Graphic Era HILL UNIVERSITY
Established by an Act of the State Legislature of Uttarakhand (Adhiniyam Sankhya 12 of 2011)
University under section 2(f) of UGC Act, 1956

Engineering Physics
Course Code : TPH 201

By Dr. Vishal Chauhan

Units

i. **Interference and Diffraction**
ii. **Polarisation, Laser, and Fibre Optics**
iii. **Special theory of relativity**
iv. **Superconductivity, and Electromagnetism**
v. **Quantum Mechanics**

Unit - I

- **Interference:** Conditions of interference, Spatial and temporal coherence, Bi-prism experiment, interference in wedge shaped film, Newton's rings.
- **Diffraction:** Fraunhofer diffraction at single slit and n-slits (Diffraction Grating). Rayleigh's criteria of resolution. Resolving power of grating.

Introduction

- **Mechanics – behavior of system when subjected to a given force.**

- **Four Basic Forces – 1. Strong**
  2. Electromagnetic
  3. Weak
  4. Gravitational

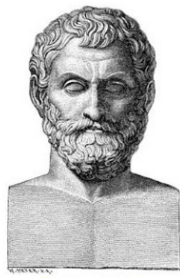
Engineering Physics
Course Code : TPH 201
By Dr. Vishal Chauhan

Graphic Era HILL UNIVERSITY
Established by an Act of the State Legislature of Uttarakhand (Adhiniyam Sankhya 12 of 2011)
University under section 2(f) of UGC Act, 1956

Contributions

- Early Developments

The light-bulb-like object engraved in a crypt under the Temple of Hathor in Egypt. (28th Century BC)



Thales of Miletus (6th Century BC) Observed appearance of charge on rubbing

- 17th Century

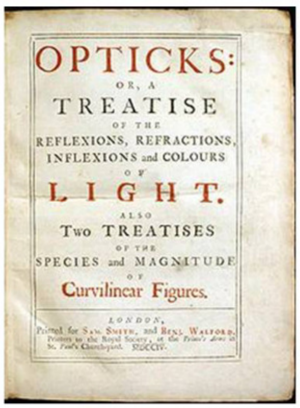
William Gilbert
Explained the dipping of the needle by the magnetic attraction of the earth

Johannes Kepler
The laws of the Rectilinear propagation of light

Issac Newton
Theory of light

Christiaan Huygens
Principle of wavefront

- 18th Century


OPTICKS:
OR, A
TREATISE
OF THE
REFLEXIONS, REFRACTIONS,
INFLEXIONS and COLOURS
OF
LIGHT.
ALSO
Two TREATISES
OF THE
SPECIES and MAGNITUDE
OF
Curvilinear Figures.
LONDON,

