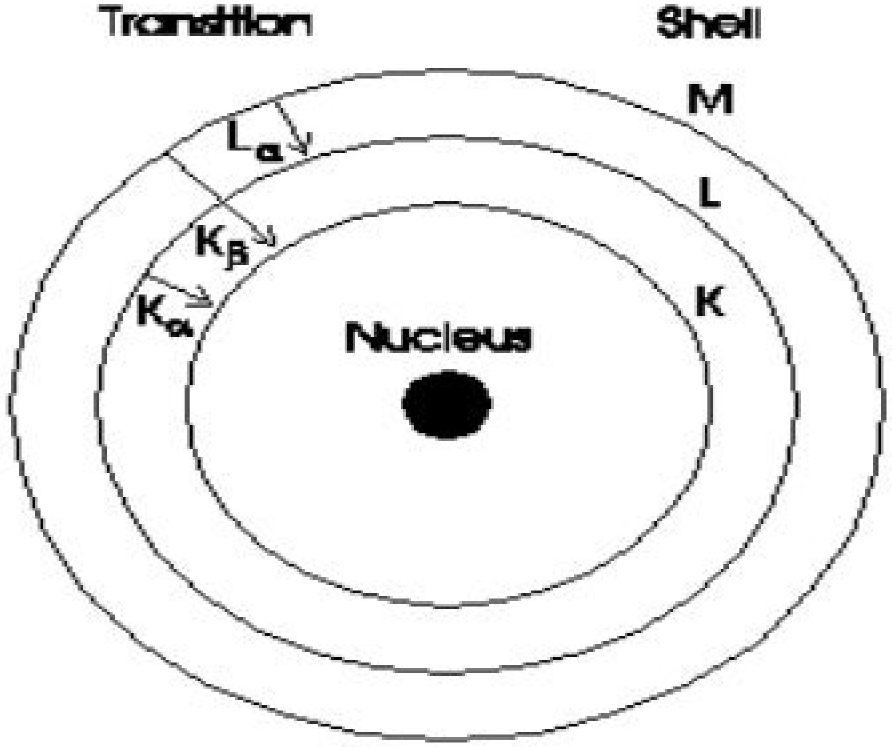


CHARACTERISTIC CASCADE

- The shell capturing the electron designates the characteristic x-ray transition, and a subscript of α *or* β indicates whether the transition is from an adjacent shell *(*α*) or* nonadjacent shell *(*β*).*
- *For e.g.*

