





Sponsored by  
**The Science Foundation College**  
**Uganda East Africa**  
**Senior one to senior six**

+256 778 633682 0753 143413

**Based on, Best for Science**

[digitalteachers.co.ug](http://digitalteachers.co.ug)



Nuture your dreams  

## SENIOR SIX TERM 1

### TOPIC 4/6: PROGRESSIVE WAVES

**Competency:** The learner investigates the propagation of progressive waves in matter and its application in different situations.

#### WAVES

##### Definition

A wave is any disturbance from an equilibrium condition that travels with time from one region to another in form of oscillation.

Or

A wave is a means of transfer of energy by a vibrating medium.

##### Classes of Waves

Waves can also be classified as mechanical waves and electromagnetic waves.

##### Mechanical waves

These are wave which require a material medium for transmission. Mechanical waves include: Sound waves, water waves, waves on strings etc.

##### Electromagnetic waves

These are wave which do not require a material medium for transmission. Electromagnetic waves include: light waves, radio waves, X-ray, ultraviolet etc.

Differences between mechanical and electromagnetic waves

Mechanical Waves	Electromagnetic waves
Need a medium for transmission.	Do not need a medium for transmission.
Cannot travel through vacuum.	Can travel through a vacuum.
Relatively slow	Very fast

Please find free new curriculum notes, exams and marking guides on [digitalteachers.co.ug](http://digitalteachers.co.ug) website

## Types of waves

There are two kinds of waves namely:

- (i) Longitudinal waves.
- (ii) Transverse waves.

### Longitudinal waves

A longitudinal wave is one in which the direction of the wave motion is the same direction as the vibration.

OR

A longitudinal wave is one in which particles vibrate in direction parallel to wave motion.

**Examples of longitudinal waves** are sound waves, waves produced by pipes and string instruments. A longitudinal wave has two regions namely: compression and rarefaction regions.

Diagram showing motion of particles for longitudinal wave.



**C** is compression region, **R** is rarefaction region.

### Compression region

**Compression region** is a region in the longitudinal wave where the vibrating particles are very close together. A particle at the centre of compression region moves from the rest position in same direction as the wave.

### Rarefaction region

**Rarefaction region** is a region in the longitudinal wave where the vibrating particles are further apart. A particle at the centre of rarefaction moves from rest position in the opposite direction to that of the wave.

### Differences between compression and rarefaction regions of longitudinal wave.

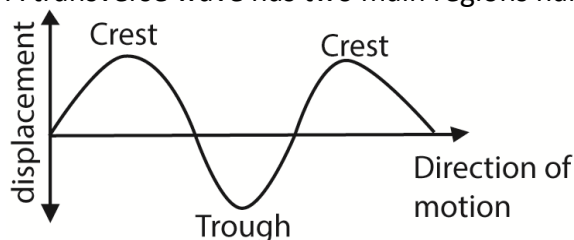
Compression	Rarefaction
Vibrating particles are very close together.	Vibrating particles are further apart.
A particle at the centre moves from rest position in a direction the same as that of the wave motion.	A particle at the centre moves from rest position in opposite direction to that of the wave motion.

## Transverse waves

**Transverse wave** is one in which particles vibrate perpendicular to the direction of wave motion.

Example: Water waves, light waves, all electromagnetic waves.

A transverse wave has two main regions namely: Crest and Trough.



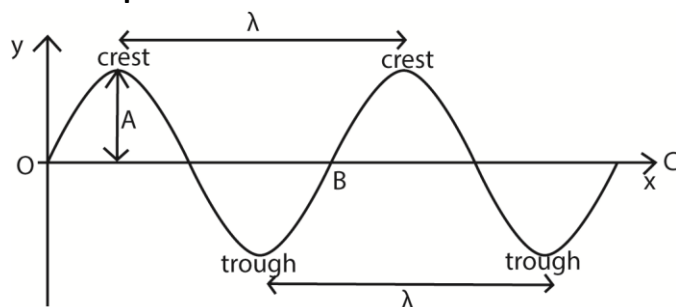
**Crest** is a region of maximum upward displacement of particles in a transverse wave.

**Trough** is a region of maximum downward displacement of particles in a transverse wave.

## Differences between a transverse wave and longitudinal wave

Transverse	Longitudinal wave
Particles vibrate perpendicular to the direction of the wave motion	Particles vibrate in a direction parallel to wave motion
Has 2 regions crest and trough	It has 2 regions, compression region and rarefaction
No variation in particle density occurs along the profile	Particle density varies along the wave profile
The distance between successive crests or troughs is the wavelength	Distance between successive rarefactions or compression is the wave length.
Can undergo polarization	Cannot be polarized.

## General presentation of a wave



Please find free new curriculum notes, exams and marking guides on [digitteachers.co.ug](https://digitteachers.co.ug) website

A wave can be represented graphically by a sine wave. The curve is drawn by plotting displacement of particles,  $y$  against distance of the particle from the source of the wave,  $x$ .

### Definition of terms

- (a) OC is the equilibrium/resting/mean position.
- (b) Displacement is a distance of any particle at any point of the wave from equilibrium position.
- (c) **Amplitude (A)** is a maximum displacement of a particle from its rest position on a wave.
- (d) **Crest** is the point on the wave profile with maximum positive displacement.
- (e) **Trough** is the point on the wave profile with maximum negative displacement.
- (f) **Cycle or oscillation:** This is a complete to and fro motion of a wave. It is equivalent to moving from O to B along the wave profile.
- (g) **Wavelength,  $\lambda$ .** This is the distance between two successive particles in a wave profile which are in phase. Particles are said to be in phase if they are at the same stage of their motion; i.e. have the same displacement from the equilibrium position and are travelling in the same direction.

As applied to a transverse waves, wavelength is the distance between two successive troughs or crests.

Applied to longitudinal waves, wavelength is the distance between two successive compressions or between two successive rarefactions.

The SI unit of wavelength is meters.

- (h) **Period, T.** This is the time taken by a wave to perform one complete cycle or oscillation. It can also be defined as the time taken by a wave to cover a distance of 1 wavelength. S.I. unit of period is Hertz (Hz) or per second.
- (i) **Ray** is a line perpendicular to wave front which shows the direction of travel of a wave.
- (j) **Phase** is a fraction of a cycle which has elapsed after a particle passing a fixed point
- (k) **Wave front**, any line of section taken through an advancing wave in which all particles are in phase or it is an imaginary line which joins the set of particles that are in phase.

Particles are in phase if they are in the same point in path at the same time and are moving in the same direction.

### Relationship between T and f

Consider a wave motion in which  $n$  cycle is made in time  $t$  seconds. One oscillation will be made in  $\frac{t}{n}$  seconds.

$$\Rightarrow T = \frac{t}{n}$$

Also in 1 second,  $\frac{n}{t}$  oscillations are made.

$$\Rightarrow f = \frac{n}{t}$$

$$\text{But } \frac{n}{t} = \frac{1}{\frac{t}{n}}$$

$$\therefore f = \frac{1}{T}$$

### Velocity of a wave

The velocity of a wave is the speed with which the wave propagates. It can also be defined as the rate of wave travel in meters per second ( $\text{ms}^{-1}$ )

### Relationship between v, f and $\lambda$

Consider a source of wave that produces waves of frequency,  $f$  and wavelength,  $\lambda$ . whenever the source makes one oscillation, the wave travels forward by one wavelength.

If  $f$  oscillations are made per second, the wave travels forward by a distance given by

$$\text{Distance} = f\lambda$$

But the distance moved per second =  $v$

$$\therefore v = f\lambda$$

### Wave motion and oscillation motion

Wave motion is a form of oscillation motion.

Oscillation motion is motion where a body or particle move to and fro in the same path.

If the oscillatory motion repeats itself at regular time intervals, then it is periodic motion.

If the periodic motion can be represented by sine curve, it is said to be harmonic motion.

**An oscillation** is defined as a complete to and fro displacement of a particle from equilibrium position. Oscillation may be mechanical or electrical oscillation.

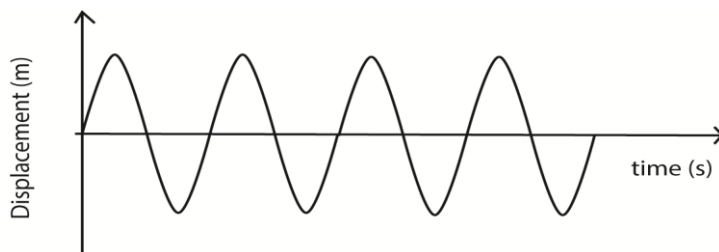
**Mechanical oscillation** are those in which energy is passed and stored by vibrating particle.

**Electrical oscillation** are those in which energy is possessed and stored in electrical and magnetic field.

### Types of oscillation

#### (a) Free oscillation

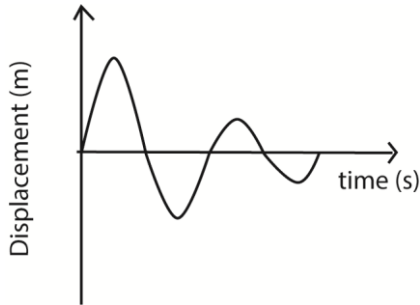
These are indefinite oscillations that occurs with constant energy and amplitude due to absence of dissipative forces (e.g. friction, air resistance and viscosity).



Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](https://digitlteachers.co.ug) website

**(b) Damped oscillation**

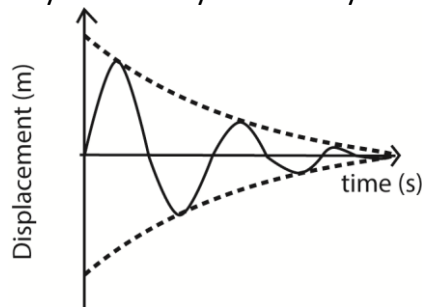
These are oscillations that progress with decreasing amplitude and energy due to dissipative forces such that the system loses energy to the surrounding and amplitude of oscillation decreases until the system finally comes to rest. The amplitude of oscillation reduces because the dissipative forces cause the system to progressively lose energy.