By Issac Newton

Benjamin Franklin
Kite experiment

Charles-Augustin de Coulomb

- 19th Century

Thomas Young

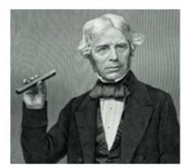
Alessandro Volta

Humphry Davy

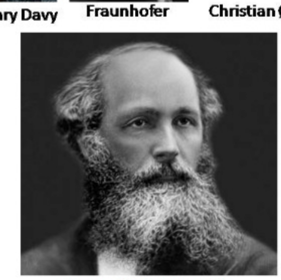
Fraunhofer

Christian Ørsted

André-Marie Ampère



Michael Faraday

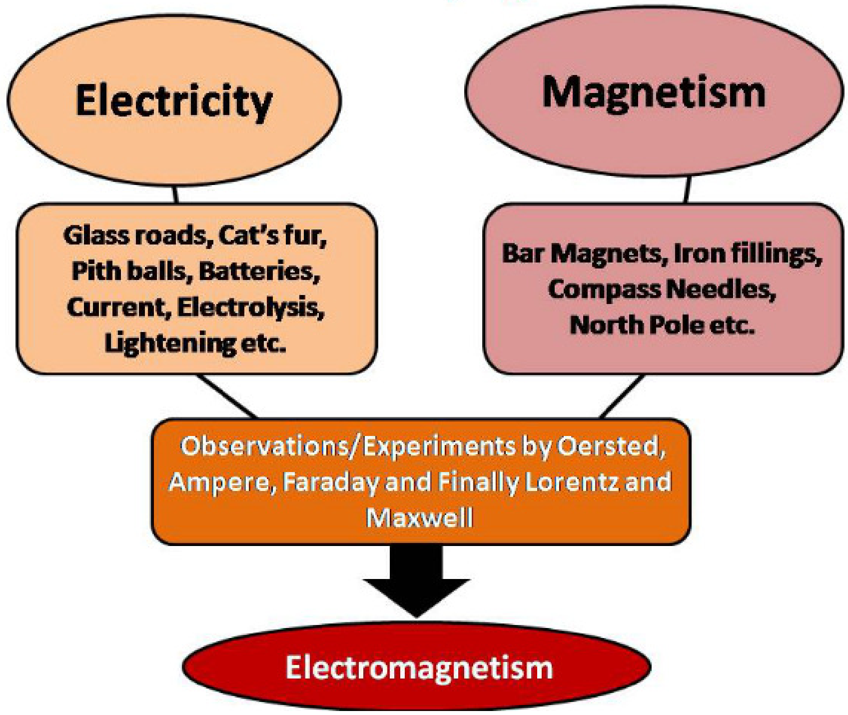


James Clerk Maxwell

- 20th Century 1927 Fifth Solvay International Conference on Electrons and Photons

Back: Auguste Piccard, Émile Henriot, Paul Ehrenfest, Édouard Herzen, Théophile de Donder, Erwin Schrödinger, JE Verschaffelt, Wolfgang Pauli, Werner Heisenberg, Ralph Fowler, Léon Brillouin.
Middle: Peter Debye, Martin Knudsen, William Lawrence Bragg, Hendrik Anthony Kramers, Paul Dirac, Arthur Compton, Louis de Broglie, Max Born, Niels Bohr.
Front: Irving Langmuir, Max Planck, Marie Curie, Hendrik Lorentz, Albert Einstein, Paul Langevin, Charles-Eugène Guye, CTR Wilson, Owen Richardson.

The unification of physical theories



"Light too is electrical in nature…"
- Faraday

- Faraday's hypothesis approved by Maxwell.
- Hertz presented experimental evidences for Maxwell's theory.
- By 1900, electricity, magnetism and optics had merged in a single unified theory.
- *"The connection between light and electricity is now established……. In every flame, in every luminous particle, we see an electrical process…..Thus, the domain of electricity extends over the whole of nature. It even affects ourselves intimately: we perceive that we posses…..an electrical organ – the eye"*

- Hertz

WAVES:

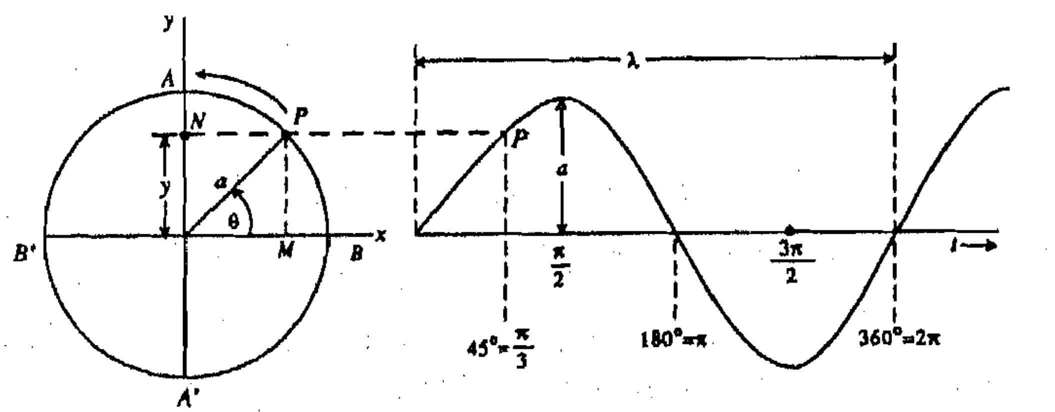
Waves can occur whenever a system is disturbed from equilibrium and when the disturbance can travel, or *propagate,* from one region of the system to another. ***As a wave propagates, it carries energy***.

- **(i)** **Mechanical waves** — waves that travel within a medium. (e.g. Sound waves, water waves)
- **(ii)** **Electromagnetic waves**—waves that can propagate even in empty space, without any medium. (e.g. light, radio waves, infrared and ultraviolet radiation, and x rays)
- **(iii)** **Matter waves** – Like light, electrons and other particles of matter can behave like waves.

Simple Harmonic Motion:

A simple harmonic motion is defined as the motion of a particle which moves back and forth along a straight line such that its acceleration is directly proportional to its displacement from a fixed point in the line, and is always directed towards that point.

The best and elementary way to represent a simple harmonic motion is to consider the motion of a particle along a reference circle;



Suppose the particle ***P*** starts from ***B*** and traces an angle θ in time ***t.*** Then its angular velocity ***w*** is

$$\omega = \frac{\theta}{t}$$ where the angle θ is measured in radians.