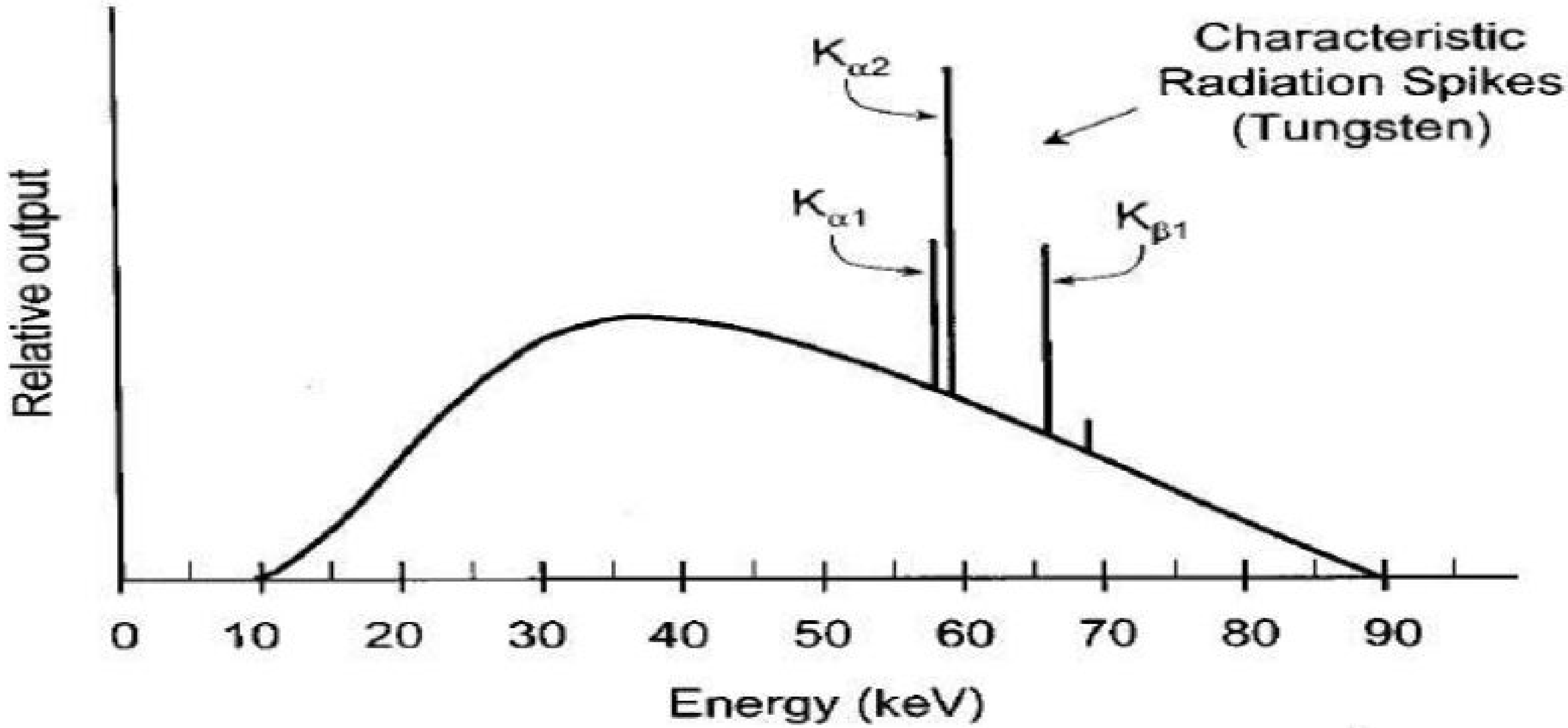
$$L \xrightarrow{\boldsymbol{K_\alpha}} K$$

$$M, N, \text{or } O \xrightarrow{\boldsymbol{K_\beta}} K$$



- A $\boldsymbol{K_\beta}$ x-ray is more energetic than $\boldsymbol{K_\alpha}$ a x-ray.
- Within each shell (other than the *K* shell*)*, there are discrete energy sub shells, which result in the fine energy splitting of the characteristic x-rays.

- For tungsten, three prominent lines on the Bremsstrahlung spectrum arise from the $K_{\alpha 1}$, $K_{\alpha 2}$, *and* $K_{\beta 1}$ transitions.
- The filtered spectrum of Bremsstrahlung and characteristic radiation from a tungsten target.
- The specific characteristic radiation energies from K_{α} and K_{β} transitions.



