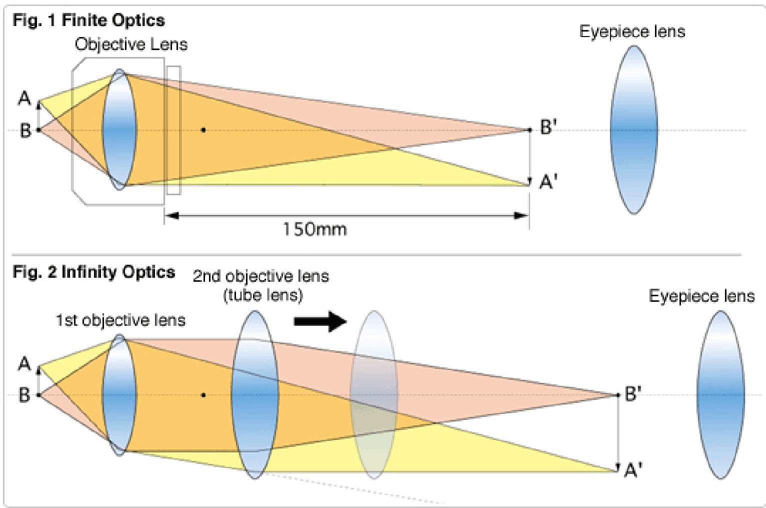
Optics is the branch of physics which involves the behavior and properties of light, including its interactions with matter and the construction of instruments that use or detect it.

Optics usually describes the behavior of visible, ultraviolet, and infrared light. Because light is an electromagnetic wave, other forms of electromagnetic radiation such as X-rays, microwaves, and radio waves exhibit similar properties.



Newton's corpuscular theory of light

Newton's corpuscular theory of light is based on the following points

1. Light consists of very tiny particles known as "corpuscular".

2. These corpuscles on emission from the source of light travel in straight line with high velocity.

3. When these particles enter the eyes, they produce image of the object or sensation of vision.

4. Corpuscles of different colors have different sizes.

Huygens's wave theory of light

Christian Huygens proposed the wave theory of light. According to Huygens's wave theory:

1. Each point in a source of light sends out waves in all directions in hypothetical medium called "ETHER".

2. Light is a form of energy.

3. Light travels in the form of waves.

4. A medium is necessary for the propagation of waves & the whole space is filled with an imaginary medium called Ether

5. Light waves have very short-wave length.

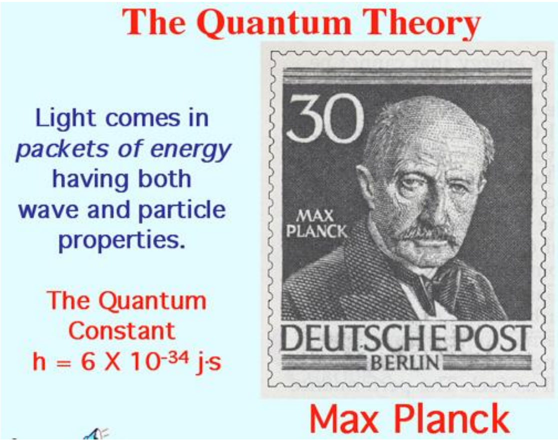
Quantum theory of light

Quantum theory was put forward by MAX-PLANCK in 1905. According to quantum theory

"Energy radiated or absorbed cannot have any fractional value. This energy must be an integral multiple of a fixed quantity of energy. This quantity is called "QUANTUM"

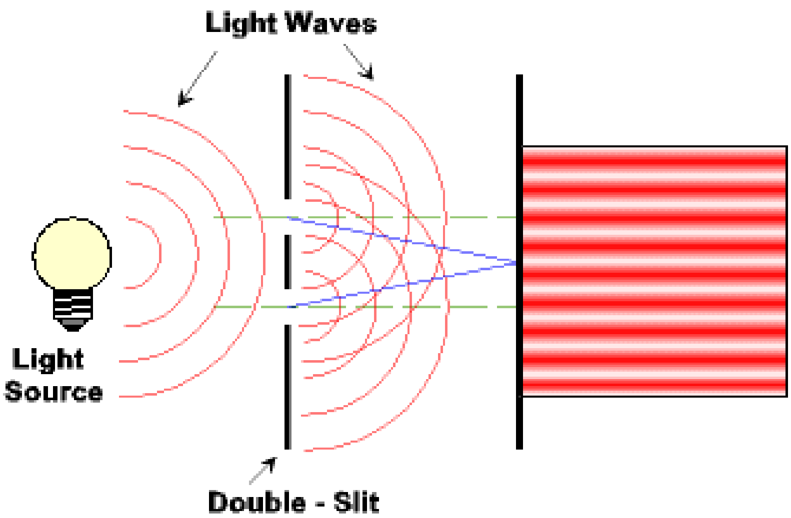
Or

Energy released or absorbed is always in the form of packets of energy or bundles of energy. These packets of energy are known as QUANTA or PHOTONS.



Interference of Light

In physics, **interference** is a phenomenon in which two waves superpose to form a resultant wave of greater or lower amplitude. Interference usually refers to the interaction of waves that are correlated or coherent with each other, either because they come from the same source or because they have the same or nearly the same frequency. Interference effects can be observed with all types of waves, for example, light, radio, acoustic, surface water waves or matter waves.



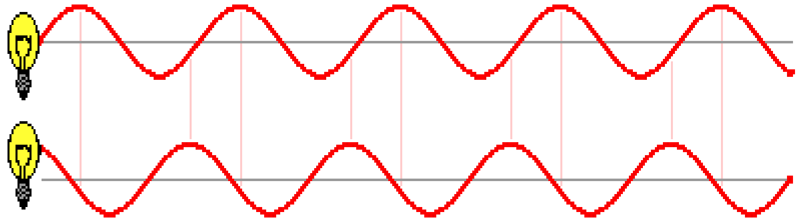
Conditions of Interference

When waves come together they can interfere constructively or destructively. To set up a stable and clear interference pattern, two conditions must be met:

1. The sources of the waves must be coherent, which means they emit identical waves with a constant phase difference.
2. The waves should be monochromatic - they should be of a single wavelength.

Coherent Sources

Those sources of light which emit light waves continuously of same wavelength, and time period, frequency and amplitude and have zero phase difference or constant phase difference are coherent sources.



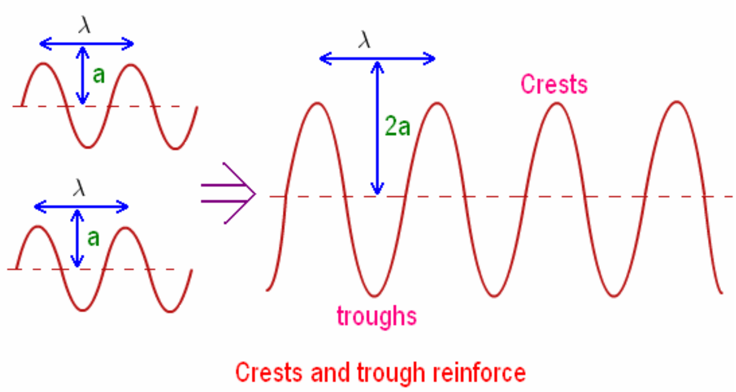
These two waves are coherent - they have a phase difference which is constant over time.