There are three types of damped oscillations

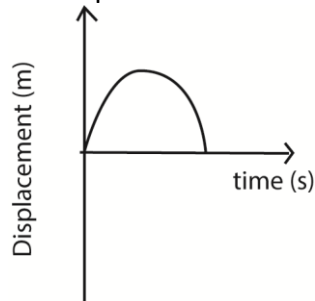
**(i) Under damped oscillation**

These are oscillations in which the system experiences low resistance/dissipative forces such that it loses energy gradually and amplitude of oscillations decrease gradually until the system finally comes to rest.



**(ii) Critically damped**

These are oscillation which occur when a system is displaced but does not oscillate and return to equilibrium position in the minimum possible time. The magnitude of resistive forces is such that they do not allow the system to vibrate past this equilibrium position.

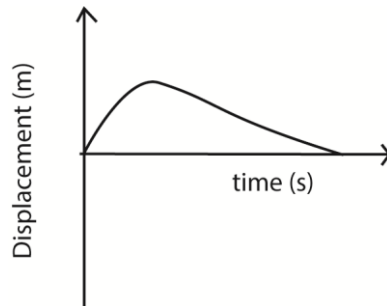


Critical damping is applied in

- Moving coil instruments such as ammeters, voltmeters to bring the pointer to rest instantly so that a reading can be taken.
- Shock absorbers
- Office doors

(iii) **Over damped oscillations**

These are oscillations which occur when a system is displaced and does not oscillate but returns slowly to the equilibrium position



**Differences between free and damped oscillations**

<b>Free oscillation</b>	<b>Damped oscillations</b>
Amplitude of oscillation remain constant	Amplitude of oscillation decrease with time
Wave energy remain constant	Wave energy decrease with time
Oscillations occur in absence of dissipative force	Oscillations occur in presence of dissipative forces
System oscillates indefinitely	System finally comes to rest

**Forced oscillations**

These are oscillations in which the system subjected to some degree of damping is made continuously oscillate by subjecting it to external periodic force

The external periodic force restores the energy lost from the system as a result of dissipative forces.

The frequency of external periodic force is known as forcing frequency.

**Progressive waves**

A progressive wave is one that consists of disturbance moving from source outwards to the surrounding regions of which energy is transferred from one region to another.

In progressive wave, the wave profile moves from a source to the surrounding region at the same speed as the wave motion. The vibrations of the particles are of the same amplitude and frequency, but the phase of vibration changes from one point to another along the wave.

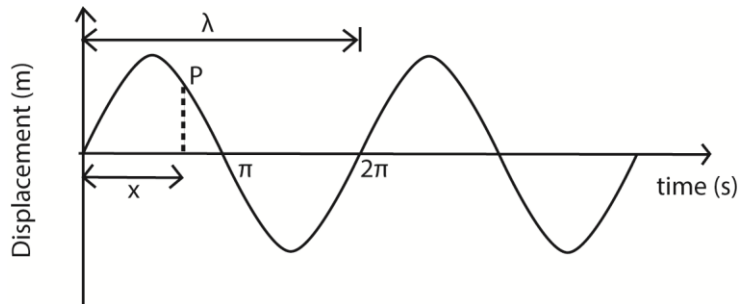
### Phase angle

The phase angle is angular displacement between two wave oscillations. It can also be angular displacement between particles at different points in another profile. Phase angle is represented by  $\phi$  and it is measured in radians.

### Phase difference

The phase difference is the difference in the phase angles at any two points along the wave motion. It is also measured in radians

Consider the wave motion below



The particle at P is said to lag behind the particle at O by phase difference  $\Delta\phi$  or  $X\phi$  determined by the horizontal distance,  $x$  of the particle P from particle O and the wavelength of the wave motion.

The phase difference is given by the expression;  $\phi = \frac{2\pi x}{\lambda}$

Where  $x$  = the difference between the two points on the wave motion

$\lambda$  = the wavelength

$\phi$  = the phase difference.

### Example 1

Find the phase difference between two waves each of wavelength 40cm when one leads the other by a distance of

(i) 20cm

$$\begin{aligned} \text{From } \phi &= \frac{2\pi x}{\lambda} \\ &= \frac{2\pi \times 20}{40} = \pi \text{ radians} \end{aligned}$$

(ii) 30cm

$$\begin{aligned} \text{From } \phi &= \frac{2\pi x}{\lambda} \\ &= \frac{2\pi \times 30}{40} = \frac{3}{2}\pi \text{ radians} \end{aligned}$$

(iii) 40cm

Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

$$\begin{aligned} \text{From } \phi &= \frac{2\pi x}{\lambda} \\ &= \frac{2\pi \times 40}{40} = 2\pi \text{ radians} \end{aligned}$$

### The progressive wave equation

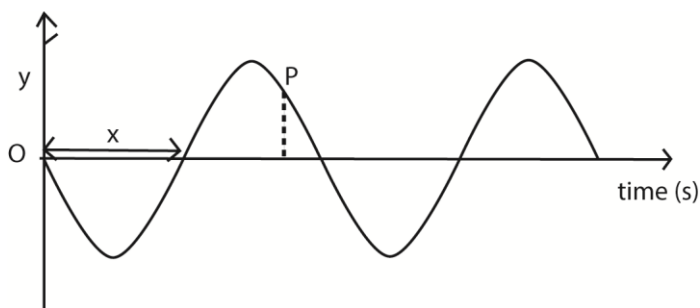
The progressive wave equation is the same as the equation for sine curve,

i.e.  $y = A \sin \omega t$

where  $y$  = displacement

$A$  = amplitude

$\omega$  = angular velocity



A particle P lags behind the particle O by a phase difference,  $\phi$ . The displacement of such a particle is given by equation  $y = A \sin(\omega t - \phi)$ .

This is the equation for a progressive wave moving in the positive x-direction.

For progressive wave moving in opposite direction, the equation is

$$y = A \sin(\omega t + \phi).$$

But from circular motion,  $\omega = 2\pi f$

$$\text{Also, } \phi = \frac{2\pi x}{\lambda}$$

Thus the progressive wave equation for a particle moving in the progressive x-direction can also be written as

$$y = A \sin\left(2\pi f t + \frac{2\pi x}{\lambda}\right)$$

$$y = A \sin 2\pi \left( f t - \frac{x}{\lambda} \right) \dots \dots \dots (i)$$

$$\text{Also from } v = f\lambda \text{ or } f = \frac{v}{\lambda}$$

$$y = a \sin 2\pi \left( \frac{vt}{\lambda} - \frac{x}{\lambda} \right)$$

$$y = a \sin \frac{2\pi}{\lambda} (vt - x)$$

$$\text{Also } f = \frac{1}{T}$$

Substituting f in equation (i)

$$y = a \sin 2\pi \left( \frac{t}{T} - \frac{x}{\lambda} \right)$$

### Example 2

The displacement,  $y$ , of a wave travelling in the direction at any time,  $t$ , is given by the equation

$$y = a \sin 2\pi \left( \frac{t}{0.5} - \frac{x}{2.0} \right)$$

- (i) Deduce the direction in which the wave is travelling.

Positive  $x$ - direction.

- (ii) Determine the speed of the wave

Comparing  $y = a \sin 2\pi \left( \frac{t}{0.5} - \frac{x}{2.0} \right)$  with  $y = a \sin 2\pi \left( \frac{t}{T} - \frac{x}{\lambda} \right)$

$$T = 0.5\text{s}; \lambda = 2.0\text{m}$$

$$\text{From } v = f\lambda \text{ but } f = \frac{1}{T}$$

$$v = 2 \times \frac{1}{0.5} = 4\text{ms}^{-1}$$

### Example 3

A sound wave propagated in the  $x$ -direction given by equation

$$y = 2 \times 10^{-7} \sin(8000t - 25x)\text{m}$$

Find

- (i) amplitude of the wave

comparing with  $y = a \sin(2\pi ft - \frac{2\pi x}{\lambda})$

$$\text{amplitude} = 2 \times 10^{-7}\text{m}$$

- (ii) speed of the wave

$$2\pi ft = 8000t \quad \text{also } \frac{2\pi x}{\lambda} = 25x$$

$$f = \frac{8000}{2\pi} \quad \lambda = \frac{2\pi}{25}$$

$$v = f\lambda$$

$$= \frac{8000}{2\pi} \times \frac{2\pi}{25} = 320\text{ms}^{-1}$$

### Example 4

A progressive wave and stationary waves each have a frequency of 240Hz and a speed of  $8\text{ms}^{-1}$ .

Calculate the

- (i) Phase difference between two vibrating points in the progressive wave which are 6cm apart.

$$\text{From } \phi = \frac{2\pi x}{\lambda} = \frac{2\pi \times 0.06}{\lambda}$$

$$\text{But } \lambda = \frac{v}{f} = \frac{8}{240} = \frac{1}{30}$$

$$\phi = \frac{2\pi \times 0.06}{\frac{1}{30}} = 3.6\pi \text{ radian}$$

- (ii) Distance between successive nodes =  $\frac{\lambda}{2} = \frac{\frac{1}{30}}{2} = \frac{1}{60}\text{m}$

### Example 5

A sound wave in x-direction is given by the equation;  $y = 1 \times 10^{-7} \sin(6600t - 20x)$   
Determine the amplitude and velocity of a wave.

Compare with  $y = A \sin(2\pi ft - \frac{2\pi x}{\lambda})$

$$\text{Amplitude} = 1 \times 10^{-7} \text{ m}$$

$$2\pi ft = 6600t$$

$$f = \frac{6600}{2\pi}$$

$$\text{Also } \frac{2\pi x}{\lambda} = 20x$$

$$\lambda = \frac{2\pi}{20} \text{ m}$$

$$v = f\lambda = \frac{6600}{2\pi} \times \frac{2\pi}{20} = 330 \text{ ms}^{-1}$$

### Example 6

(a) Describe how the amplitude of a forced oscillation builds up to constant value.

In forced oscillation, an oscillating system is subjected to an external periodic force which supplies energy to system. This energy builds the amplitude to the required level and then restores the energy lost by friction, viscosity and/or air resistance.

