Unit : 9
PHYSICAL OPTICS
Quick notes:

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★ **PHYSICAL OPTICS** → study of properties and nature of light.

1. Nature of light:

* Light is a **transverse**, electromagnetic wave
* Light can travel through **vacuum**

→ Dual nature:

1. **Background:**
- Important development about nature of light was work of **Maxewell.**

↳ Light → a form of high frequency electromagnetic waves.

2. **Two fields:**

↳ The electric and magnetic field vectors are oscillating perpendicular to direction of propagation of waves.

3. **Velocity:**

↳ 3×10^8 m/s.

4. **Nature:**

↳ Do not require medium.

5. **DUAL** – **Particle** nature (by **Newton**)
   – **wave** nature (by **Huygen**)

Light
Dual Nature

Particle	wave
• Photoelectric effect	• reflection
• Compton shift	• rarefaction
	• diffraction
	• Interference
	• Polarization

→ Wavefront : (wave's pattern)

- 'The locus of all the points in a medium which have same phase is known as wavefront'

example:

- a small stone dropped in water (Pond) produces a **series of circular crests** moving out of the **source**

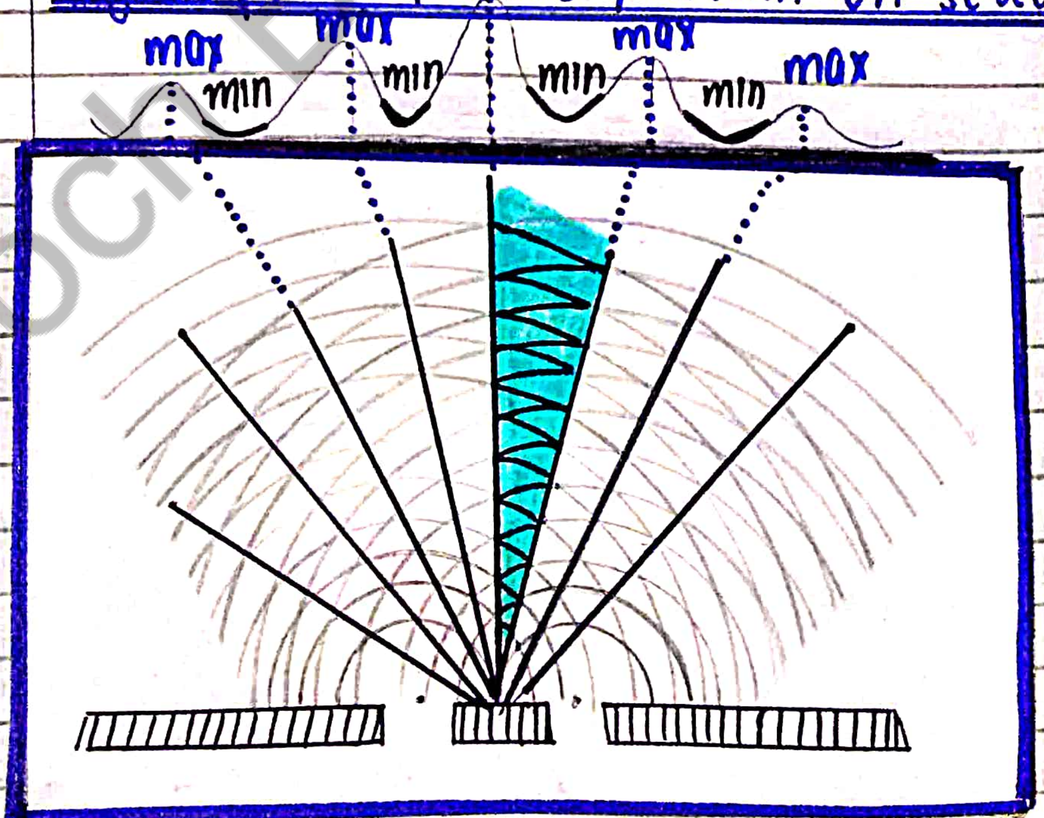
	circular wavefront	Plane wave-front
definition	A portion of spherical wave~~front~~.	A straight portion of special wavefront.
example	In case of point source of light, the wavefronts will be concentric spheres.	When sunlight reache earth, it is in form of plane wavefront

Young's Double Slits Experiment
(YDSE)

→ **Introduction:**

1) In 1801, Thomas Young peformed his famous double slit experiment.
2) Through his experiment he proved the **wave nature of light**.
3) The principle is based upon the **division of wavefront**.
4) For **coherency**, he splitted the wavefront of the **same monochromatic light** into two parts.