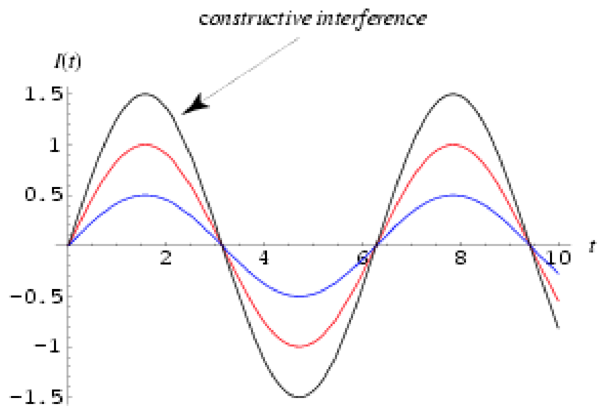
There are two types of interference.

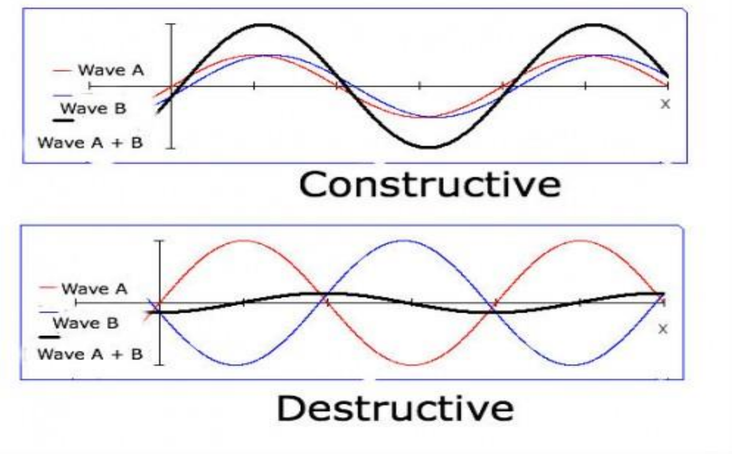
1. Constructive Interference
2. Destructive Interference

Constructive Interference

When two light waves superpose with each other in such a way that the crest of one wave falls on the crest of the second wave, and trough of one wave falls on the trough of the second wave, then the resultant wave has larger amplitude and it is called constructive interference.

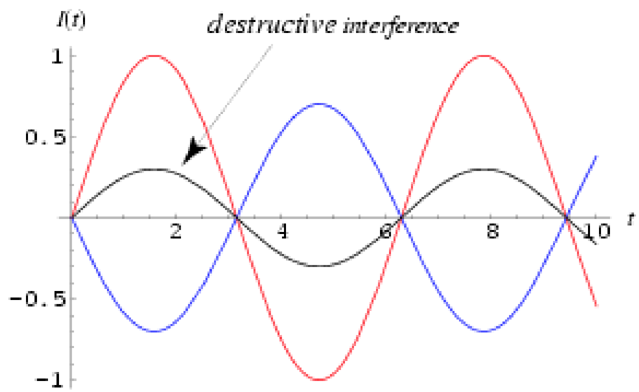


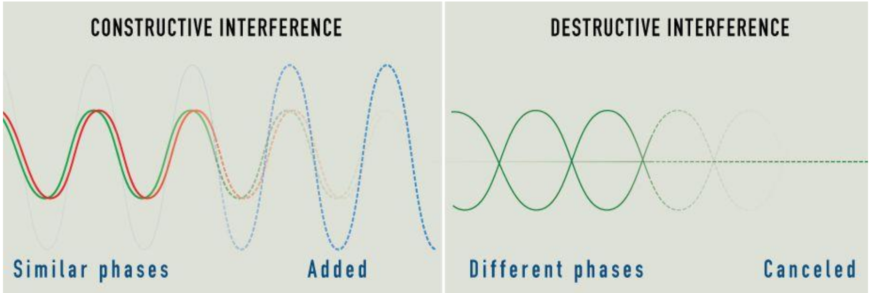




Destructive Interference

When two light waves superpose with each other in such a way that the crest of one wave coincides the trough of the second wave, then the amplitude of resultant wave becomes zero and it is called destructive interference.





Young's Double Slit Experiment

In 1801, an English physicist named Thomas Young performed an experiment that strongly inferred the wave-like nature of light.

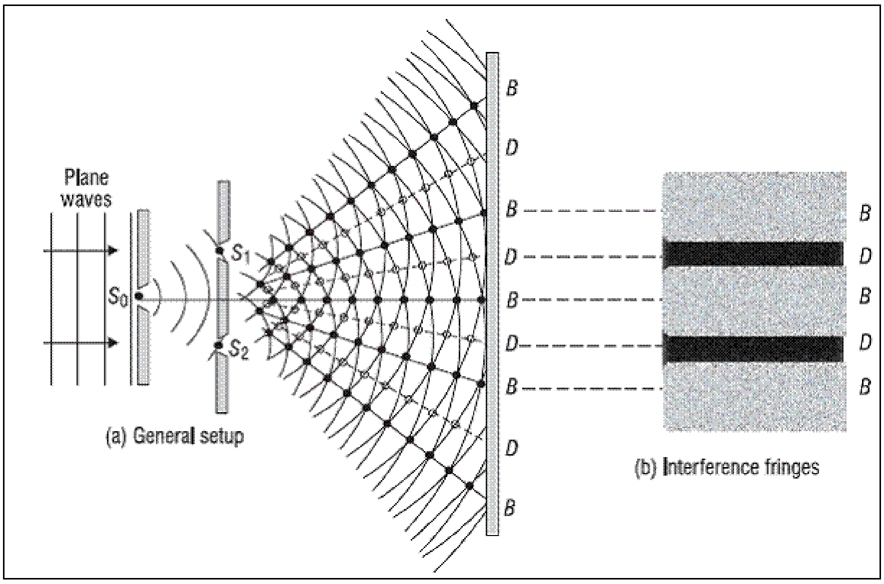


Fig: Young's double slit experiment

Thomas Young demonstrated the experiment on the interference of light. He allowed, light to fall on a pinhole S_0 and then at some distance away on two pinholes S_1 and S_2. S_1 and S_2 are equidistant from S_0 and are close to each other. Spherical waves spread out from S_0. Spherical waves also spread out from S_1 and S_2. These waves are of the same amplitude and wavelength. On the screen interference bands are produced which are alternatively dark and bright. The points such as B are bright because the crest due to the one wave coincides with the rest due to the other and therefore they reinforce with each other. The points such as D are dark because of the crest of one falls to on the trough of the other and they neutralize the effect of each other. Points, similar to B, where the trough of one falls on the trough of the other, are also bright because the two waves reinforce.

