CHAPTER EIGHT:

X- RAYS AND RADIOACTIVITY:

Introduction:

In 1895, Rontgen, a German Physicist was experimenting with a cathode ray tube. He noticed that some barium platinocynide crystals, glowed brightly in the neighbourhood of the cathode ray tube. He also realized that some photographic plates which he had carefully wrapped, and left near the tube had become fogged. He traced the cause of this to the fact that, a kind of invisible radiation was proceeding in a straight line from the tube. This radiation is able to penetrate matter, which is opaque to ordinary light and for this reason, it was able to penetrate the wrapping material of the photographic plates and have an effect on them. These rays which he called x-rays, were coming from the florescent glass wall of the tube at the place where it was struck by the cathode rays, which are a stream of electrons produced by the tube. When he placed his hand between the tube and screen, a faint shadow of his hand appeared on the screen in which the bones were clearly visible, since they were more opaque to x-ray than flesh.

Properties of x-rays:

- They are electromagnetic rays which are similar to light.
- They travel in straight line, and have the same speed as that of light in vacuum.
- They are not deflected or affected by electric and magnetic fields.
- They can ionize gases and travel in vacuum.
- They affect photographic films.
- They can penetrate matter and can be absorbed by certain materials.

Importance/ uses of x-rays:

- Used in radiotherapy, i.e. in the destruction of diseased cells as in cancer treatment.
- Used to detect bone fracture and sprain.
- Used in medicine for medical diagnosis.
- Used in the detection of flaws and cracks in metal casting and welding.
- Used in x-ray crystallography, in which the crystal structure of elements are determined.

Dangers or hazards of x-rays:

- X-rays cause cancer and skin burns.
- X-rays cause damage to cells and tissues.
- X-rays produce genetic changes which appear in later generations.
- X-rays can cause graying and baldness.

N/B: These given facts prove that even though x-ray is quite good, it can be very dangerous if not properly used. For this reason, certain precautions or measures must be taken, when x-ray is being used.

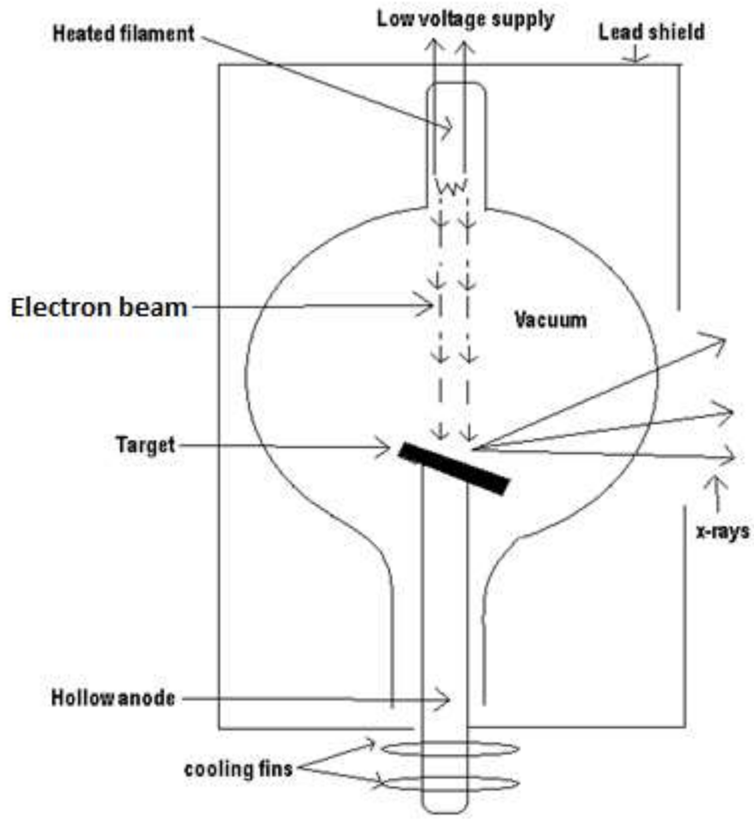
Precautions taken:

(i) X-ray machines are surrounded by lead shields, which absorb all stray radiation.

(ii) Workers who handle x-ray machines, or those likely to be exposed to this type of radiation, wear protective clothing.

(iii) Using remote control to handle x-ray machines.

Production of x-rays:



- The production of x-ray is by means of the x-ray tube.
- It consists of a filament (cathode), which is connected to a heater circuit.
- The tube also consists of a target (anode), which is made up of a high melting point material such as tungsten, which may be embedded in a copper block of high thermal conductivity.
- X-rays are always produced when fast moving electrons are brought to a stop or a halt in a target material.
- By switching the current on, the filament which gets heated emits electrons by means of thermionic emission.
- At the same time, a high voltage source is made to exist between the anode and the cathode.
- The released electrons are accelerated by this high voltage, and focused toward the anode so as to bombard it.
- The stopping of these fast moving electrons in the target, leads to the production of x-rays.
- The electronic bombardment of the anode also leads to the production of heat, which is conducted away by the copper block if it is available.
- Alternatively, the anode may be hollow in order for water to flow through for

cooling purposes. - Cooling fins may also be provided for this cooling purpose.
- Due to the amount of heat produced in the target as a result of the electronic bombardment, the target must be made of a high melting point material.

The quality of x-ray:

This refers to the penetration power of the x-ray, and under this we have two types of x-ray and these are:

(1) Hard x-ray.

(2) Soft x-ray.

Hard x-ray:

- The hardness of x-ray refers to the relative magnitude of the x-ray photon energy, which depends on the accelerating voltage.
- Hard x-rays are high energy x-rays, which have high penetration power.
- They have high frequencies and short wavelengths, and are produced at high accelerating voltage.

