Interference

Objectives

After going through this module the learner will be able to :

- Understand Young's double slit experiment
- Derive an expression for fringe width
- Graphically represent intensity of fringes on a screen
- Explain the factors which could affect interference fringes in double slit experiment
- Visualize fringes due to monochromatic and polychromatic light.

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Interference of light
- Interference of light waves young's double slit experiment
- Fringe width
- Summary

Unit Syllabus

UNIT 6: Optics

Chapter–9: Ray Optics and Optical Instruments

Ray optics: Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue colour of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Chapter 10 Wave Optics

Wave optics: Wavefront and Huygens's principle, reflection and refraction of plane wave at a plane surface using wavefronts, proof of laws of reflection and refraction using Huygens's principle, Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope. Polarisation, plane polarised light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

Module Wise Distribution Of Unit Syllabus - 15 Modules

Module 1	● Introduction ● How we will study optics ● Light facts ● Ray optics, beams ● Light falling on surfaces of any shape texture ● Peculiar observations
Module 2	● Reflection of light ● Laws of reflection ● Reflection of light by plane and spherical surfaces ● Spherical Mirrors aperture, radius of curvature, pole principal axis ● Focus, Focal length, focal plane ● Image – real and virtual ● Sign convention ● The mirror equation, magnification ● To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror ● Application of mirror formula
Module 3	● Refraction of light ● Optical density and mass density ● Incident ray, refracted ray emergent ray ● Angle of incidence, angle of refraction angle of emergence

	To study the effect on intensity of light emerging through different coloured transparent sheets using an LDR ● Refractive index ● Oblique incidence of light, Snell's law ● Refraction through a parallel sided slab, Lateral displacement, factors affecting lateral displacement ● To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab ● Formation of image in a glass slab
Module 4	● Special effects due to refraction ● Real and apparent depth ● To determine the refractive index of a liquid using travelling microscope ● Total internal reflection ● Optical fibres and other applications
Module 5	● Refraction through a prism ● Deviation of light - angle of deviation ● Angle of minimum deviation ● Expression relating refractive index for material of the prism and angle of minimum deviation ● To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation ● Dispersion, spectrum
Module 6	● Refraction at spherical surfaces ● Radius of curvature ● Refraction by a lens ● Foci, focal plane, focal length, optical center, principal axis ● Formation of images real and virtual ● Lens maker's formula ● Lens formula and magnification ● Sign convention

	● Application of lens formula ● Power of lens ● Combination of thin lenses in contact
Module 7	● To study the nature and size of image formed by a ii) convex lens ii) concave mirror using a candle and a screen ● To determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v ● To determine the focal length of a convex mirror using a convex lens ● To find the focal length of a concave lens using a convex lens ● To find the refractive index of a liquid by using a convex lens and a plane mirror
Module 8	● Scattering of light – ● Blue color of sky ● Reddish appearance of the sun at sunrise and sunset ● Dust haze
Module 9	● Optical instruments ● Human eye ● Microscope ● Astronomical telescopes reflecting and refracting ● Magnification ● Making your own telescope
Module 10	● Wave optics ● Wavefront ● Huygens's principle shapes of wavefront ● Plane wavefront ● Refraction and reflection of plane wavefront using Huygens's principle ● Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	● Superposition of waves

	• Coherent and incoherent addition of waves
Module 12	• Interference of light • Young’s double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Factors affecting formation of fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young’s experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

Module 12

Words You Must Know

Let us remember the words we have been using in our study of this physics course.

- Incident ray: Path of light from a source in any preferred direction of propagation
- Reflected ray: Path of light bounced off from a surface at the point of incidence
- Refracted ray: Path of light when it propagates from one transparent medium to another.

- Normal at the point of incidence: Normal to the surface at the point of incidence. important when the surface is spherical or uneven
- Converging and diverging rays: Rays of light may converge to or seem to diverge from a point after reflection or refraction such rays are called converging or diverging rays.
- Laws of reflection: Laws followed by light rays whenever reflection takes place
- The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane
- The angle of reflection is equal to the angle of incidence
- Snell's law: For oblique incidence of light on a transparent medium surface

$$refractive\ index = \frac{\sin i}{\sin r}$$

- The angle of refraction is not equal to the angle of incidence.
- A ray of light propagating from a rarer to a denser medium moves towards the normal. This can be observed for obliquely incident rays.
- Plane mirror: A polished surface with infinite radius of curvature
- Spherical mirror- concave and convex: spherical mirrors are part of spherical surfaces. The polished surface makes them concave or convex.
- Spherical lens-convex and concave: Transparent medium bounded by spherical surfaces, if a thin block of medium has two surfaces bulge out, they form a convex lens
- Prism: A rectangular block cut along its diagonal gives two prisms. Each piece has two refracting surfaces, a base and the angle between the refracting surfaces (in this case $=90^0$) is called angle of prism.
- Light Wave. Light is part of the electromagnetic spectrum. They are transverse waves, origin of light is from electromagnetic transitions of electrons inside the atoms giving out the radiation. The frequency depends upon the source. Wavelength depends upon the medium in which light is travelling.
- Wavefront: Defined as a surface of constant phase.
- Huygens principle
    - Each point of the wavefront is a source of a secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. These wavelets emanating from the wavefront are usually referred to as secondary wavelets.

- If we draw a common tangent (in the forward direction) to all these spheres, we obtain the new position of the wavefront at a later time.

- Huygens's construction: Wavefronts drawn on the basis of Huygens principle
- Superposition of waves: if two (or more) waves travelling through the same medium at the same time meet, the net displacement of the medium at any time becomes equal to the algebraic sum of the individual displacements.
- Coherent sources of light:

  Two sources are said to be coherent if they obey the following properties:

  (a) Two sources must be emitting waves of the same wavelength or frequency.

