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Reference Books:
Concepts of Modern Physics - Arthur Beiser
Modern Physics - Murugeshan R. and Sivaprasad K.

X-rays

X-rays are highly energetic electro-magnetic radiations having very short wavelength ranging from 1Å to 100Å. It was first discovered by Roentgen(1895). When fast moving electrons are made to strike a target metal of high atomic number and melting point, X-rays are produced. According to the wavelength of X-ray or energy associated with it, X-ray is divided into two categories;

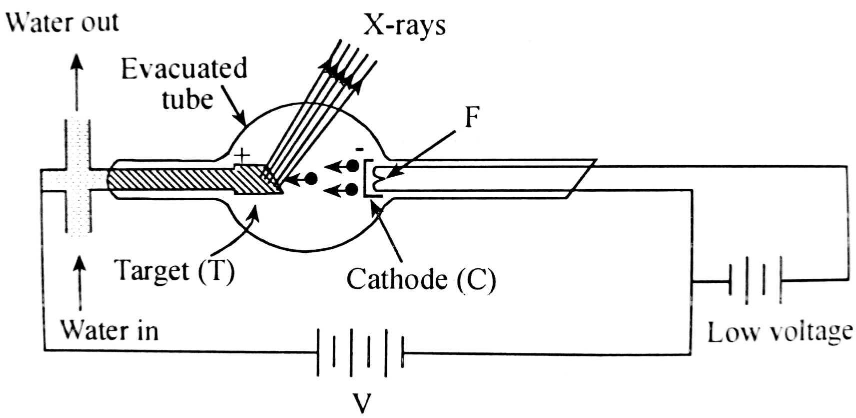
1. Soft X-ray
2. Hard X-ray

X-ray of longer wavelength is taken as soft X-ray and that of shorter wave length is taken as hard X-ray.

Characteristics

- X-rays are not deflected by electric and magnetic fields.
- They can travel with velocity of light.
- They have ionizing power i.e. they can ionize the gas atom or matter through which they pass.
- They can produce photoelectric effect.
- They can show the phenomenons like diffraction, interference, polarization etc. similar to that of ordinary light.
- They can pass through opaque solids like wood, paper and thin sheet of metals.

Production of X-rays
(Coolidge tube)



It consists of a highly evacuated($\sim 10^{-5}$ mm of Hg) glass tube having a filament F at one end connected with a low tension. At the other end, a target metal is placed. A high *p.d.* is maintained between filament (F) and target (T). A metal reflector (C) is used to focus the electrons on the target metal. A cooling system is arranged to cool the target which gets heated during the production of X-rays.

When a small potential is applied to the filament electrons are produced from it. These electrons are accelerated by applying a very high potential between F and T. The electrons, focused by the metal reflector are then allowed to fall on the target with high speed. When fast moving electrons strike the target metal, X-rays are produced. However, only around 2% energy of electrons is used to produce X-rays and the rest 98% of energy produces heat on target metal. Because of this reason a metal of high atomic no. and melting point is used in the production of X-rays. Cold water is continuously circulated to cool it down.

Intensity Control

Intensity of X-rays actually symbolizes the number of X-rays present in a beam. An electron can produce only one X-ray. Hence, the intensity of X-rays depends on the number of electrons striking the target metal. Number of electrons depends on the current passing through the filament. So, controlling the current passing through the filament by adjusting the low tension / potential applied, we can control the intensity of X-rays.

Quality Control

Frequency of X-rays resembles the quality of X-rays. Thus, quality of X-ray means energy of X-rays. As, energy of electrons is used(converted) to produce X-rays, energy of X-rays depends on the energy of electrons striking the target. Kinetic energy of electrons accelerated by *p.d.* of V volts is given as,

$$\tfrac{1}{2}mv^2 = eV$$

Thus, energy depends on the applied high potential.