It is not possible to show interference due to two independent sources of light, because a large number of difficulties are involved. The two sources may emit light waves of largely different amplitude and wave length and the phase difference between the two may change with time.

Theory of Interference Fringes

Consider, a narrow monochromatic source S and two pinholes S_1 and S_2, equidistant from S. S_1 and S_2 acts as two coherent sources separated by a distance d.

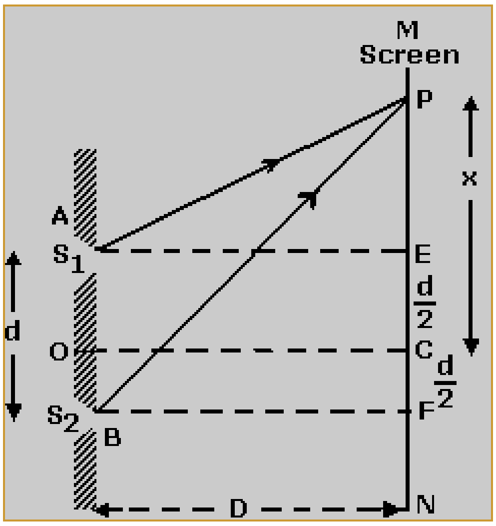


Fig: Young's double slit experiment

Let a screen be placed at a distance D from the coherent source. The point C on the screen is equidistant from S_1 and S_2. Therefore, the path difference between the two waves is zero. Thus, the point C has maximum intensity.

Consider a point P at a distance x from C. The waves reach at the point P from A and B.

Here,

$PE = x - \frac{d}{2}$

$PF = x + \frac{d}{2}$

Now from the triangle PAE we get,

$$(AP)^2 = D^2 + \left(x - \frac{d}{2}\right)^2 \text{ ------------------------(1)}$$

Similarly, from the triangle PBF we get

$$(BP)^2 = D^2 + \left(x + \frac{d}{2}\right)^2 \text{------------------------(2)}$$

Subtracting equation (1) from equation (2)

$$(BP)^2 - (AP)^2 = \left[D^2 + \left(x + \frac{d}{2}\right)^2\right] - \left[D^2 + \left(x - \frac{d}{2}\right)^2\right]$$

$$\text{or, } (BP)^2 - (AP)^2 = D^2 + x^2 + xd + \frac{d^2}{4} - D^2 - x^2 + xd - \frac{d^2}{4}$$

$$\text{or, } (BP)^2 - (AP)^2 = 2xd$$

$\mathrm{or,(BP - AP)(BP + AP) = 2xd}$

$\mathrm{or,(BP - AP) = 2xd/(BP + AP)}$------------------------(3)

As, $d \ll D$. So, we can assume that $BP \approx AP \approx D$. So, from equation (3) we can write-

$\mathrm{(BP - AP) = 2xd/(D + D)}$

$\mathrm{or,(BP - AP) = 2xd/(D + D)}$

$\therefore \mathrm{(BP - AP) = xd/D}$

But $(BP - AP)$ is the path difference of the light at point P.

$\therefore$ The path difference $= \mathrm{xd/D}$ ----------------------------(4)

Again, we know, the phase difference $= \frac{2\pi}{\lambda} \times$ the path difference.

So, the phase difference of the light at point P $= \frac{2\pi}{\lambda} \times \frac{\mathrm{xd}}{\mathrm{D}}$ -----------------(5)

Condition for bright fringes:

If the path difference is a whole number multiple of wavelength λ, then the points will be bright.

i.e., $\frac{\mathrm{x\,d}}{\mathrm{D}} = \mathrm{n}\,\lambda$ Where n = 0, 1, 2, 3……………..

$\therefore \mathrm{x} = \frac{\mathrm{n}\,\lambda\,\mathrm{D}}{\mathrm{d}}$---------------------------------(6)

This equation gives the distances of the bright fringes from the point C. At C, the path difference is zero and a bright fringe is formed.

When $\mathrm{n} = 0,\ \mathrm{x_0} = 0$

$\mathrm{n} = 1,\ \mathrm{x_1} = \frac{\lambda\,\mathrm{D}}{\mathrm{d}}$

$\mathrm{n} = 2,\ \mathrm{x_2} = \frac{2\,\lambda\,\mathrm{D}}{\mathrm{d}}$

$\mathrm{n} = 3,\ \mathrm{x_3} = \frac{3\,\lambda\,\mathrm{D}}{\mathrm{d}}$

…………………………….

$\mathrm{n} = \mathrm{n},\ \mathrm{x_n} = \frac{\mathrm{n}\,\lambda\,\mathrm{D}}{\mathrm{d}}$

Therefore, the distance between any two consecutive bright fringes

$\mathrm{x_2 - x_1} = \frac{2\,\lambda\,\mathrm{D}}{\mathrm{d}} - \frac{\lambda\,\mathrm{D}}{\mathrm{d}} = \frac{\lambda\,\mathrm{D}}{\mathrm{d}}$ --------------------------------------(7)

Condition for dark fringes:

If the path difference is an odd number multiple of half wavelength, then the point will be dark.

i.e., $\frac{x\,d}{D} = \frac{2n+1}{2}\lambda$

$\therefore\ x = \frac{(2n+1)\,\lambda\,D}{2d}$

This equation gives the distances of the dark fringes from the point C.

When, $n = 0,\ \ x_0 = \frac{\lambda\,D}{2\,d}$

$n = 1,\ \ x_1 = \frac{3\,\lambda\,D}{2\,d}$

$n = 2,\ \ x_2 = \frac{5\lambda\,D}{2d}$

$$n = 3,\ \ x_3 = \frac{7\,\lambda\,D}{2\,d}$$

……………………………

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

The distance between any two consecutive dark fringes,

$x_2 - x_1 = \frac{5\,\lambda\,D}{2d} - \frac{3\lambda\,D}{2d} = \frac{\lambda\,D}{d}$ ---------------------------(8)

The distance between any two-consecutive bright or dark fringes is known as fringe width.

