X-Ray

1. Introduction

X- ray is invisible and highly penetrating electromagnetic radiation of much shorter wavelength than UV ray and typically longer than gamma ray (as shown in Fig. (1)).

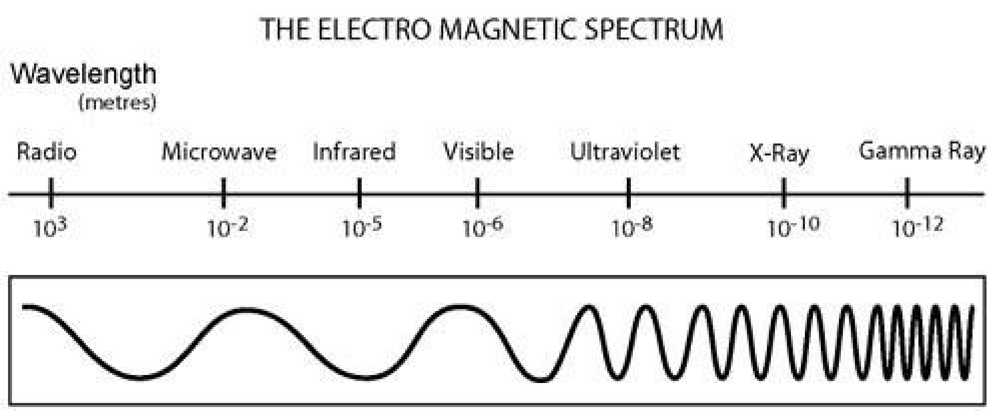

Fig. (1): The electromagnetic spectrum

The formula for wavelength of x-ray is given by the following equation:

$$\lambda = \frac{h\upsilon}{E} \qquad (1)$$

{ $E = hf$ (Planks formula) and $f = \frac{c}{\lambda} \Rightarrow E = \frac{h\upsilon}{\lambda} \Rightarrow \lambda = \frac{h\upsilon}{E}$}

Where: $h = 6.63\times10^{-34}$ *J.sec* (Planks constant), $c = 3\times10^{8}$ *m/ sec* (Velocity of light),

E= Energy of a photon in eV or joules, f = Frequency.

Note 1: how to convert the energy from eV to joules:

$1eV = 1.6\times10^{-19}\ J$

If energy in joules to converted to eV: divided by $1.6\times10^{-19} J$

$$E(J).\frac{1\ eV}{1.6\times10^{-19}J} = (\ )eV$$

If energy in eV to converted to joules: multiplying by $1.6\times10^{-19}\ J$

$$E(eV).\frac{1.6\times10^{-19}J}{1\ eV} = (\ )J$$

So we can rewrite the eq (1) in a simple way when the energy in eV:

$$E = \frac{(6.63\times10^{-34}J.\sec\ )(3\times10^{8}\frac{m}{sec})}{(1.6\times10^{-19}J)E(eV)} = \frac{1.99\times10^{-25}}{(1.6\times10^{-19}J)E(eV)}m$$

$$= \frac{1.24\times10^{-6}}{E(eV)}\ m$$

Note 2:

$1\mu m = 1\times10^{-6}\ m$, $1nm = 1\times10^{-9}\ m$ and $1Å = 1\times10^{-10}$ m

$1KeV = 10^{3}\ eV$ and $1MeV = 10^{6}\ eV$.

2. The properties of x-ray

1. It is electromagnetic radiation has wavelength between (0.1-100) A°.
2. It is undeflected in electric and magnetic field (discharge).
3. X-ray is ionizing radiation.
4. The most spectacular property is their ability to penetrate materials.
5. It is polarization and show reflection, refraction and diffraction.

3. The production of x-ray

The basic components of an x-ray tube and their function in x-ray production are listed in the following (see Fig.(2)):

1. X-rays are produced by employing a thermionic tube in which the electrons are obtained from a heated filament in glass envelope evacuated to high degree.
2. The electrons produced are accelerated from cathode to anode by large difference of potential between 10-1000 KV.
3. The Target is a metal having a high melting point and high atomic number. For medical purposes the target is made of tungsten because of high melting point (3380 ˚C) and has high atomic number (Z=74).
4. 1% of the energy of the electrons goes into the production of x-ray, the rest appearing as heat in the target and so it's made hollow to permit cooling water or oil to be circulated through it.
5. The intensity of x-ray depends on the number of electrons that strike the target. The frequency of x-ray depends on the potential different between the cathode and anode.