The displacement, y, of N from θ at time ***t,*** is thus given by y = ON = ***OP*** sin ***NPO***

= ***a*** sin θ [$\angle$***NPO*** = $\angle$***POB*** = θ]

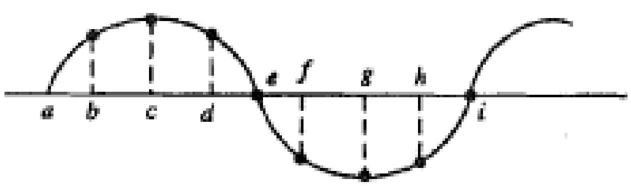
$$\omega = \frac{\theta}{t}, \text{ so that } \theta = \omega t$$

$$\boxed{y = a \sin \omega t}$$

This is the equation of simple harmonic motion.

Wave Motion:

So far we considered a single particle, P, executing simple harmonic motion. Let us consider a number of particles which make a continuous elastic medium. If any particle is set in vibration, each successive particle begins a similar vibration, but a little later than the one before it, due to inertia. Thus, the phase of vibration changes from particle to particle until we reach a particle at which the disturbance arrives exactly at the moment when the first particle has completed one vibration. This particle then moves in the same phase as the first particle. These simultaneous vibrations of the particles of the medium together make a wave. Such a wave can be represented graphically by means of a displacement curve drawn with the position of the particles.



Graphical representation of a wave.

It can be seen from the figure above that the wave originating at point **(a)** repeats itself after reaching at point **(i).** The distance (***ai),*** after travelling which the wave-form repeats itself, is called the **wavelength** and is denoted by λ. It is also evident that during the time ***T*** while the panicle at **(a)** makes one vibration, the wave travels a distance **λ.** Hence the velocity v of the wave is given by $v = \frac{\lambda}{T}$

If **n** is the frequency of vibration then **n = 1/T.** Hence we have **v = nλ**

Particles in Same Phase:

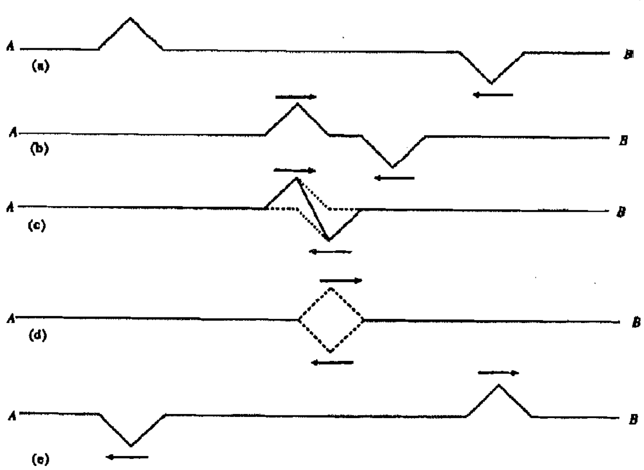
Particles **(a)** and **(i)** have equal displacements (= zero) and both are tending to move upwards. They are said to be in the same phase. The distance between them is one wavelength. Hence, wavelength is the distance between two nearest particles vibrating in the same phase. Two vibrating particles will also be in the same phase if the distance between them is **nλ**, where ***n*** is an integer.

Particles in Opposite Phase:

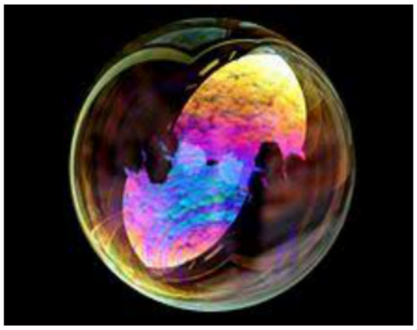
Particles (a) and (e), both have the same displacement (= zero), but while a is tending to go up, (e) is tending to move downwards. They are said to be in opposite phase. The distance between them is λ/**2.** The particles are out of phase if the distance between them is **(2n-1)** λ/**2** where ***n*** is an integer.

PRINCIPLE OF SUPERPOSITION:

In any medium, two or more waves can travel simultaneously without affecting the motion of each other. Therefore, at any instant the resultant displacement of each particle of the medium is merely the vector sum of displacements due to each wave separately. This principle is known as "principle of superposition". It has been observed that when two sets of waves are made to cross each other, then after the waves have passed out of the region of crossing, they appear to have been entirely uninfluenced by the other set of waves. Amplitude, frequency and all other characteristics of the waves are as if they had crossed an undisturbed space.