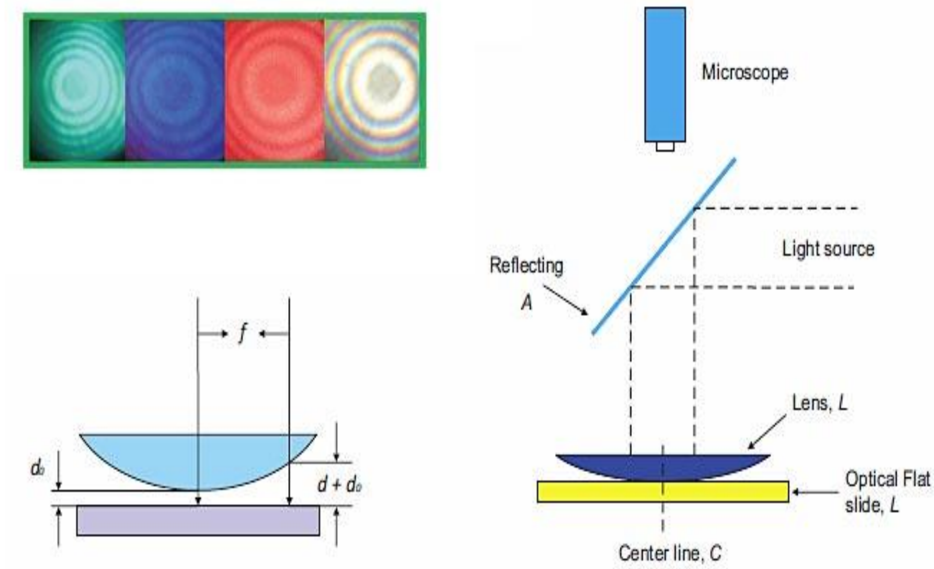
Therefore, alternately bright and dark parallel fringes are formed. The fringes are formed on both sides of C. Moreover, from equations (7) and (8), it is clear that the width of the bright fringe is equal to the width of the dark fringe. All the fringes are equal in width and are independent of the order of the fringe. The breadth of a bright or a dark fringe is, however, equal to half the fringe width and is equal to $\frac{\lambda D}{2d}$.

The fringe width = $\frac{\lambda D}{d}$

Therefore, (i) the width of the fringe is directly proportional to the wavelength of light, $\propto \lambda$. (ii) The width of the fringe is directly proportional to the distance between the two sources, $\propto \frac{1}{d}$. Thus, the width of the fringe increases (a) with increase in wavelength (b) with increase in the distance D and (c) by bringing the two sources A and B close to each other.

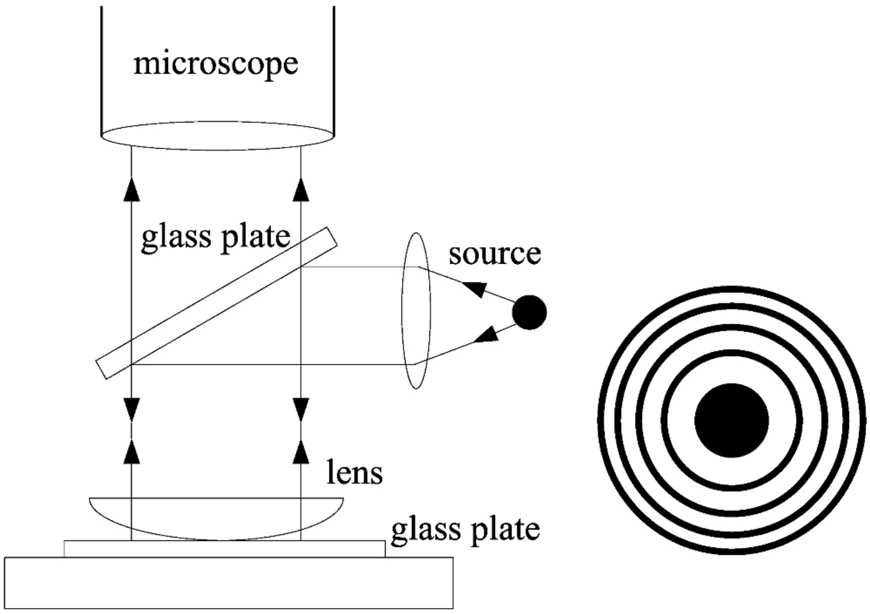
Newton’s Ring

Newton's ring is a phenomenon in which an interference pattern is created by the reflection of light between two surfaces—a spherical surface and an adjacent flat surface. It is named after Isaac Newton, who first studied them in 1717.



Newton’s Ring Experiment

When a Plano-convex lens of long focal length is placed on a plane glass plate, a thin film of air is enclosed between the lower surface of the lens and the upper surface of the plate.

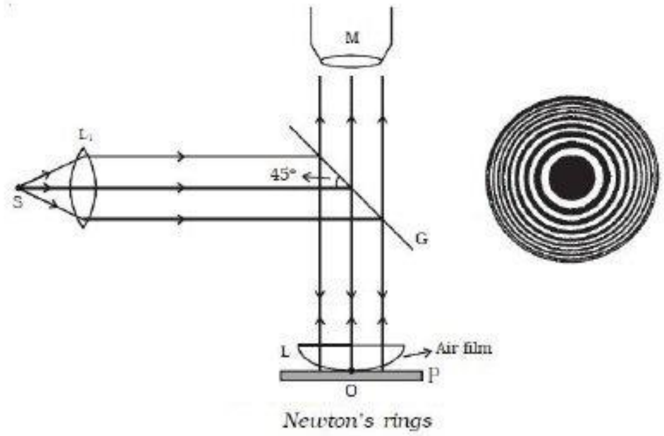


(a) (b)

The thickness of the air film is very small at the point of contact and gradually increases from the center outwards. The fringes produced with monochromatic light are circular. The fringes are concentric circles, uniform in thickness and with the point of contact as the center. When viewed with white light, the fringes are colored. With monochromatic light, bright and dark circular fringes are produced in the air film.

Determination of the Wavelength of Sodium Light using Newton's Ring

The arrangement used is shown in the figure below. S is a source of sodium light. A parallel beam of light from lens L_1 is reflected by the glass plate G inclined at an angle of 45^0 to the horizontal. L is a plano-convex lens of large focal length. Newton's rings are viewed through G by the travelling microscope M focused on the air film. Circular bright and dark rings are seen with the center dark. With the help of travelling microscope, the diameter of the n^{th} ring can be measured.