When all energy of electrons is converted into energy of X-rays, then X-rays having high frequency are produced. Therefore,

$$\tfrac{1}{2}mv^2 = eV = \text{max}^m \text{ energy of X-rays}$$

$$\Rightarrow h\nu_{max} = \frac{1}{2}mv^2 = eV$$

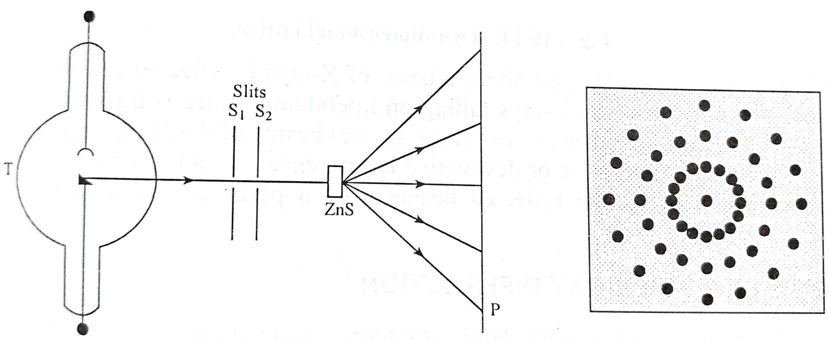
$$\Rightarrow \boxed{\nu_{max} = \frac{eV}{h}}$$

If λ_{min} be the minimum possible wavelength of X-ray produced and 'c' be the velocity of light in air, then we have,

$$\lambda_{min} = \frac{c}{\nu_{max}} = \frac{c}{\frac{eV}{h}}$$

$$\Rightarrow \boxed{\lambda_{min} = \frac{hc}{eV}}$$

Diffraction of X-rays and Laue's experiment



Laue showed that if X-rays are allowed to pass through a crystal, a diffraction pattern is obtained.

The experimental set up for Laue's experiment is as shown in figure, in which X-rays produced by a source are collimated by using two slits S_1 and S_2. The collimated beam of X-rays is allowed to pass through a ZnS crystal. The transmitted beam of X-rays are allowed to fall on the photographic plate. After an exposure of several hours, the plate is developed. On observing the plate, a central spot along with many faint and regular spots around it are seen. This indicates, that the incident X-ray beam has been diffracted from the various crystal planes. These spots are known as Laue spots. These spots are arranged according to different geometrical patterns fro different crystals, depending on their structure.

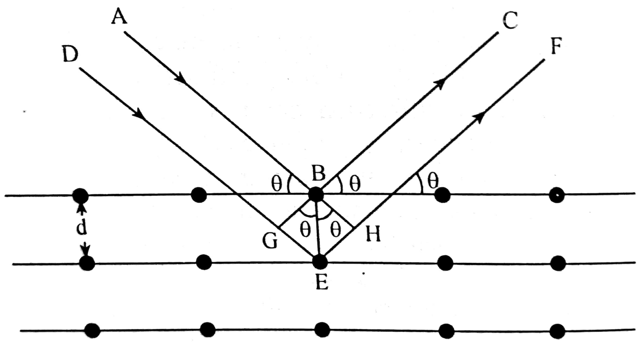
Hence, two main conclusions can be drawn from this experiment i.e.,

1. X-rays are electromagnetic waves as they are diffracted from the crystal lattice.
2. The atoms of a crystal are arranged in a regular three dimensional lattice and the space between them act like diffraction grating.

Bragg's Law

When a monochromatic beam of X-ray incidents on the atoms in a crystal lattice, each atoms acts as a source of scattering radiation of same wavelength. The crystal acts as a series of parallel reflecting planes. Bragg's law states that,

> "The intensity of reflected X-rays at certain angles will be maximum when the path difference between reflected beams from two different planes becomes equal to an integral multiple of wavelength of X-rays."



Consider a crystal having inter-planar distance 'd' consisting of parallel planes. Suppose a parallel beam of X-rays, incidents on crystal lattice with glancing angle θ. Let two rays AB and DE be reflected from atoms lying on two consecutive crystal planes and travel along BC and EF respectively. According to Bragg, the intensity of these reflected beam will be maximum, when path difference between them is equal to the integral multiple of wavelength of X-rays.