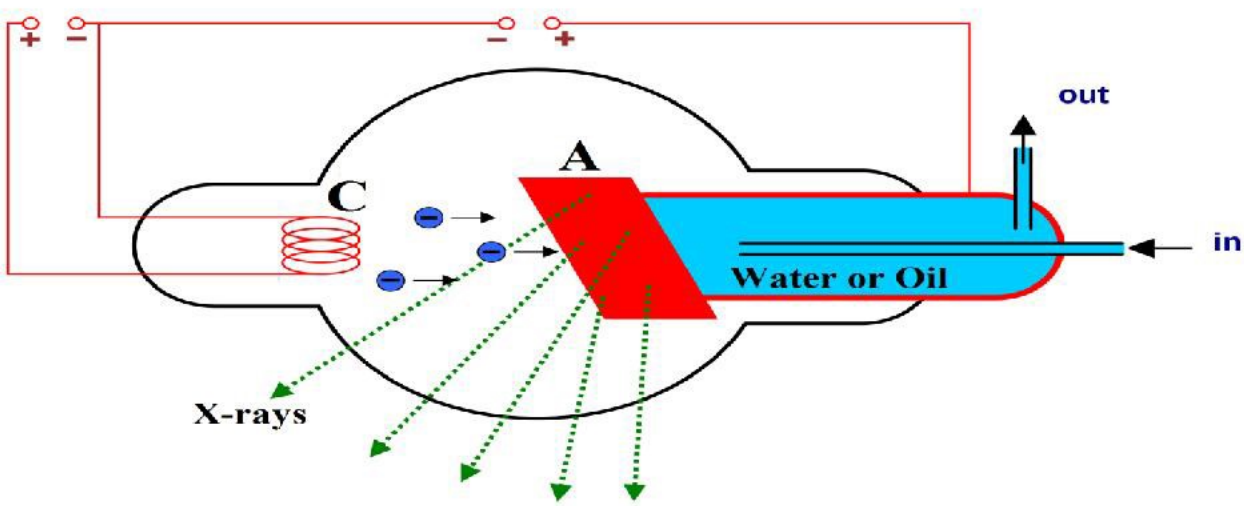

Fig. (2): X-rays tube

4. Mechanism of x-ray production

There are two kinds of mechanism:

(a) Breaking radiation

Some of the bombarding electrons make solid hits and lost most or all of their energy in just one collision. These electrons are rapidly decelerated and stopped suddenly and an energetic pulse of electromagnetic radiation is produced, the radiation emitted is in the wavelength range of x-ray. The German name of this process: is Bremsstrahlung which means “breaking radiation” and it is also means white radiation since it is similar to white light and has a range of wavelength. This is the chief mechanism by which radiation is produced in the x-ray tubes which are used in the physical, medical and industrial applications (see Fig.(3)).

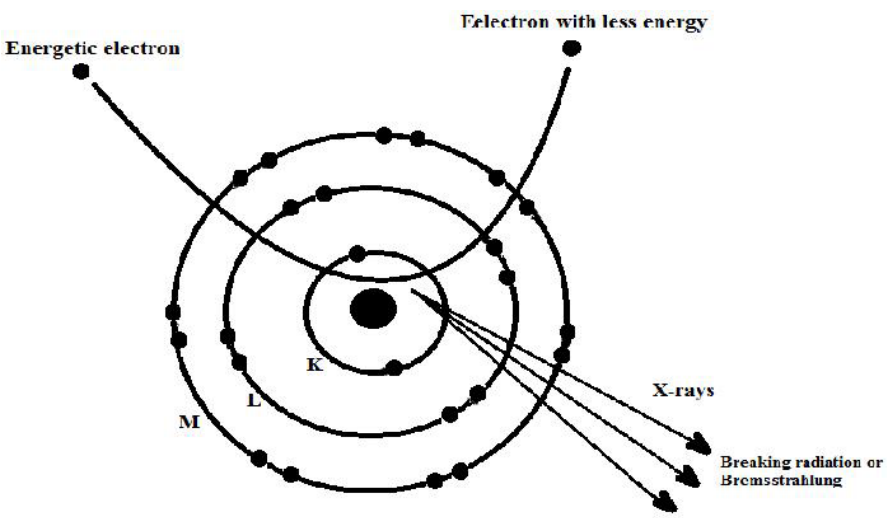

Fig. (3): Breaking radiation (Bremsstrahlung)

This method depends on:

1. The atomic number of the target.
2. The potential difference between anode and cathode.

This mechanism is an inverse photoelectric effect in which an electron produces a photon, but in photoelectric effect we found that photon of a given energy produce “photoelectrons”.