(b) The displacement in meters of a plane progressive wave is given by the equation

$$y = 0.2 \sin\left(\pi \left(200t - \frac{20x}{17}\right)\right). \text{ Find the}$$

- (i) Amplitude
- (ii) Wavelength
- (iii) Speed of the wave

Compare with  $y = A \sin 2\pi \left(ft - \frac{x}{\lambda}\right)$

(i) Amplitude = 0.2

(ii)  $\frac{2\pi x}{\lambda} = \frac{20\pi x}{17}$

$$\lambda = 1.7 \text{ m}$$

(iii)  $2\pi ft = 200\pi t$

$$f = 100 \text{ Hz}$$

$$v = f\lambda = 1.7 \times 100 = 170 \text{ ms}^{-1}$$

### Example 7

The frequency of a wave is 600Hz and is travelling at a speed of 340ms<sup>-1</sup>. Find the phase difference between two points which are

- (i) 0.17m apart

$$\text{Phase difference } \phi = \frac{2\pi x}{\lambda}$$

$$\lambda = \frac{v}{f} = \frac{240}{600} = 0.57m$$

$$\phi = \frac{2\pi \times 0.17}{\frac{340}{600}} = 0.6\pi$$

(ii) 1.7m apart

$$\phi = \frac{2\pi \times 1.7}{\frac{340}{600}} = 6\pi$$

phase difference = 0

### Principle of superposition

When two waves travel through a medium, their combined effect at any point can be found by the Principle of Superposition

This states that the resultant displacement at any point is the sum of the separate displacements due to the two waves.

The superposition principle is used to explain the formation of stationary waves

### Wave front

A wave front is a section through an advancing wave along which all particles are in phase.

Along a wave front every particle transmitting the wave is at the same distance from the source of the wave and is in the same state of disturbance.

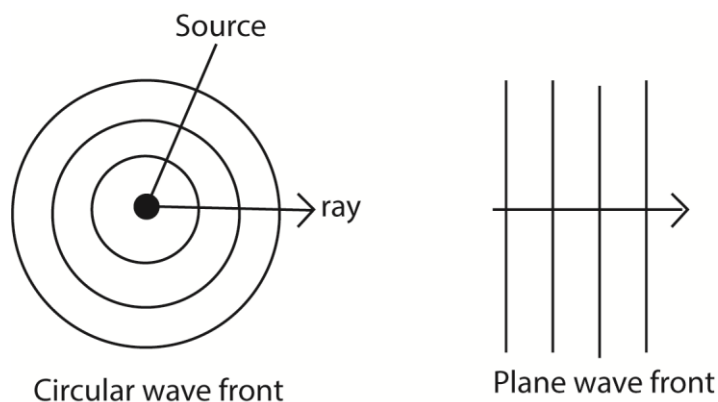
Therefore the two major forms of wave front which are circular and plane fronts.

### Circular wave fronts

Consist of wave front that are concentric circles with the source wave at the center. Such wave front can be obtained when a surface of still water is disturbed by a round object.

Plane wave front are wave fronts in which the wave are parallel to each other. Such wave fronts can be obtained when the surface of water is disturbed by plane object such as a ruler.

Light is thought to be propagated to the earth as plane wave fronts.



### General properties of waves.

All waves can undergo

- Reflection
- Refraction
- Diffraction
- interference

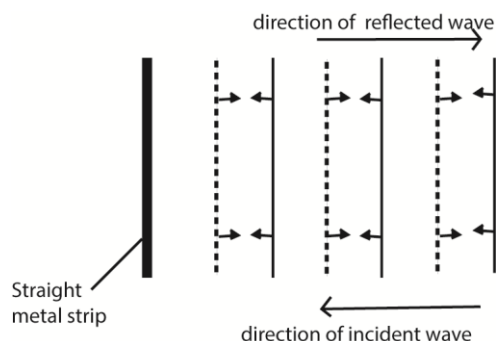
### Reflection of waves

This is the bouncing back of waves from an obstacle

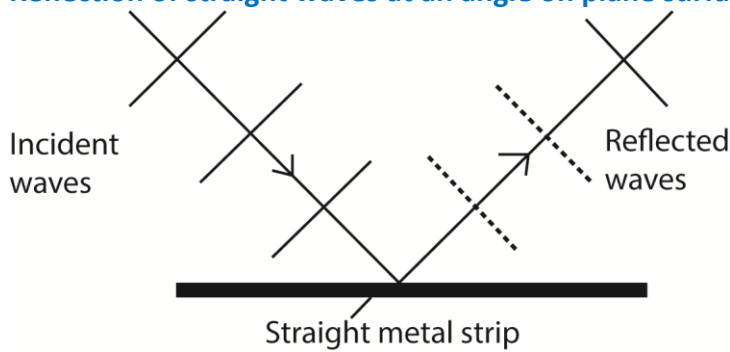
Reflection can be shown by standing a straight metal strip as a plane reflector and curved metal strip as concave and convex reflector in water

#### a) Reflection of straight waves perpendicularly at plane surface

A straight metal strip attached to a vibrator using vibrations generated by electric motor, is placed in water and another straight metal strip is placed in water parallel to the vibrator. Then the electric motor is switched on and the straight waves are incident normally reflected along the same path as plane waves.



### b) Reflection of straight waves at an angle on plane surface



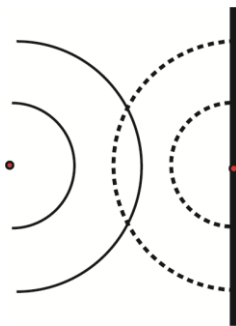
For reflection at plane surface both the incident and reflected waves are straight and have equal spacing because the incident and reflected waves have the same speed and wavelength as the wave is travelling in water of same depth.

### Laws of reflection of waves

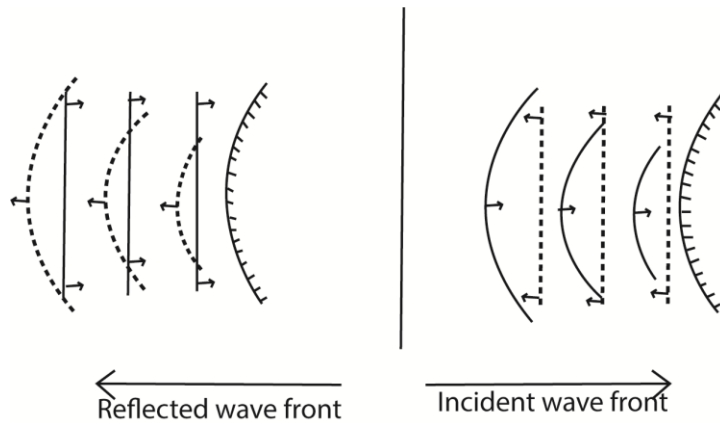
- i) The incident wave, reflected wave and the normal at the point of incidence all lie in the same plane.
- ii) The angle of incidence of waves is equal to the angle of reflection of the wave.

### c) Reflection of circular waves at a straight plane surface

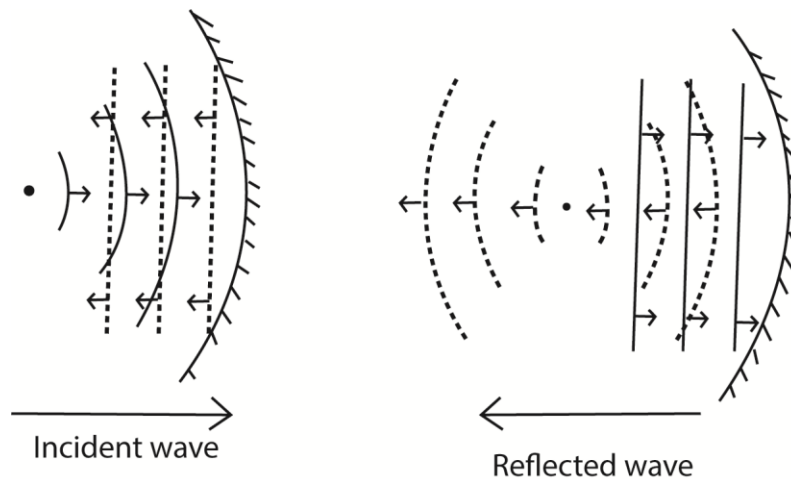
**Circular waves Incident on straight reflector** the source "S" corresponds to the object and T corresponds to virtual source of the reflected waves, The distance  $SM = MI$ . "MI" and "SM" are at right angles to the reflector.



### d) Reflection of waves on a convex reflector surface



### e) Reflection of waves on a concave reflector surface



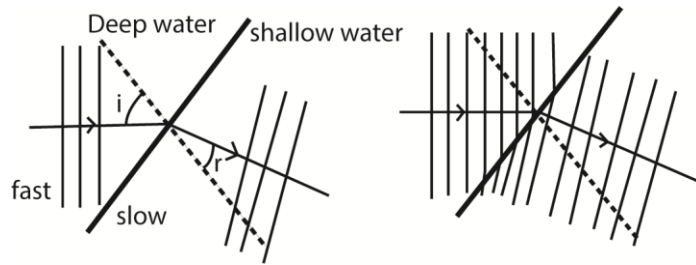
The reflected wave-fronts are circular, converging towards and passing through the principal focus F.

#### Points to consider when drawing

- (a) The focal point F becomes the centre of the circular waves.
- (b) The circular waves should be equally spaced. The distance of spacing should be the wavelength.
- (c) The spacing for the circular waves should be the same as that for the straight waves.

### Refraction of waves

Waves formed in ripple tanks can be refracted by placing a sheet of glass in water to make it shallow. The continuous straight waves in the shallow water are found to be closer to one another than in deep water. This implies that the wavelength of the wave is less in shallow water than in deep water. In short the wavelength of a wave in shallow water is shorter even though the frequency is the same.

