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### C. Law of Symmetry of crystals.

Depending upon the arrangement of structural units, different crystals have different symmetry. In order to understand symmetry, we shall first consider the kinds of symmetry elements a molecule may possess and the symmetry operations generated by symmetry elements. We will discuss these one by one.

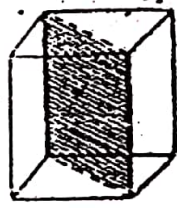
**1. Symmetry elements** : A symmetry element is a geometrical entity such as a line (or axis), a plane or a point with respect to which one or more symmetry operations may be carried out. The various types of elements are as follows:

(a) **Plane of symmetry**: A crystal is said to possess a plane of symmetry when an imaginary plane passing through the centre of crystal can divide it into two parts such that one is the exact mirror image of the other. The standard rotation for a plane of symmetry is indicated by  $\sigma$ .

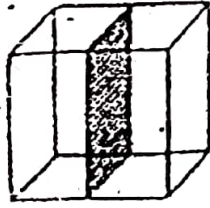
(b) **Axis of symmetry**: It is a line about which the crystal may be rotated so that it represents the same appearance more than once during a complete revolution. If the equivalent configuration occurs twice, thrice, four and six times, i.e., after rotation of  $180^\circ$ ,  $120^\circ$ ,  $90^\circ$  and  $60^\circ$ , the axes of rotation are known as two-fold (diad), three fold (triad), four-fold (tetrad) and six-fold (hexad), axes of symmetry respectively. The axes of symmetry is indicated by C. If it is two fold, it is indicated by  $C_2$ . Similarly, three-fold and four-fold axes of symmetry are indicated by  $C_3$  and  $C_4$  respectively.

(c) **Centre of symmetry**: It is a point that any line drawn through it will meet the surface of the crystal at equal distances on either side. It is important to mention here that a crystal may possess a number of planes or axis of symmetry but it can only have one centre of symmetry.

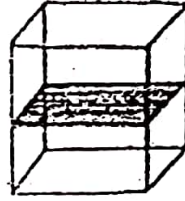
Now we will illustrate the various elements of symmetry as shown in Fig (1).



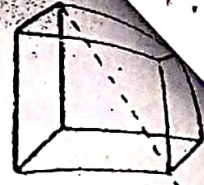
(1a)



(1b)



(1c)

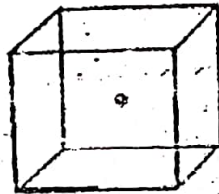


(1d)

Figs (1) a, 1(b) and 1(c) show the plane of symmetry. Figs. 1(d), 1(e) and 1(f) represent the three-fold axis, four-fold axis and two-fold axis of symmetry respectively. Figs (1) g) and (1 h) represent the centre of symmetry.



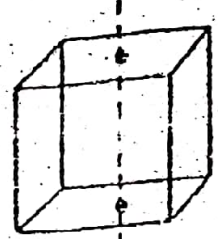
(1e)



(1f)



(1g)



(1h)

Fig. 1.

A cube has thirteen axis of symmetry (three four-fold, four three-fold, six two-fold), nine planes of symmetry and one centre of symmetry, i.e., 23 elements of symmetry altogether.

**2. Symmetry Operations :** A symmetry operation is a movement of a body, such that, after the movement has been carried out, every point of the body is coincident with an equivalent point (or perhaps the same point) of the body in its original orientation.

There are four principle operations for repeating figure: (a) Translation operation (b) Rotation operation (c) Reflection operation across a line in two dimensions or plane in three dimensions and (d) Inversion through a point (Fig. 2)



Rotation



Reflection

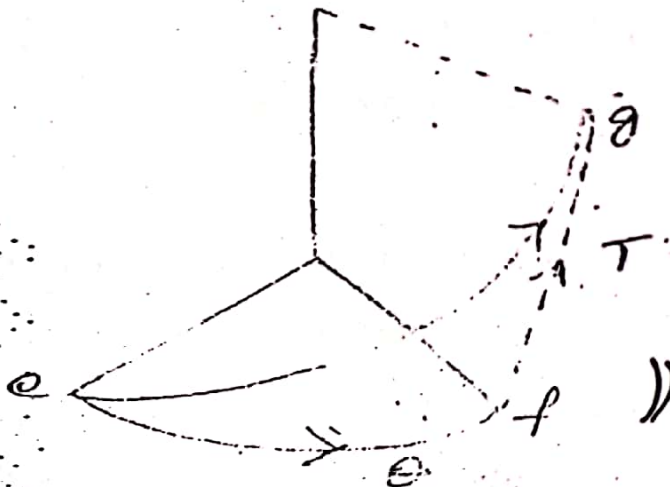


Inversion

Fig. 2.

### Screw axis

It is possible to combine proper rotation with a translation parallel to the rotation axis. The operation is shown in the fig. Where a rotation from e to f by an amount  $\Theta$  combined with a translation from f to g by an amount T is equivalent to a screw motion from e to g. The symmetry element that corresponds to such a motion is called a screw axis.



After n rotations through an angle  $\Theta$  and n translations T along the screw axis, the cumulative translation distance in the direction of the axis must equal some multiple

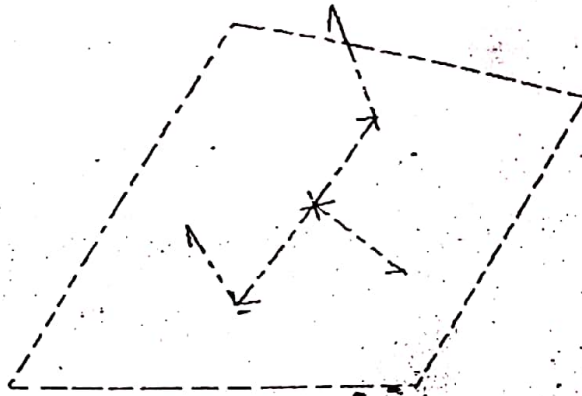
of the lattice translation  $mt$ . In other words

$$nT = mt \text{ where } n \text{ and } m \text{ are integers}$$

$$T = mt / n$$

## Glide Planes

It is possible to combine a reflection with a translation parallel to the reflection plane. Such a combination is called a glide reflection. The symmetry element related to the resulting pattern is called a glide plane.