  (b) The amplitude of the waves produced by the two sources must be either equal or approximately equal.

  (c) The waves produced by the two sources must have either the same phase or a constant phase difference
- Incoherent sources of light

  Two sources are said to be incoherent if they obey the following properties:

  (a) Two sources may be emitting waves of the same wavelength or frequency.

  (b) The amplitude of the waves produced by the two sources may not be either equal or approximately equal.

  (c) The waves produced by the two sources do not have either the same phase or a constant phase difference.

Introduction

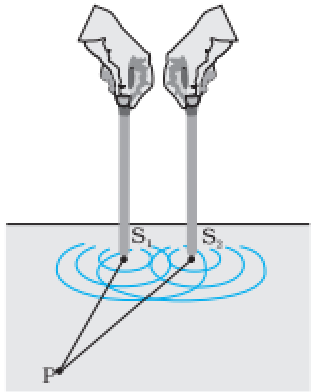
We will discuss the interference pattern produced by the superposition of two waves. You may recall that we had discussed the superposition principle. The superposition principle states, the resultant displacement produced by a number of waves is the vector sum of the displacements produced by each of the waves.

In the previous module we used water waves to discuss the meaning of phase and path difference

Interference Of Light

Coherent And Incoherent Addition Of Waves

Consider two needles S_1 and S_2 moving periodically up and down in an identical fashion in a trough of water



Two needles oscillating in phase in water represent two coherent sources.

They produce two water waves, and at a particular point, the phase difference between the displacements produced by each of the waves does not change with time; when this happens the two sources are said to be coherent.

You also recall our discussion on what will happen at point P which is equidistant from S_1 and S_2

Hence at point P for which

$$S_1 P = S_2 P$$

Since the distances S_1P and S_2P are equal, waves from S_1 and S_2 will take the same time to travel to the point P and waves that emanate from S_1 and S_2 in phase will also arrive at the point P, in phase.

Thus, if the displacement produced by the source S_1 at the point P is given by

$$y_1 = a \cos \omega t \text{ then,}$$

the displacement produced by the source S_2 (at the point P) will also be given by

$$y_2 = a \cos \omega t$$

Thus, the resultant of displacement at P would be given by

$$\mathbf{y = y_1 + y_2 = 2\, a \cos \omega t}$$

Since the intensity is the proportional to the square of the amplitude, the resultant intensity will be given by $I = 4I_0$

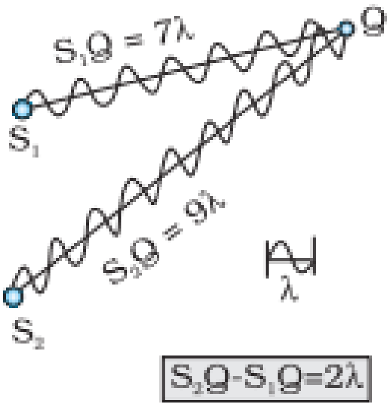
Where I_0 represents the intensity produced by each one of the individual sources;

I_0 is proportional to a^2.

In fact at any point on the perpendicular bisector of S_1 and S_2, the intensity will be $4I_0$.

The two sources are said to interfere constructively and we have what is referred to as constructive interference.

We next consider a point Q



for which $S_2Q - S_1Q = 2\lambda$

The waves emanating from S_1 will arrive exactly two cycles earlier than the waves from S_2 and will again be in phase

Thus, if the displacement produced by S_1 is given by

$y_1 = a \cos \omega t$

then the displacement produced by S_2 will be given by

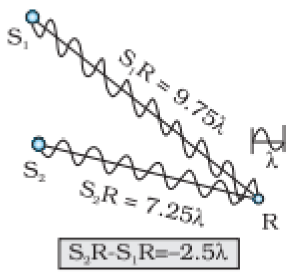
$y_2 = a \cos(\omega t - 4\pi) = a \cos \omega t$

where we have used the fact that a path difference of 2λ corresponds to a phase difference of 4π.

The two displacements are once again **in phase** and the intensity will again be 4 I_0 giving rise to **constructive interference**.

In the above analysis we have assumed that the distances S_1Q and S_2Q are much greater than d (which represents the distance between S_1 and S_2) so that although S_1Q and S_2Q are not equal, the amplitudes of the displacement produced by each wave are very nearly the same.

We next consider a point R



for which $S_2R - S_1R = -2.5\,\lambda$

The waves emanating from S_1 will arrive exactly two and a half cycles later than the waves from S_2.

Thus if the displacement produced by S_1 is given by

$$y_1 = a\cos\omega t$$

then the displacement produced by S_2 will be given by

$$y_2 = a\cos(\omega t + 5\pi) = -a\cos\omega t$$

where we have used the fact that a path difference of 2.5λ corresponds to a phase difference of 5π. The two displacements are **now out of phase** and the two displacements will cancel out to give **zero intensity**.

This is referred to as **destructive interference**.

To summarise: If we have two coherent sources S_1 and S_2 vibrating in phase, then for an arbitrary point P whenever the path difference,

$$S_1P \sim S_2P = n\lambda \qquad (n = 0, 1, 2, 3 \ldots)$$

We will have constructive interference and the resultant intensity will be $4I_0$; the sign ~ between S_1P and S_2P represents the difference between S_1P and S_2P

On the other hand, if the point P is such that the path difference,

$$S_1P \sim S_2P = (2n+1)\lambda/2 \ (n = 0, 1, 2, 3 \ldots)$$

we will have destructive interference and the resultant intensity will be zero.