Soft x-rays:

- These are low energy x-rays which have low penetration power.

- They are produced at low accelerating voltage and have long wavelengths.

N/B:

- The penetrating power of x-ray determines its quality.

- The quality of X-ray depends on the voltage between the anode and the cathode.

(Q1)An x-ray tube is operated at 50kv. Calculate the shortest wavelength.

Soln:

P.d across the tube (the accelerating voltage) = V = 50kv = 50 x 10^3v.

Electronic charge = 1.6 x x10^{-19}Js.

Velocity of light = C = 3 x 10^8m/s.

Let the shortest wavelength = λ_{min}.

But since eV = $\frac{hc}{\lambda_{min}}$

$=> \lambda_{\min} = \frac{hc}{eV}$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{1.6 \times 10^{-19} \times 50 \times 10^{3}}$

$= 2.48 \times 10^{-11}$m

=> The shortest wavelength of the x-ray = 2.48×10^{-11}m.

(Q2) A 150kv x-ray is absorbed by a proton at rest. Calculate the resulting velocity of the proton. [Assume the mass of proton = 1.67×10^{-27}kg]

Soln:

Let m = the mass of proton = 1.67×10^{-27}

Let U = the resulting velocity of the proton.

Then the kinetic energy acquired by the proton is given by $\frac{1}{2}mu^2$.

The energy of x-ray absorbed by the proton = E = hf = eV.

Since the kinetic energy of the proton = the energy absorbed by the proton,

=> $\frac{1}{2}mu^2 = eV$, where V = 150kv = 150×10^3v

=> From $\frac{1}{2}mu^2 = eV$

$=> U^2 = \frac{2eV}{m} => U = \sqrt{\frac{2eV}{m}}$

$=> U = \sqrt{\frac{2 \times 1.6 \times 10^{-19} \times 150 \times 10^{3}}{1.67 \times 10^{-27}}}$

= U = 5.36×10^6ms^{-1}.

(Q3)An X-ray tube works at a potential difference of 100kv. Calculate

(i) the energy of the electrons as they hit the target.

(ii) the cut-off wavelength of the x-ray emitted.

Soln:

(i)The p.d across the tube (the accelerating voltage), V = 100kv = 100 x 10^3V.

But the energy of the electron = eV = 1.6 x 10^{-9} x 100 x 10^3J

= 1.6 x 10^{-14}J.

(II)Since the energy absorbed by the x-ray = the energy of the electron.

=> hf = ev and since f = $\frac{c}{\lambda_{min}}$ => $\frac{hc}{\lambda_{min}}$ = eV

=> $\lambda_{min} = \frac{hc}{eV}$

=> $\lambda_{min} = \frac{6.6 \text{ x } 10^{-34} \text{x } 3 \text{ x } 10^{8}}{1.6 \text{ x } 10^{-14}}$

= 1.24 x 10^{-11}m

Since λ_{min} = the cut off wavelength => the cut off wavelength = 1.24 x 10^{-11}m.

(Q4)In an x-ray picture, the bones appear white in a dark background.

Explain

Soln:

- The bones contain large amount of calcium, which is a good absorber of x-ray, while the fresh is made up of elements which are poor absorbers of x-ray.

- When x-rays are directed on a body, the bones absorb most of these rays and for this reason, develop out clearly (white) on a photographic film.

- Since the x-ray passes through the flesh with little absorption onto the photographic film, it develops out black.

- In a simplified form, since the bones are more opaque to the x-rays than the flesh, they develop clearly on a photographic film.

(Q4) An x-ray tube is operating at 150kv and 20mA. If 1% of the energy appears in the form of x-rays,

(a) calculate the rate of heat production in the target.

(b)If no attempt were made to cool the target, determine how quickly a copper target of mass 1.5×10^2kg and specific heat capacity $395 Jkg^{-1}k^{-1}$, will begin to melt?

[Melting point of copper at room temperature o $27^{0c} = 1083^{0c}$].

Soln:

Since 1% of the energy appears in the form of x-rays, then the remaining 99% appears in the form of heat.

The rate of heat production = 99% x I.V where I = current flowing and V = the applied p.d.

$I = 20mA = 20 \times 10^{-3}A$

$V = 150kv = 150 \times 10^3 v$

The rate of heat production (i.e. the amount of heat produced per second in the target) = $\frac{99}{100} \times 20 \times 10^{-3} \times 150 \times 10^3 J/s$

= 2970J/s.

(b)If no attempt were made to cool the target, then the amount of heat absorbed by the target to reach its melting point = $Mc(\theta_2 - \theta_1)$, where M = mass of the target = 1.5×10^2kg, C = the specific heat capacity of the target, θ_2 = the final temperature = the melting point of the target = 1083^0c.

θ_1= the initial temperature of the target (room temperature) = 27^0c.

Heat absorbed by the target before melting $= Mc(\theta_2 - \theta_1)$, $= 1.5 \times 10^2 \times 395 \times (1083 - 27^0)$

$= 150 \times 395 \times 1056 = 62.6 \times 10^6 J$

Let t = the time taken for the target to melt.

Then the heat generated per second within the target = $\frac{62.6 \text{ x } 10^6}{t}$

But heat generated per second within the target = 2970J/s

=> $2970 = \frac{62.6 \text{ x } 10^6}{t}$

=>$2970t = 62.6 \text{ x } 10^6$

=> $t = \frac{62.6 \text{ x } 10^6}{2970}$

=> t = 21066 sec

= 351 minutes.