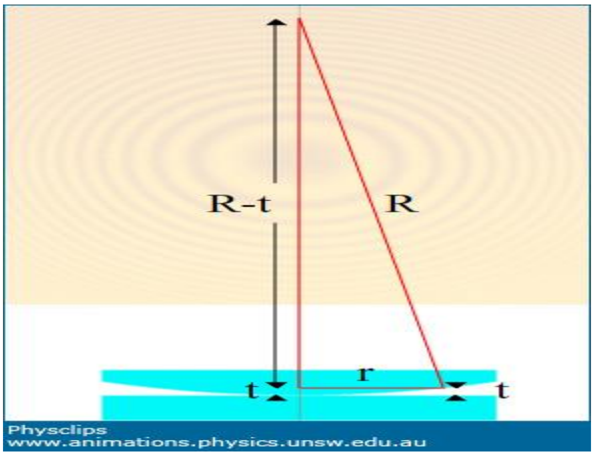


Fig.: Newton's ring experiment

The optical path difference between the rays is given by

$\Delta = 2\mu t\cos(r) - \frac{\lambda}{2}$ --------------------------------(1)

Since, $\mu = 1$ for air and the incident angle $r = 0°$ therefore $\cos(r) = 1$ for normal incidence of light, so from equation (1) we can write-

$\Delta = 2t - \frac{\lambda}{2}$ --------------------------------------(2)

Let R be the radius of curvature of the lens. Let a dark fringe be located at distance r from the middle point of the lens and the thickness of the air film at r distance be t. By the Pythagorus theorem,

$R^2 = r^2 + (R-t)^2$

or, $R^2 = r^2 + R^2 - 2Rt + t^2$

$\therefore\ r^2 = 2Rt - t^2$ -------------------------------------(3)

As $R \gg t$, so $2Rt \gg t^2$. So, equation (3) can be written as

$r^2 = 2Rt$ ---------------------------------------(4)

Dark ring occurs when the optical path difference is

$\Delta = \frac{(2m+1)\lambda}{2}$ where, m=0,1,2,3 ……….

$$\text{or, } 2t - \frac{\lambda}{2} = \frac{(2m+1)\lambda}{2}$$

$\therefore\ 2t = m\lambda$ ------------------------------------(5)

where m=1,2,3, 4, ………..

substituting the value of equation (5) into equation (4), we get-

$r^2 = mR\lambda$

As here r is the radius of the m[th] ring. So, it can be denoted by r_m.

$r_m^2 = mR\lambda$ ---(6)

Suppose, the diameter of the m[th] ring = D_m.

But, $r_m = \frac{D_m}{2}$

$$\frac{D_m^2}{4} = mR\lambda$$

$D_m^2 = 4mR\lambda$ --(7)

Let the diameter of the $(m + n)$th dark ring be D_{n+m}. Similarly, we can write

$D_{m+n}^2 = 4(m + n)R\lambda$ -----------------------------(8)

Subtracting equation from number (7) from (8)

$D_{n+m}^2 - D_n^2 = 4\,(n+m)\,\boldsymbol{\lambda}\,R - 4\,m\,\boldsymbol{\lambda}\,R$

$\boldsymbol{\lambda} = \frac{D_{n+m}^2 - D_n^2}{4nR}$

Hence, $\boldsymbol{\lambda}$ can be calculated.

Suppose, the diameter of the 5 th ring and the 15 th ring are determined. Then, n = 15 – 5 = 10

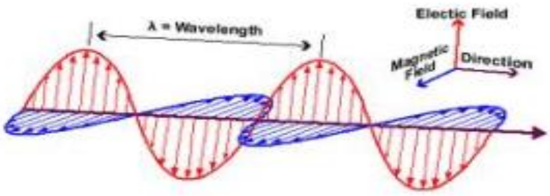
$\boldsymbol{\lambda} = \frac{D_{15}^2 - D_5^2}{4\times10\times R}$

The radius of curvature of the lower surface of the lens is determined with the help of spherometer but more accurately it is determined by Boy's method. Hence the wavelength of a given monochromatic source of light can be determined.

Polarization

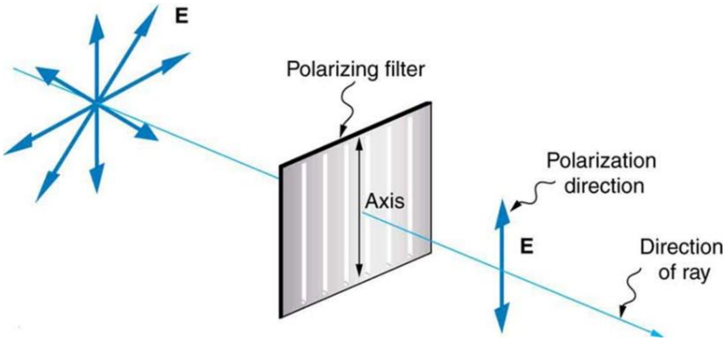
The process by which light waves vibrating in different planes can be made to vibrate in a particular plane is called polarization of light. Sound waves in a gas or liquid do not exhibit polarization, since the oscillation is always in the direction the wave travels.

In an electromagnetic wave, both the electric field and magnetic field are oscillating but in different directions.



Light wave

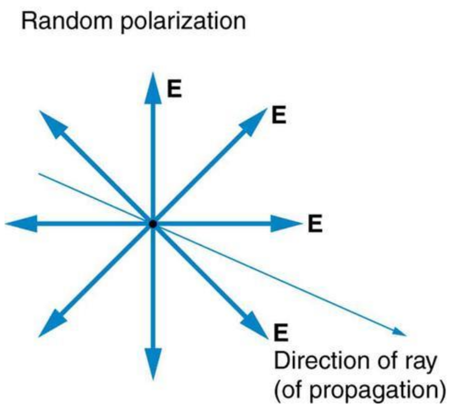
Fig. 1



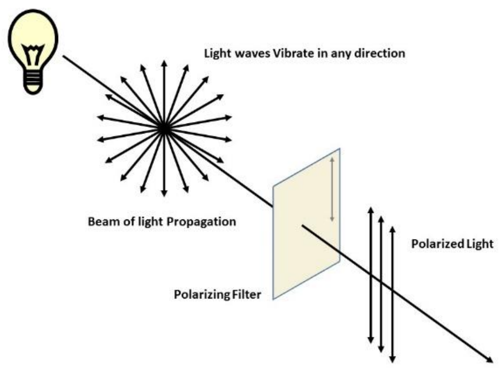
Electromagnetic Waves

Some terms relating to polarization

(1) Unpolarized light: Ordinary light waves whose vibrations normal to the direction of propagation, spread all around the source with equal amplitude is called unpolarized light. The figure given below shows the unpolarized light.

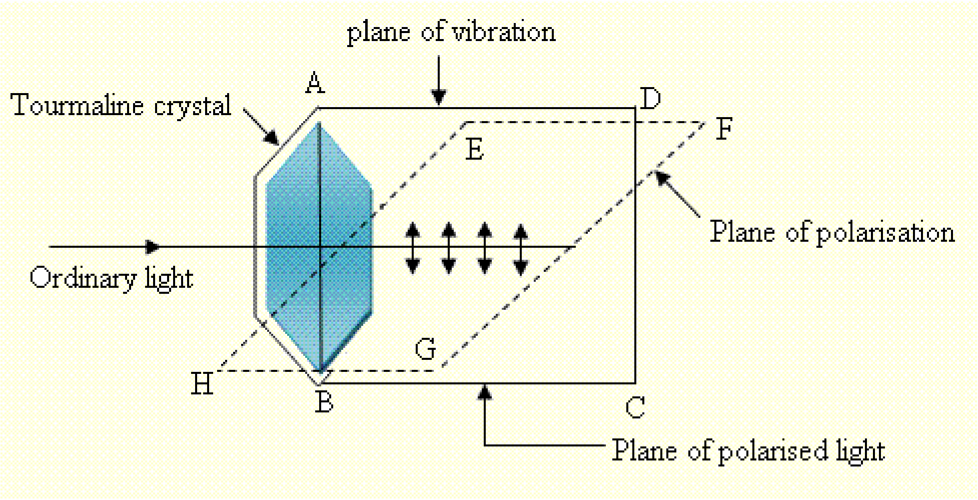


(2) Polarized light: The transverse light waves vibrating on a particular plane or parallel to it is called polarized light.