Now, for any other arbitrary point G, let the phase difference between the two displacements be φ. Thus, if the displacement produced by S_1 is given by

$$y_1 = a\cos\omega t$$

the displacement produced by S2 would be

$$y_2 = a\cos(\omega t + \varphi)$$

and the resultant displacement will be given by

$$y = y_1 + y_2 = a[\cos\omega t + \cos(\omega t + \varphi)]$$

$$= 2a\cos(\varphi/2)\cos(\omega t + \varphi/2)$$

The **amplitude** of the resultant displacement is **2a cos (φ/2)** and therefore the intensity at that point will be

$$I = 4I_0\cos^2(\varphi/2)$$

If $\varphi = 0, \pm 2\pi, \pm 4\pi \ldots$ which corresponds to the condition for constructive interference leading to maximum intensity.

On the other hand, if $\varphi = \pm\pi, \pm 3\pi, \pm 5\pi \ldots$

we will have destructive interference leading to zero intensity.

Now if the two sources are coherent (i.e., if the two needles are going up and down regularly) then the phase difference φ at any point will not change with time and we will have a stable interference pattern; i.e., the positions of maxima and minima will not change with time.

However, if the two needles do not maintain a constant phase difference, then the interference pattern will also change with time and, if the phase difference changes very rapidly with time, the positions of maxima and minima will also vary rapidly with time and we will see a "time-averaged" intensity distribution.

When this happens, we will observe an average intensity that will be given by

$$< I \geq 4I_0 \ < cos^2\left(\frac{\varphi}{2}\right) >$$

The time-averaged quantity $< \cos^2 (\varphi/2) >$ will be 1/2.

This is also intuitively obvious because the function $\cos^2 (\varphi/2)$ will randomly vary between 0 and 1 and the average value will be 1/2.

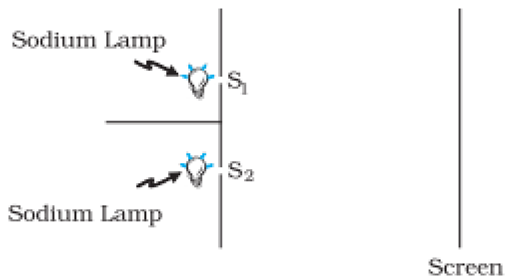
The resultant intensity will be given by $I = 2\, I_0$ at all points.

When the phase difference between the two vibrating sources changes rapidly with time, we say that the two sources are incoherent and when this happens the intensities just add up. This is indeed what happens when two separate light sources illuminate a wall.

Interference Of Light Waves And Young's Experiment

We will now discuss interference using light waves.

If we use two sodium lamps illuminating two pinholes.



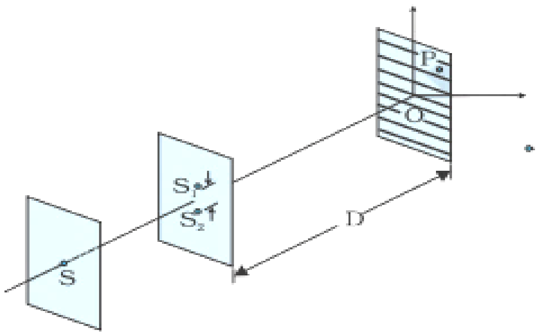
If two sodium lamps illuminate two pinholes S_1 and S_2,**The intensities will add up and no interfere.This is because of the fact that the light wave emitted from an ordinary source (like a sodium lamp) undergoes abrupt phase changes in times of the order of 10^{-10} seconds. Thus the light waves coming out from two independent sources of light will not** have any fixed phase relationship and would be incoherent, when this happens, as discussed in the previous section, the intensities on the screen will add up.

Light waves have very small wavelengths

So the questions are

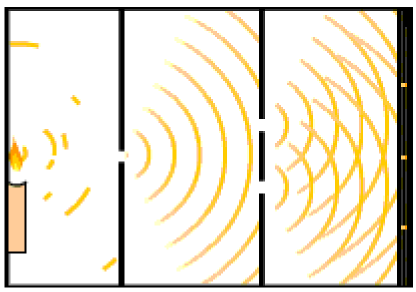
- How should we arrange an apparatus that can give sustained interference patterns?
- How will we satisfy the conditions for interference?
- What will we see?
- How will we see?
- Where will we see the interference pattern ?

British physicist Thomas Young used an ingenious technique to "lock" the phases of the waves emanating from S_1 and S_2.He made two pinholes S_1 and S_2 (very close to each other) on an opaque screen



(a)

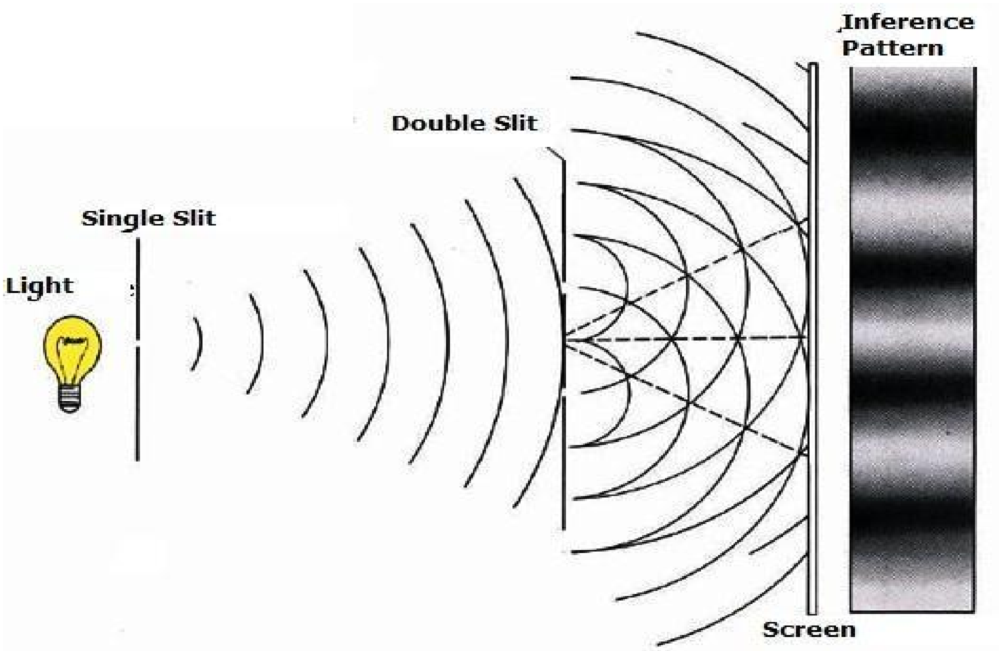
These were illuminated by another pinhole, that was in turn, lit by a bright source.Light waves spread out from S and fall on both S_1 and S_2.**The following diagrams are given to help you imagine the arrangement and what must be happening to the waves. The gif is good**