INTERFERENCE OF LIGHT



Coherent Sources

Two sources are said to be coherent sources if they produce two waves having same frequency, same waveform and having a constant phase difference between them which does not change with time.

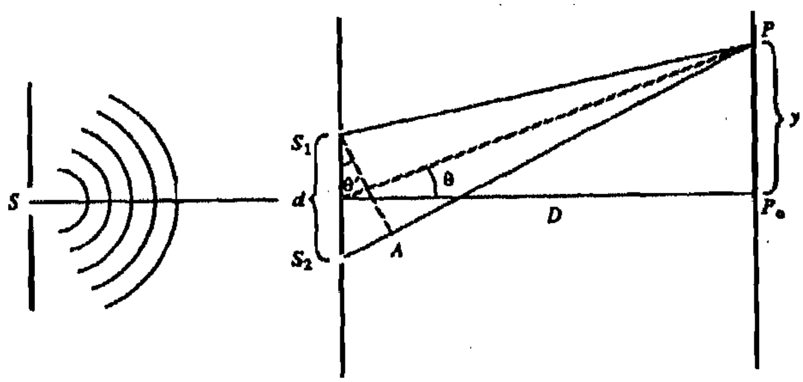
Conditions for sustained Interference

1. Coherent Sources
2. Wavelength, Time Period, Frequency
3. Amplitude and Intensity
4. Sources must be extremely small
5. Separation between sources must be small
6. Distance between sources and screen
7. Direction

1. Temporal Coherence: The average time during which definite phase relation exists.

2. Spatial Coherence: The phase relationship between the waves reaching at two different points.

Expressions for Resultant Amplitude and Intensity



$$y_1 = a_1 \cos\omega t \quad \text{------ (1)}$$

$$y_2 = a_2 \cos(\omega t + \delta) \quad \text{------ (2)}$$

$$y = y_1 + y_2$$

$$= a_1 \cos\omega t + a_2 \cos(\omega t + \delta)$$

$$\boxed{\because \cos(A+B) = \cos A \cdot \cos B - \sin A \sin B}$$

$$= a_1 \cos\omega t + a_2 [\cos\omega t \cdot \cos\delta - \sin\omega t \cdot \sin\delta]$$

$$= a_1 \cos\omega t + a_2 \cos\omega t \cdot \cos\delta - a_2 \sin\omega t \cdot \sin\delta$$

$$= (a_1 + a_2 \cos\delta) \cos\omega t - (a_2 \sin\delta) \sin\omega t$$

Let $(a_1 + a_2 \cos\delta) = A\cos\phi$ ------ (3)

$(a_2 \sin\delta) = A \sin\phi$ ------ (4)

$$= A\cos\phi \cdot \cos\omega t - A\sin\phi \cdot \sin\omega t$$

$$\boxed{y = A[\cos(\omega t + \phi)]}$$

If we square and add eqn, (3) & (4)

$$(3)^2 + (4)^2 \Rightarrow$$

$$A^2\cos^2\phi + A^2\sin^2\phi = (a_1 + a_2\cos\delta)^2 + (a_2\sin\delta)^2$$

$$A^2(\sin^2\phi + \cos^2\phi) = a_1^2 + a_2^2\cos^2\delta + 2a_1a_2\cos\delta + a_2^2\sin^2\delta$$

$$A^2(1) = a_1^2 + a_2^2(\sin^2\delta + \cos^2\delta) + 2a_1a_2\cos\delta$$

$$A^2 = a_1^2 + a_2^2 + 2a_1a_2\cos\delta$$

$(\because \text{Intensity} = A^2)$

$$\boxed{I = a_1^2 + a_2^2 + 2a_1a_2\cos\delta} \quad \text{——— (5)}$$

Expression for resultant Intensity

——x——

Maximum and Minimum Intensity:

In equation 5, for maximum intensity, the value of **cosδ** should be maximum, i.e. +1

$$I_{max} = a_1^2 + a_2^2 + 2a_1a_2$$

$$\boxed{I_{max} = (a_1 + a_2)^2}$$

$$\left[\begin{array}{l} \cos\delta = +1 \\ \delta = 2n\pi, \text{ where } n = 0, 1, 2 \ldots \end{array}\right]$$

