Radiation Physics

Hussein Ali Madlool

Radiology Techniques Department

2nd Class

Al-Mustaqbal University college

Lecture 4: production of X-Ray

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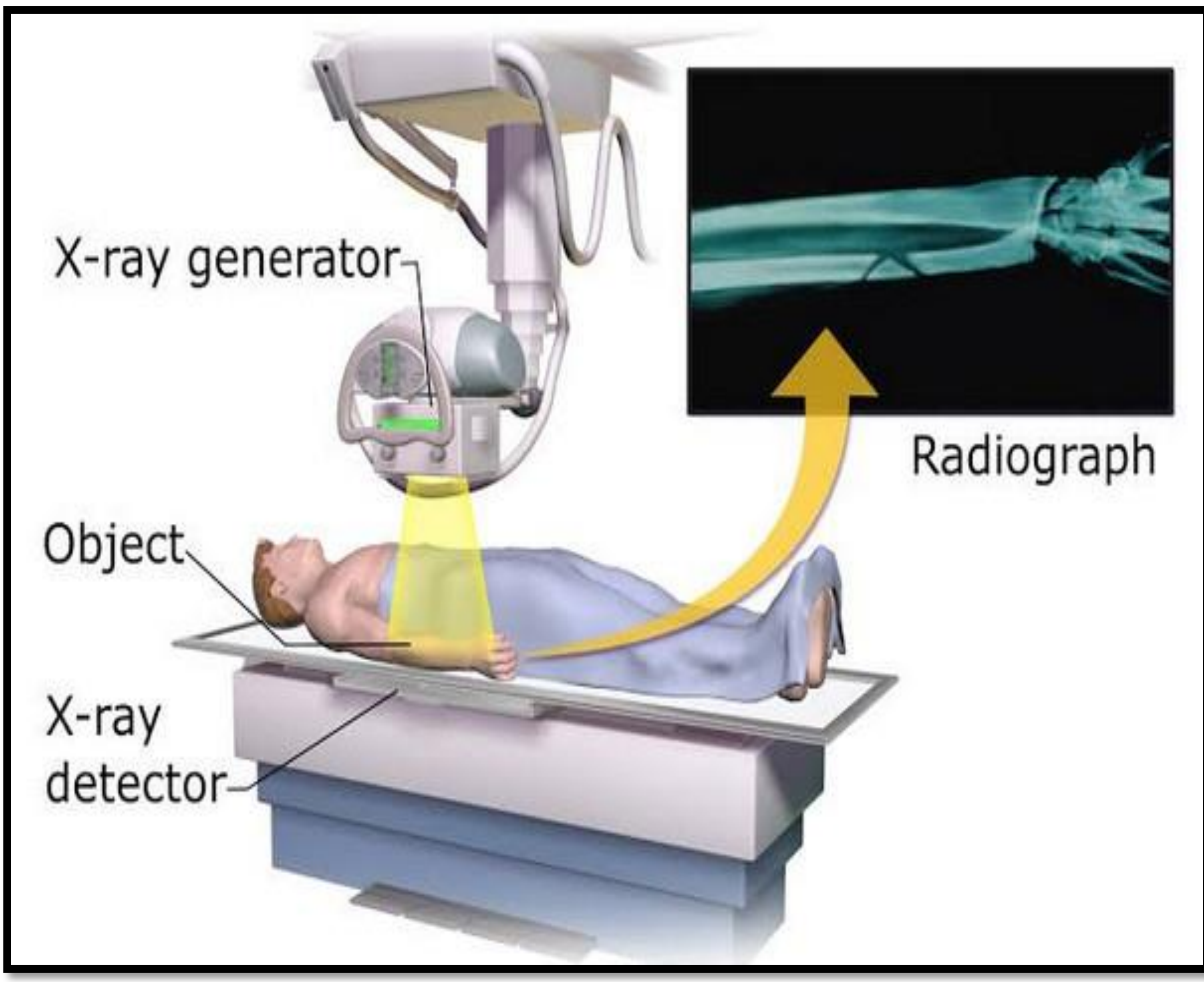
Discovery of X-rays

Over a century ago in 1895, Wilhelm Roentgen discovered the first example of ionizing radiation, X-rays. The key to Roentgens discovery was a device called a Crooke's tube, which was a glass envelope under high vacuum, with a wire element at one end forming the cathode, and a heavy copper target at the other end forming the anode. When a high voltage was applied to the electrodes, electrons formed at the cathode would be pulled towards the anode and strike the copper with very high energy. Roentgen discovered that very penetrating radiations were produced from the anode, which he called x-rays. He named his discovery "x rays" because "x" stands for an unknown quantity



Production of X-ray

X-rays are electromagnetic radiation of shorter wavelength (few nm) and they travel in straight line with a velocity equal to light.