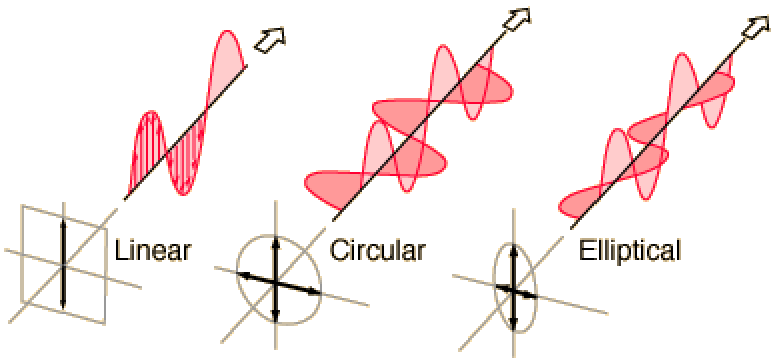
(3) **Plane of vibration:** The plane in which the particles of the light waves vibrate is called the plane of vibration. The below figure shows the plane of vibration. ABCD is the plane of vibration.

(4) **Plane of polarization:** The plane which exists normal to the plane of vibration is called the plane of polarization. In the figure EFGH is the plane of polarization.



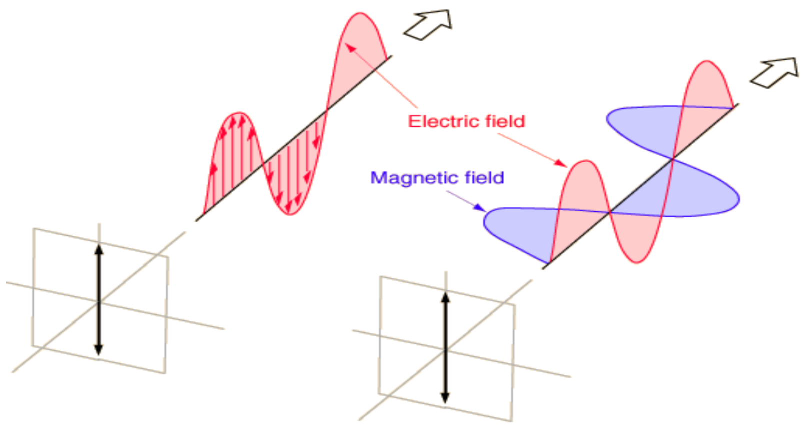
Classification of Polarization

Light in the form of a plane wave in space is said to be linearly polarized. Light is a transverse electromagnetic wave, but natural light is generally unpolarized, all planes of propagation being equally probable. If light is composed of two plane waves of equal amplitude by differing in phase by 90°, then the light is said to be circularly polarized. If two plane waves of differing amplitude are related in phase by 90°, or if the relative phase is other than 90° then the light is said to be elliptically polarized.



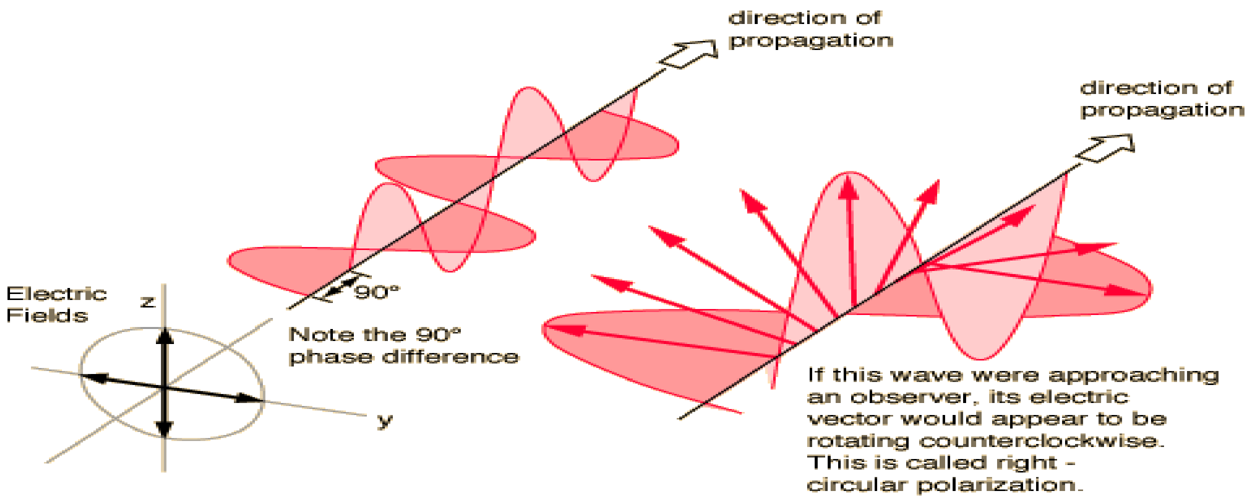
<u>Linear Polarization</u>

A plane electromagnetic wave is said to be linearly polarized. The transverse electric field wave is accompanied by a magnetic field wave as illustrated.



Circular Polarization

Circularly polarized light consists of two perpendicular electromagnetic plane waves of equal amplitude and 90° difference in phase. The light illustrated is right- circularly polarized.



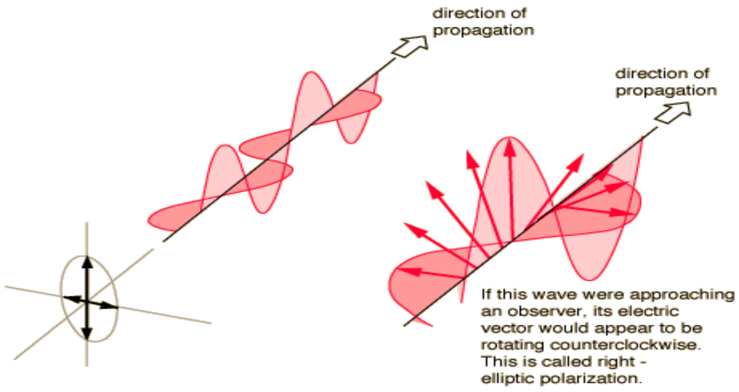
If light is composed of two plane waves of equal amplitude but differing in phase by 90°, then the light is said to be circularly polarized. If you could see the tip of the electric field vector, it would appear to be moving in a circle as it approached you.