The translation component T of a glide plane is equal to one-half of the normal translation of the lattice in the direction of the glide. Thus a glide along the a axis has  $T = \frac{1}{2} a$  and is called a 'a' glide. Similarly a diagonal glide can have  $T = \frac{1}{2} a + \frac{1}{2} b$  or  $\frac{1}{2} b + \frac{1}{2} c$  etc.

## 2.1 DIFFRACTION METHODS

### X-ray Diffraction

X-rays can be used to investigate the internal structure of crystals. It was Laue (1912) who first suggested the use of X-rays in determining the structure of crystals. His experiment was further developed by W.L Bragg and others. However, the following methods have been developed for the study of X-ray diffraction of crystals.

1. **Laue's Photographic Method:** Laue (1912) showed that if X-rays are allowed to pass through a crystal, a diffraction pattern is obtained which gives the positions of molecules or ions in a crystal. The experimental equipment employed by Laue is relatively simple and shown in Fig. (1).

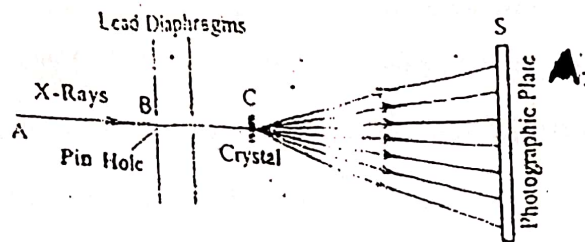


Fig. 1. Diffraction of white X-rays by a single stationary crystal.



Fig. 2.

'A' is a source of X-rays which is usually obtained from a tungsten target at about 60,000 volts. Before passing through the crystal, the X-rays are passed through a slit system (B) to obtain a fine pencil. Then the X-rays are permitted to pass through a crystal, (C) which is set on a holder to adjust its orientation. The emergent beam from the crystal is made to fall on a photographic plate (S) which is kept at a few centimeters from the crystal. On doing this a Laue photograph is obtained on the photographic plate as shown in Fig. (2). The photograph consists of a central spot which arises due to undeviated beam. The central spot is surrounded by spots which arise from different diffracted beams. From the arrangement of spots on a diffraction pattern, one can get some idea about the symmetry and the position of molecules in the crystal.

From Laue's diffraction pattern, one can deduce the geometry of the structural units of the crystals.

**2. X-Ray Spectrophotometer Method:** A simple interpretation of Laue diffraction pattern was given by W.L. Bragg. In 1915 Bragg devised a simple method for the study of crystals by X-rays. He pointed out that when a beam of X-rays is passed through a crystal, each atom in the path acts as scattering centre and, thus emits secondary radiations. However, reflection of X-rays can take place at certain angles when the path difference of emitted ray from the successive planes is a whole number multiple of the wave-length.)

### Derivation of Bragg's Equation:

Consider a set of parallel atomic planes whose spacing is  $d$  and let a narrow monochromatic beam of X-rays fall upon these parallel planes at a glancing angle  $\theta$ . Fig (3). Each atom in a given layer, according to Huygen's principle, becomes the centre of expanding wavelets whose envelope gives rise to reflected wave front. As in the case of optical reflection, the reflected wave front will have maximum intensity at an angle  $\theta$  to this plane which is equal to the glancing angle.

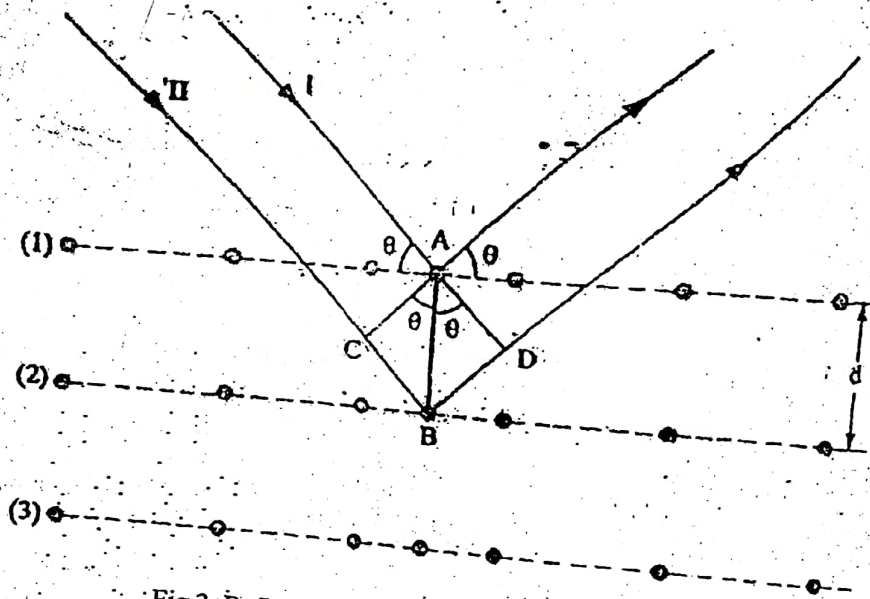


Fig 3. Reflection of X-rays from lattice planes of crystal

Each parallel layer in the given set gives rise to the reflected wave front. The condition for constructive interference between the reflected wavefronts is that the path difference between the reflected wavefront from one layer and that from the next must be equal to an exact wave-length or an integral multiple of it.