https://commons.wikimedia.org/wiki/File:Young%2BFringes.gif

see the pattern being created by animation

What kind of pattern will we see on the screen and why is it so predictable?



Conditions for observing sustained observable pattern

- The two sources should continuously emit waves of same frequency or wavelength.
- The two sources of light should be coherent.
- Amplitudes of the waves should be equal.
- The two sources should be narrow.
- The interfering waves should travel along the same direction.
- The sources should be monochromatic.
- The distance between the sources should be small and the distance between the two sources and the screen should be large

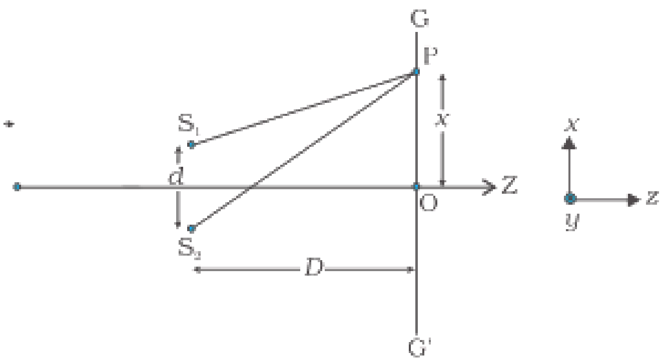
Why do we make the two pinholes close and very small?

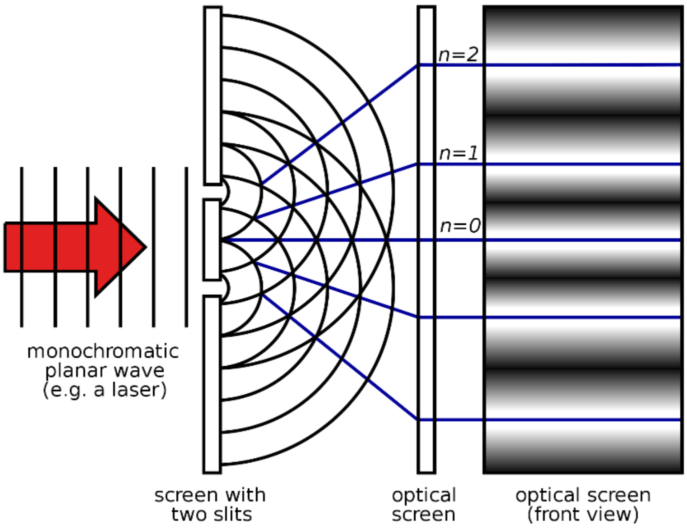
S_1 and S_2 then behave like two coherent sources because light waves coming out from both S_1 and S_2 are derived from the same original source. The fact that the two are close and very small helps a single wavefront to affect both and any abrupt phase change in S will manifest in exactly similar phase changes in the light coming out from both S_1 and S_2. The size of the slit /hole should be comparable to the wavelength of light.

Thus, the two sources S_1 and S_2 will be locked in phase; i.e., they will be coherent like the two vibrating needle in our water wave example.

Thus spherical waves emanating from S_1 and S_2, light spreads out from both S_1 and S_2 and falls on the screen .it is essential that waves from both sources overlaps on the same part of the screen, if one is covered the other produces a wide smoothly illuminated patch on the screen but when both slits are open, the patch is seen to be crossed by dark and bright bands called interference fringes.

The interference fringes will be seen on the screen GG





https://commons.wikimedia.org/wiki/File:Two-Slit_Experiment_Light.svg

The pattern is predictable mathematically and is called fringes,

Think About This

- What if the slits were in the y-z plane, in which plane would we get the fringes?
- What if we use yellow light? Would the dark fringes be black?
- What if we had a spherical screen around the slit arrangement what would the fringes look like?
- What would be the size of distribution (wide span) of fringes on the screen?

Mathematical Explanation Of What We See On The Screen

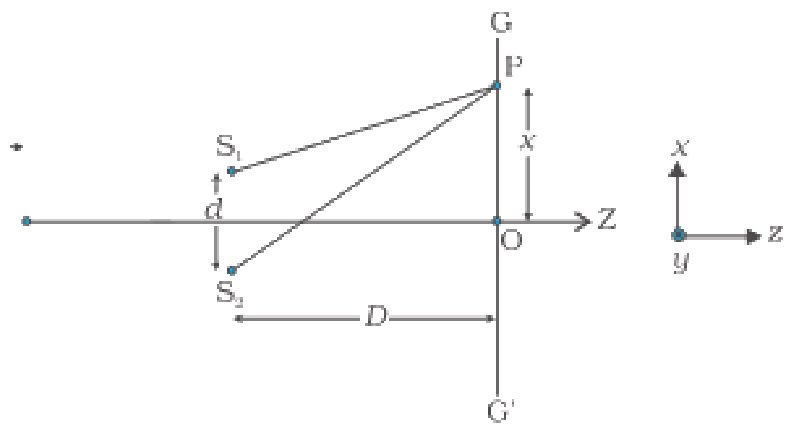
The positions of maximum and minimum intensities can be calculated; in two dimensions it is easy.