→ Figure (Interference pattern on screen)



dark spots  destructive interference

bright spots  constructive interference

→ Experimental arrangement:

1. He illuminated light on two very small & very close slits.
2. Both slits will behave like a secondary source
3. Hence light coming from S_1 (A) & S_2 (B) is **coherent.**

→ Components:

- **A & B** → two very close narrow slits ‖ C
- **E** → distance b/w A & B
- **C** → to make waves uniform/perfect
- **S** → Path difference i.e BQ
- **L** → distance b/w slits & screen
- **d** → slit separation
- **Y** → Position of fringes / fringe spacing
- **O** → constructive interference occurs
- **P** → Point on screen
- **Q** → Point on BP such that BP > AP

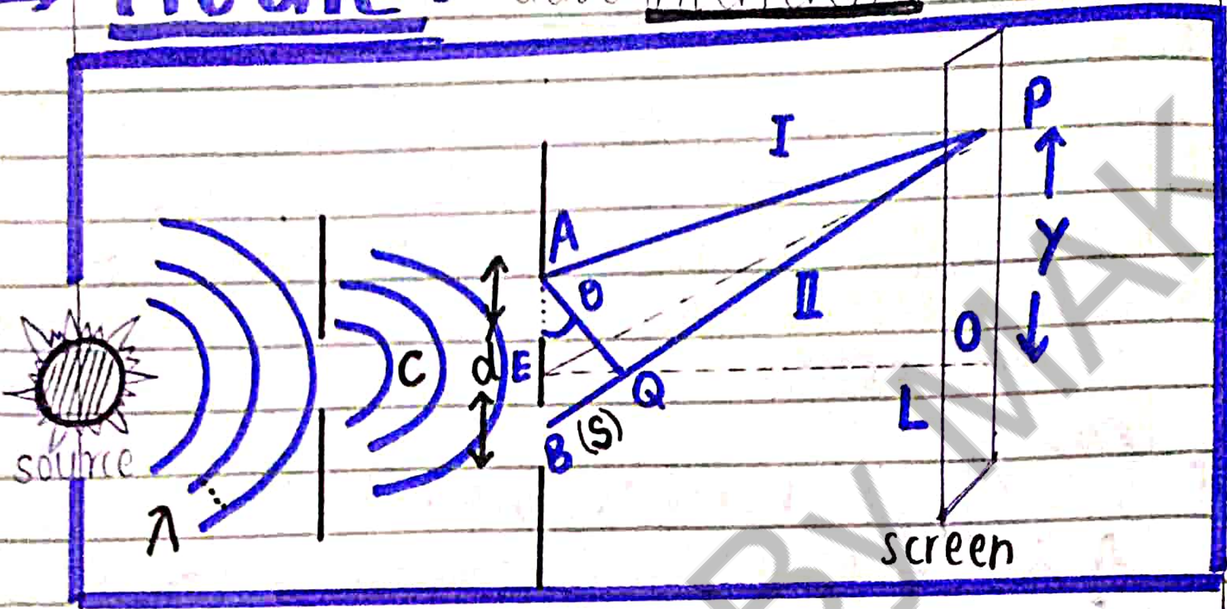
→ Observation:

He observed a pattern of dark and bright fringes

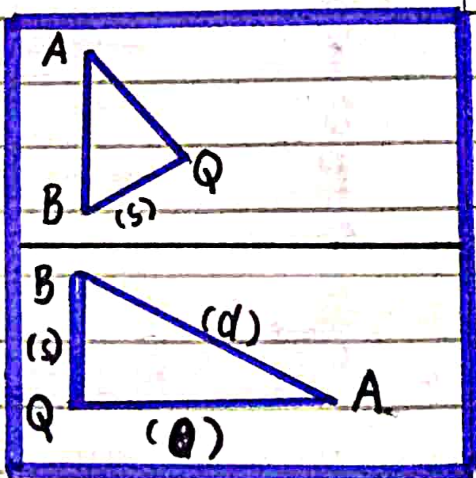
- **Maxima** → where crest falls on crest (bright fringe)
- **Minima** → where crest falls on trough (dark fringes)
- **maxima** → **constructive interference**
- **minima** → **destructive interference**

→ **Consideration:** consider a monochromatic light from a source through narrow slit C falls on 2 other slits A & B. Diffraction occurs at A & B. Then superposition of waves from slit A & B to cause interference

→ **Figure:**



→ Mathematical derivation:



In ΔABQ,

$$\sin\theta = \frac{Perp}{Hyp} = \frac{BQ}{AB} = \frac{s}{d}$$

$$\sin\theta = \frac{s}{d}$$

$$d\sin\theta = s$$

$$\boxed{s = d\sin\theta}$$

$$m\lambda = d\sin\theta$$

Constructive	**Destructive**
$BQ = s = d\sin\theta$	$BQ = d\sin\theta$
$d\sin\theta = m\lambda$	$d\sin\theta = (m+\frac{1}{2})\lambda$
$m = 0, \pm1, \pm2, \pm3$	$m = 0, \pm1, \pm2$

→ Interference in Thin Film :

- **Principle** : division of amplitude
- **Thin film:**

A transparent medium whose thickness is very small (comparable to λ of light).

- **Film**

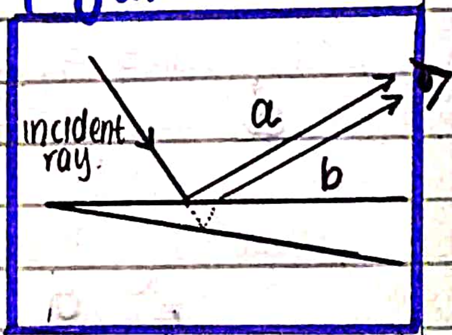
Film is a thin strip of plastic that is usually used in photography by exposure of light

→ **example** :

- Oil film on surface of water
- surface of soap bubble
- cracks in glass plate

→ **Explanation** :

figure:



- **consideration**:

→ consider a thin film of a **refracting medium** with a **thin wedge shaped**.

- **Proof** :

→ A beam of monochromatic light of wavelength λ is incident on upper surface of **thin film**

- Part 'a' → reflected from **upper surface**
- Part 'b' → reflected from **lower surface**

⇒ path of ray a < path of ray b

Path difference depends –
- Thickness of film
- Nature of film
- Angle of incidence

Phase change:

↳ When wave travels from a medium;

- **Phase change 180° (π rad):**
- Lower refractive index ⇒ Higher refractive index
- **No phase change:**
- Higher refractive index ⇒ Lower refractive index

MICHELSON'S Interferometer

→ **Introduction:**

An optical instrument.

→ **purpose:**

To measure distance precisely

→ **Principle:**

Interference of light

→ **construction:**

(1) Two plane mirrors — M_1 (movable), M_2 (fixed)

(2) Two glass plates — A (partial reflector, beam splitter), B (compensator)

purpose: → to make sure path lengths are equal [I = II]

→ **Working:**

→ Glass plate (A) splits the light beam into **two** parts

→ Reflected part (I)	Transmitted part (II)
distance	
• Beam (I) will travel L_1 distance to mirror M_1	Beam (II) will travel L_2 distance to M_2
Reflection	
• Then reflected back to A.	Then reflected back to A
Observer	
• Again some part will get refracted & seen by observer	Finally, gets reflected by A to reach observer's eye