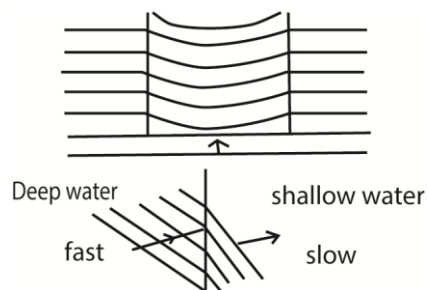


1. The direction of the wave when it strikes shallow water at a right angle does not change.
2. The wave speed is reduced in shallow water hence wavelength decreases. So when drawing the refracted waves are closely spaced
3. The frequency of the wave motion does not change.

Since speed " $V = f\lambda$ ". In shallow water the wavelength decreases yet the frequency remains constant, so the speed of the wave decreases in shallow water. The wave travels faster in deep water because the wave length increase yet the frequency remains constant.

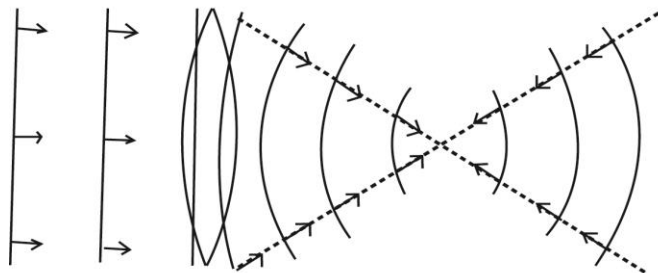
Refraction results in a wave slowing down the speed and changing direction as the wave enters shallow water.

### A glass plate placed in ripple tank at normal to the wave

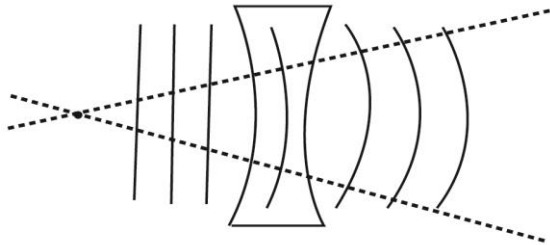


### Refraction of straight waves at curved surfaces

#### a) Converging refractor



**b) Diverging refractor**

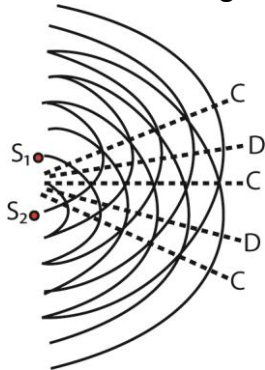


**Interference**

Interference is when two identical waves moving in the same direction are superposed on one another. Waves are superposed when one wave is placed on top of the other. For this to occur the amplitudes and frequencies of the two waves should be the same.

**Coherent sources** are sources which produce waves of the same frequency and amplitude which are always in phase or have a constant phase difference.

In the ripple tank, the two waves are produced by two ball ended dippers attached to the vibrator receiving vibration from the electric motor.



Where:

"C" is constructive interference

"D" is Destructive interference

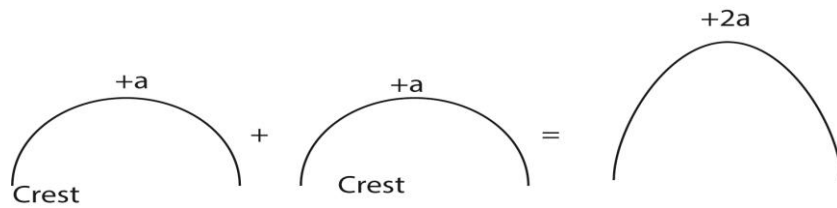
"S<sub>1</sub>" and S<sub>2</sub> are sources of vibration

From principle of superposition;-

Where the two waves are superposed in the same phase e.g. crests of one wave fall on the crests of another constructive interference occurs.

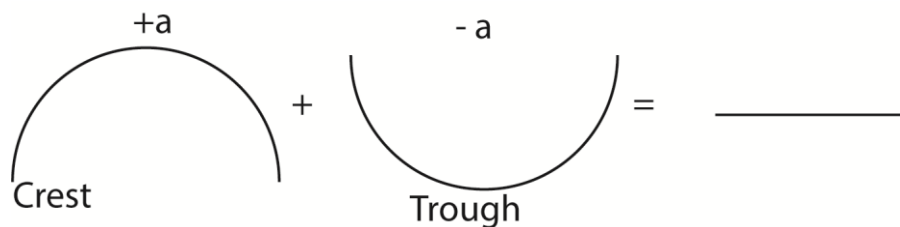
Where the two waves are superposed such that they are exactly out of phase e.g. crests of one wave are superposed on the troughs of the other identical wave, no disturbance is obtained. These positions are called destructive interference.

### Constructive interference



$n^{+a} + n^{+a} = n^{+2a}$  displacement  $(+a) + (+a) = +2a$  occurs when the displacement due to two waves combine to produce larger displacement. This happens when the wave crests overlap. Or the waves are in phase.

### Destructive interference



Occurs when, the crest of one wave falls in the trough of another. This produces an effect of no displacement such waves are in antiphase.

If two waves in question are sound waves, then during constructive interference, a very loud sound is heard while during destructive interference no sound or near silence is heard.

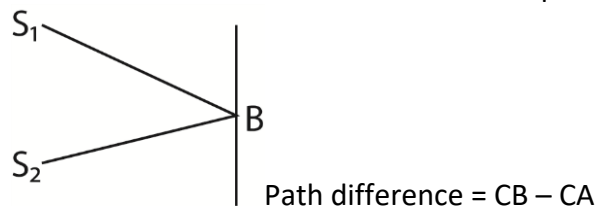
### Conditions for interference to occur

- Superimpose two waves in the same direction
- The waves must have the same frequency
- The waves must have the same amplitude
- The waves must have a constant phase difference.

### Path difference as applied in interference

The path difference is the difference in optical paths travelled by the two waves before they meet or superpose.

Consider two sources of waves  $S_1$  and  $S_2$  producing waves that travel along the Paths AB and CB



The path difference can be used to predict whether constructive or destructive interference will occur at the point of superposition.

- (a) If the path difference is a whole number multiple of the wavelength of a wave, the constructive interference occurs. I.e. for constructive interference to occur the path difference should be zero or a whole number multiple of full wavelength.  
Or path difference =  $n\lambda$  where  $\lambda$  = wavelength of a wave,  $n = 0, 1, 2, 3 \dots$
- (b) If the path difference is an odd multiple of half wavelength, the destructive interference occur. i.e. for the destructive interference to occur,  
Path difference =  $\frac{\lambda}{2}(2n + 1)$ ;  $n = 0, 1, 2, 3 \dots$

### Differences between constructive and destructive interference

Constructive interference	Destructive interference
Occurs when the crest of one meets the crest of another or when the trough of one wave meets a trough of another.	Occurs when a crest one wave meets a trough of another
Reinforcement occurs	Cancellation occurs
Resultant intensity is maximum or higher	Resultant intensity is minimum or lower
Occurs when the path difference is a whole number multiple of full wavelength i.e. path difference = $0$ or $n\lambda$	Occurs when the path difference is an odd number multiple of a half wavelength $\frac{\lambda}{2}(2n + 1)$

### Example 10

Two speakers producing sound of the same frequency are placed 50m apart facing each other, an observer walks from one speaker to the other along the line of the speakers.

- (i) What does the observer hear?

The observer hears alternate loud and soft or near silence. The loudness and near to silence sound come at equal interval.

- (ii) Explain the observation in (i) above.

The loud speakers act as coherent sources producing sound of the same frequency. The two waves from the loud speakers superpose and interference occurs.

Constructive interference occurs where the path difference is a whole number of the wavelength of sound so that reinforcement occurs and loud sound is heard.

Destructive interference occurs where the path difference is an odd multiple of half wavelength of sound and no sound is heard.

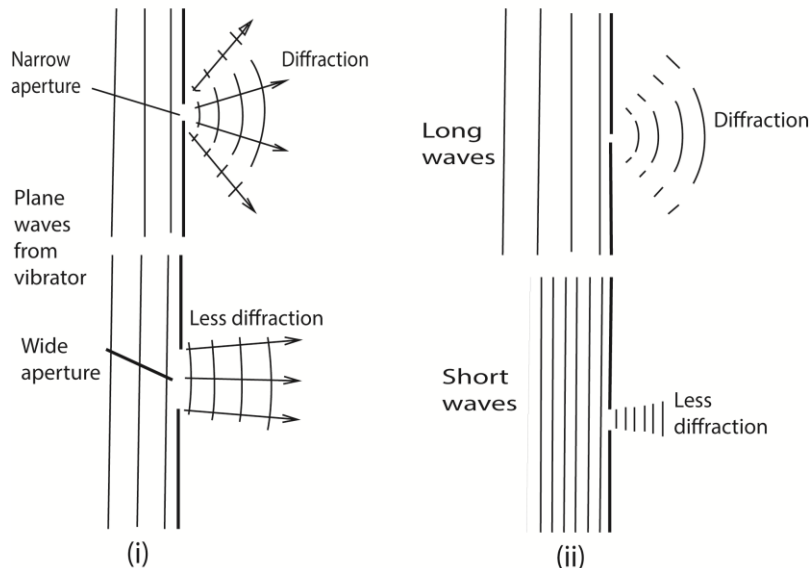
### DIFFRACTION OF WAVES

Diffraction is the spreading of waves when they pass through apertures or around obstacles. The general phenomenon of diffraction may be illustrated by using water waves in a ripple tank.

For diffraction to occur the dimension/size of aperture or obstacle must be of the order of the wavelength of the wave; i.e. the width of the aperture must be of the same order as the diffracted wave.

The diffraction of Plane waves through a narrow and wide aperture is illustrated below

#### Diffraction of waves



Generally, the smaller the width of the aperture in relation to the wavelength, the greater is the spreading or diffraction of the waves

Secondary, the longer the wavelength of the wave to be diffracted the greater the diffraction or spreading.

Light waves have very short wavelengths that diffraction around obstacles of normal size is negligible that we are unable to see around corners while sound waves of longer wavelength are reasonably diffracted that we are able to hear around corner.