- In an X-ray tube the heated material is known as the filament. The filament is heated by passing electrical current through it.
- The liberated electrons were repelled by the negative charge of the filament (cathode) and accelerated toward a positive target (the anode "tungsten").
- Therefore, the interaction of electron with the target is the basis for X-ray production.
- Because of the vacuum they are not hindered in any way, and bombard the target with a velocity around half the speed of light.
- The tube current increases exponentially with increasing filament current and might, typically.

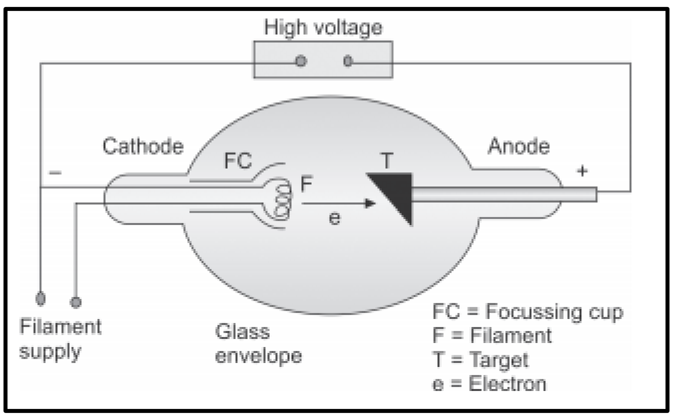


Figure 1: The simple X-ray tube

- The electrons are accelerated by the high voltage source toward a solid target called the anode which is made out of a metal of high atomic weight like tungsten, or metals like copper and molybdenum.

$$W = eV$$

$$K.E = eV$$

- The kinetic energy of the electrons is converted into X-rays (1%) and into heat (99%). Inside the tube.

Electron Interaction With The Target

- When the electron arrives at the target, it interacts in many ways as follows (Figure 2).

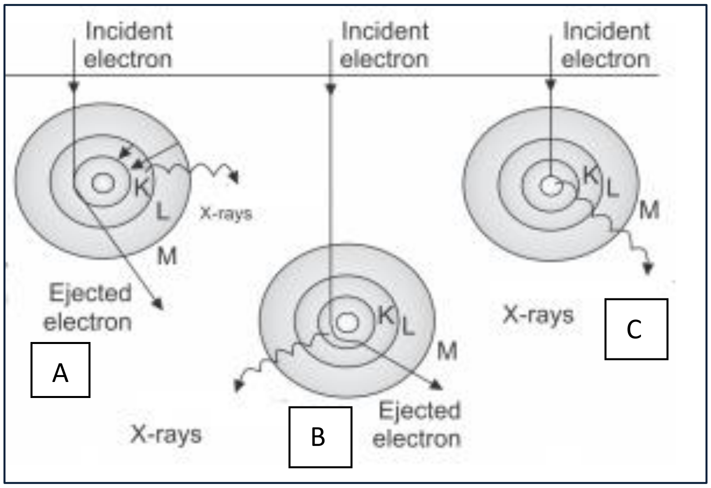


Figure 2: Interaction of electron with target atoms

A. In this process, the incident electron directly hit the K shell, transfers sufficient energy and removes the K shell electron. The vacancy in the K shell is filled by an electron moving inwards from the outer shell. During this transition, the difference in binding energies of the two shells is given out as X-ray photon.

B. The electron is a negative particle, it is attracted by the positive nucleus. It is made to orbit partially around the nucleus, decelerates and goes out with reduced energy. The loss of energy appears in the form of X-ray photons

C. The electron may hit the nucleus directly and is stopped completely in a single collision. The entire electron energy appears as bremsstrahlung radiation. This type of interaction is very rare, but capable of giving high energy X-rays.

What is the λ_{min} , E_{max} and υ_{max} in x-ray spectra?

It is useful to calculate the electron velocity, the maximum X-ray photon energy $\mathbf{E_{max}}$ and the minimum X-ray photon wavelength $\boldsymbol{\lambda_{min}}$ associated with a given tube kilovoltage.

$$K.E = \frac{1}{2} m_e v^2 = eV = h\upsilon$$

$$K.E = E_{max} = h\upsilon_{max} = hc / \lambda_{min} = eV$$

$$\lambda_{min} = hc / eV \qquad\qquad \upsilon_{max} = eV / h$$

A tube operating at only 30 kV is considered. The energy of each electron is given by the product of its charge (e coulombs) and the accelerating voltage (V volts)

$eV = 1.6 \times 10^{-19}$ (C) $\times 3 \times 10^4$ (V)

$= 4.8 \times 10^{-15}$ J (or 3×10^4 electron volts, i.e. 30 keV)