TUNGSTEN-74

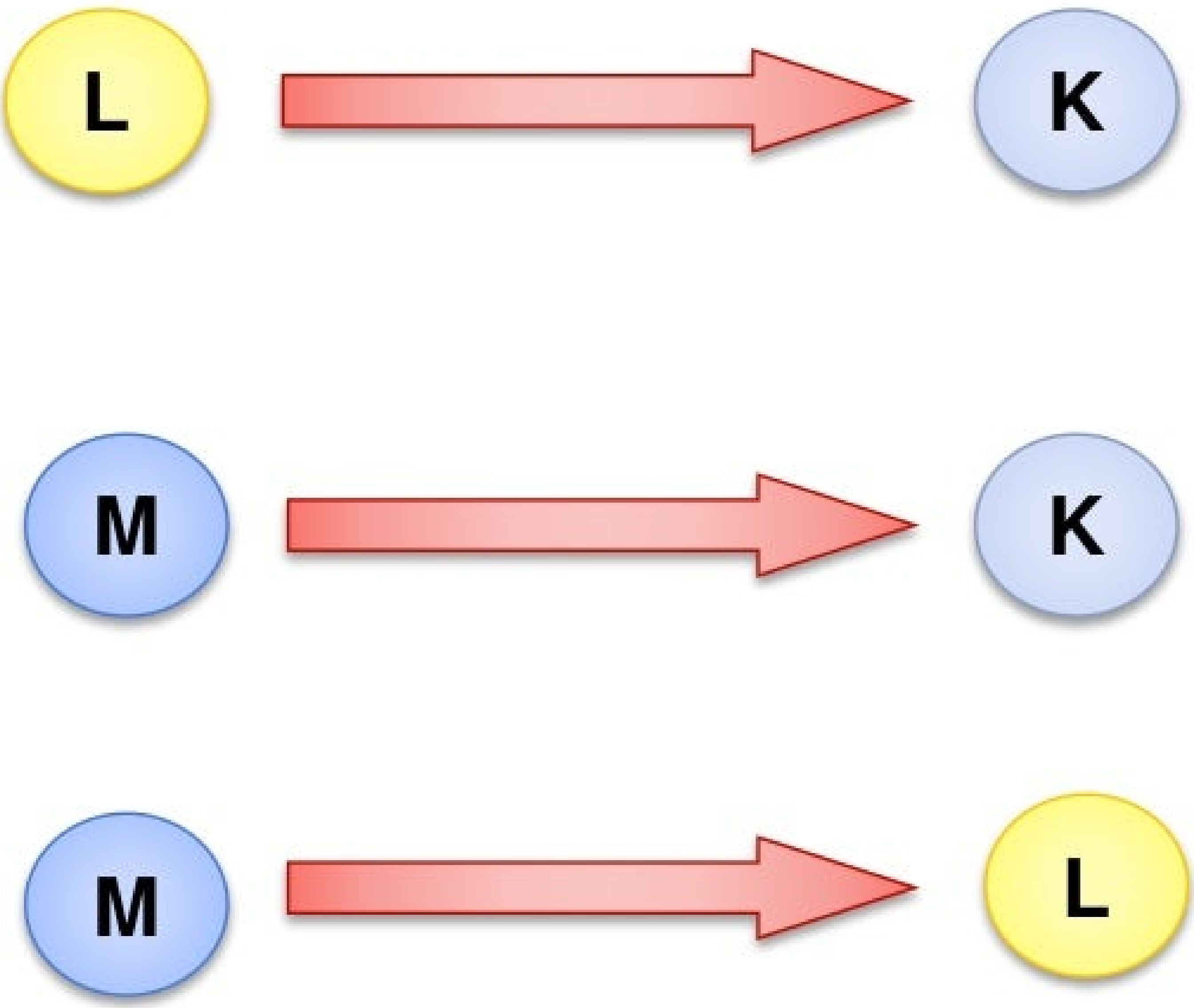
BINDING ENERGIES
OF DIFFERENT SHELL ELECTRONS

