**Fundamentals of Radio-physics**

**First Semester**

# Lecture4 : X–rays production

**By**

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# X–rays production:

**To produce x–rays in an x-ray tube we need:**

1. Source of electrons, a cathode filament which is negatively charged.

2. An evacuated space (with low pressure 10-6 tor) to remove obstructions to electrons so they can speed up to reach the anode with high kinetic energy.

3. High positive voltage applied between cathode and anode to accelerate the negative electrons. In diagnostic radiography, this is usually within the range 40 to 120 Kev.

4. Target or anode which is positively charged to attract electrons to produce x-rays. 99% of energy of most electrons striking the target is dissipated in the form of heat the remaining few energy (0.2%) produce useful x-rays. Anode rotates to distribute heat, also additional cooling is required.

5.When these projectile electrons hit the heavy metal atoms of the x-ray tube target, they transfer their kinetic energy to the target atoms.

- Approximately 99% of the kinetic energy of projectile electrons is converted to heat.
- The production of heat in the anode increases directly with increasing x-ray tube current
- Heat production also increases directly with increasing kVp.
- Interaction with the outer shell electrons of an atom generating heat.
- Interaction with the inner shell electrons or the nuclei themselves generating X-rays

6. Lead shielding is necessary to contain scattered electrons and x-rays by absorbing them.

7. Filter usually made of Aluminum is used to absorb low energy photons.

8. The space between the tubes insert (the enveloped and electrode) and the shield is filled with oil, the oil converts heat from the insert to the tube shield (oil used to cool the target), Rotating anode is used also for cooling.

The intensity of x – ray beam produced when the electron strike the anode is highly **dependent on** the anode material:

1. The higher the atomic number **(Z)** of the target, the more efficiency x-ray are produced.

2. The target material used should also have a high melting point since the heat produced when the electrons are stopped in the surface of the target is substantial.

Nearly all x– ray tubes use tungsten targets. The atomic number (Z) of tungsten is 74, and its melting point is about $3400C^0$

## Types of x-rays

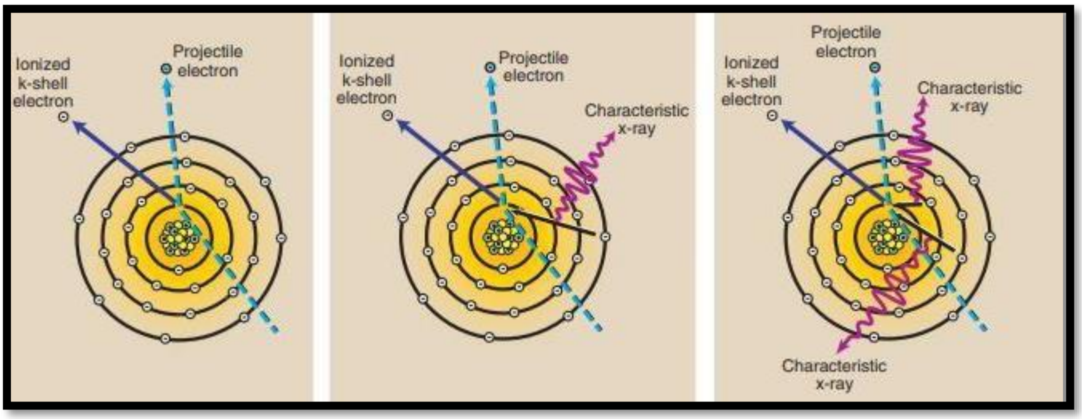
X-ray photons produced by an X-ray tube are heterogeneous in energy. **There are two types** of X-ray spectrum, namely,

**a) characteristic spectrum**

**b) bremsstrahlung or continuous spectrum**

## Characteristic Radiation

-Characteristic x-rays result when the interaction is sufficiently violent to ionize the target atom through total removal of an inner-shell electron.
-Characteristic x-rays are emitted when an outer-shell electron fills an inner-shell void.
Figure below illustrates how characteristic x-rays are produced.




**Question:**
A K-shell electron is removed from a tungsten atom and is replaced by an L-shell electron. What is the energy of the characteristic x-ray that is emitted?
K-shell electrons have binding energies of 69 keV, and L-shell electrons are bound by 12 keV.
Therefore, the characteristic x-ray emitted has energy of :

$$\mathbf{E_x = E_k - E_L}$$

69 − 12 = 57 keV.

□ Only the K-characteristic x-rays of tungsten are useful for imaging.