In Fig. (3) two parallel rays I and II are reflected by two atoms A and B in two adjacent layer; B being vertically below A. The ray reflected from B travels a longer distance than that reflected from A. Draw AC and AD perpendiculars to the direction of the incident and the reflected rays. Each of these lines makes an angle  $\theta$  with AB.

whose length is equal to the spacing  $d$ . Further,  $CB = BD = AB \sin \theta = d \sin \theta$ . The additional path traveled by the ray reflected from the second layer is equal to  $(CB + BD)$ . Thus, the condition for constructive interference between the two rays is

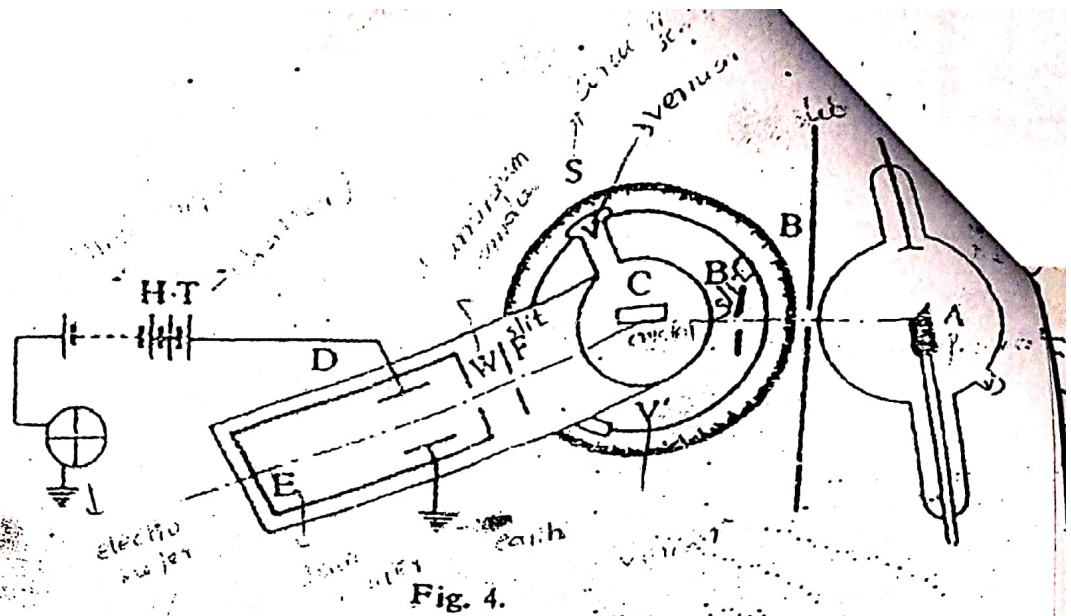
$$CB + BD = n\lambda$$

or  $2d \sin \theta = n\lambda$

where  $n$  is an integer. This is known as Bragg's equation and gives the condition which must be satisfied for the reflection of X-rays from a set of atomic planes.

**Bragg's Spectrometer method:** In order to measure the glancing angle  $\theta$ , an X-ray spectrometer, similar in construction to an optical spectrometer, is used. The essential parts of Bragg's X-ray spectrometer are depicted in Fig. 4.

- (i) X-rays from the anticathode A, limited to a narrow pencil by two adjustable slits B and B', are allowed to fall upon the crystal C which is mounted in wax on the table of spectrometer and its position can be noted from the vernier V which is capable of moving along the circular scale S.
- (ii) The reflected rays after passing through the slit F enter the ionization chamber E through a narrow aluminium window W.
- (iii) The chamber is mounted on an arm and its position is noted from the vernier V'.
- (iv) One of the plates of the ionization chamber is connected to the positive of a H.T. battery whereas the negative of which is connected to a quadrant electrometer. The other plate has been earthed.



(v) The deflection in the electrometer gives the intensity of reflected X-rays.

**Determination of crystal structure of Bragg's Law** : First of all, allow the X-rays to fall on the crystal surface and then rotate the crystal. X-rays are reflected from various lattice planes. The intense reflections are noted with the help of Bragg's X-ray spectrometer. Record the glancing angle for each intense reflection. By using the Bragg's equation, ratio of lattice spacing for various groups of planes can be obtained. This ratio comes to be different for different crystals. The experimentally observed ratio is then compared with the calculated ratio, and thus a particular structure may be identified.

Some standard ratios are as follows:

$$(i) \quad d_{(100)} : d_{(110)} : d_{(111)} = 1 : \frac{1}{\sqrt{2}} : \frac{1}{\sqrt{3}} \quad (\text{Simple cubic lattice})$$

$$(ii) \quad d_{(100)} : d_{(110)} : d_{(111)} = 1 : \frac{1}{\sqrt{2}} : \frac{2}{\sqrt{3}} \quad (\text{Face centred cubic lattice})$$

$$(iii) \quad d_{(100)} : d_{(110)} : d_{(111)} = 1 : \sqrt{2} : \frac{1}{\sqrt{3}} \quad (\text{Body centred cubic lattice})$$

The above method is illustrated in the case of sodium chloride. In this the maximum intensity of reflections occurs at the glancing angles of  $5.9^\circ$ ,  $8.4^\circ$  and  $5.20^\circ$  for (100), (110) and (111) faces respectively for first order reflections. Thus, in the case of NaCl



$$d_{(100)} : d_{(110)} : d_{(111)} = \frac{1}{\sin 5.9^\circ} : \frac{1}{\sin 8.4^\circ} : \frac{1}{\sin 5.2^\circ}$$

$$d_{(100)} : d_{(110)} : d_{(111)} = \frac{1}{0.103} : \frac{1}{0.146} : \frac{1}{0.091} = 1 : 0.704 : 1.155 = 1 : \frac{1}{\sqrt{2}} : \frac{2}{\sqrt{3}}$$

The above values are in full agreement with the values predicted theoretically. Thus, we can safely say that the crystal of NaCl has a face-centred cubic lattice.