K-70 KeV

L-12 KeV

M-2.8 KeV

For Tungsten



70-12 = 58 KeV

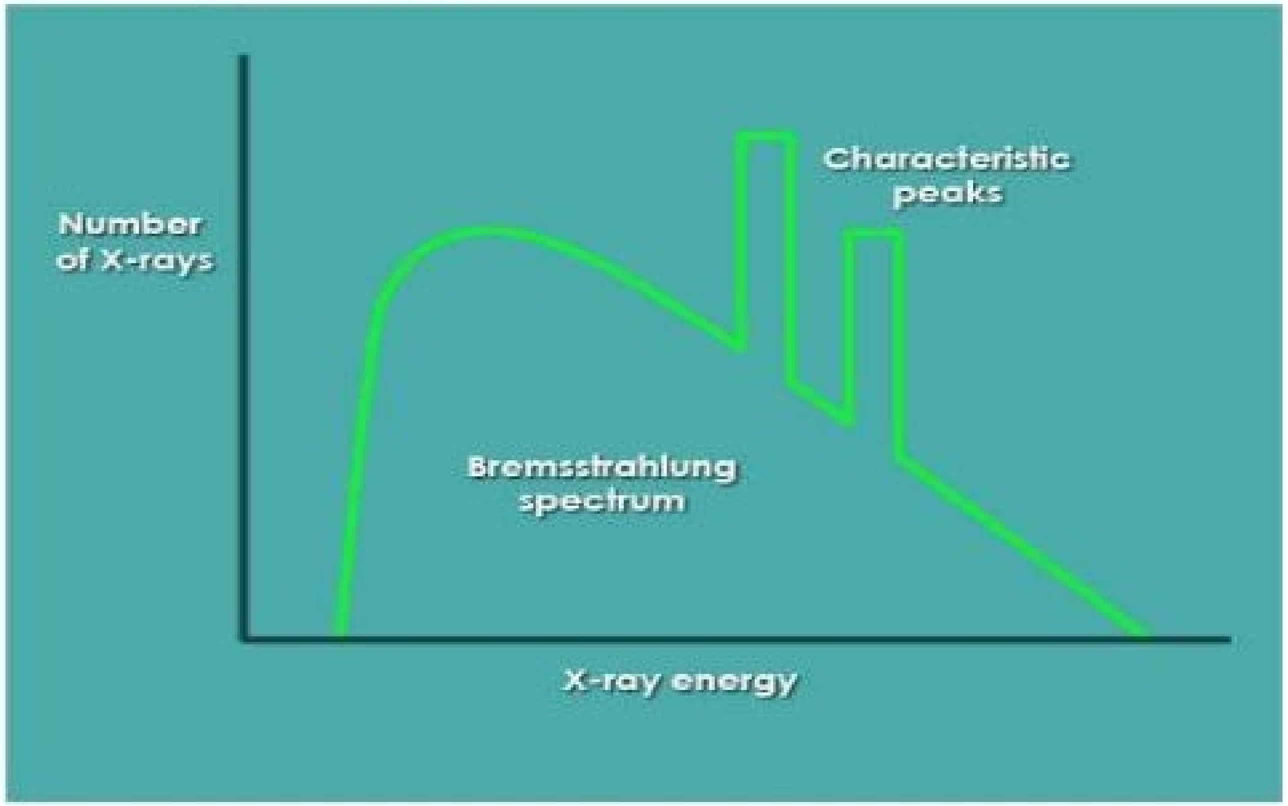
70-3 = 67 KeV

12-3 = 9 KeV

X-ray Emission Spectrum

- If a relative number of x-ray photons were plotted as a function of their energies we can analyze the x-ray emission spectrum.
- Understanding the x-ray emission spectra is key to understanding how changes in kVp, mA, time and filtration affects the optical density and contrast of the radiograph.