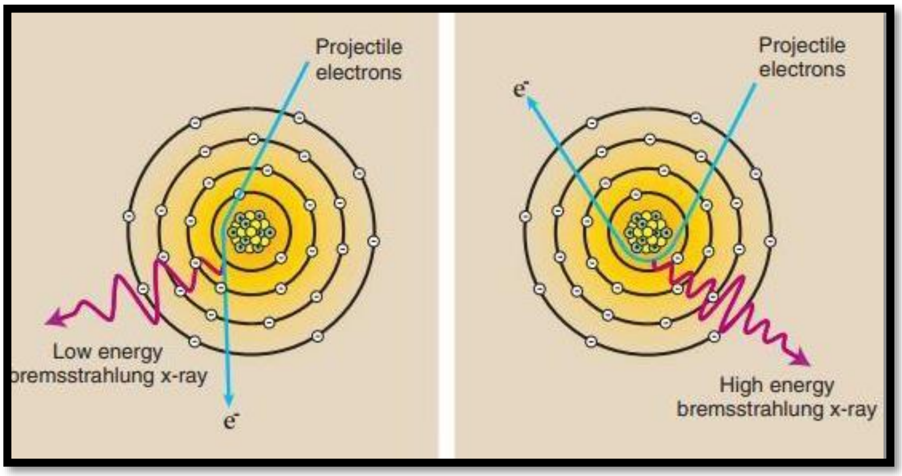
| Characteristic | ELECTRON TRANSITION FROM SHELL L Shell | M Shell | N Shell | O Shell | P Shell | Effective Energy of X-ray |
|---|---|---|---|---|---|---|
| K | 57.4 | 66.7 | 68.9 | 69.4 | 69.5 | 69 |
| L | | 9.3 | 11.5 | 12.0 | 12.1 | 12 |
| M | | | 2.2 | 2.7 | 2.8 | 3 |
| N | | | | 0.52 | 0.6 | 0.6 |
| O | | | | | 0.08 | 0.1 |

- the **Kα** radiation has photon energy; $E_K - E_L = 58$ keV
- the **Kβ** radiation has photon energy; $E_K - E_M = 67$ keV

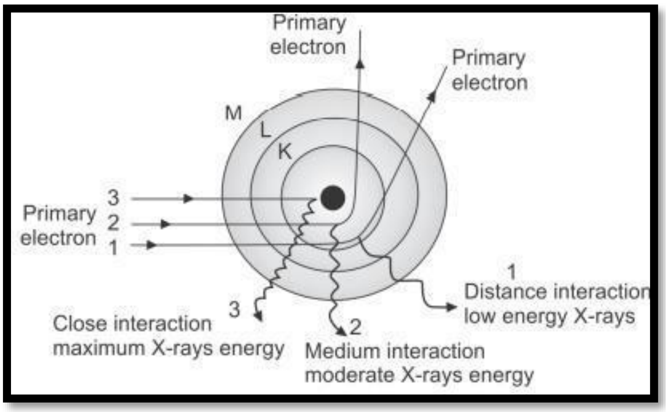
This type of x-radiation is called characteristic because it is characteristic of the target element.

## Bremsstrahlung Radiation

Bremsstrahlung x-rays are produced when a projectile electron is slowed by the nuclear field of a target atom nucleus




A projectile electron that completely avoids the orbital electrons as it passes through a target atom may come sufficiently close to the nucleus of the atom to come under the influence of its electric field (Figure below). Because the electron is negatively charged and the nucleus is positively charged, there is an electrostatic force of attraction between them




 The closer the projectile electron gets to the nucleus, the more it is influenced by the electric field of the nucleus

 The maximum amount of energy that can be emitted equals the kV. This is rare: It occurs when an electron is completely stopped by this braking force