### 3. Powder Crystal Method:

In all the above described methods, a single crystal is required whose size is much larger than microscopic dimensions. However, in the powder method, the crystal sample need not be taken in large quantity but as little as 1 mg of the material is sufficient for the study. The powder method was devised independently by Debye and Scherrer in Germany and by Hull in America about the same time (1916).

Arrangement: the experimental arrangement of this method is shown in the Fig. (5).

Its main features are outline below:

- (i) 'A' is the source of X-rays which can be made approximately monochromatic by a filter 'F' (not shown in the figure).
- (ii) allow the X-ray beam to fall on the powdered specimen 'P' through the slits S<sub>1</sub> and S<sub>2</sub> (not shown in figure). The function of these slits is to get a narrow pencil of X-rays.

(iii) Fine powder 'P' stuck on a hair by means of gum is suspended vertically in the axis of a cylindrical camera. This enables sharp lines to be obtained on the photographic film which is bent in the form of a circular arc surrounding the powder crystal.

(iv) The X-rays after falling on the powder pass out of the camera through a cut in the film so as to minimise the fogging produced by the scattering of the direct beam.

- (v) On a photographic plate the observed pattern consists of traces as shown in (5).

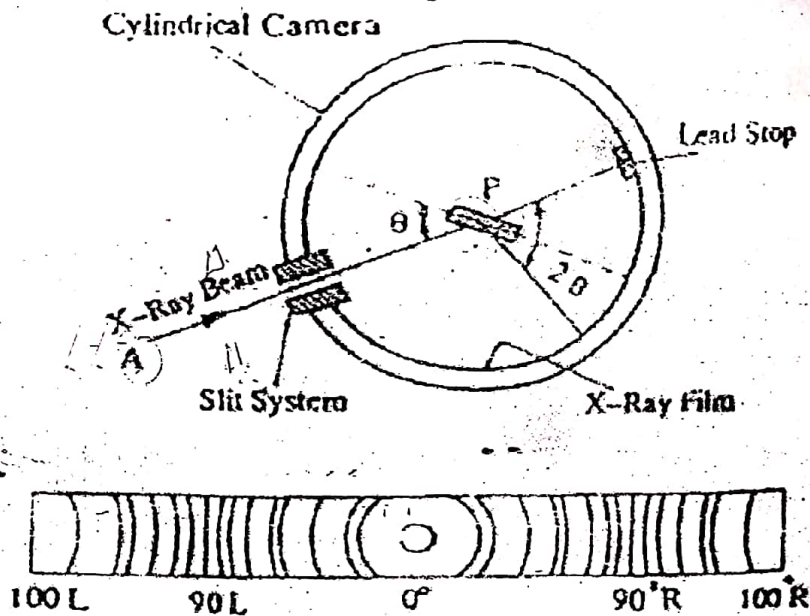


Fig 5 Arrangement of lines in a powder photograph.

The crystal structure can be obtained from the arrangement of the traces and their relative intensities.

If the angle of incidence is  $\theta$ , then the angle of reflection will be  $2\theta$ . If the film radius is 'r', the circumference  $2\pi r$  corresponds to a scattering angle of  $360^\circ$ . Then, we can write

$$\frac{1}{2\pi r} = \frac{2\theta}{360^\circ} \quad \text{or} \quad \theta = 360^\circ \times \frac{1}{4\pi r}$$

From the above equation, the value of  $\theta$  can be calculated and substituting this value in the Bragg's equation, the value of  $d$  can be calculated.

$$n\lambda = 2d \sin \theta$$

After having found out Bragg's angle  $\theta$  one can easily determine various interplanar faces using the formula  $2d \sin \theta = n\lambda$ . For the first order reflection the

repeated distances are related to the lattice constants a, b, c to the Miller indices h, k, l by the equations.

$$\text{For cubic systems : } \frac{1}{d^2} = \frac{h^2 + k^2 + l^2}{a^2}$$

$$\text{For tetragonal : } \frac{1}{d^2} = \frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2}$$

$$\text{For orthorhombic : } \frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\text{For hexagonal : } \frac{1}{d^2} = \frac{4}{3} \left[ \frac{h^2 + k^2 + hk}{a^2} \right] + \frac{l^2}{c^2}$$

### Applications of X-ray diffraction

- 1) It can be used to determine the molecular structure.
- 2) The chemical formula can be determined
- 3) Bond lengths, bond angle and torsion angles can be obtained to a **high** degrees of accuracy.
- 4) Ionic and covalent radii can be derived from bond length data.
- 5) It can be used for determining the complete structure of metals and alloys.
- 6) It also help to distinguish between the allotropic modification by the same substance.
- 7) The absolute configuration of the Chiral molecules can be determined.
- 8) Ground state structural and bonding effects can be studied Eg. Trans influence, Steric influence, inter molecular distance and hydrogen bonding.
- 9) It can be used to determine the structure of rubber.
- 10) It can be used to give an indication of possible solution reaction gateways.