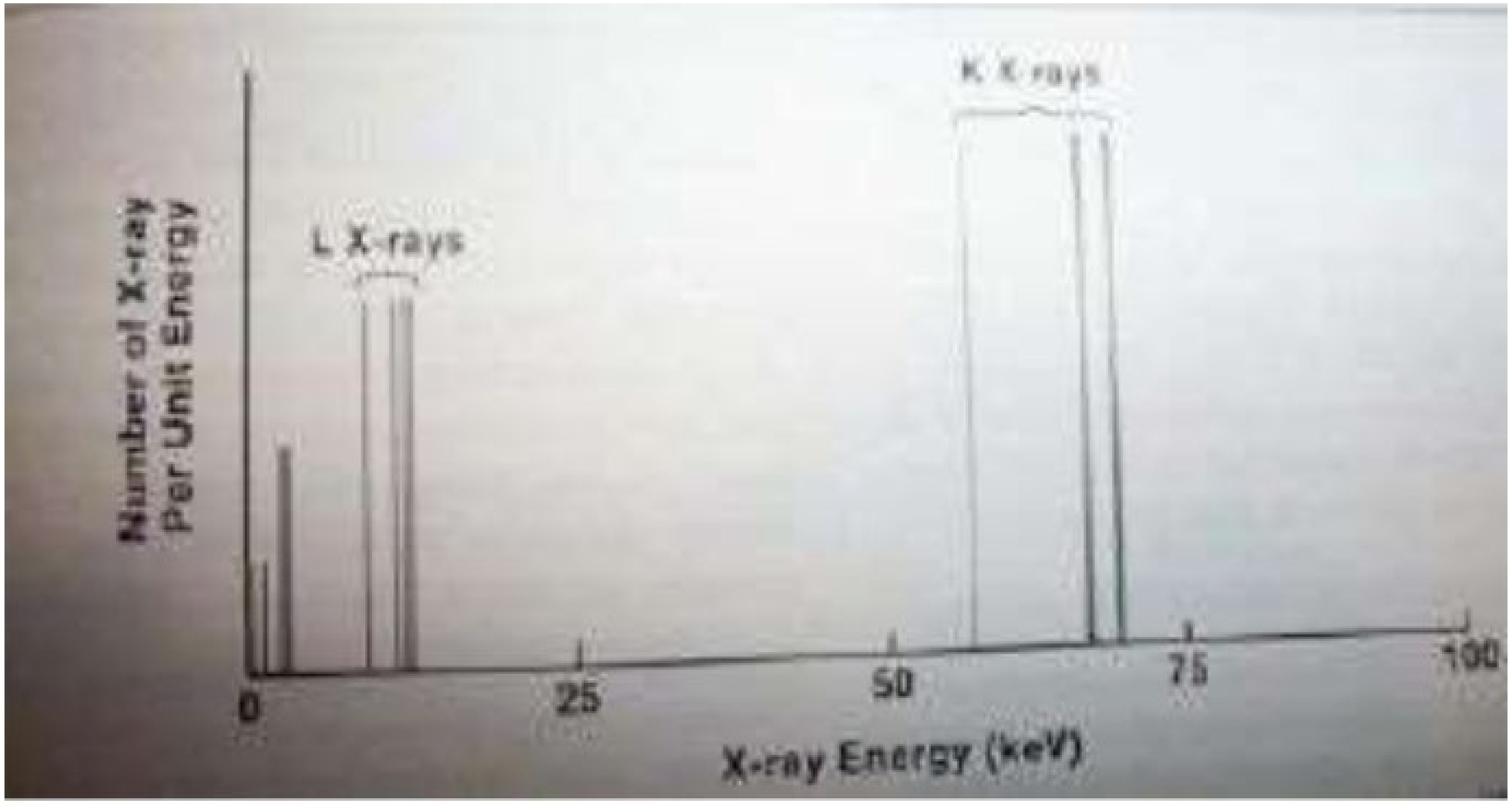
The X-ray spectrum



Discrete X-ray Spectrum

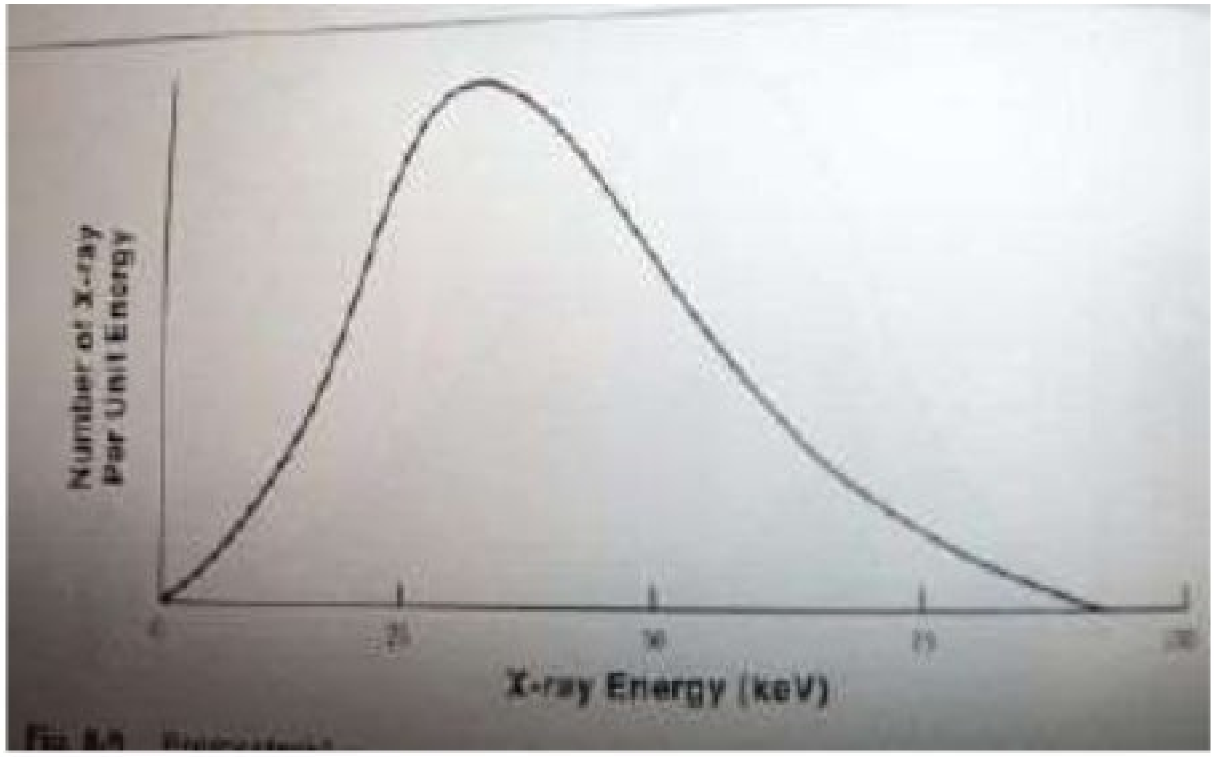
- Characteristic x-rays have a precisely fixed or discrete energies.
- These energies are characteristic of the differences between electron binding energies of a particular element.
- For tungsten you can have one of 15 energies.