goal → to reach observer's eye

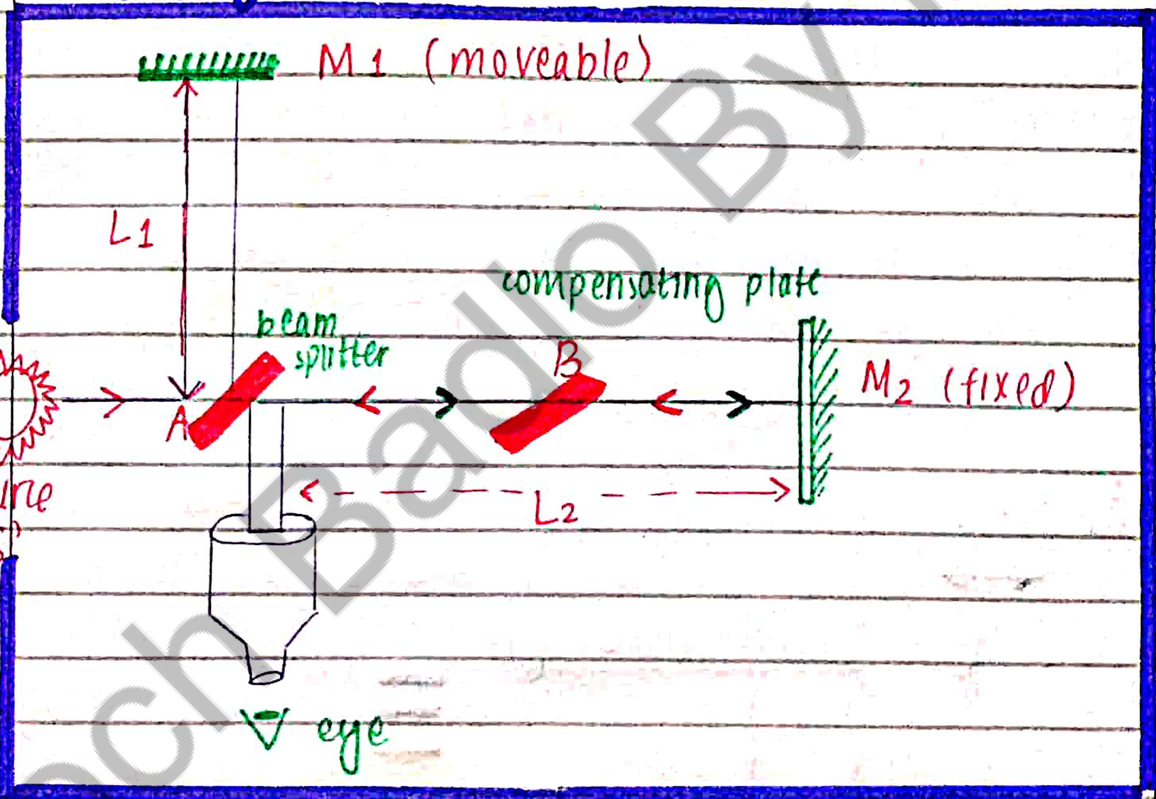
Purpose.

glass plate B → compensator

- so that the path length of ray 1 and 2 is equal

I = II

→ **FIGURE:**



Diffraction

★ **definition**:

→ The property of **bending** of light around obstacles & **spreading** of light waves into the geomatrical shadow of obstacle

★ **condition**:

→ To observe diffraction;

• the **size** of slit, opening, obstacle **=** **wavelength** of light used.

★ **example**:

1. Young's double slit experiment

The light passing through **narrow slit** C, bends around corners of C, to reach A & B.