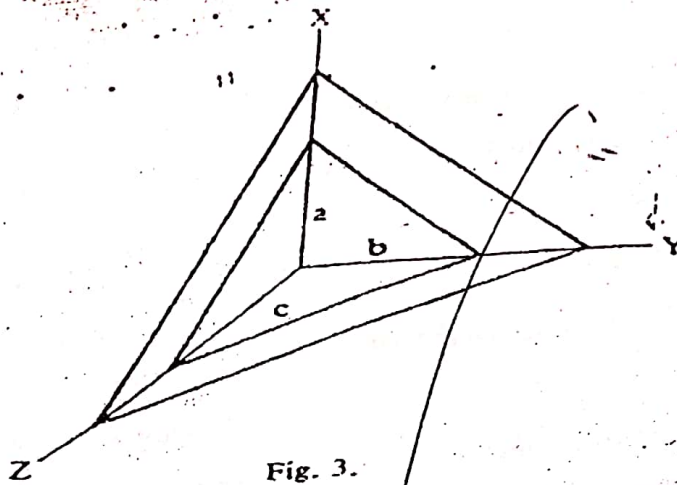
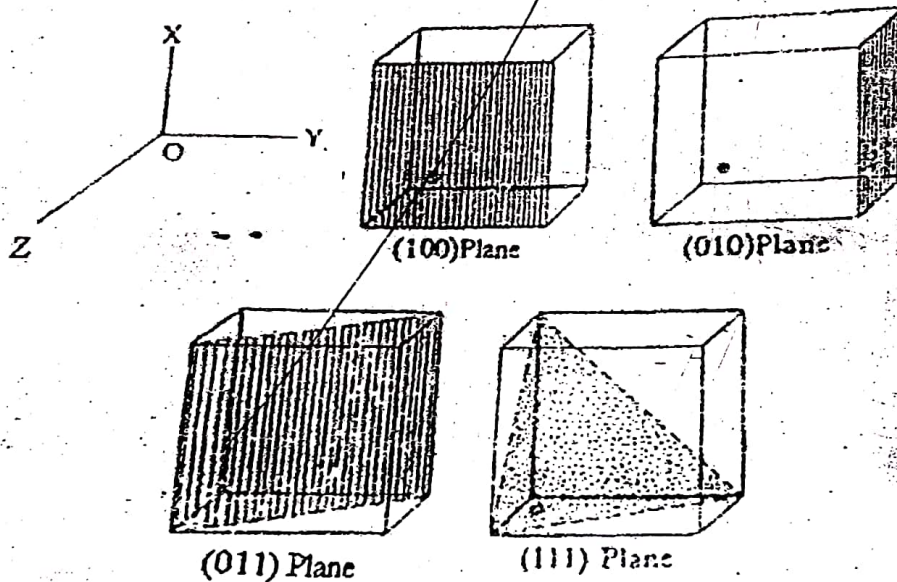


Fig. 3.

**Miller's Indices.** Miller indices of a plane are the reciprocals of the distances from the origin at which a given face intersects the three axes. Let us consider a plane which is parallel to Z-axis. Then the plane will cut the Z-axis at infinity. Immediately one would suggest that the ratio of the intercepts would be

$$x : y : z = 3a : b : \infty c \quad (3)$$



This Miller indices of Eq. (3) will be  $\frac{1}{2} : 1 : 1/\infty$ , i.e.,  $1 : 2 : 0$ . This plane is simply indicated as (120).

cesium ion is having eight chloride ions as its nearest neighbours. From Fig. 1, it can be observed that each chloride ion is also surrounded by eight cesium ions which are also disposing towards the corners of a cube. Thus, both types of ions in cesium chloride are in equivalent positions and the stoichiometry is 1:1 and the coordination number is 8:

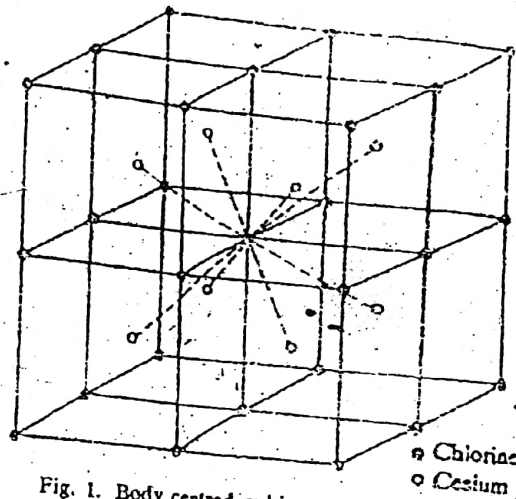


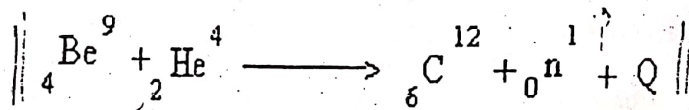
Fig. 1. Body centred cubic structure of CsCl.

## NEUTRON DIFFRACTION

### Discovery of Neutron

When  ${}^9_4\text{Be}$  was bombarded by alpha particles from polonium, no protons were ejected. Instead of that, a highly penetrating radiation was obtained which was capable of knocking out protons from target like paraffin containing hydrogen.

Chadwick suggested that such radiation cannot be gamma rays because they may not have so much kinetic energy to dislodge a massive particle like proton. The radiation was only due to the uncharged particles known as neutrons formed according to the following equation.



The existence of neutron was confirmed. The mass of neutron has been found to be  $1.675 \times 10^{-27}$  kg. which is almost equal to that of a proton. In the free state, neutron is unstable and it undergoes spontaneous disintegration to give a proton, an electron and a neutrino.

Neutron has a half life period of about 20 min. Since neutron has no charge it should not have any may moment. But experiments have shown that it has got definite magnetic moment. This indicates that though neutron is neutral as a whole it possess some type of charge bearing structure. Since neutron has small mass with no charge, it has very high penetrating ability and has been successfully employed as projectiles for the artificial transmutation of elements.