- There are 15 energies
- There are 5 vertical line representing K x-rays.
- 4 representing L x-rays.
- Remaining represent lower energy outer shell electrons.



- K x-rays are the only characteristic x-rays of tungsten that have sufficient energy to be of value in radiography.

Continuous X-ray Spectrum



- The Bremsstrahlung x-ray energies range from zero to a peak and back to zero.
- This is referred to as the Continuous X-ray Spectrum.

- The majority of the useful x-rays are in the continuous spectrum.
- The maximum energy will be equal to the kVp of operation.
- This is why it is called kVp (peak).

X-Ray Energy Spectra

X-ray photons produced by an x-ray machine are heterogenous in energy. The energy spectrum shows a continuous distribution of energies for the bremsstrahlung photons superimposed by characteristic radiation of discrete energies.

If no filtration, inherent or added, of the beam is assumed, the calculated energy spectrum will be a straight line and mathematically given by Kramer's equation
$IE = KZ(Em - E)$

where I_E is the intensity of photons with energy, E;
Z is the atomic number of the target;
E_m is the maximum photon energy; and K is a constant.

As pointed out earlier, the maximum possible energy that a bremsstrahlung photon can have is equal to the energy of the incident electron.

The maximum energy in kiloelectron volts is numerically equal to the applied kilovolts peak (kVp).

However, the intensity of such photons is zero as predicted by the previous equation, that is, $I_E = 0$ when $E = E_m$.

The unfiltered energy spectrum is modified as the photons experience inherent filtration (absorption in the target, glass walls of the tube, or thin beryllium window).