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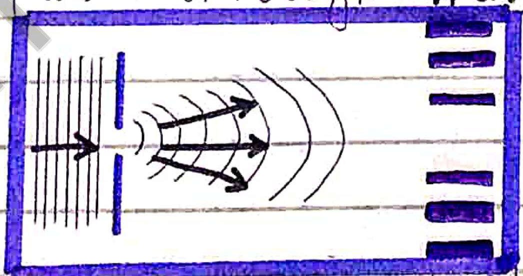
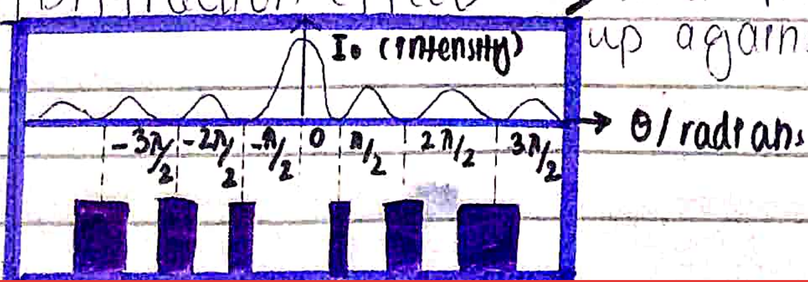
i. Diffraction effects are produced → when beam of monochromatic light passes through **narrow slit**.



ii. Central Maximum ⇒ high intensity & very broad as compared to others.

iii Diffraction effects → when knife is held up against monochromatic light source



Bragg's Law

→ Consideration:

Consider **two parallel x-rays I & II** are **incident** at the **first & second** layer of a **crystal**.

→ Components:

d ⋯> separation b/w two layers

θ ⋯> glancing angle

↳ complementary angle **to** → angle of incidence

→ Condition:

The two reflected rays from **successive planes** will **reinforce** eachother **IF** the path difference b/w them is **integeral multiple of λ.**

→ Derivation:

- Since, distance covered by **ray II > ray I**
- So, path difference b/w rays is given by ;

$$\text{Path difference} = BC + CB' = m\lambda \quad (1)$$

From ΔABC,

$$\frac{BC}{AC} = \sin\theta$$

$$BC = AC\sin\theta$$

$$\therefore AC = d$$

$$BC = d\sin\theta \quad (2)$$

From ΔAC'B,

$$\frac{CB'}{AC} = \sin\theta$$

$$CB' = AC\sin\theta$$

$$\therefore AC = d$$

$$CB' = d\sin\theta \quad (3)$$

→ Putting eq **(2)** and **(3)** in **(1)**;

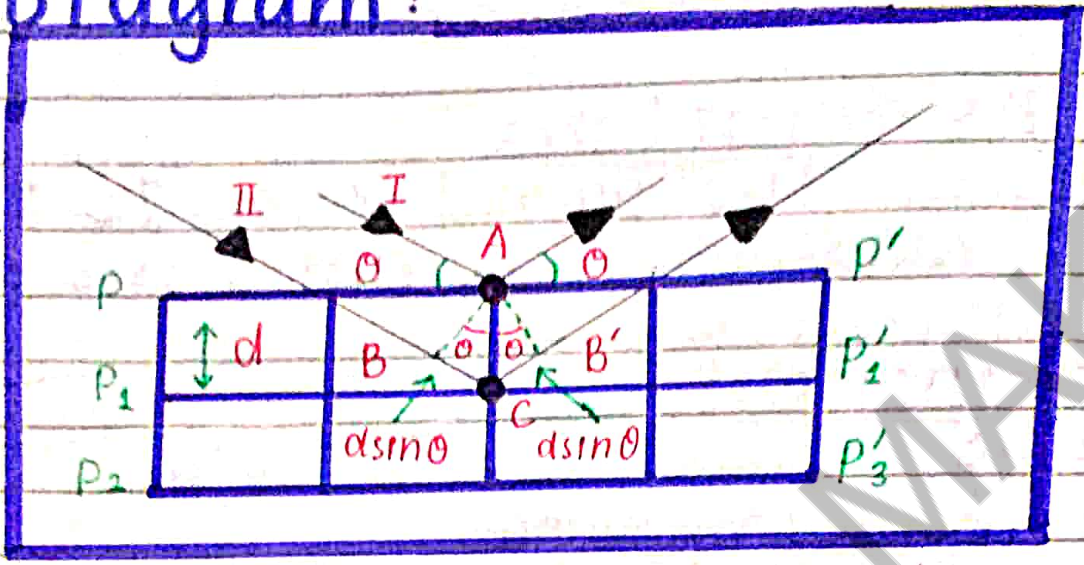
$$d\sin\theta + d\sin\theta = m\lambda$$