(b) K-x-rays or characteristic x-rays

It is very important kind of collision energy exchange; the bombarding electrons may have enough energy to produce ions by removing inner electron (K-shell) from the target atom when an outer electron falls into such a vacancy it will radiate a photon in the wavelength range of x-ray (see Fig.(4)). This mechanism produces x-rays having particular wavelengths which are characteristic of the target materials.

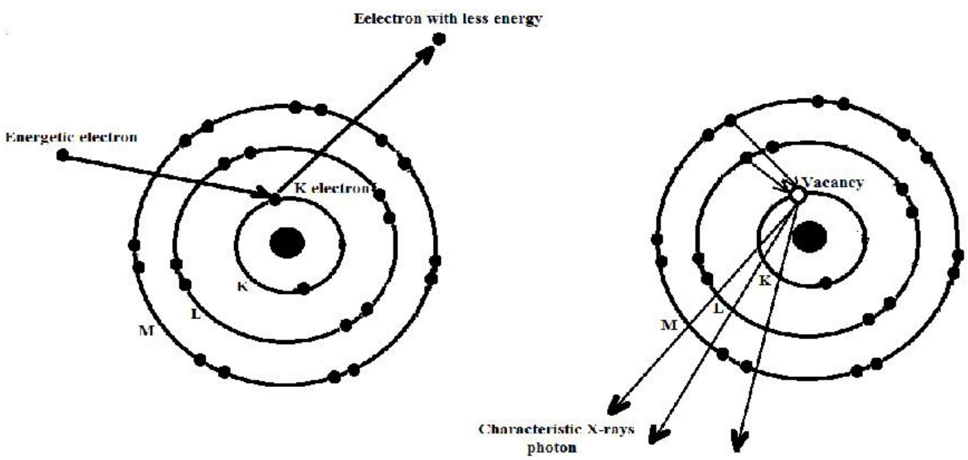

Fig. (4): characteristic X-rays (K-X-rays)

A characteristic x ray is emitted when an electron fills an inner-shell vacancy, as shown in Fig. (5) for several transitions in this approximate energy level diagram for a multiple-electron atom.

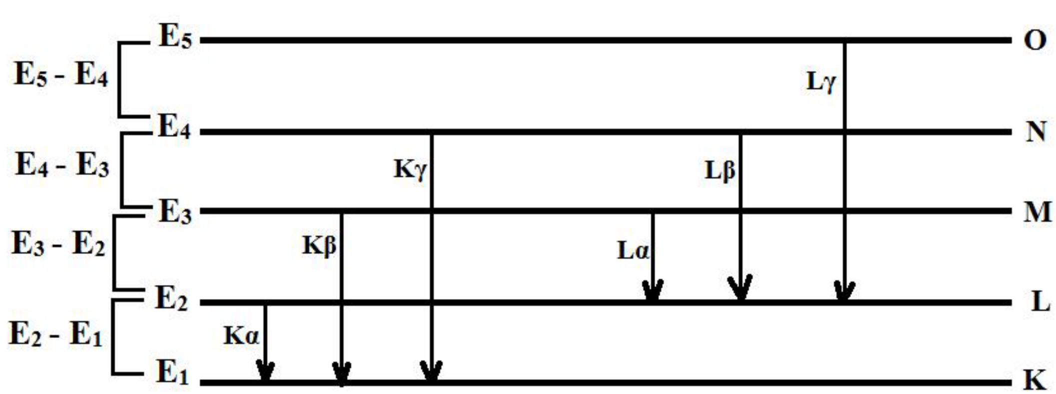

Fig. (5): The energy levels diagram

Characteristic x rays are labeled according to the shell that had the vacancy and the shell from which the electron came. A Kα x-ray, for example, is produced when an electron coming from the n = 2 shell fills the n = 1 shell vacancy.

Note 3: The energy required to ionize an atom by removing:

- an outer electron is 100 eV.
- an inner electron is 120000 eV.