#### In summary diffraction of the wave depends on

- (i) Dimension of the aperture
- (ii) Wavelength of the wave.

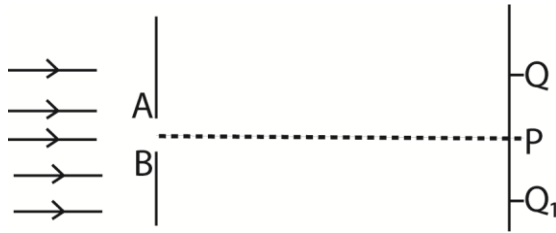
### Huygens' Principle

Every point on a wave front may be regarded as a source of secondary spherical wavelets which spread out with the wave velocity. The new wave front is the new envelope of these secondary wavelets.

### Diffraction at a single slit

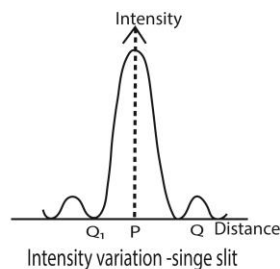
Diffraction at a single slit is explained by Huygens' Principle.

Suppose parallel light is incident on a narrow rectangular slit A and B



- Each point on the same wave front between A, B acts as a secondary centre of disturbance, and sends out wavelets beyond the slit.
- All the secondary centres are coherent, and their combined effect at any point such as P or Q can be found by summing the individual waves there, from the Principle of Superposition.
- At P, most of the wavelets arrive in phase causing constructive interference leading to formation of the central bright band.
- On outwards from P, an increasing number of wavelets arrive out of phase and hence the bright bands reduces in intensity until a dark band is formed where all wavelets arrive out of phase.
- Farther away from P parallel to AB, the intensity rises again to a much smaller maximum producing less bright band than at P.
- More and more alternative bright and dark bands of reducing intensities are formed further from P parallel to AB where wavelets meet in phase and out of phase respectively.

The graph of intensity against distance and corresponding diffraction band are shown below.



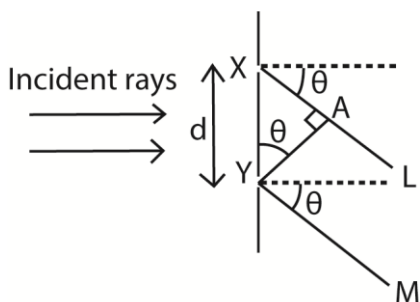
Diffraction band formed by a single small rectangular aperture

### Diffraction of light at more than one slit using diffraction grating

A **diffraction grating** is a large number of close parallel equidistant slits, ruled on glass or metal using diamond pencil

Like single narrow rectangular slit, when parallel monochromatic light is incident normally to two or more slits of a diffraction grating each slit produces an image with a bright central or principal maximum diffraction band, together with subsidiary maxima diffraction bands which are much less bright. This time, however, the pattern is crossed by a number of interference bands, which are due to interference of waves from different slits.

**Deriving an expression for angular position of  $n^{\text{th}}$  order principal maximum produced by transmission diffraction grating.**



Suppose X and Y are corresponding points in consecutive slits where  $XY = d$ , and the grating is illuminated normally by monochromatic light of wavelength,  $\lambda$ , the direction,  $\theta$ , the diffracted ray XL, and YM have path difference,  $XA$

$$\text{From } \sin \theta = \frac{XA}{d}; XA = d \sin \theta$$

The path difference for all corresponding points in the two slits have the same path difference,  $d \sin \theta$ . So other pairs of slits throughout the grating are treated the same way.

Also for bright or principle maxima to be obtained, the path difference =  $n\lambda$ .

$$\therefore d \sin \theta = n\lambda; \text{ where } d = \text{slit separation, } \lambda = \text{wavelength, } \theta = \text{angular momentum}$$

**Example 8**

Light of wavelength  $5.0 \times 10^{-7} \text{m}$  falls on a grating with 600 lines per mm, determine the highest order of diffraction that can be observed.

$$\lambda = 5.0 \times 10^{-7} \text{m}$$

$$\sin \theta = \frac{n\lambda}{d}; d = \frac{1}{600000} \text{m}^{-1}$$

$$l = 1 \times n \times 0.5 \times 10^{-6} \times 600000$$

$$n = \frac{1}{0.5 \times 10^{-6} \times 600000} = \frac{1}{3 \times 10^{-2}} = \frac{100}{30} = 3 \frac{1}{3}$$

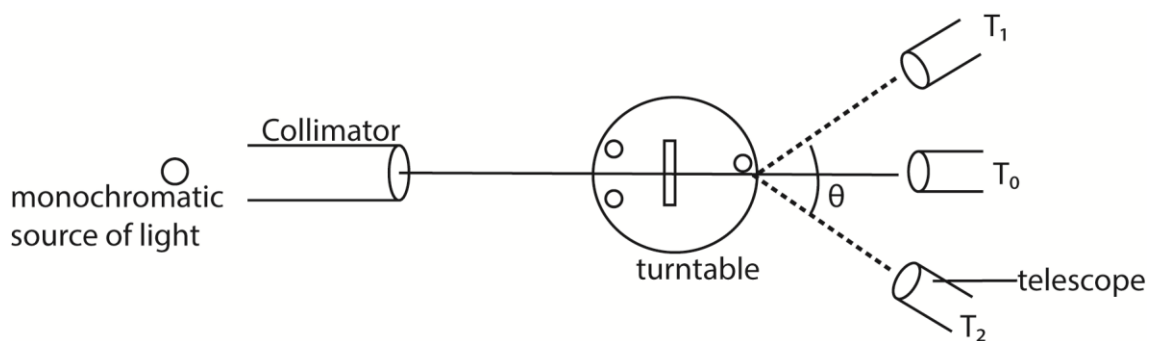
**Measurement of the wavelength of monochromatic light using a diffraction grating and a spectrometer.**

(a) Make the following adjustment

- The collimator C is adjusted such that parallel rays emerge from it.
- The telescope is adjusted so that parallel rays entering it are brought to a focus at the cross wire near its eyepiece.
- The table is levelled so that the plane of P is parallel to the axis of rotation of the telescope.

Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

(b)



- The grating is placed on the table so that its plane is normal to incident light
- The readings of the first diffraction image are observed on both sides of the normal at  $T_1$  and  $T_2$ .
- The angular difference is  $2\theta$ , and the wavelength is calculated from  $\lambda = d \sin \theta$ , where  $d$  is the spacing of the slits, obtained from the number of lines per centimeter of the grating.
- If a second order image is obtained for a diffraction angle  $\theta$ , then  $\lambda = d \sin \theta/2$ .

### Differences between the spectra produced by a prism and that produced by diffraction grating

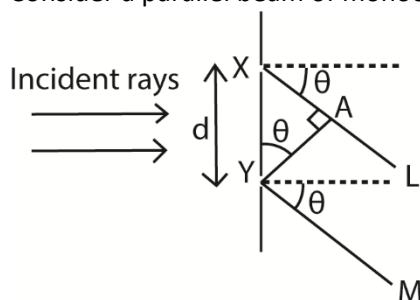
Prism	Diffraction grating
<ul style="list-style-type: none"><li>- Produce single spectrum at a time</li><li>- Shorter wavelengths are deviated most</li><li>- Produce less pure spectrum</li></ul>	<ul style="list-style-type: none"><li>- Many spectra at a time</li><li>- Longer wavelength are deviated most.</li><li>- Produce more pure spectrum</li></ul>

### Example 9

A diffraction grating of spacing  $d$ , is illuminated normally with light of wavelength,  $\lambda$ .

(a) (i) Derive the condition for concurrence of diffraction maxima. (03marks)

Consider a parallel beam of monochromatic light incident on a grating of spacing  $d$ .



The path difference  $XA = d \sin \theta$

For constructive interference, diffraction maxima occurs when the path difference is an integral multiple of wavelength,  $\lambda$ .

i.e. path difference =  $n\lambda$

thus  $d \sin \theta = n\lambda$  where  $n = 0, 1, 2, 3, \dots$

- (ii) Describe briefly the intensity distribution on screen placed beyond the grating (02marks)

The central principle maxima is the most intense; the intensity decreases on the either side.

- (iii) What is the effect on diffraction pattern when grating with larger number of lines is used (02marks)

The diffraction maxima (image) becomes narrower and shaper

- (b) Light of wavelength  $5.8 \times 10^{-7} \text{m}$  is incident on diffraction grating of 500 lines per mm. Find the

- (i) Diffraction angle for second order image (03marks)

$$d = \frac{l}{N} = \frac{1 \times 10^{-3}}{500} = 2 \times 10^{-6} \text{m}$$

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

$$\sin \theta = \frac{n \lambda}{d} = \frac{2.0 \times 5.8 \times 10^{-7}}{2 \times 10^{-6}} = 0.58$$

$$\theta = 35.5^\circ$$

- (ii) Maximum number of images formed. (02marks)

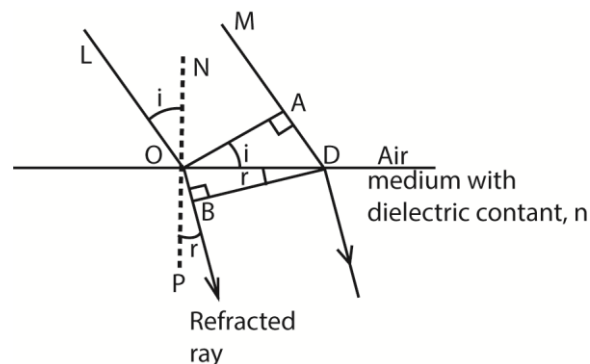
$$d = n_{\max} \lambda$$

$$n_{\max} = \frac{d}{\lambda} = \frac{2 \times 10^{-6}}{5.8 \times 10^{-7}} = 3.4$$

$$\therefore n_{\max} = 3$$

### Refractive index of a medium using Huygens' Principle at Plane Surface

Consider a beam of parallel rays between LO and MD incident on the plane surface of the medium from air in the direction shown, and suppose that a plane wave front has reached the position OA at a certain instant; every point on OA acts as a secondary source of wavelets.