If $a_1 = a_2$

$$\boxed{I_{max} = 4a^2}$$

$$\left[\begin{array}{l} \cos\delta = -1 \\ \delta = (2n+1)\pi \\ \text{where } n = 0, 1, 2 \ldots \end{array}\right]$$

$$I_{min} = a_1^2 + a_2^2 - 2a_1a_2$$

$$\boxed{I_{min} = (a_1 - a_2)^2}$$

If $a_1 = a_2$

$$\boxed{I_{min} = 0}$$

Average Intensity (I_{av}):

$$I_{av} = \frac{\int_0^{2\pi} I\, d(\delta)}{\int_0^{2\pi} d(\delta)} , \quad \left(\because I = a_1^2 + a_2^2 + 2a_1a_2\cos\delta\right)$$

$$= \frac{\int_0^{2\pi} (a_1^2 + a_2^2 + 2a_1a_2\cos\delta)\, d\delta}{\int_0^{2\pi} d(\delta)}$$

$$= \frac{\int_0^{2\pi} a_1^2\, d\delta + \int_0^{2\pi} a_2^2\, d\delta + \int_0^{2\pi} 2a_1a_2\cos\delta\, d\delta}{[\delta]_0^{2\pi}}$$

$$= \frac{a_1^2[\delta]_0^{2\pi} + a_2^2[\delta]_0^{2\pi} + 2a_1a_2[\sin\delta]_0^{2\pi}}{(2\pi - 0)}$$

$$= \frac{a_1^2(2\pi-0) + a_2^2(2\pi-0) + 2a_1a_2[\sin(2\pi) - \sin(0)]}{2\pi}$$

$$= \frac{a_1^2(2\pi) + a_2^2(2\pi) + 2a_1a_2(0-0)}{2\pi}$$

$$= \frac{(a_1^2 + a_2^2)\cancel{2\pi}}{\cancel{2\pi}}$$

$$\boxed{I_{av} = a_1^2 + a_2^2}$$

if $a_1 = a_2$, $\boxed{I_{av} = 2a^2}$

Fringe Width :→

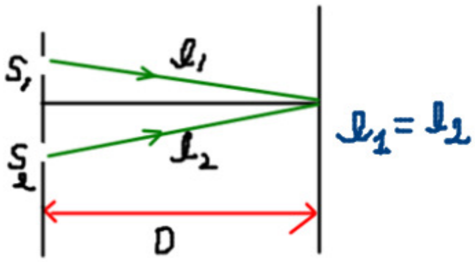


Fig.1

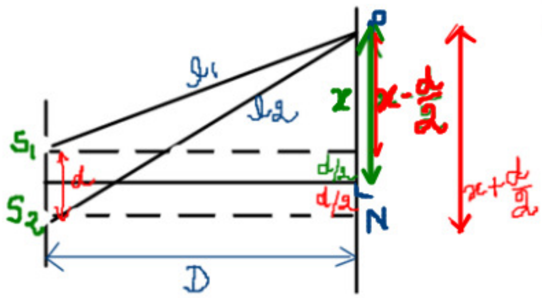


Fig2.

For constructive interference

(Phase difference) $\phi = 0^\circ, 360^\circ, 720^\circ - -$

(Path difference) $\quad = 0^\circ, \lambda, 2\lambda - - -$

$\therefore \quad \phi = n\lambda$ (constructive)

For destructive interference

(Phase difference) $\phi = 180^\circ, 560^\circ - - -$

(Path difference) $= \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2} ..$

From Figure(2) here→ $(l_2 > l_1)$

$l_2 - l_1 =$ path difference

so first we can compute

$(l_2^2 - l_1^2)$

ΔS_2NP :→ $\quad l_2^2 = D^2 + \left(x + \frac{d}{2}\right)^2$

& ΔS_1MP: $\quad l_1^2 = D^2 + \left(x - \frac{d}{2}\right)^2$

$$l_2^2 - l_1^2 = \cancel{D^2} + \left(x + \frac{d}{2}\right)^2 - \cancel{D^2} \quad \left(x - \frac{d}{2}\right)^2$$

$$\boxed{\because a^2 - b^2 = (a+b)\cdot(a-b)} \qquad a = \left(x + \frac{d}{2}\right), \quad b = \left(x - \frac{d}{2}\right)$$

$$l_2^2 - l_1^2 = \left(x + \cancel{\frac{d}{2}} + x - \cancel{\frac{d}{2}}\right) \cdot \left(\cancel{x} + \frac{d}{2} - \cancel{x} + \frac{d}{2}\right)$$

$$\{\text{Path diff}\} = (2x)\cdot\left(\frac{\cancel{2}d}{\cancel{2}}\right)$$

$$\boxed{n\lambda = 2xd} \quad \text{Path diff. (constructive interference)}$$

$$\because l_2^2 - l_1^2 = (l_2 - l_1)\cdot(l_2 + l_1)$$

$$(l_2 - l_1)\cdot(l_2 + l_1) = 2xd$$

$\because d << D \quad \because l_2 - l_1 = n\lambda$ (for constructive Inter.)