If while looking at the source, the electric vector of the light coming toward you appears to be rotating counterclockwise, the light is said to be right-circularly polarized. If clockwise, then left-circularly polarized light. The electric field vector makes one complete revolution as the light advances one wavelength toward you. Another way of saying it is that if the thumb of your right hand were pointing in the direction of propagation of the light, the electric vector would be rotating in the direction of your fingers.

Circularly polarized light may be produced by passing linearly polarized light through a quarter-wave plate at an angle of 45° to the optic axis of the plate.

Elliptical Polarization

Elliptically polarized light consists of two perpendicular waves of unequal amplitude which differ in phase by 90°. The illustration shows right- elliptically polarized light.



Production of linearly polarized light

Linearly polarized light may be produced from unpolarized light using of the following five optical phenomena:

1. Reflection
2. Refraction
3. Scattering
4. Selective absorption (dichroism) and
5. Double refraction

Brewster's Law

In 1811 Brewster's proposed it. The law states that the tangent of the angle at which polarization is obtained by reflection is numerically equal to the refractive index of the medium.

If θ_p is the angle and μ is the refractive index of the medium, then

$$\mu = \tan\theta_p$$

This is known as Brewster's law.

Mathematical derivation:

If natural light is incident on a smooth surface at the polarizing angle, it is reflected along PC and refracted along PB, as shown in figure. Brewster found that the maximum polarization of reflected ray occurs when it is at right angle to the refracted ray.

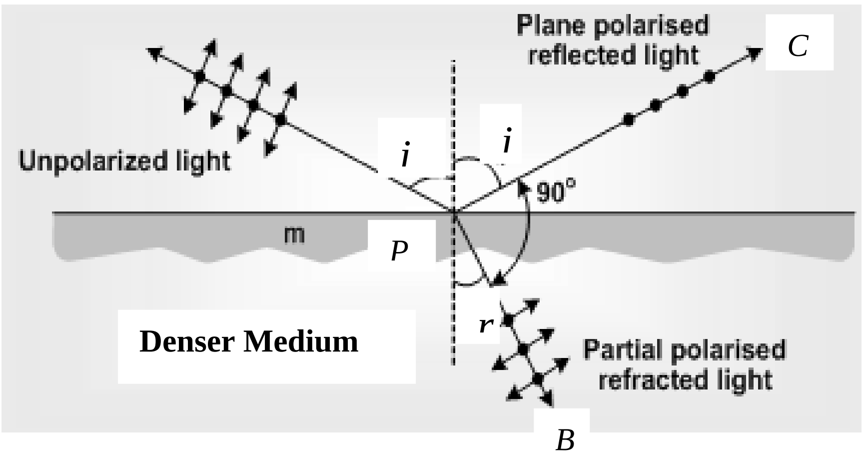


Fig.: Production of plane polarized light by the method of reflection.

It means that

$i + r = 90°$

$\therefore r = 90° - i$ ----------------------------------(1)

Where, i and r represents the incident angle and the refractive angle respectively.

According the Snell's law,

$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$ -----------------------------------(2)

Where μ_2 and μ_1 are the absolute refractive index of the reflecting surface and the surrounding medium.

It follows from equation (1) and (2) that

$$\frac{\sin i}{\sin(90° - i)} = \frac{\mu_2}{\mu_1}$$

$$\text{or,} \frac{\sin i}{\cos i} = \frac{\mu_2}{\mu_1}$$

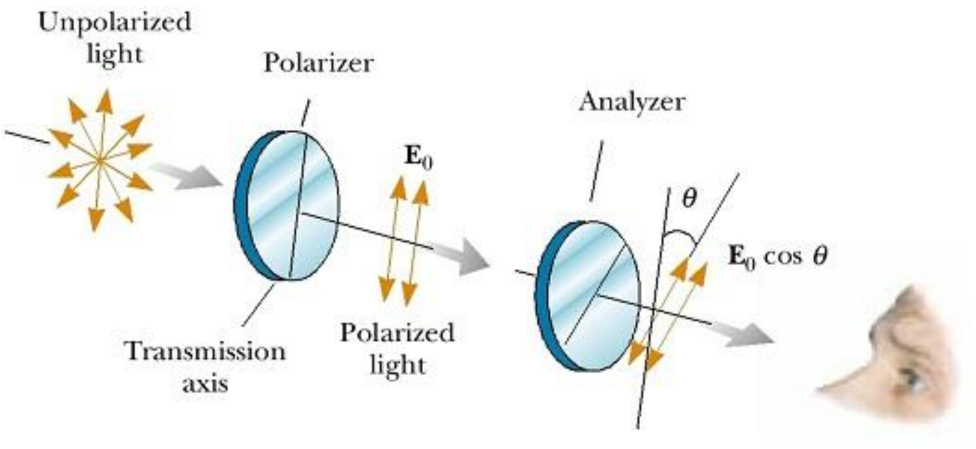
$\therefore \tan i = \frac{\mu_2}{\mu_1}$ ---------------------------------(3)

Equation (3) shows that the polarizing angle depends on the refractive index of the reflecting surface. The polarizing angle i is also known as Brewster angle and denote as θ_B. Light reflected from any angle other than Brewster angle is partially polarized.

Specific rotation:

The specific rotation for a given wavelength of light at a given temperature is defined conventionally as the rotation produced by one decimeter long column of the solution containing 1 gm of optically active material per c.c. of solution. It is denoted by S.

$$[S]_\lambda^t = \frac{\theta}{l \times C} = \frac{Rotation\ in\ degrees}{length\ in\ decimeters\ \times conc.in\frac{gm}{c.c.}} = \frac{10\theta}{l(cm)C}$$



Malues Law:

According to malus, when completely plane polarized light is incident on the analyzer, the intensity I of the light transmitted by the analyzer is directly proportional to the square of the cosine of angle between the transmission axes of the analyzer and the polarizer.