For an arbitrary point P on the line GG′ to correspond to a maximum,

We must have S_2 P – S_1 P (path difference) = nλ (integral multiple of wavelength; n = 0, 1, 2, 3, 4….).So at n = 0 means path deference is zero, the waves from S_1 and S_2 reach the point on the perpendicular bisector line of the slit plane, the screen plane is parallel to the slit plane. the waves will reach in phase and constructive interference will take place making the central line bright .Now,

In order to find out how far away is the point P (bright fringe) from the central bright fringe

Let us consider our arrangement **geometrically**



$$\left(S_2P\right)^2 - \left(S_1P\right)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right] = 2\times d\times x$$

where S_1S_2 = d and OP = x. Thus

$$S_2P - S_1P = \frac{2xd}{S_2P + S_1P}$$

If x, d<<D then negligible error will be introduced if $S_2P + S_1P$ (in the denominator) is replaced by 2D.

For example,

for d = 0.1 cm, D = 100 cm, OP = 1 cm (which correspond to typical values for an interference experiment using light waves),

It is a good idea to understand the distances involved by imagining the arrangement. The screen is placed far away from the slits.

We have

$$S_2P + S_1P = \left[(100)^2 + (1.05)^2\right]^{1/2} + \left[(100)^2 + (0.95)^2\right]^{1/2}$$

$$\approx 200.01\ cm$$

Thus if we replace $S_2P + S_1$ by 2 D, the error involved is about 0.005%. In this approximation, we can say

$$S_2P - S_1P \sim \frac{x}{D}$$

Hence we will have **constructive interference** resulting in a bright region when

$$x = x_n = \frac{n\lambda D}{d};\ \ n = 0, \pm 1, \pm 2, ...$$

On the other hand, we will have a **dark region if**

$$x = x_n = \left(2n + \frac{1}{2}\right)\frac{\lambda D}{d};\ \ n = 0, \pm 1, \pm 2, ...$$

Thus dark and bright bands appear on the screen, as shown in Figure and it is these bands are called **fringes. The above result shows dark and bright fringes are equally spaced.**

Fringe Width-The Distance Between Two Consecutive Bright And Dark Fringes

The fringes are equally spaced and we can find the distance between two consecutive dark or bright fringes

The nth (say 3rd) bright fringe

$$x \ or \ x_n = \frac{n\lambda D}{d}$$

And we can write the expression for n+1 (3 + 1 = 4) bright fringe

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

The difference $x_{n+1} - x_n$ is the required fringe width β

$$\beta = \frac{\lambda D}{d}$$

The distance between any two consecutive bright **fringes** or two consecutive dark **fringes** is called **fringe width. Fringe width** or thickness of a dark **fringe** or a bright **fringe** is **equal.**

Fringe width depends upon

- λ-Wavelength of light incident on the double slits.
- D the distance between the slit plane and the screen.
- d distance between the slits.

What about the size of the slit?

In principle we should observe a continuous change in the intensity, bright and dark points with grey regions. Means you will see that there is a gradation in intensity from one fringe to the next

From superposition of waves, following conditions for interference, the resultant wave was given by

$= 2a\cos(\varphi/2)\cos(\omega t + \varphi/2)$

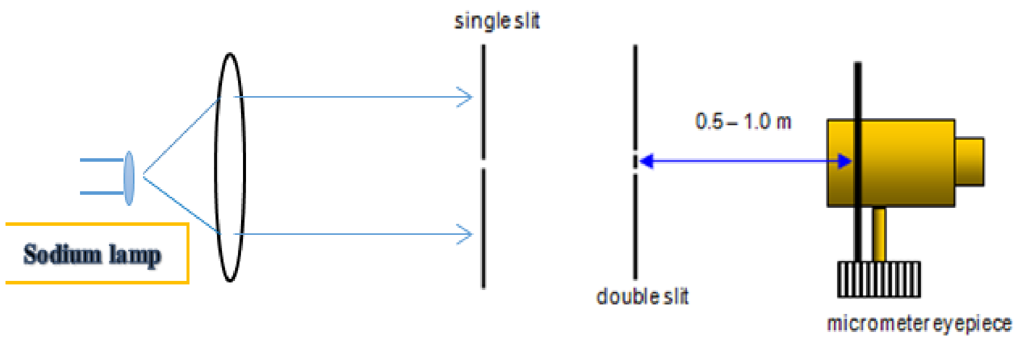
The amplitude of the resultant displacement is 2a cos (φ/2) and therefore the intensity at that point will be

$I = 4I_0\varphi/2$

If $\varphi = 0, \pm 2\pi, \pm 4\pi$..... or if $\varphi = \pm\pi, \pm 3\pi, \pm 5\pi \ldots$

How Do We See Fringes?

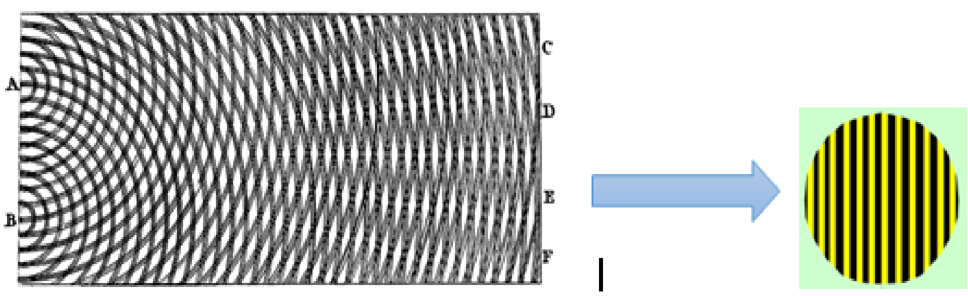
The fringe pattern can be seen clearly using a travelling microscope



A practical arrangement using plane wavefront

In order to determine the shape of the interference pattern on the screen we note that a particular fringe would correspond to the locus of points with a constant value of $S_2P - S_1P$. Whenever this constant is an integral multiple of λ, the fringe will be bright and whenever it is an odd integral multiple of λ/2 it will be a dark fringe.