$$n\lambda = \frac{2xd}{(l_2 + l_1)}, \quad \text{here} \quad l_2 \approx l_1 \approx D$$

$$\therefore \quad l_2 + l_1 = 2D$$

$$\therefore \quad n\lambda = \frac{\cancel{2}xd}{\cancel{2}D} \Rightarrow n\lambda = \frac{xd}{D} \quad \text{or} \quad \boxed{n\lambda = \frac{x_n d}{D}}$$

Fringe width $(\omega$ or $\beta)$

$\omega = x_2 - x_1$ (Position of second fringe - Position of first fringe)

$= x_{n+1} - x_n$ (Position of (n+1)th fringe - Position of (n)th fringe)

$\because n\lambda = x_n d/D$ or $x_n = n\lambda D/d$

$$= x_{n+1} - x_n$$

$$= \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d}$$

$$= \cancel{\frac{n\lambda D}{d}} + \frac{\lambda D}{d} - \cancel{\frac{n\lambda D}{d}}$$

$$\boxed{\omega = \frac{\lambda D}{d}}$$

Fringe width in case of bright fringe.

For destructive interference, the path difference $= (2n+1)\frac{\lambda}{2}$

$\because x_n = n\lambda D/d$, now $x_n = (2n+1)\frac{\lambda D}{2d}$

where n = 0,1,2,3…..

$$\because \omega = x_{n+1} - x_n$$

$$= \frac{\{2(n+1)+1\}\lambda D}{2d} - \frac{(2n+1)\lambda D}{2d}$$

$$= \frac{(2n+3)\lambda D}{2d} - \frac{(2n+1)\lambda D}{2d}$$

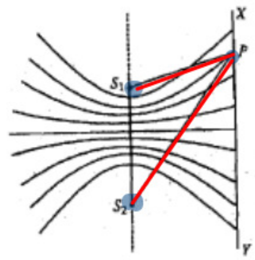
$$= \frac{\cancel{2}\lambda D}{\cancel{2}d}$$

$$\boxed{\omega = \frac{\lambda D}{d}}$$

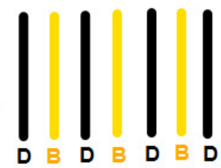
Fringe width for destructive interference or two consecutive dark fringes.

Therefore, fringe width is independent of n.

Shape of the fringes

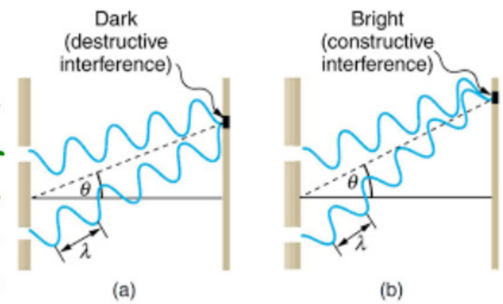


Due to large hyperbola we see only linear part



Conditions for sustained Interference

1. Coherent Sources
2. Wavelength, Time Period, Frequency
3. Amplitude and Intensity
4. Sources must be extremely small
5. Direction must be same
5. Separation between sources must be small (d) $\longrightarrow$ $\because \omega = \frac{D\lambda}{d}$, $\omega \propto \frac{1}{d}$, small d, large ω
6. Distance between sources and screen (D) $\longrightarrow$ $\omega \propto D$ large D, large ω



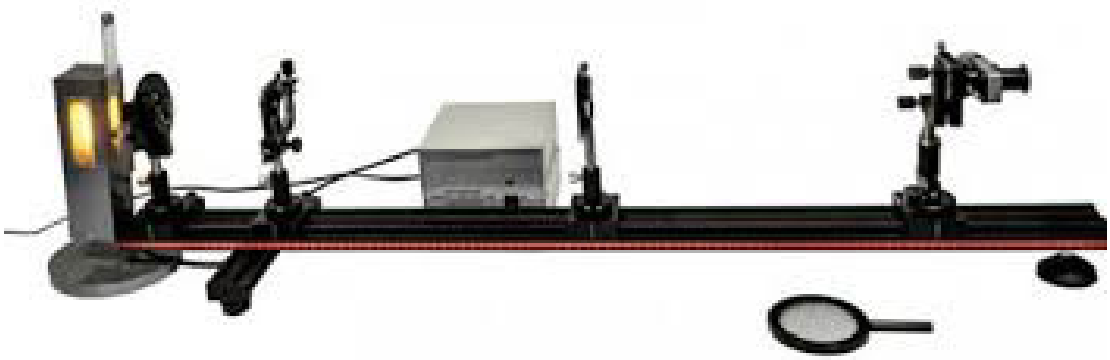
Some example problems:

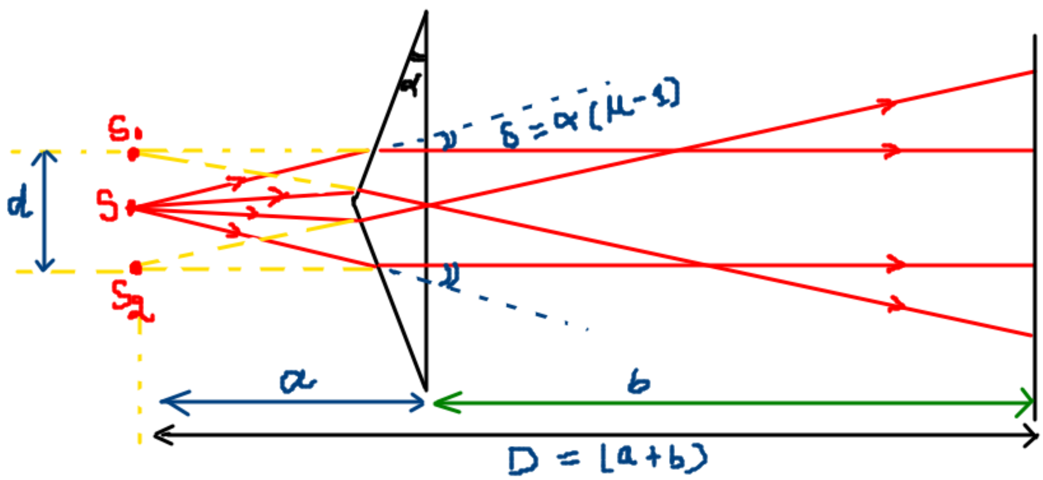
Q. Two coherent sources are 2mm apart and are illuminated with a monochromatic light of wavelength 589.6 nm. Fringes are observed at a distance of 60 cm from the sources. Find the fringe width.

Q. Two straight and narrow parallel slits 3 mm apart are illuminated by a monochromatic light of wavelength 5.9×10^{-5} cm. Fringes are obtained on a 60 cm distant screen from the slits. Find the value of fringe width.

Q. Two coherent sources of monochromatic light of wavelength 6000Å produce an interference pattern on a screen kept a t a distance of 1 meter from them. The distance between two consecutive bright fringes on the screen is 0.5 mm. Find the distance between the two coherent sources.

Fresnel's Bi-prism experiment:





$\because \boxed{\omega = \frac{\lambda D}{d}}$ We can determine the wavelength of a monochromatic light; $\boxed{\lambda = \frac{\omega d}{D}}$

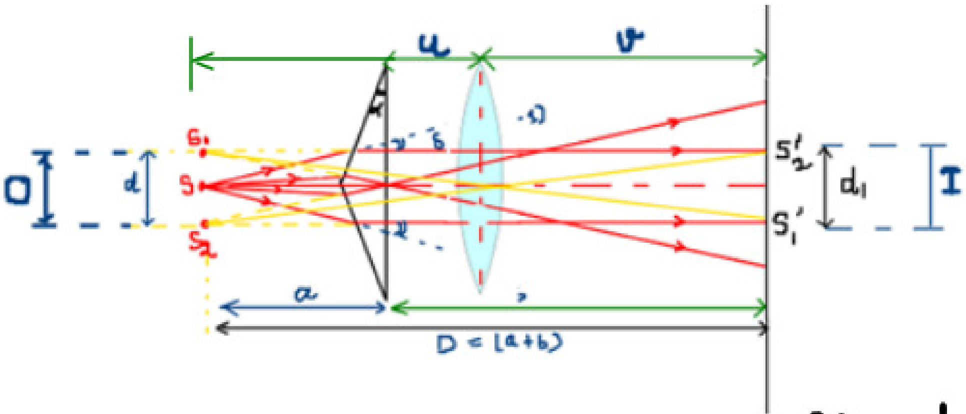
1. D is obtained by scale on optical bentch.