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

This equation is Bragg's law

where $m = 1, 2, 3 \ldots$

→ **Diagram:**



Uses:

1. used to determine inter-planing spacing
2. determining structure of biological molecules i-e **Hemoglobin**
3. double-helix structure of **DNA**.
4. determine λ of **X-rays**

$$d = \frac{m\lambda}{2\sin\theta}$$

$$\lambda = \frac{2d\sin\theta}{m}$$

Diffraction Grating

⇒ Introduction:

→ Grating:
A **glass/plastic plate** on which very fine **equidistant parallel** lines are drawn i-e **(scratches)**

- **Length** → 2 to 3 cm
- **width** → 2 to 3 mm

Slit : The spaces b/w each scratch
Lines ⟶ 400-5000 lines per cm
Principle → interference & diffraction

→ grating element :
The distance b/w centres of two adjacent lines

value : grating element $= \frac{L}{N}$

$$d = \frac{L}{N}$$

$$d = \frac{1cm}{N}$$

⇒ Working:

(1) Beam of monochromatic light
A parallel beam of monochromatic light falls on grating, sends out waves from each slit

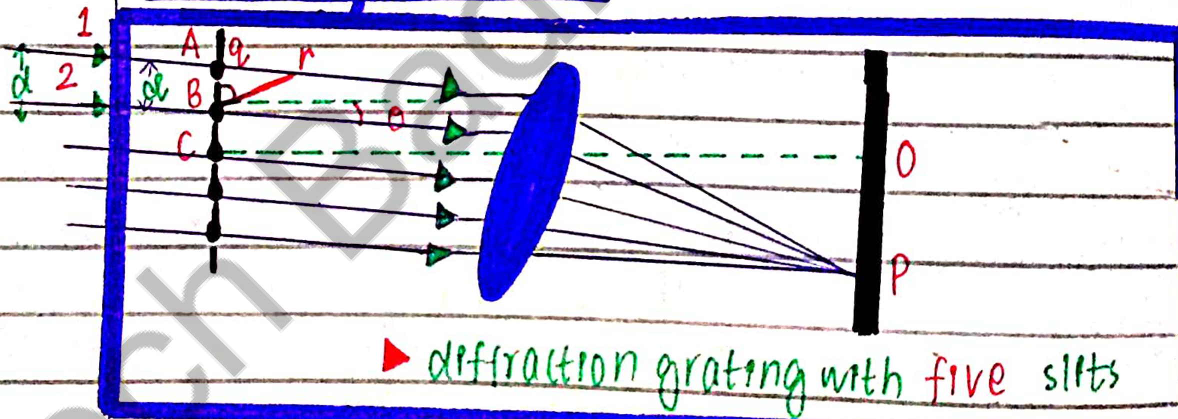
(2) Waves from adjacent slits
Along certain directions, waves from adjacent slits are in phase & reinforce each other

(3) **Parallel lines after diffraction:**
The parallel lines after diffraction through grating make an angle θ with **normal** at point of **incidence**

(4) **Role of convex lens:**
These rays are then brought to focus at point **P** on screen by **convex** lens

(5) **Constructive interference:**
If the path diffraction b/w ray **1** & **2** is λ, then constructive interference takes place & **bright** fringes are observed

→ Diagram:



diffraction grating with five slits

→ Derivation:

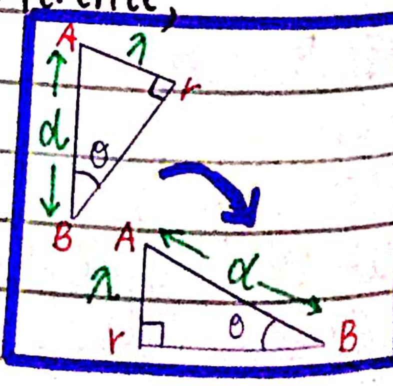
• condition for constructive interference;

$Ar = \lambda$

$AB = d$

From ΔABr,

$\sin\theta = \frac{Perp}{Hyp} = \frac{Ar}{AB} = \frac{\lambda}{d}$



$$d \sin\theta = \lambda$$

Diffraction of X-rays by crystal

→ Introduction:

→ X-rays is a type of electromagnetic radiation of much shorter λ of order 10^{-10} m

condition: in order to observe diffraction,

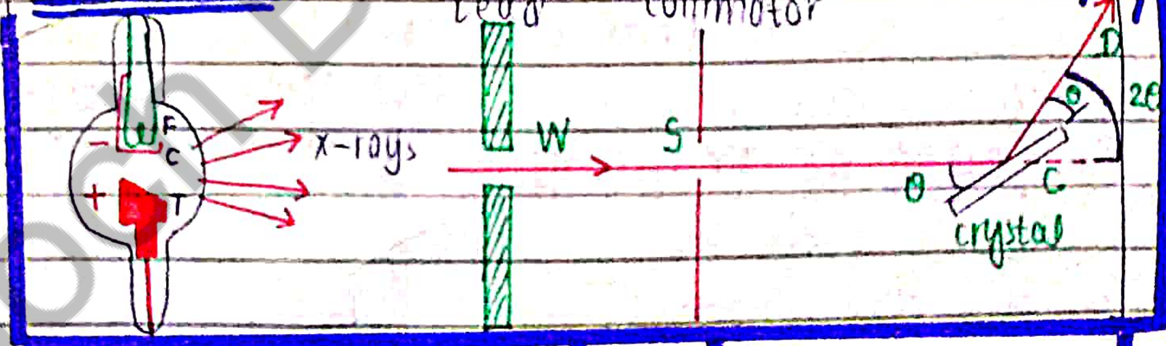
∴ grating spacing = order of wavelength of radiation used

→ Why we use NaCl crystal?

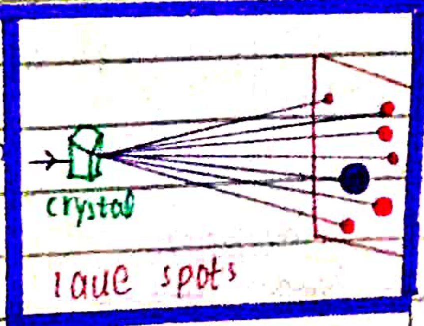
(1) The atoms of crystal are uniformly spaced in planes and distance 'd' apart.

(2) The spacing of atoms in crystal is so small that the x-rays bend

→ FIGURE:



→ experiment:



(1) a narrow beam of x-rays from x-ray is collimated through slit and allowed to fall on NaCl crystal.

(2) The transmitted beam enters detector D

(3) The Laue photograph obtained consists of central spot surrounded by many other spots. They're called Laue spots

Polarization

→ **definition:**
Polarization is the process by which the **electric & magnetic** vibrations of **light waves** are restricted to a **single plane of vibration.**

→ **goal/purpose:**
To determine whether light waves are **longitudinal** or **transverse**

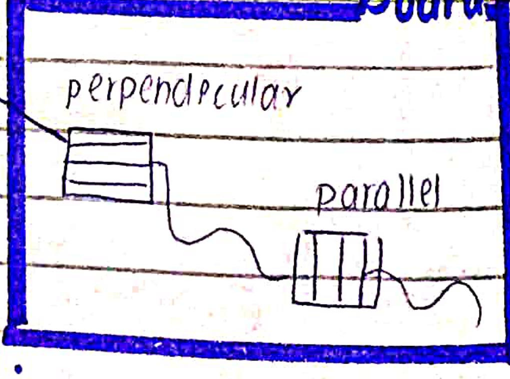
→ **property exhibited by:**
Polarization is the property exhibited by only **transverse waves**

Proof:

→ To prove that only transverse waves exhibit this property.

→ **consideration:**
∴ consider a **transverse wave** on a **string** which passes through **slot 'p'** in **wooden board.**

▪ **case of Transverse:**
When ; slot is
parallel → waves pass
perpendicular → waves DONOT pass



▪ **case of Longitudinal:**
Whether the slot is parallel or perpendicular, the waves pass anyways.