So we will see a pattern like this on the cross wires of the eyepiece.



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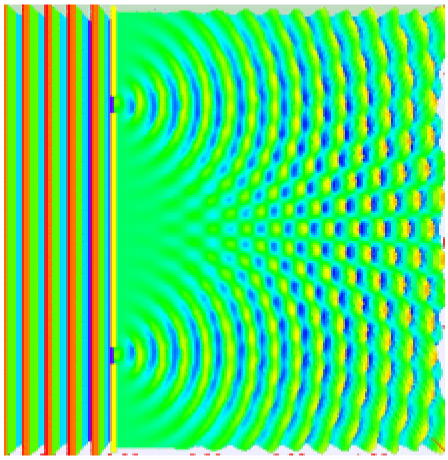
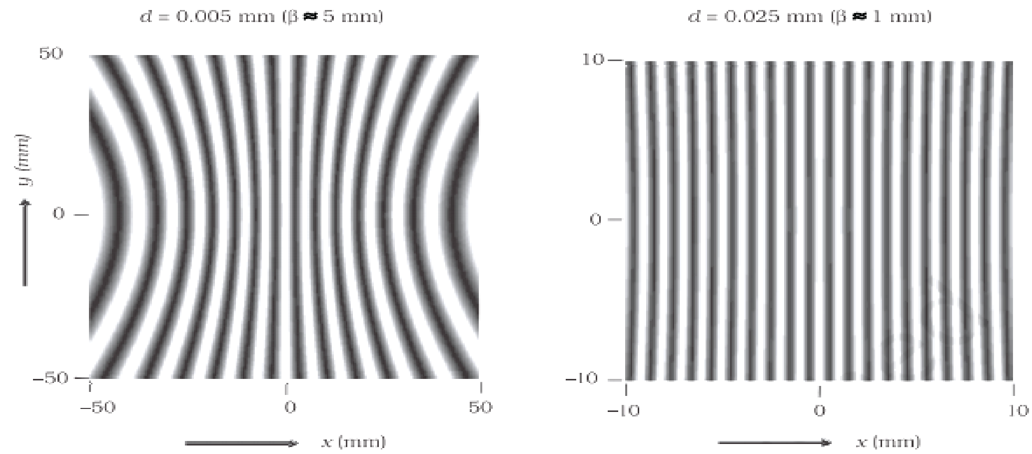


https://upload.wikimedia.org/wikipedia/commons/thumb/3/33/Doubleslit3Dspectrum.gif/220px-Doubleslit3Dspectrum.gif

Now, the locus of the point P lying in the x-y plane such that $S_2P - S_1P$ (= Δ) is a constant, is a hyperbola. Thus the fringe pattern will strictly be a hyperbola; however, if the distance D is very large compared to the fringe width, the fringes will be very nearly straight lines as shown.



Computer generated fringe pattern produced by two point source S_1 and S_2 on the screen GG′ ; (a) and (b) correspond to d = 0.005 mm and 0.025 mm, respectively (both figures correspond to D = 5 cm and $\lambda = 5 \times 10^{-5}$ cm.)

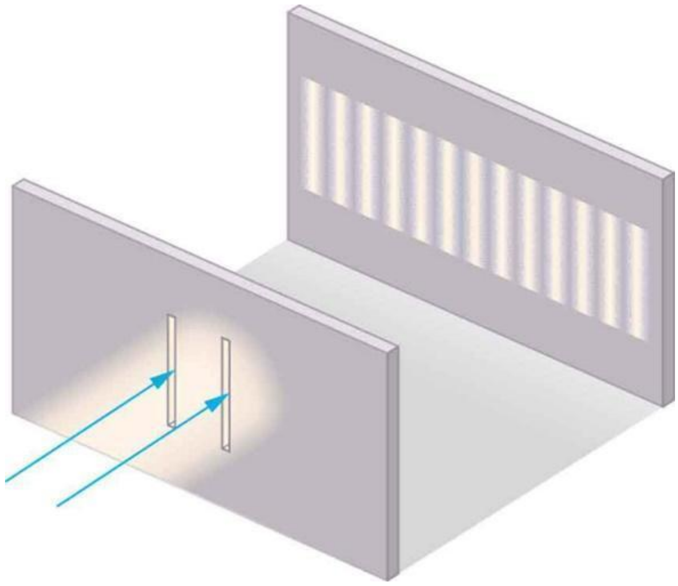
(Adopted from OPTICS by A. Ghatak, Tata McGraw Hill Publishing Co. Ltd., New Delhi, 2000.)

Wave Nature Of Light And Interference Experiment

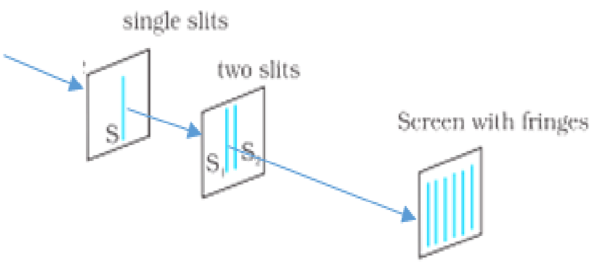
One of the main deductions from the experiment was that the wave nature of light was established, confirmed and applied.Quoting from the Nobel lecture of **Dennis Gabor***

The wave nature of light was demonstrated convincingly for the first time in 1801 by Thomas Young by a wonderfully simple experiment.He let a ray of sunlight into a dark room, placed a dark screen in front of it, pierced with two small pinholes, and beyond this, at some distance, a white screen. He then saw two darkish lines at both sides of a bright line, which gave him sufficient encouragement to repeat the experiment, this time with spirit flame as light source, with a little salt in it to produce the bright yellow sodium light. This time he saw a number of dark lines, regularly spaced; the first clear proof that light added to light can produce darkness. This phenomenon is called interference. Thomas Young had expected it because he believed in the wave theory of light.We should mention here that the fringes are straight lines although S1 and S2 are point sources.