2. Fringe width can be measured using eye-piece.

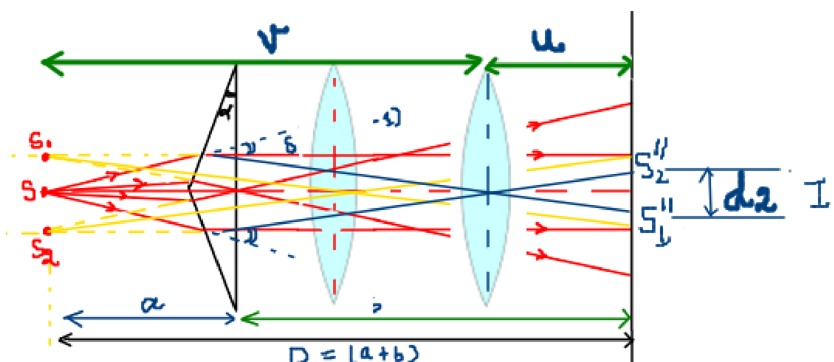
3. Now our task is to determine the value of (d).

4. There are mainly two methods to determine the value of d,
i.e. (i) Displacement Method (ii) Deviation Method.

1. Displacement Method for the calculation of (d).



$$\text{Magnification of lens} = \frac{I}{O} = \frac{v}{u} = \frac{d_1}{d} \qquad \text{——— (1)}$$



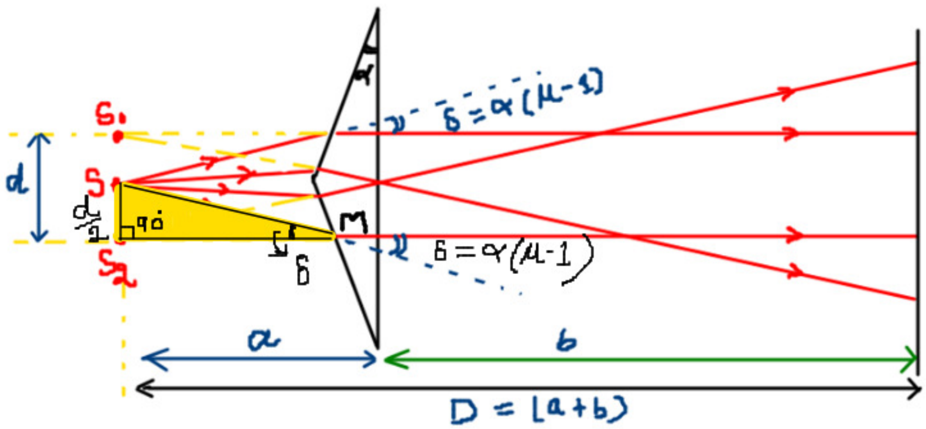
$$\text{Magnification of lens} = \frac{I}{O} = \frac{u}{v} = \frac{d_2}{d} \qquad \text{——— (2)}$$

$$(1) \times (2) \Rightarrow \quad \frac{d_1}{d} \times \frac{d_2}{d} = \frac{\cancel{v}}{\cancel{u}} \times \frac{\cancel{u}}{\cancel{v}}$$

$$d^2 = d_1 d_2$$

$$\boxed{d = \sqrt{d_1 \cdot d_2}}$$

1. **Deviation Method for the calculation of (d).**



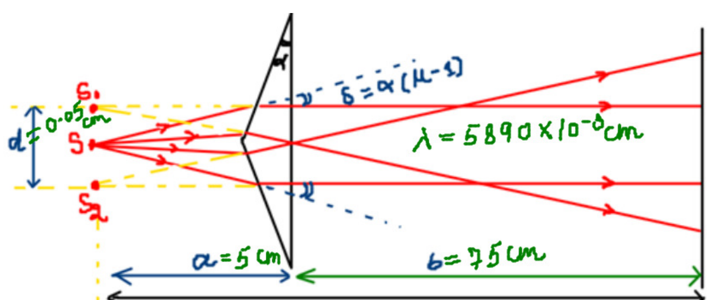
In $\triangle SS_2M \Rightarrow \tan\delta = \frac{SS_2}{S_2M} = \frac{d}{2a}$

if δ is very small, $\tan\delta \approx \delta$

or $\delta = \frac{d}{2a}$, $\boxed{d = 2\delta a}$ $\because$ $\boxed{\delta = \alpha(\mu-1)}$

$\therefore \boxed{d = 2(\mu-1)\alpha a}$

Q. A biprism is placed at a distance of 5 cm in front of a narrow slit, illuminated by sodium light ($\lambda = 5890\times10^{-8}$ cm) and the distance between the virtual sources is found to be 0.05 cm. Find the width of the fringes observed in an eye-piece placed at a distance of 75 cm from the biprism.



$D = (a+b) = 80$ cm

$\because \omega = \frac{\lambda D}{d} \Rightarrow \frac{5890\times10^{-8}\times80}{0.05}$

$\boxed{\omega = 9424\times10^{-5} \text{ cm}}$