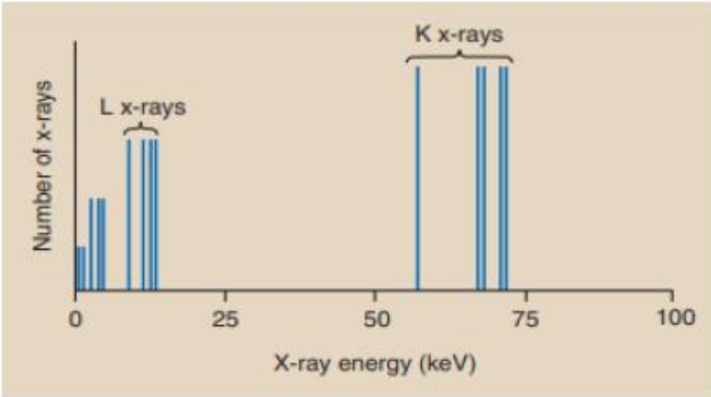
Bremsstrahlung x-rays have a range of energies and form a continuous emission spectrum
The maximum energy (in keV) of a bremsstrahlung x-ray is numerically equal to the kVp of operation
• In the diagnostic range, most x-rays are bremsstrahlung x-rays
• At 100 kVp, approximately 15% of the x-ray beam is characteristic, and the remaining is bremsstrahlung

## X-ray Spectrum (Characteristic and Bremsstrahlung)

The relative intensity of the K x-rays is greater than that of the lower energy characteristic x-rays because of the nature of the interaction process

K x-rays are the only characteristic x-rays of tungsten with sufficient energy to be of value in diagnostic radiology

Characteristic x-rays have precisely fixed (discrete) energies and form a discrete emission spectrum.

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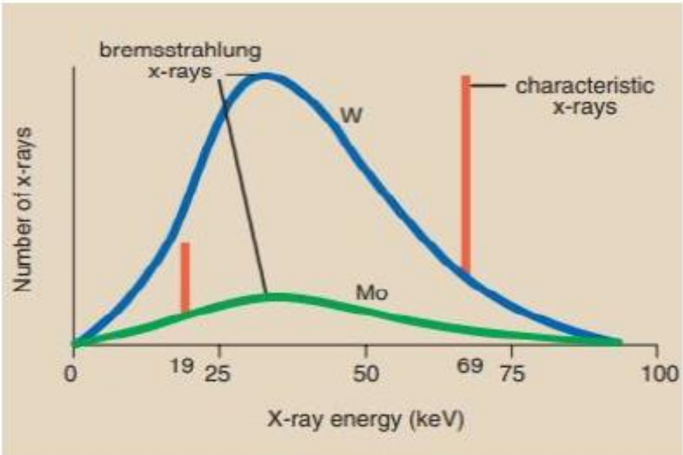
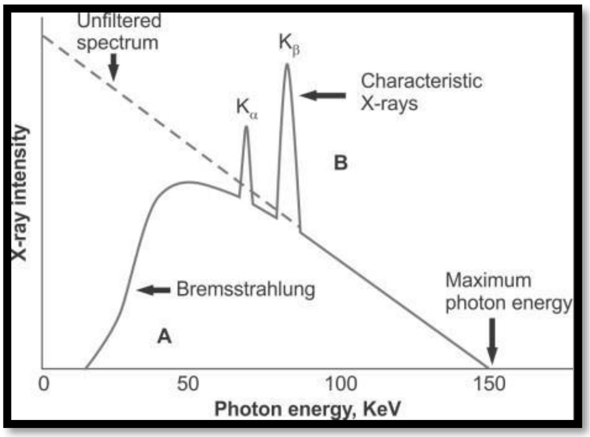



The bremsstrahlung spectrum is much lower because the atomic number of Mo is low (Z = 42), and x-ray production is much less efficient. A line extends above the curve at 19 keV to represent the K-characteristic x-rays of molybdenum.




## What is the $\lambda_{min}$ , $E_{max}$ and $\upsilon_{max}$ in x-ray spectra?

X-ray energy is inversely proportional to its wavelength. As x-ray wavelength increases, x-ray energy decreases

$E = h\upsilon$ $\upsilon = c/\lambda$ $E = hc / \lambda$

$E = 1.24 / \lambda$ $\lambda = 1.24 / E$

The minimum wavelength of x-ray emission corresponds to the maximum x-ray energy, and the maximum x-ray energy is numerically equal to the kVp.

$K.E = eV$ $E_{max} = h\upsilon_{max}$

$= hc / \lambda_{min} = eV$

$K.E = E_{max} = eV$

***Q/Calculate the minimum wavelength of X-rays emitted when electrons accelerated through 30 kV strike a target.***

**Answer is:- f** = ev/h

$[1.6 \times 10^{-19} \times 3 \times 10^{4}] / 6.63 \times 10^{-34} = 7.2 \times 10^{18}$ Hz

Therefore the wavelength

($\lambda = c/f$) is $0.41 \times 10^{-10}$ m = 0.04 1 nm (compared with some 600 nm for yellow light)