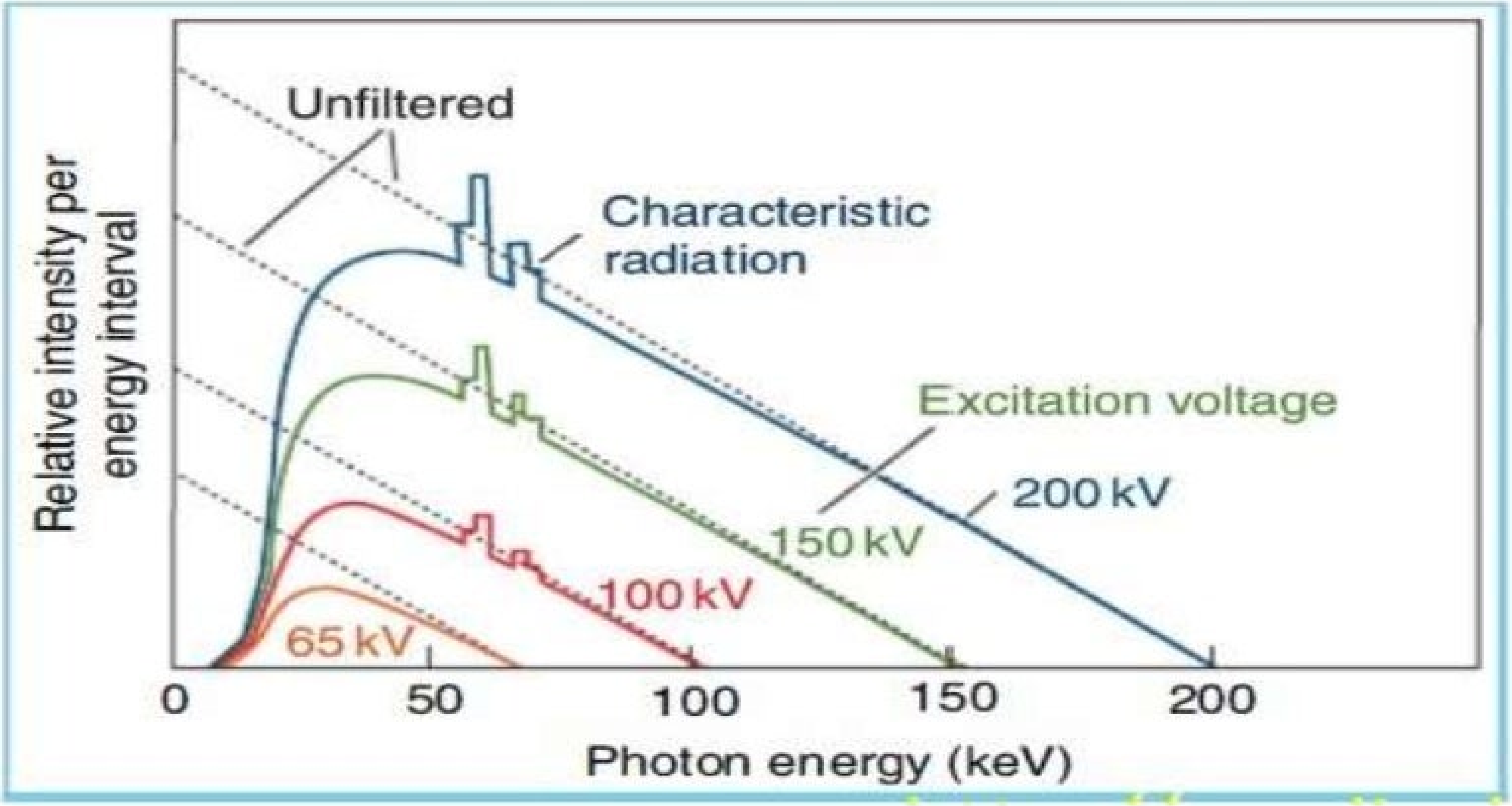
The inherent filtration in conventional x-ray tubes is usually equivalent to about 0.5- to 1.0-mm aluminum. Added filtration, placed externally to the tube, further modifies the spectrum.

It should be noted that the filtration affects primarily the initial low-energy part of the spectrum and does not affect significantly the high-energy photon distribution.

Filtration

- The purpose of the added filtration is to enrich the beam with higher-energy photons by absorbing the lower-energy components of the spectrum.
- As the filtration is increased, the transmitted beam hardens, i.e., it achieves higher average energy and therefore greater penetrating power.
- Thus, the addition of filtration is one way of improving the penetrating power of the beam.
- The other method, of course, is by increasing the voltage across the tube.

- The total intensity of the beam (area under the curves in fig.)decreases with increasing filtration and increases with voltage, a proper combination of voltage and filtration is required to achieve desired hardening of the beam as well as acceptable intensity.



- The shape of the x-ray energy spectrum is the result of the alternating voltage applied to the tube, multiple Bremsstrahlung interactions within the target, and filtration in the beam.

