X-RAYS

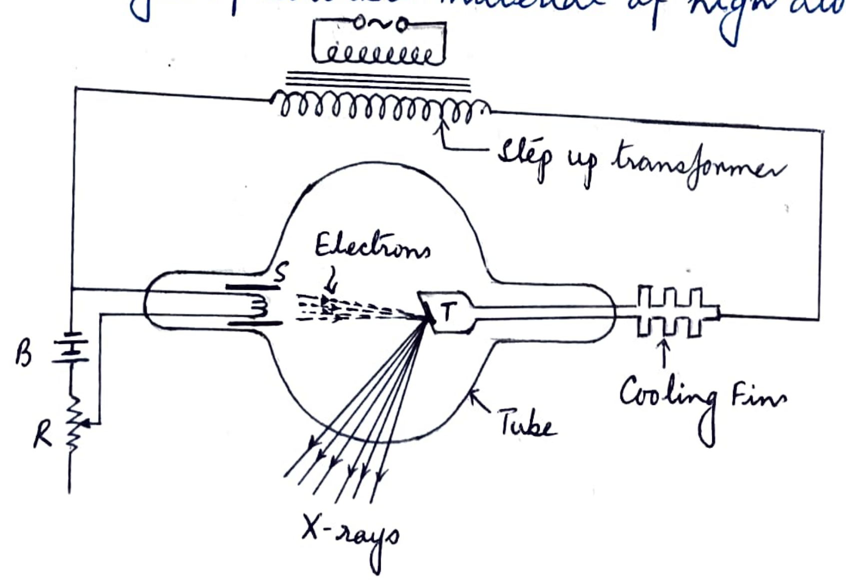
INTRODUCTION TO X-RAYS

Rontgen in 1895 discovered the X-rays. After performing a series of experiments Rontgen concluded that when a beam of fast moving electrons strike a solid suitable metallic target, an invisible highly penetrating radiation is produced. Because of their unknown nature Rontgen called these radiations as X-rays. Actually, X-rays are electromagnetic waves of very short wavelength ranging from 0.01 Å to 100 Å.

PRODUCTION OF X-RAYS USING COOLIDGE TUBE

The X-rays are produced when fast moving electrons strike a metallic target of suitable material.
The basic requirement for the production of X-rays are —

(i) a source of electrons
(ii) an effective means of accelerating the electrons, and
(iii) a target of suitable material of high atomic weight.



A Coolidge tube is shown in the figure above. It consists of a highly evacuated hard glass ~~tube~~ bulb containing a cathode and an anode. The cathode consists of a tungsten filament F and is heated by passing a current through it from a low tension battery of 5 to 10 volts. The electrons are emitted by the process of thermionic emission from the cathode. The filament is surrounded by a molybdenum cylinder S kept at a negative potential with respect to the filament F. Due to this, the electrons emitted from the filament are collimated into a fine pencil of electronic beam.

The target T consists of a copper block in which a piece of tungsten or molybdenum is fitted. The anode should have the following characteristics:—

(i) It should have high atomic weight to reduce hard X-rays.

(ii) It should have high melting point so that it is not melted due to the bombardment of fast moving electrons because this causes enormous amount of heat generation.

(iii) It should have high thermal conductivity to carry away the generated heat.

The target is placed at an angle of 45° with the path of electron beam. The target is cooled by flowing cold water into a hollow tube attached with it. A high A.C. potential of about 20000 volts is applied between the filament F and the target T. This is achieved with the help of a step-up transformer. Due to this high potential difference, the electrons emitted from the filament are accelerated. When these accelerated electrons strike the target, they give up their kinetic energy and thereby produce X-rays. Here it is to be noted that only a small percentage of the electron energy at the target is converted into X-rays while the rest of energy is dissipated as heat. Due to this heating, the target gets heated. So in order to save the target, it is constantly cooled by cooling arrangement.

* The intensity of X-rays depends upon the number of electrons striking the target. ie. the intensity of X-rays depends upon the rate of emission of electrons from the filament. This can be controlled by varying the filament current with the help of rheostat R included in filament circuit. Thus, in Coolidge tube, the intensity of X-rays can be controlled.