To calculate path difference, draw two perpendicular BG and BH,

$$\therefore \text{Path difference} = GE + EH \tag{1}$$

From geometry, we have,

$$\angle GBE = \angle HBE = \theta$$

Again, from $\triangle$ BGE,

$$\sin\theta = \frac{GE}{BE} \Rightarrow GE = BE\sin\theta$$

$$\therefore GE = d\sin\theta \tag{2}$$

And, from △ BHE,

$$\sin\theta = \frac{EH}{BE}$$

$$\therefore EH = d\sin\theta \tag{3}$$

From eqt^{n}s (1), (2) and (3)

$$\therefore \text{Path difference} = d\sin\theta + d\sin\theta$$

$$= 2d\sin\theta$$

Now, from Bragg's law, for maximum intensity, the path difference must be integral multiple of λ.

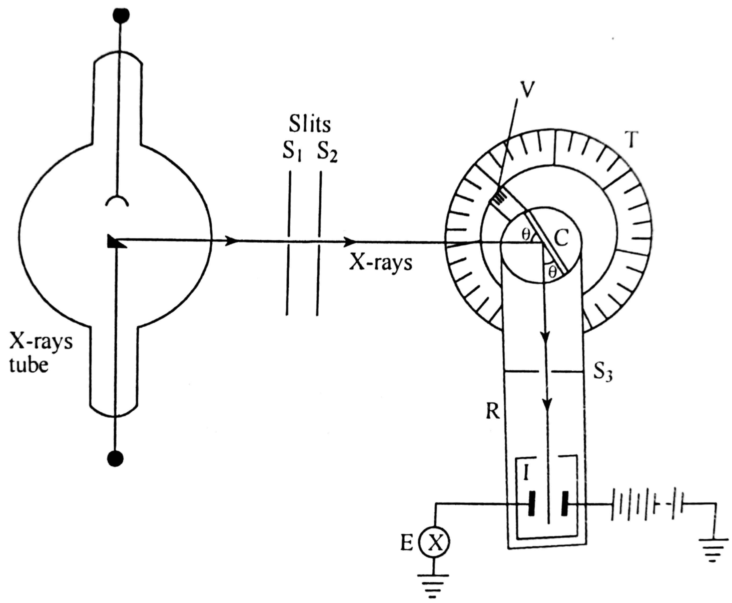
$$\boxed{\therefore 2d\sin\theta = n\lambda}$$

where n = 1, 2, 3, 4, ...

Bragg's X-ray Spectrometer

The spectrometer is used to study the intensity of reflected X-ray from the crystal surface. Basically, it consists of three components.

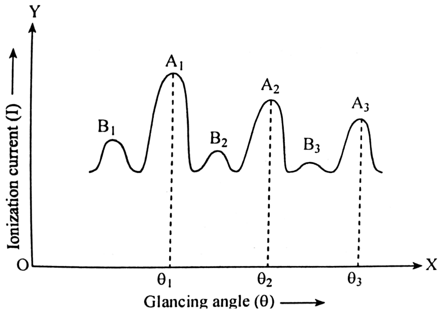
1. Source of X-rays
2. A crystal held on a circular table
3. Ionization chamber



(S_1, S_2, S_3 = *Collimating slits* C = *Crystal* T = *Turn table* I = *Ionization chamber* E = *Electrometer*)

Monochromatic X-ray is produced from the source. The beam is collimated with the help of slits S_1 and S_2 and then falls on the crystal under study. The crystal is placed on the rotating table, so that glancing angle can be changed and corresponding intensity of X-ray can be studied. The X-rays after reflection enters into the ionization chamber after being collimated by the slits S_3. Reflected X-ray ionizes the gas in the ionization chamber. The ions are collected by the electrode and the ionization current can be read on the electrometer(Ammeter).

By turning the table for different glancing angle, intensity of X-ray is studied by observing various ionization current. On plotting the intensity and glancing angle, various prominent peaks are observed with gradual decrease in intensity as shown in the graph.



The glancing angles θ_1, θ_2, θ_3 corresponding to the peaks A_1, A_2 ,A_3 are obtained from the graph. It is observed that,

$$\sin\theta_1 : \sin\theta_2 : \sin\theta_3 = 1 : 2 : 3$$

This, shows that A_1, A_2 ,A_3 refers to the first, second and third order reflections of the same wavelength.