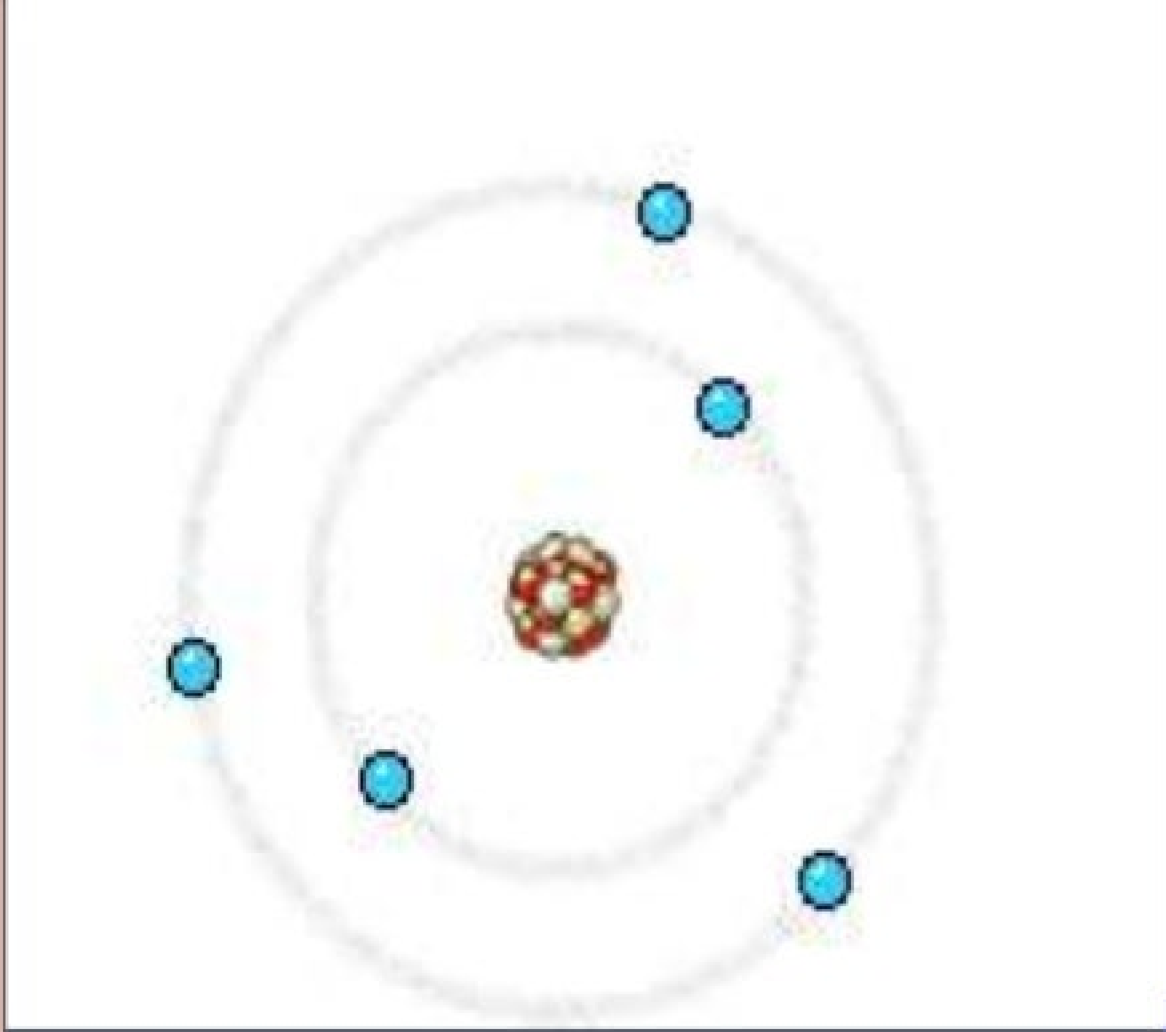
- Because of the x-ray beam having a spectral distribution of energies, which depends on voltage as well as filtration, it is difficult to characterize the beam quality in terms of energy, penetrating power, or degree of beam hardening.

Factors affecting X ray Emission

- The output of an x-ray tube is often described by the terms quality, quantity, and exposure.
  - Quality describes the penetrability *of* an x-ray beam, with higher energy x-ray photons having a larger HVL and higher "quality."
  - Quantity refers to the number of photons comprising the beam.
  - Exposure is a measure of ionization per unit mass of air

Factors affecting X-Ray beam quality and quantity

An increase in	Results in
Current(mAs)	An increase in quantity; no change in quality
Voltage (kVp)	An increase in quantity and quality
Added filtration	A decease in quantity and an increase in quality
Target atomic number(Z)	An increase in quantity and quality
Voltage ripple	A decrease in quantity and quality



Thank you