** The quality of X-rays is measured by their penetrating power which is a function of potential difference between the cathode and the target. Higher is the accelerating voltage, higher is the speed of striking electrons and consequently more penetrating X-rays are produced. High penetrating X-rays are called hard X-rays whereas low penetrating X-rays are termed as Soft X-rays. Thus, the quality of X-rays can be controlled in a modern Coolidge tube by varying the potential difference between the cathode and target.

MINIMUM WAVELENGTH OF X-RAYS

The X-rays consist of continuous range of frequencies upto maximum frequency $\nu_{max.}$ or minimum wavelength $\lambda_{min.}$ This is known as continuous spectrum.

OR

The limiting wavelength below which continuous X-ray spectrum does not exist is called cut-off wavelength or minimum wavelength. It is denoted by λ_{min}.

The expression for minimum wavelength of emitted X-rays is given by

$$\lambda_{min} = \frac{ch}{eV} \qquad \text{------ (i)}$$

where $c = 3 \times 10^8$ m/sec, h = Planck's constant $= 6.62 \times 10^{-34}$ joule-second, e = electronic charge $= 1.602 \times 10^{-19}$ coulomb and V = accelerating potential.

Substituting the values of c, h and e in eqn. (i), we get

$$\lambda_{min.} = \frac{3 \times 10^8 \times 6.62 \times 10^{-34}}{1.602 \times 10^{-19}\, V} \text{ meter.}$$

$$= \frac{1.24 \times 10^{-6}}{V} \text{ meter}$$

$$= \frac{12400}{V} \text{ Å} \qquad \text{where } 1 \text{ Å} = 10^{-10} \text{ m.}$$

Thus,

$$\boxed{\lambda_{min} = \frac{12400}{V} \text{ Å}}$$

PROPERTIES OF X-RAYS

The X-rays possess the following properties:—

(i) X-rays are electromagnetic waves of very short wave-length. They travel in straight lines with the velocity of light. They are invisible to eyes.

(ii) Under suitable conditions, X-rays are reflected and refracted like ordinary light.

(iii) They exhibit the property of interference, diffraction and polarisation like ordinary light.

(iv) They are not deflected by electric and magnetic fields.

(v) X-rays can penetrate through substances like wood, flesh, thick paper, thin sheets of metals etc. which are opaque to ordinary light.

(vi) They cause fluorescence in many substances like barium, cadmium, tungsten, zinc sulphide etc.

(vii) X-rays can ionise a gas through which they pass.

(viii) When X-rays fall on certain metals, they liberate photo-electrons (Photo-electric effect.).

(ix) When X-rays fall on heavy metals, they produce secondary X-rays.

(x) X-rays have destructive effect on living tissues. They can destroy the white Blood Corpuscles.

APPLICATIONS OF X-RAYS

X-rays have great applications in industry, engineering, medicine and scientific research work.

Industrial and engineering applications of X-rays.

Some of the applications are:—

(i) X-rays are used to detect any defect in radio-valves, tennis balls, rubber tyres and the presence of pearls in oysters.

(ii) X-rays can be used for testing the homogeneity of welded joints, insulating materials etc.

(iii) X-rays are used to detect cracks in structures like in the body of aeroplanes and motor cars.

(iv) X-rays can be used to analyse the structure of alloys and other composite bodies by determining the crystal form in an ingot with the help of diffraction of X-rays.

(v) They are also used to study the arc structure of materials like rubber, cellulose, plastic fibres etc.

Medical Applications

Some of the medical applications are :—

(i) The most common use of X-rays is to get the photo-graph of interior of human body. The photograph is known as radiograph and it is used to detect fracture, diseased organs, foreign matter like bullets and formation of stones in human body.

(ii) X-rays have curative properties. They are used to destroy abnormal internal tissues. They are also used for the treatment of cancer.

(iii) Hard X-rays are used to destroy tumours very deep inside the body.

Applications of X-rays in pure scientific research —

Some of the applications are :—

(i) X-rays are used for studying the structure of crystalline solids and alloys.

(ii) They are used in the analysis of the structure of the crystals and structure of atoms.

(iii) X-rays are also used for analysing the structure of complex organic molecules.

(iv) X-rays are used in determining the atomic number and identification of various chemical elements.

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Numerical

1. If an X-ray tube is operated at 24824 volts, what is the minimum wavelength of X-rays?

$$\lambda_{min} = \frac{12400}{V} \text{Å} = \frac{12400}{24824} \text{Å} = 0.5 \text{Å} \quad \text{Ans.}$$