The neutrons are classified into 1) slow neutrons 2) Cold neutrons 3) Thermal Neutrons 4) Epithermal Neutrons 5) Resonance Neutrons 6) Intermediate Neutrons 7) High energy and Ultra energy Neutrons. Fast moving Neutrons are associated with De Broglie wavelength  $\lambda = h / mv$ . The wave length neutron is equal to the atomic spacing in the crystal. So we can expect Bragg type of reflection when neutrons interact with nucleus of atom or ion.

Neutrons can be obtained when some nuclei interact with gamma rays.



By using gamma ray of a particular energy, mono energetic neutrons can be obtained.

### Neutron Sources

Radioactive materials are the main sources of neutron. For neutron diffraction a mixture of Be powder and Radium bromide is used as a neutron source. A strong

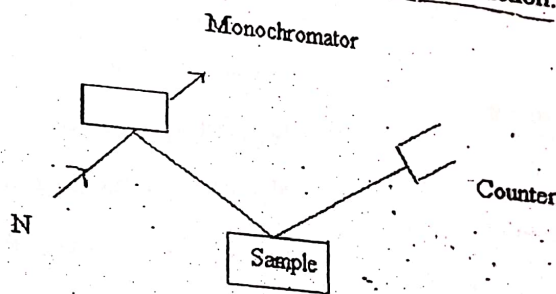
corrosion resistant alloy is used as a container. The other sources are Pu - Be, Am Be, nuclear reactor etc.

### Detection of Neutrons

Neutrons can be detected only by means of secondary charge particles released by passing neutrons. The secondary charged particles may be protons. These protons are released by collision of neutrons with hyd. Nuclei. Counters filled with  $^{10}\text{BF}_3$  may also be used to detect neutrons.

### Neutron Diffraction

Neutron diffraction experiment is similar to X-ray diffraction.



The crystal monochromator is adjusted to get neutrons of selected energy value. Then the monochromatic neutron beam is diffracted by the crystal under investigation. The diffracted ray is measured with a counter. Debye scherrer method may be followed if the substance is in the powder form.

### Origin of Neutron Diffraction

The diffraction of X-rays is caused by the orbital electrons of the atoms in the substance through which the rays pass. The atomic nuclei do not contribute anything to the scattering of X-rays. The diffraction of neutrons is caused by a) nuclear scattering

and (b) magnetic scattering. The nuclear scattering is brought about by interaction of neutrons with the protons or neutrons of the atomic nuclei and depends upon (i) nuclear size and (ii) nuclear structure. Magnetic scattering arises from the interaction between the magnetic moment of the neutrons with the permanent magnetic moments of atoms or ions concerned. For eg.  $\text{Fe}^{3+}$  has unpaired electrons and therefore it has permanent magnetic moment when  $\text{Fe}^{3+}$  scatters a beam of neutrons, the scattering is due to both the nucleus and the electron cloud of iron atom.

In neutron scattering, when the Bragg condition for scattering is satisfied, sharp maxima are obtained due to nuclear scattering and a diffuse background due to magnetic scattering. It is possible to distinguish between the two types of scattering by the fact that neutron waves are polarized by magnetic scattering and not by nuclear scattering.

In ferromagnetic substances, the magnetic moments of neighbouring atoms are arranged parallel and in antiferromagnetic substances, the magnetic moments of two neighbours are opposed. Examples of ferromagnetic substances are transition metals such as Fe, Co and Ni and those of antiferromagnetic substances are ionic salts of transition metals such as  $\text{Fe}_2\text{O}_3$  and  $\text{MnF}_2$ .

Neutron diffraction can experimentally distinguish between ferromagnetic and antiferromagnetic crystal structure. The diffraction pattern can indicate the direction of alignment of spins within the crystal. For example, the crystal structure of manganous oxide  $\text{MnO}$ , has been obtained by neutron diffraction. It is antiferromagnetic and has the rock-salt structure.

### Structure of Ice

This has been established with X-ray and neutron diffraction data. The common form of ice has a structure related to that of wurtzite; the oxygen atoms occupy the sites of both Zn and S atoms of Wurtzite; the H atoms are located just off the lines



joining the oxygen atoms. In ice the non-bonded O-O distance is  $2.24 \text{ \AA}$  and the O-bond distances is  $1.01 \text{ \AA}$

### Neutron Diffraction and Intervalence Compounds

A compound containing an element in two different oxidation states is an intervalence compound. For eg.  $\text{Fe}_3\text{O}_4$ , one ion is divalent and the other two are trivalent ( $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ ). These two iron species  $\text{Fe}^{2+}$  and  $\text{Fe}^{3+}$  in  $\text{Fe}_3\text{O}_4$  cannot be distinguished by X-ray diffraction.

However this is possible with neutron diffraction because these 2 ions, having different numbers of unpaired electrons, scatter neutrons differently. Essentially, these two have different magnetic scattering capacities.

### Applications of Neutron diffraction

- 1) Neutron diffraction may be used to study solids in the form of powder or single crystals to establish crystal structures.
- 2) It supplements the information derived from X-ray diffraction data.
- 3) It locates and characterises water molecules in hydrates.
- 4) Neutron diffraction studies on ferromagnetic and antiferromagnetic materials are useful for the investigation of mag. properties of alloys.
- 5) It is useful in the study of order disorder transitions of alloys.
- 6) Neutron diffraction can be used to locate the position of hydrogen atom in the presence of heavy atoms with considerable accuracy. Eg.  $\text{NaH}$ ,  $\text{PbO}$  etc.
- 7) Neutron diffraction locates the nuclei of atoms. X-ray diffraction locates the electron clouds. So the combination of the two techniques provides information about the bond between atoms.