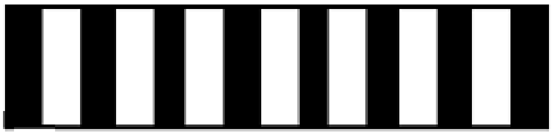
If we had slits instead of the point sources each pair of points would have produced straight line fringes resulting in straight line fringes with increased intensities.

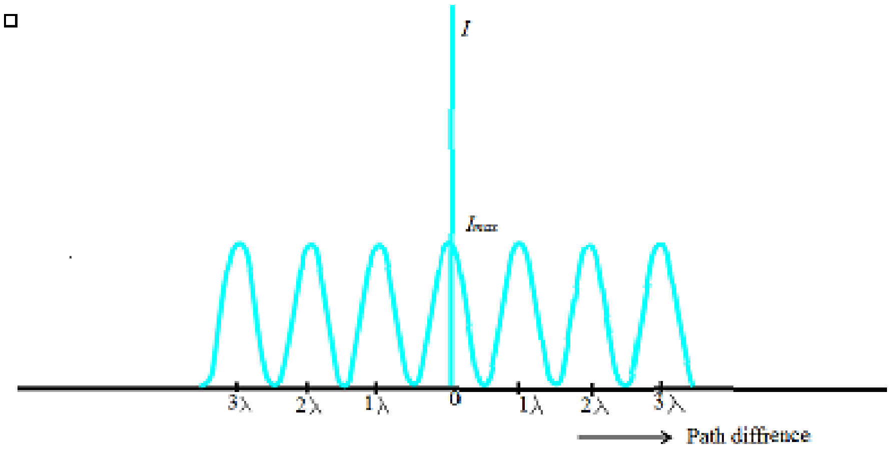


https://cnx.org/contents/xT9BP3W2@4/Youngs-Double-Slit-Experiment



Fringe Pattern And Graphical Representation Of Intensity





Application Of Young's Double Slit Experiment

- The fringe width is given by

$$\beta = \frac{\lambda D}{d}$$

we can

- Determine the wavelength of light
- Disperse the light into components
- Show the wave nature of light

Example

Two slits are made one millimetre apart and the screen is placed one metre away. What is the fringe separation when blue green light of wavelength 500 nm is used?

Solution

Fringe spacing

$\frac{D\lambda}{d} = \frac{1\times5\times10^{-7}}{1\times10^{-3}}$

$= 5\times10^{-4}$ mm

= 0.5 mm

Example

What is the effect on the interference fringes in a Young's double-slit experiment due to each of the following operations?

(a) the screen is moved away from the plane of the slits;
(b) The (monochromatic) source is replaced by another (monochromatic) source of shorter wavelength;
(c) the separation between the two slits is increased;
(d) the source slit is moved closer to the double-slit plane;
(e) the width of the source slit is increased;
(f) the monochromatic source is replaced by a source of white light?

Solution

(In each operation, take all parameters, other than the one specified, to remain unchanged.)

Solution

(a) Angular separation of the fringes remains constant (= λ/d). The actual separation of the fringes increases in proportion to the distance of the screen from the plane of the two slits.
(b) The separation of the fringes (and also angular separation) decreases. See, however, the condition mentioned in (d) below.
(c) The separation of the fringes (and also angular separation) decreases. See, however, the condition mentioned in (d) below.
(d) Let *s* be the size of the source and S its distance from the plane of the two slits. For interference fringes to be seen, the condition s/S < λ/d should be satisfied; otherwise, interference patterns produced by different parts of the source overlap and no fringes are seen. Thus, as S decreases (i.e., the source slit is brought closer), the interference pattern gets less and less sharp, and when the source is brought too close for this condition to be valid, the fringes disappear. Till this happens, the fringe separation remains fixed.

(e) Same as in (d). As the source slit width increases, the fringe pattern gets less and less sharp. When the source slit is so wide that the condition $s/S \leq \lambda/d$ is not satisfied, the interference pattern disappears

(f) The interference patterns due to different component colours of white light overlap (incoherently). The central bright fringes for different colours are at the same position. Therefore, the central fringe is white. For a point P for which $S_2P - S_1P = \lambda b/2$, where λb ($\approx$ 4000 Å) represents the wavelength for the blue colour, the blue component will be absent and the fringe will appear red in colour. Slightly farther away where $S_2Q - S_1Q = \lambda b = \lambda r/2$ where λr ($\approx$ 8000 Å) is the wavelength for the red colour, the fringe will be predominantly blue. Thus, the fringe closest on either side of the central white fringe is red and the farthest will appear blue. After a few fringes, no clear fringe pattern is seen.

Example

In Young's double-slit experiment, the slits are separated by 0.28 mm and the screen is placed 1.2 m away. The distance between the central bright fringe and the fourth bright fringe is measured to be 1.2 cm. Determine the wavelength of light used in the experiment.

Solution

Given: $d = 0.28mm = 2.8\times10^{-4}m$

$D = 1.2\,m$

$x = 1.2\,cm = 1.2\times10^{-2}\,m$

$n = 4$

$\lambda = ?$

For bright fringes,

$x = n\lambda\frac{D}{d}$

Putting the values of given variables

We have

$1.2\times10^{-2} = \frac{4\times\lambda\times1.2}{2.8\times10^{-4}}$

$\lambda = \frac{1.2\times10^{-2}\times2.8\times10^{-4}}{4\times1.2}$

$\lambda = 0.7\times10^{-6}m$

Example

In Young's double-slit experiment using monochromatic light of wavelength λ, the intensity of light at a point on the screen where path difference is λ, is K units. What is the intensity of light at a point where path difference is λ/3?