In time  $t$ , secondary wavelets from  $O$  travels a distance  $OB = vt$  (where  $v$  = velocity of light in the medium).

In the same time,  $t$ , the secondary wavelength in air travels a distance  $AD = ct$

The tangent  $BD$  to the secondary wavelet is the new wavefront.

$$\sin i = \frac{AD}{OD} \text{ and } \sin r = \frac{OB}{OD}$$

$$\text{From snell's law, } n = \frac{\sin i}{\sin r}$$

Please find free new curriculum notes, exams and marking guides on [digitteachers.co.ug](http://digitteachers.co.ug) website

$$\begin{aligned}
&= \frac{AD}{OD} \div \frac{OB}{OD} \\
&= \frac{AD}{OD} \times \frac{OD}{OB} = \frac{AD}{OB} = \frac{ct}{vt} = \frac{c}{v}
\end{aligned}$$

### Example 10

Monochromatic light propagating in air is incident obliquely onto a plane boundary with a dielectric of refractive index, n.

- (a) Use Huygens' principle to show that speed, V, of light in the dielectric is given by

$$V = \frac{c}{n} \text{ where } c \text{ is the speed of light. (06marks)}$$

- (b) (i) If the wavelength of the light is 600nm in air, what will it be in a dielectric of refractive index 1.50? (04marks)

Let  $f_0$  and  $f$  be frequencies of light in vacuum and in the medium, then

$$f_0 = f$$

$$\frac{c}{f_0} = \frac{V}{f}$$

$$\text{But } \frac{\lambda_0}{\lambda} = \frac{c}{V} = n$$

$$\lambda = \frac{\lambda_0}{n} = \frac{600}{1.5} = 400\text{nm}$$

- (ii) Sodium light of wavelength  $5.890 \times 10^{-7}\text{m}$  and  $5.896 \times 10^{-7}\text{m}$  fall normally on a diffraction grating. If the first order beam, the two sodium lines are separated by 2minutes, find the spacing of grating (03marks)

For first order diffraction,  $d \sin \theta = \lambda$

$$\sin \theta_1 = \frac{\lambda_1}{d} \dots\dots\dots (i)$$

$$\sin \theta_2 = \frac{\lambda_2}{d} \dots\dots\dots (ii)$$

$$\text{but } \sin \theta_2 = \left( \theta_1 + \frac{2}{60} \times \frac{\pi}{180} \right)$$

Eqn.(ii) – Eqn. (i)

$$\begin{aligned}
&\sin \left( \theta_1 + \frac{\pi}{60 \times 180} \right) - \sin \theta_1 = \frac{\lambda_2 - \lambda_1}{d} \\
&= 2 \cos \left( \theta_1 + \frac{\pi}{60 \times 180} \right) \sin \left( \frac{\pi}{60 \times 180} \right) = \frac{\lambda_2 - \lambda_1}{d} \\
&= \left( \frac{5.896 - 5.890}{d} \right) \times 10^{-7} \text{m}
\end{aligned}$$

## Interference of light waves

The conditions necessary for permanent interference fringes between two sources of light

- The wave trains must have nearly the same or equal amplitudes.
- There must be a constant phase relationship between the two wave trains.
- The source must be very close to each other.
- The screen must be very as far as possible from the sources compared to separation of light sources.

**NB:** Since emission of light is always spontaneous; the above conditions are only possible if the source of waves is the same.

### Formation of interference patterns

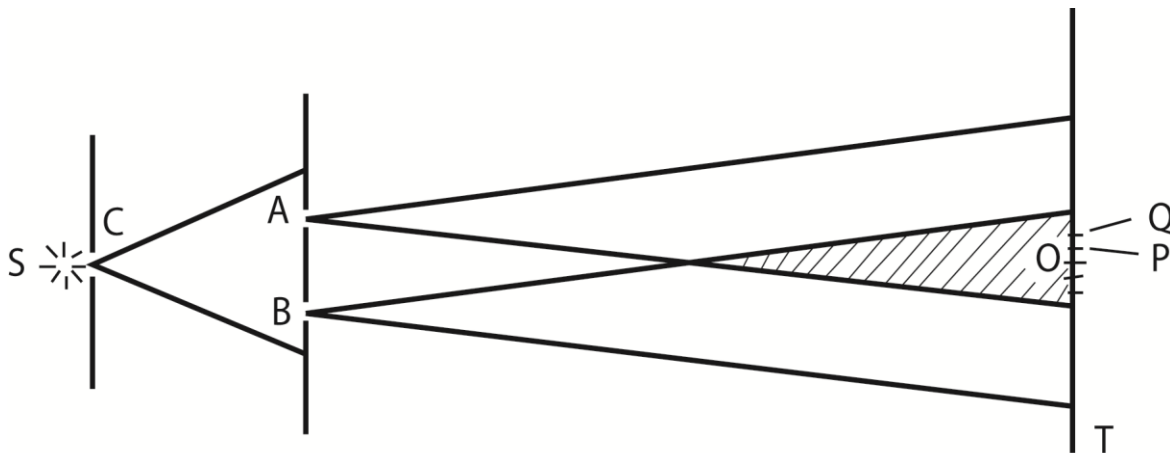
When two waves of equal frequency and equal wavelength (coherent sources) travel in the medium, they superpose where they meet in phase, reinforcement takes place resulting in a region of maximum intensity. Where they meet completely out of phase, cancellation takes place and a region minimum intensity form. Permanent alternate region of maximum and minimum intensity are therefore observed which is referred to as interference pattern.

### Division of wave front

This is a process of getting two coherent waves from a single wave front. This may be achieved by using Young's double slits or biprism or diffraction grating

### Formation light interference pattern by division of wave front using double slits.

One of the first demonstrations of the interference of light waves by division of wave front was carried out YOUNG in 1801



A source, S, of monochromatic light in front of a narrow slit C, and two very narrow slits A, B, close to each other, in front of C.

S is narrow, the light which emerges from A and B is coherent since it comes from the same wave front

Interference thus takes place in the **shaded** region, where the light beams overlap forming bright and dark bands on either side of O on a screen T, where O is on the perpendicular bisector of AB where light from A overlaps that from B.

As  $AO = OB$ , a bright band is obtained at O.

At a point P close to O, such that  $BP - AP = \lambda/2$ , where  $\lambda$  is the wavelength of the light from S, a dark band is obtained.

At a point Q such that  $BQ - AQ = \lambda$ , a bright band is obtained; and so on .for either side of O.

The bands are due to interference since covering A or B, the bands disappear.

- (i) Constructive interference (maximum intensity) occurs when the two waves meet at a point when they are in phase. This occurs when the path difference between the waves is an integral multiple of wavelength.
- (ii) Destructive interference (minimum intensity) occurs when the two waves meet when they are completely out of phase. This occurs when the path difference between waves is an odd multiple of half the wavelength

### Note that

1. If the source slit S is moved nearer the double slits the separation of the bands is unaffected but their intensity increases.
2. If the distance apart d of the slits is diminished, keeping S fixed, the separation of the bands increases.
3. If the source slit C is widened, the bands gradually disappear. The slit C is then equivalent to a large number of narrow slits, each producing its own band system at different places. The bright and dark bands of different systems therefore overlap, giving rise to uniform illumination.

It can be shown that, to produce interference bands which are recognizable, the slit width of C must be less than  $\lambda D'/d$ , where  $D'$  is the distance of C from the two slits A, B.

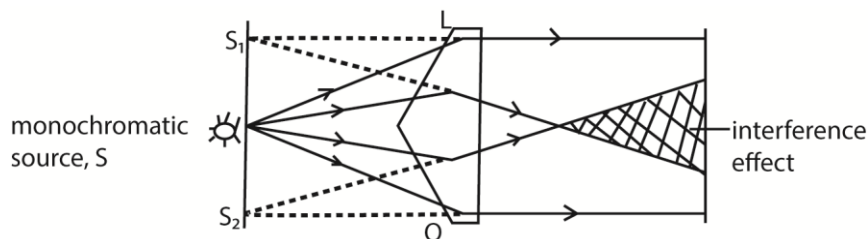
4. If one of the slits, A or B, is covered up, the bands disappear.
5. If white light is used the central band is white, and the bands either side are coloured. Blue is the colour nearer to the central band and red is farther away.

The path difference to a point O on the perpendicular bisector of the two slits A and B is zero for all colours, and consequently each colour produces a bright band here. As they overlap, a white band is formed. Farther away from O, in a direction parallel to the slits, the shortest visible wavelengths, blue, produce a bright band first.

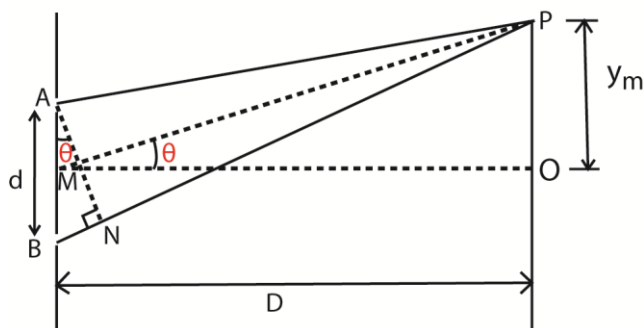
### Production of two coherent sources using a biprism

- A prism of a very large angle is placed with its refractive edge facing a monochromatic source of light, S.
- Light incident on face L is refracted to appear to come from a point  $S_1$  and that incident on Q appears to come from  $S_2$  due to refraction.

- The two sources are coherent since they originate from the same source S leading to interference where they superpose.



### Separation of Bands in Young's double slit experiment



A and B are coherent sources.