8) Neutron diffraction has also been applied to the structure of gaseous molecules like  $O_2$ ,  $N_2$ ,  $CF_4$  and  $CH_4$ . The structure of liquefied gases have also been studied with Neutrons.

The chief draw back of neutron diffraction is that the neutron sources are expensive and not readily available.

#### Difference between X – ray and Neutron

1) Interacts with electrons	1) Interacts with nuclear alone (Exception: Atoms with magnetic moment.)
2) Diffracted ray can be recorded on a film.	2) Diffracted beam cannot be recorded on a film Counter should be used.
3) Magnetic structures of materials cannot be studied.	3) Magnetic structures of materials can be studied.
4) Position of light atoms in the presence of heavy atoms cannot be determined.	4) Position of light atoms in the presence of heavy atoms can be determined.
5) Liquids and gases give diffused diffraction pattern.	5) Liquids and gases can be easily studied.

#### ELECTRON DIFFRACTION

Planck established that light has not only wave nature but also particle nature. This is known as wave particle dualism of radiation. In 1924 a French physicist Lonius de Broglie extended the dual character of light to matter particles and suggested that all matter in motion (eg. atoms or molecules, electrons, protons, neutrons etc) have a dual character and possess wave properties such as wavelength, amplitude and frequency.

The wave term associated with matter particle is called de-Broglie's matter wave

#### de – Broglie's Equation

$$\lambda = \frac{h}{mv} = \frac{h}{m} \times \sqrt{\frac{m}{2Ve}}$$

$$\lambda = \frac{h}{\sqrt{2Vem}} \quad \text{---(1)}$$

If a potential difference of 10 volts is applied, the wavelength,  $\lambda$  of the electron wave emerging out would be equal to 3.877 Å. Similarly, if the potential difference is varied between 10 and 10,000 volts,  $\lambda$  should vary between 3.877 Å and 0.1226 Å. It is well known that X-rays have the wavelengths in this range.

When the accelerated electrons fall on the nickel crystal shown in Fig. The electrons of a definite wavelength are deflected from the crystal in different directions. The angle of diffraction ( $\theta$ ) can be measured with the help of an electron detector (called collector) which is connected with a sensitive galvanometer and can be moved along a

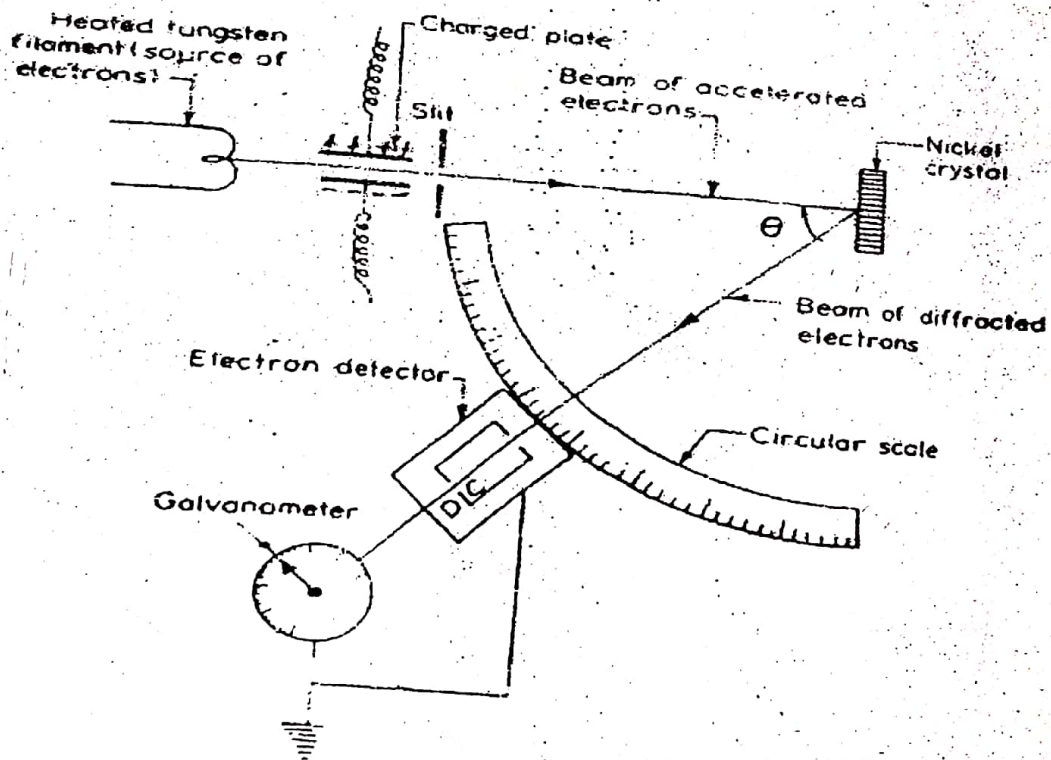


Fig. Davisson and Germer's experiment to verify the wave-nature of moving electrons.

graduated circular scale. The electron detector has two walls C and W which insulated from each other. The nickel crystal which is known to be of the face-centered cubic type is cut so as to have a smooth reflecting surface parallel to the lattice plane (1,1,1).