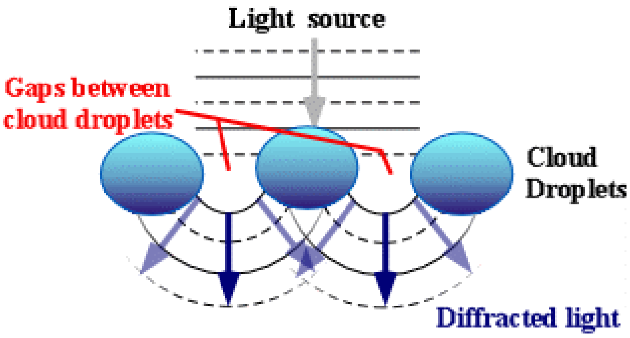
If E_1 is the intensity of the transmitted wave and θ is the angle between the planes of polarizer and the analyser. Then,

$E_1 \propto cos^2 \theta$

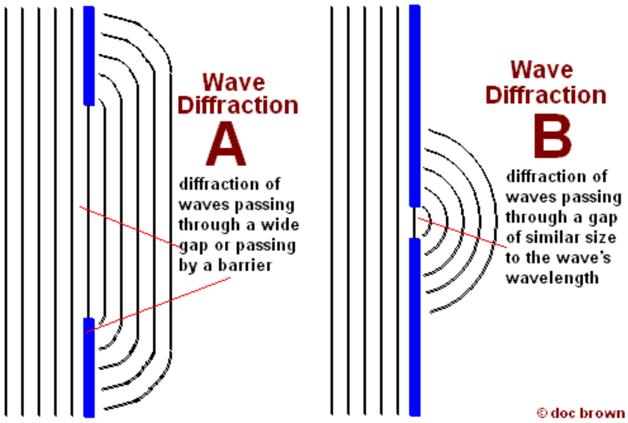
$E_1 = E\, cos^2 \theta$; Where E is the intensity of the incident polarized light.

This is known as Malues law of polarization.

Diffraction is the slight bending of light as it passes around the edge of an object. The amount of bending depends on the relative size of the wavelength of light to the size of the opening. If the opening is much larger than the light's wavelength, the bending will be almost unnoticeable. However, if the two are closer in size or equal, the amount of bending is considerable, and easily seen with the open eye.



In the atmosphere, diffracted light is actually bent around atmospheric particles -- most commonly, the atmospheric particles are tiny water droplets found in clouds. Diffracted light can produce fringes of light, dark or colored bands. An optical effect that results from the diffraction of light is the silver lining sometimes found around the edges of clouds or coronas surrounding the sun or moon. The illustration above shows how light (from either the sun or the moon) is bent around small droplets in the cloud.



Condition of diffraction

There are two conditions for the production of diffraction

(1) In case of straight edge: The edge should be very sharp and its width is to be equal to or is of the order of the wavelength, λ of light.

(2) In case of thin hole: the diameter of the hole should be extremely very small such that it is equal to or is of the order of the wavelength λ of light.

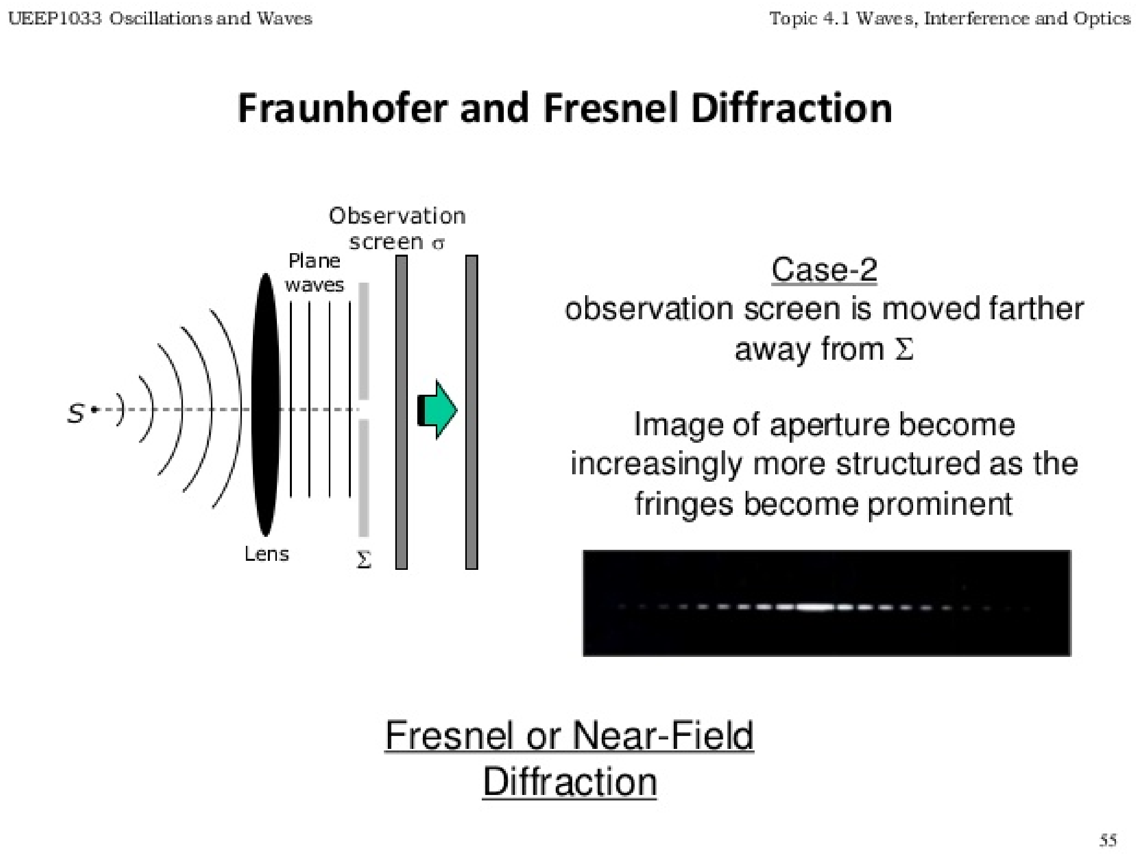
Diffraction is of two types

(1) Fresnel’s class of diffraction
(2) Fraunhofer’s class of diffraction

<u>Fresnel’s class of diffraction</u>

When the source of light and the screen are at finite distance from the inside obstacle, then the diffraction observed due to the obstacle is called the Fresnel class of diffraction.

In this type of diffraction wave fronts are generally spherical or cylindrical. This type of diffraction occurs in a straight edge, fine wire and narrow slit.

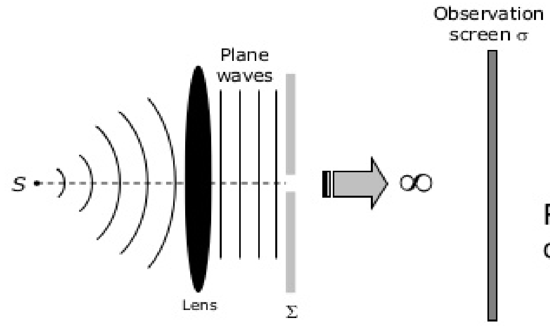


<u>Fraunhofer’s class of diffraction</u>

When the source of light and the screen are effectively at infinite distance from the obstacle or aperture causing diffraction, then that type of diffraction is called Fraunhofer’s class of diffraction.

In this type of diffraction wave fronts incident on the obstacle or aperture is plane.

Fraunhofer and Fresnel Diffraction



Fraunhofer or Far-Field Diffraction

Case-3
observation screen is at very great distance away from Σ

Projected pattern will have spread out considerably, bearing a little or no resemblance to the actual aperture

Thereafter moving the screen away from the aperture change only the size of the pattern and not its shape