Solution

Case I: Path difference = λ

Phase difference = 2×λ = 2**π**

Intensity of light = K

$K = I_1 + I_2 + 2\sqrt{I_1I_2} \cos cos\ 2\pi$

For monochromatic light

$I_1 = I_2 = I$

$K = 2I + 2I\times1 = 4I$

Case II: Path difference = λ/3

Phase difference = 2λ/3

Now intensity of light = $K^{'}$

$K^{'} = I_1 + I_2 + 2\sqrt{I_1I_2} \cos cos\ \frac{2\lambda}{3}$

$K^{'} = 2I - 2I\times\frac{1}{1}$

$K^{'} = I$

By comparing both the intensities we get,

$K^{'} = \frac{K}{4}$

Example

A beam of light consisting of two wavelengths, 650 nm and 520 nm, is used to obtain interference fringes in a Young's double-slit experiment.

(a) Find the distance of the Fourth dark fringe on the screen from the central maximum for wavelength 650 nm.

(b) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide?

The separation between the slits is 0.13 mm and the screen is situated at a distance of 1.2 m.

Solution

Given: d = 0.13 mm = 1.3×10^{-4} m

D = 1.2 m

λ_1 = 650 nm = 650×10^{-9} m

λ_2 = 520 nm = 520×10^{-9} m

(a) $x = ?$

For the dark fringe

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

$$x = \frac{7\times650\times10^{-9}\times1.2}{2\times1.3\times10^{-4}}$$

$$x = 2.1\times10^{-4} m$$

(b) Let the n[th] bright fringe of λ_1 coincides with the (n+1)[th] bright fringe of λ_2, then

$$x' = n\beta = (n + 1)\beta'$$

$$\frac{(n+1)}{n} = \frac{\beta}{\beta'} = \frac{\lambda_1}{\lambda_2}$$

$$n = \frac{\lambda_2}{\lambda_1 - \lambda_2} = \frac{520}{650-520} = 4$$

$$x' = n\beta = n\frac{\lambda_1 D}{d}$$

$$x' = \frac{4\times650\times10^{-9}\times1.2}{1.3\times10^{-4}}$$

$$x' = 2.4\times10^{-4} m$$

Example

In a double-slit experiment the angular width of a fringe is found to be 0.2° on a screen placed 1 m away. The wavelength of light used is 600 nm.What will be the angular width of the fringe if the entire experimental apparatus is immersed in water? Take the refractive index of water to be 4/3.

Solution

$\theta = 0.2° = 0.2 \times \frac{\pi}{180} rad$

$angular\ width\ when\ immersed\ in\ water\ \theta^{'} = ?$

We know that

$\theta = \frac{\beta}{D} = \frac{\lambda D}{dD} = \frac{\lambda}{d}$

From the above formula we can conclude that $\theta \propto \lambda$

Hence,

$\frac{\theta^{'}}{\theta} = \frac{\lambda^{'}}{\lambda}$

$\lambda^{'} = \lambda/\mu$

So,

$\theta^{'} = \theta/\mu$

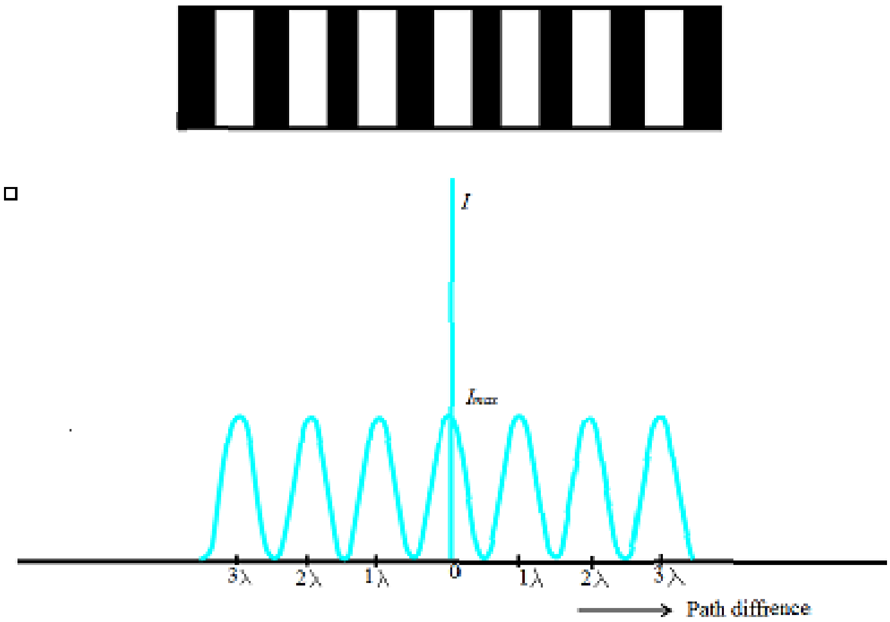
$\theta^{'} = \frac{0.2}{4/3} = 0.15°$

Summary

- Light from coherent sources can superpose to give a predictable interference pattern of bright and dark fringes Superposition of light waves is possible only
- Fringes can be viewed in the laboratory using a monochromatic light and suitable arrangement to obtain essential conditions for sustained pattern by coherent sources.
- Young's double slit arrangement uses a single wavefront to get closely placed coherent sources of equal wavelength, same intensity and constant phase relation.
- Fringe width is the distance between two consecutive bright or dark fringes

$$\beta = \frac{\lambda D}{d}$$

- The fringe pattern can be depicted graphically



- Young's experiment can be used to determine the wavelength of light