5. X-ray spectrum

It is relation between the intensity ($I_\circ$) and the wavelength (λ) of the x-ray. Fig. (6) illustrates the x-ray emission spectrum that is obtained from a copper target (Z=29). Where the continuous curve is due to the Bremsstrahlung and the peaks represent the characteristic x-ray. When the target material of the x-ray tube is bombarded with electrons accelerated from the cathode filament, the continuous spectra and characteristic spectra are produced. The continuous spectra consist of a range of wavelengths of x-rays with minimum intensity (measured in counts per second) dependent on the target material and the voltage across the x-ray tube.

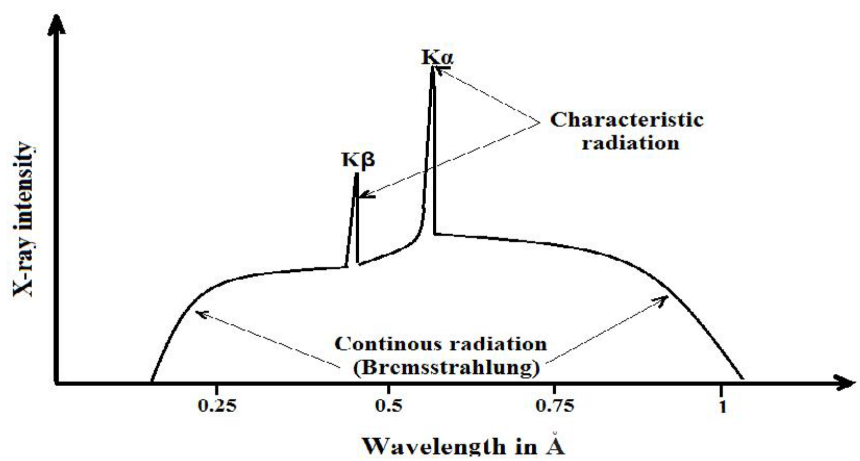

Fig. (6): The x-ray spectrum for copper target.

Whereas, the characteristic spectra, is produced at high voltage as a result of specific electronic transitions that take place within individual atoms of the target material. These characteristic x-rays have a much higher intensity than those produced by the continuous spectra, with Kα x-rays having higher intensity than Kβ x-rays. The important point here is that the wavelength of these characteristic x-rays is different for each atom in the periodic table (of course only those elements with higher atomic number have L- and M - shell electrons that can undergo transitions to produce x-rays). A filter is generally used to filter out the lower intensity Kβ x-rays. Furthermore, many of the low-energy ("soft") x-ray photons produced are absorbed in the glass walls of the x-ray tube.

6. The absorption of x-ray

In general if x-rays pass through matter each x-rays either does not interact at all or it is removed completely from the beam by absorption or scattering, this case an exponential attenuation with increasing absorber thickness.

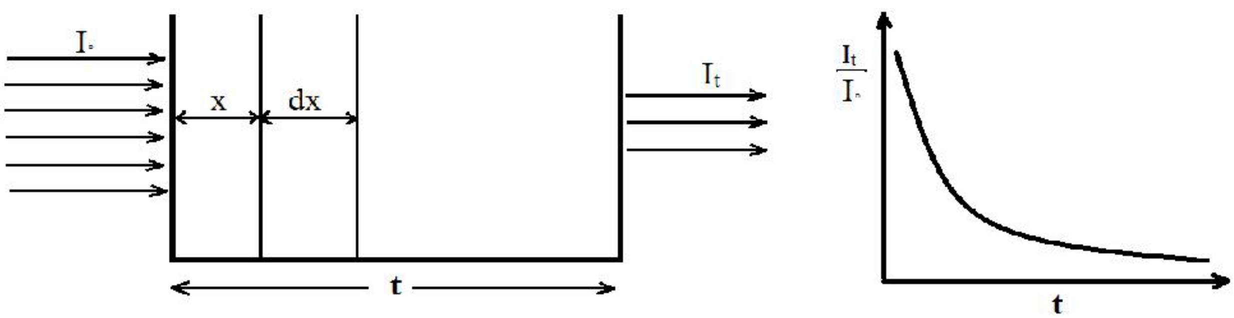

Fig. (7): The absorption of x-ray.

If I_o (x-rays per unit time) incident normally on an absorber. At a penetration depth(x), the unaffected beam has intensity (I_t).

The fractional number of x-rays removed from the beam will be proportional to (*dx*):

$$-\frac{dI}{I} \propto dx \Rightarrow -\frac{dI}{I} = \mu\, dx \qquad (2)$$

Where μ is the proportionality constant and it is called *linear attenuation coefficient*. Integration of equation (2) yield:

$$I_t = I_\circ e^{-\mu t} \qquad (3)$$