The intensities of electron waves scattered by the Ni crystal at different angles were measured and it was found that the most intense reflection took place when the angle of reflection was  $50^\circ$  and the electrons were accelerated through 54 volts. Substituting  $V = 54$  volts in de Broglie's equation (i), we get the value of wavelength,  $\lambda$  of the electron wave equal to  $1.668 \text{ \AA}$  as shown below.

$$\lambda = \frac{12.26}{\sqrt{54 \text{ volts}}} \quad \text{\AA} = \frac{12.26}{7.3484} \text{ \AA}$$

$$\text{or } \lambda = 1.668 \text{ \AA}$$

By substituting  $n = 1$  (first order Bragg's reflection occurs),  $\theta = 50^\circ$  and  $d = 1.075 \text{ \AA}$ , the value of  $\lambda$  is obtained using Bragg's equation (ii)  $n\lambda = 2d \sin \theta$  as

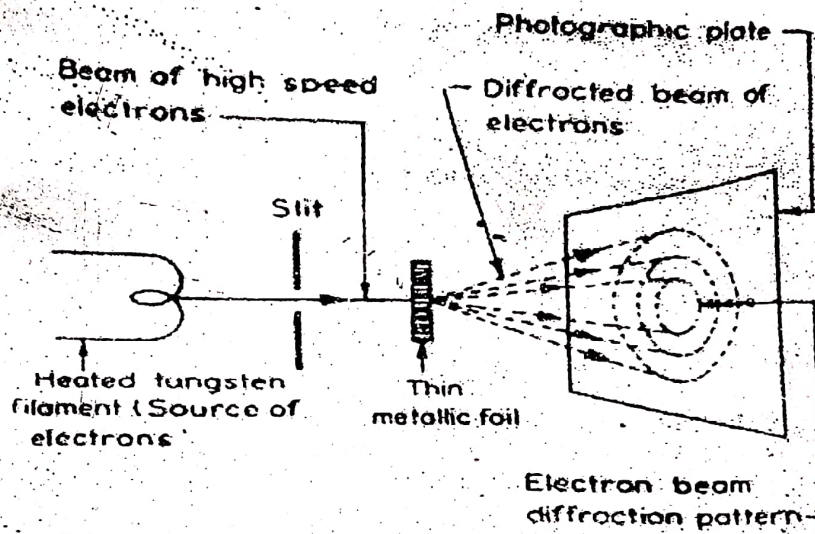
$$\begin{aligned} 1 \times \lambda &= 2 \times 1.075 \times \sin 50 \\ &= 2 \times 1.075 \times 0.7660 \\ &= 1.648 \text{ \AA} \end{aligned}$$

The value of  $\lambda$  calculated from Bragg's equation (ii) is found to be in full agreement with that found from the de Broglie's equation (i). The close agreement between the two values of  $\lambda$  confirms the wave-nature of moving electrons as suggested by de Broglie.

### Thomson and Reid's experiment

In 1928, English physicists G.P. Thomson and A. Reid, working with high-speed electrons, showed that when a narrow beam of high-speed electrons produced

from heated tungsten filament was allowed to fall on the surface of a thin metallic foil like Al, Au, Pt etc. and the diffracted electrons are received on a photographic plate kept a short distance away, these electrons produce a diffused luminous spot composed of concentric bright and dark rings which are called electron beam diffraction rings or patterns as shown in Fig.

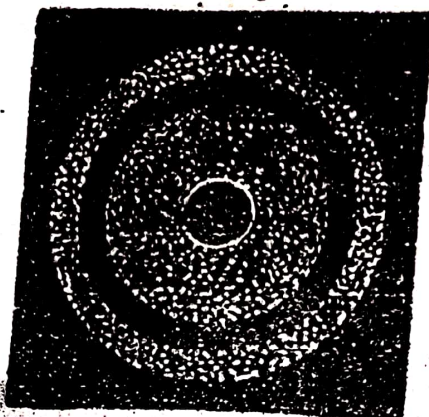


#### Thomson and Reid's experiment to verify the wave-nature of electrons

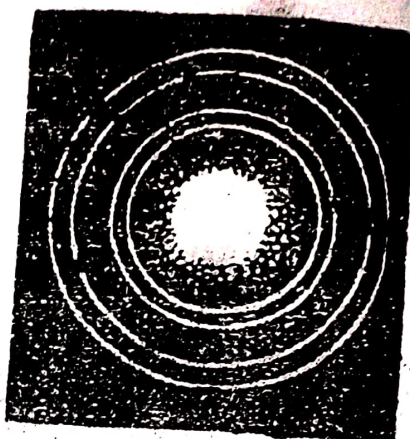
These diffraction rings given by electron beam are found to be similar to those given by X-rays (which are waves) when they are diffracted by the same metal foil. This similarity between the electron beam diffraction rings and those of X-rays confirms that electrons are also waves.



ES, or ions  
ag. organisms; crystal  
to surface. Crystals



(a)



(b)

(a) Electron beam diffraction rings

(b) X-rays beam diffraction rings

#### Applications of electron diffraction

Electron diffraction has found a very high place in science, industry and Technology because of the following applications.

- 1) Debye showed that positions of atoms in molecules could be determined from measurements on the scattering of X-rays by gases and vapours. Similarly, it was assumed that electron beams could also be used.
- 2) Mark and Weird using electrons of 43,000 V energy corresponding to de Broglie wavelength  $0.0578 \text{ \AA}$  determined atomic arrangements and interatomic distances in a number of gases and vapours such as  $\text{CO}_2$ ,  $\text{Br}_2$ ,  $\text{CCl}_4$ ,  $\text{C}_6\text{H}_6$ ,  $\text{C}_6\text{H}_{14}$  etc.
- 3) It is used in the structural analysis of organic materials prepared in thin films.
- 4) It is used in the study of lubrication by graphite, grease and oils.
- 5) It is used in the study of orientation, lattice parameter and perfection of evaporated thin film.
- 6) It is used in exploring the structure of thin surface layers such as oxide layers on metal surfaces.