The electron velocity can be obtained from the fact that its kinetic energy is

$\frac{1}{2} m_e v^2_e$

Hence

$$\frac{1}{2} m_e v^2_e = 4.8 \times 10^{-15} \text{ J}$$

where $m_e = 9 \times 10^{-31}$ kg and v_e is velocity of electron

From above, the maximum X-ray photon energy E_{max} is 4.8×10^{-15} J and the minimum wavelength is obtained by substitution in

$$\lambda_{min} = \frac{hc}{eV} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{4.8 \times 10^{-15}} = 4.1 \times 10^{-11} \text{ m (or 0.041 nm)}$$

The X-ray Spectrum

The X-ray production can be seeing as a continuous spectrum of radiation superimposed by two peaks of well-defined wavelength. There are two types of X-ray spectrum, namely, (a) bremsstrahlung or continuous spectrum and (b) characteristic spectrum.

- A bremssrahlung spectrum consists of X-ray photons of all energies up to maximum in a continuous fashion, which is also known as white radiation, because of its similarity to white light.

- A characteristic spectrum consists of X-ray photons of few energy, which is also called as line spectrum. The position of the characteristic radiation depends upon the atomic number of the target.

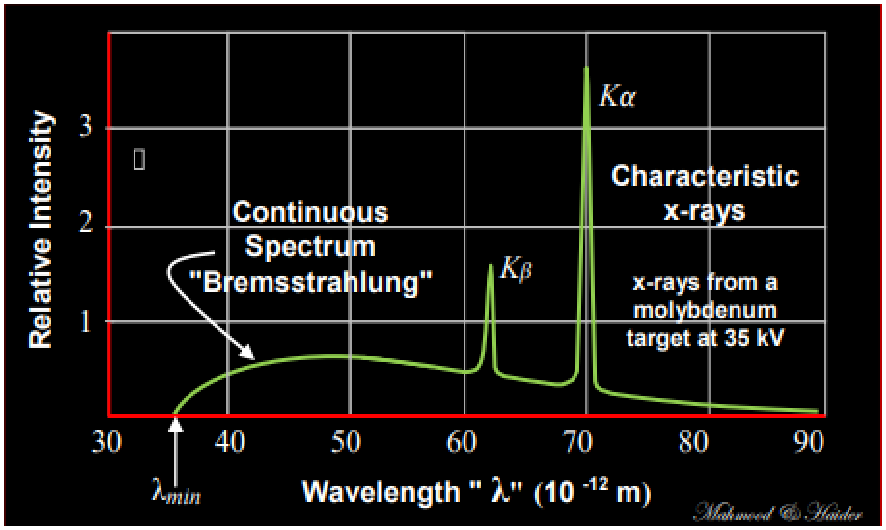


Figure 4: Wavelength distribution of X-Ray production in a molybdenum target.

The two peaks of Figure 4, labeled K_β and K_α , are part of what is called the Characteristic X-Ray Spectrum. Similar peaks appear for greater wavelengths or smaller frequencies.

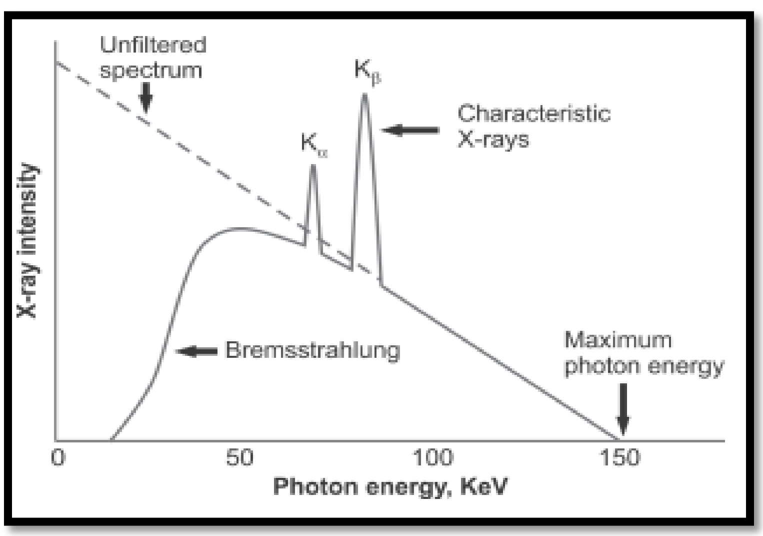


Figure 5: X-ray spectrum,

- The choice of target material in an x-ray tube affects the efficiency of x-ray production and the energy at which characteristic x rays appear.
- The efficiency is greater the higher the atomic number of the target.
- As the energy of the electrons bombarding the target increases, the high-energy limit of the x-ray spectrum increases correspondingly. The height of the spectrum also increases with increasing tube voltage because the efficiency of bremsstrahlung production increases with electron energy (see figure).