Suppose waves from A and B superpose at P to form bright fringe

Suppose P is the position of the  $n$ th bright band, so that  $BP - AP = m\lambda$

Let  $OP = y_m =$  distance P to O; the center of the band system, where MO is the perpendicular bisector of AB

If a length  $PN = PA$  is described on PB, then

The path difference  $BN = BP - AP = m\lambda$

In practice AB is very small compared to PM thus, AN meets PB practically at right angle and thus  $\theta$  is very small that  $d\sin\theta = d\tan\theta$

$$\Rightarrow BN = d\tan\theta = \frac{dy_m}{D}$$

For the  $m^{\text{th}}$  bright fringe,  $BN = m\lambda$ , where  $\lambda$  is the wavelength

$$\Rightarrow \frac{dy_m}{D} = m\lambda$$

$$y_m = \frac{m\lambda D}{d}$$

For  $(m + 1)^{\text{th}}$  bright fringe,  $\frac{dy_{m+1}}{D} = (m + 1)\lambda$

$$y_{m+1} = \frac{(m+1)\lambda D}{d}$$

$$\text{Fringe separation, } y = y_{(m+1)} - y_m = \frac{(m+1)\lambda D}{d} - \frac{m\lambda D}{d} = \frac{\lambda D}{d}$$

Please find free new curriculum notes, exams and marking guides on [digitteachers.co.ug](http://digitteachers.co.ug) website

### Example 11

With reference to Young's double slit experiment,

- (i) Explain how interference pattern is formed.

#### Solution

When two coherent waves travel in a medium, they meet and superimpose.

Where they meet in phase, constructive interference takes place and intensity is increased (or maximum)

Where they meet out of phase, cancellation takes place and intensity reduces (minimum)

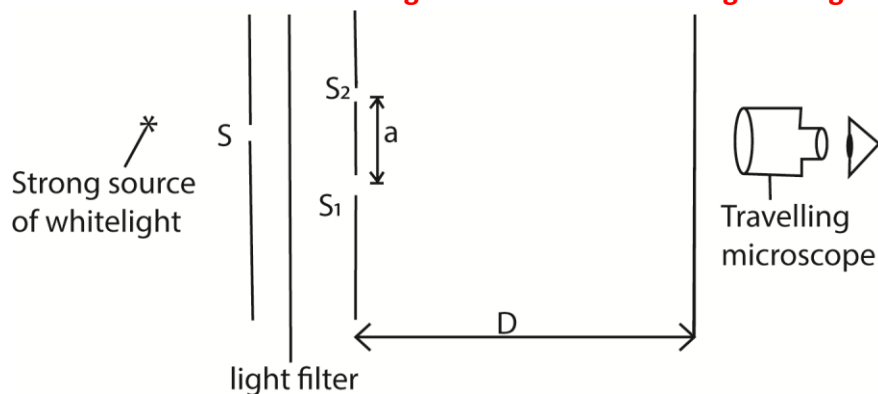
Patterns of alternative regions of maximum and minimum intensities are formed that form interference pattern.

- (ii) State what happens to the fringes when the source of light is moved nearer to the slits.  
The intensity of fringes increase but their separation remain unaffected.
- (iii) state what happens to fringes when the separation of slits is changes  
Increase in separation of slits reduces fringe separation.
- (iv) describe the appearance of fringes when white light is used  
When white light is used, colored fringes are observed. The central fringe is white, followed by blue and red fringes farther off.  
Outwards the colors overlap leading to white illumination

- (a) Calculate the separation of the slits if the distance from slits to the screen is 800mm and the 8<sup>th</sup> bright fringe is formed 5mm from the center of the fringe system given that the wavelength of light is  $6.2 \times 10^{-7}$ m

$$y = \frac{n\Delta\lambda}{d}$$
$$d = \frac{n\Delta\lambda}{y} = \frac{8 \times 800 \times 10^{-3} \times 6.2 \times 10^{-7}}{5 \times 10^{-2}} = 7.94 \times 10^{-4} \text{m}$$

### Measurement of the wavelength of monochromatic light using Young's double slit method



The set up is as shown above, where S, S<sub>1</sub>, and S<sub>2</sub> are narrow slits through which light diffracts forming interference fringes on a transparent screen. The position of the screen is adjusted until fringes are seen

Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

clearly. The number of fringes occupying a measured length along the screen is counted and the width  $y$  of a single fringe determined. The distance  $D$ , of the double slit from the screen is measured using a meter rule and the separation,  $a$ , of the double slit determined using a travelling microscope. The wavelength  $\lambda = ay/D$

### Example 12

- (i) In an experiment to determine wavelength of light using Young's method, two slits, a separation of 1.2mm were used. When the screen was placed 18.0cm from slits, 30 bright fringes occupying a distance 2.5mm was obtained. Find wavelength of light used (04marks)

$$\text{Slit separation, } d = 1.2 \times 10^{-3} \text{ m}$$

$$\text{Number of bright fringes, } n = 30$$

$$\text{Distance from center of } n\text{th fringe, } x_n = 2.5 \times 10^{-3} \text{ m}$$

$$\text{Distance from the slits to screen, } D = 18.0 \text{ cm} = 0.18 \text{ m}$$

$$\text{Using } x_n = \frac{n\lambda D}{d}$$

$$2.5 \times 10^{-3} = \frac{30 \times \lambda \times 0.18}{1.2 \times 10^{-3}}; \lambda = 5.56 \times 10^{-7} \text{ m}$$

- (ii) A diffraction grating has 500 lines per mm and illuminated normally with monochromatic light of wavelength 589nm. Find the maximum number of diffraction image obtained. (04 marks)

$$d = \frac{1 \times 10^{-3}}{500}$$

$$n = \frac{d}{\lambda} = \frac{1 \times 10^{-3}}{500 \times 589 \times 10^{-9}} = 2.39$$

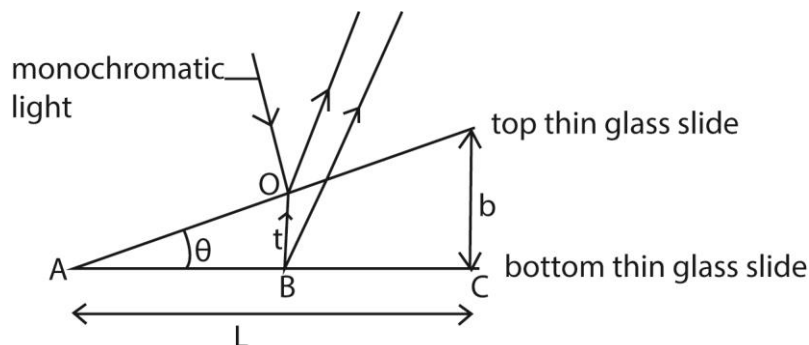
$$\therefore \text{the maximum order of diffraction} = 3$$

### Appearance of Young's interference fringes pattern using source of white light

- A central white fringe with colored edges is observed due to overlapping colored fringes. Here the path difference is zero
- Since the violet color has the lowest wavelength, then a violet fringe will be the first fringe on the either side of the central white fringe. The farthest fringe is red
- After a few fringes, the fringe pattern become invisible due to much overlapping

### Interference in thin air wedge films

Thin air wedge is formed by inclining two thin glass slides at a small angle  $\theta$ .



- When monochromatic light is incident normally inclined glass slides at  $O$ ;

- Part of light is reflected on the bottom part of the top glass slide while part of the transmitted light is reflected at B on the top part of the bottom glass slide.
- The two reflected waves are coherent since both have originated from the same centre of disturbance at O, and they produce an interference phenomenon if brought together by the eye or in an eyepiece.
- Their path difference is  $2t$ , where  $t$  is the small thickness of the air-film at O.
- The wave reflected at bottom part of top glass slide suffers no phase change while that reflected from top part of lower glass slide at B at boundary with a denser medium suffers a phase change of  $\pi$  due to reflection which is equivalent to an additional path of  $\frac{\lambda}{2}$
- Therefore a dark band is formed at the point of contact A of the slide instead of bright fringe.
- Hence for constructive interference (bright fringes),  $(2t + \frac{\lambda}{2}) = n\lambda$ , for  $n = 1, 2, 3, \dots$
- Destructive interference (dark fringes)  $2t = n\lambda$ , for  $n = 1, 2, 3, \dots$

NB. If the wedge surfaces make perfect optical contact at one edge, the bands are straight lines parallel to the line of intersection of the surfaces. If the glass surfaces are uneven, and the contact at one edge is not regular, the bands are not perfectly straight.

### Thickness of Thin Foil in air wedge

- If there is a bright band at C at the edge of the foil, the thickness  $b$  of the foil is given by  $2b = (m + \frac{1}{2})\lambda$ , where  $m$  is the number of bright bands between A and C.
- If there is a dark band at C, then  $2b = m\lambda$ .
- Thus by counting  $m$ , the thickness  $b$  can be found.

### Example 13

When the slides are illuminated with light of wavelength 500nm, 10 dark fringes are observed to occupy a distance of 2.5mm. Determine the diameter of the wire.

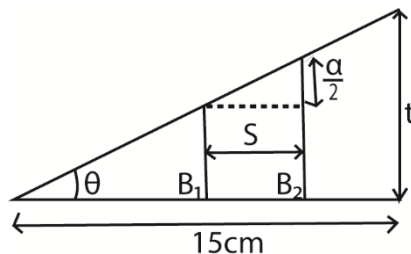
Thickness,  $t$

$$\Delta X = \frac{\lambda s}{2t}$$

$$t = \frac{\lambda s}{2\Delta X} = \frac{500 \times 10^{-9} \times 5 \times 10^{-2}}{2 \times 2.5 \times 10^{-3}} = 5 \times 10^{-5} \text{m}$$

### Example 14

Two glass slides in contact at one end are separated by a sheet of paper 15cm from the line of contact to form an air-wedge. When the air wedge is illuminated normally by light of wavelength  $6.0 \times 10^{-7} \text{m}$ , interference fringes of separation 1.8mm are found in reflection. Find the thickness of the paper. (04marks).



Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

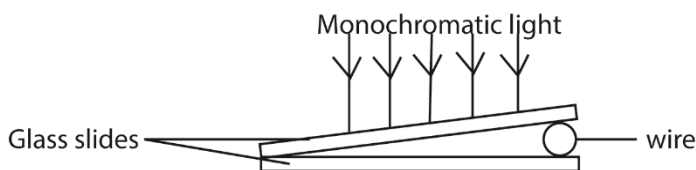
$$S = 1.8 \times 10^{-3} \text{ m}$$

$$\tan \theta = \frac{\lambda}{2S} = \frac{t}{L}$$

$$t = \frac{\lambda L}{2S} = \frac{6.0 \times 10^{-7} \times 15 \times 10^{-2}}{2 \times 1.8 \times 10^{-3}} = 2.5 \times 10^{-5} \text{ m}$$

### Example 15

An air wedge is formed by placing two glass slides of length 5.0cm in contact at one end and separated by a wire on the other end as shown below



When the slides are illuminated with light of wavelength 500nm, 10 dark fringes are observed to occupy a distance of 2.5mm. Determine the diameter of the wire

Let the diameter be,  $t$

$$\Delta X = \frac{\lambda s}{2t}$$

$$t = \frac{\lambda s}{2\Delta X} = \frac{500 \times 10^{-9} \times 5 \times 10^{-2}}{2 \times 2.5 \times 10^{-3}} = 5 \times 10^{-5} \text{ m}$$

### Example 16

Two glass slide in contact at one end are separated by a wire of diameter 0.04mm at the other end to form a wedge. Fringes are observed when light of wavelength  $5.0 \times 10^{-7} \text{ m}$  is incident normal to the slides. Find the number of fringes which can be observed. (03marks)

Solution

$$2t = n\lambda$$

$$n = \frac{2t}{\lambda} = \frac{2 \times 0.04 \times 10^{-3}}{5 \times 10^{-7}} = 160$$

### Angle $\theta$ of the air wedge

The small angle  $\theta$  of the wedge is given by  $\frac{b}{L}$ , where  $L$  is the distance  $AC$ , and by measuring  $L$  with a travelling microscope focused on the air-film,  $\theta$  can be found.

When the separation of fringe is  $y$ , and wavelength length of light is  $\lambda$

$$\text{Then, } \tan \theta = \frac{\lambda}{2y}$$

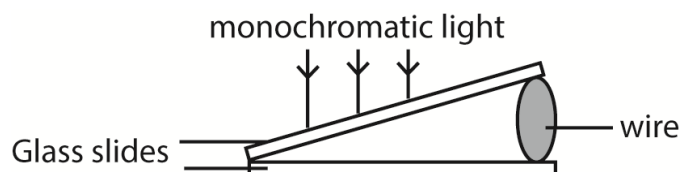
### Example 17

Two glass slides are separated by a thin wire to form an air wedge. When the wedge is illuminated normally by light of wavelength  $5.6 \times 10^{-7} \text{ m}$ , a total of 20 fringes occupying a distance of 15mm are obtained. Calculate the angle of the wedge.

$$\begin{aligned}\tan \phi &= \frac{\lambda}{2y}; y = \frac{15}{20} \times 10^{-3} = 0.75 \times 10^{-3} \text{m} \\ &= \frac{5.6 \times 10^{-7}}{2 \times 0.75 \times 10^{-3}} = 5 \\ \phi &= 0.021^\circ\end{aligned}$$

### Example 18

An air wedge is formed by placing two glass slides of length 5.0cm in contact at one end and a wire at the other end as shown in the figure below



Viewing from vertically above, 10 dark fringes are observed to occupy a distance of 2.5mm when the slides are illuminated with light of wavelength 500nm.

Determine the diameter of the wire. (04marks)

### Solution

$$\text{Fringe separation} = \frac{2.5 \times 10^{-3}}{10} = 2.5 \times 10^{-4} \text{m}$$

$$\lambda = 500 \text{nm} = 5 \times 10^{-7} \text{m}$$

$$\tan \theta = \frac{\lambda}{2y} = \frac{5 \times 10^{-7}}{2 \times 2.5 \times 10^{-4}} = 1 \times 10^{-3}$$

$$\theta = 1 \times 10^{-3} \text{ or } 0.06^\circ$$

### Replacing the air with a liquid in air wedge.

If a liquid wedge is formed between the plates, the optical path difference becomes  $2nt$ , where the air thickness is  $t$ ,  $n$  being the refractive index of the liquid.

An optical path difference of  $\lambda$  now occurs for a change in  $t$  which is  $n$  times less than in the case of the air-wedge.

The spacing of the bright and dark bands is thus  $n$  times closer (reduces) than for air, and measurement of the relative spacing enables  $n$  to be found.

### Example 19

Explain what will be observed if a liquid is introduced between the slides (02mark)

$$\begin{aligned}\text{From refractive index, } n_l &= \frac{c}{v_{\text{liquid}}} = \frac{f\lambda_{\text{air}}}{f\lambda_{\text{liquid}}} \\ \therefore \lambda_{\text{liquid}} &= \frac{f\lambda_{\text{air}}}{n_l}\end{aligned}$$

where  $c$  and  $v_{\text{liquid}}$  are velocities of light in air and liquid and  $\lambda_{\text{air}}$  and  $\lambda_{\text{liquid}}$  are wavelength of light in air and liquid respectively.

Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

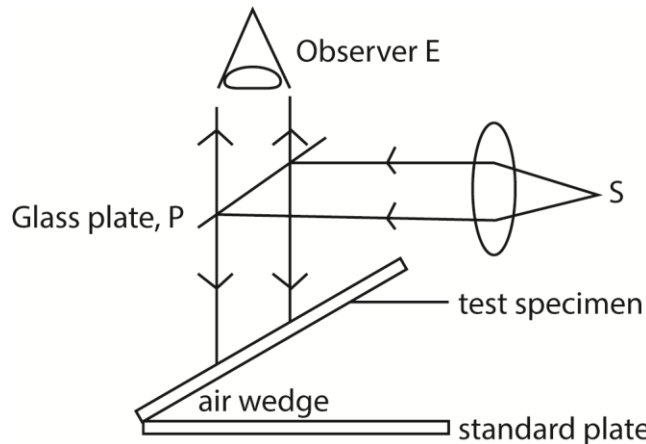
Fringe separation,  $y = \frac{\lambda_{air}}{2 \tan \theta}$  where  $\theta$  is the wedge angle.

The new fringe separation,  $y' = \frac{\lambda_{liquid}}{2 \tan \theta} = \frac{\lambda_{air}}{2n \tan \theta}$

Hence fringe separation is reduced by a factor of  $n$  in relation to that of air wedge

Experiment how flatness of surface can be determined by interferences from air wedge.

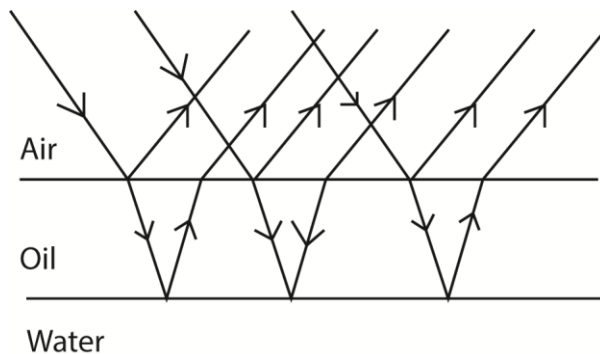
- The surface under test is made to form an air-wedge with a plane glass surface of standard smoothness as shown below.



- A parallel beam of monochromatic light from source, S, is reflected from a glass plate, P to fall normally to the air wedge.
- Light reflected by the air wedge is observed.
- Irregularity in the surface of test specimen will show up as irregularity in the fringe pattern.

### Reasons for appearance colored oil drop on a rainy day.

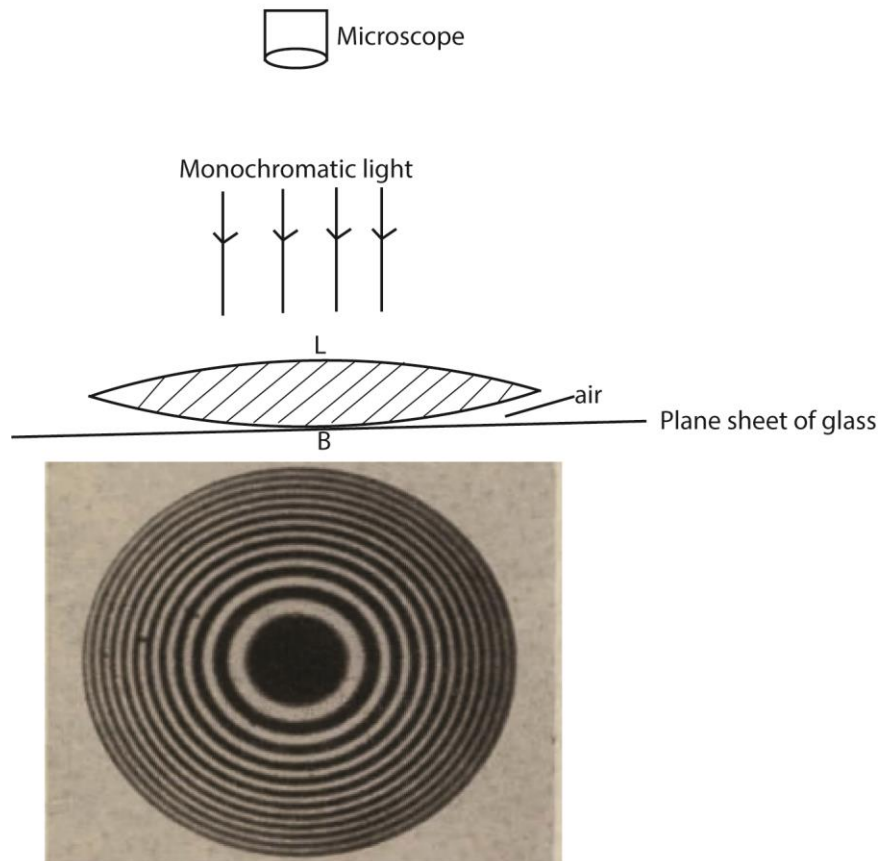
- Then white light incident on the oil film, is partly reflected and partly refracted.
- Dispersion occurs due to refraction.
- The dispersed rays are reflected at oil-water interface.
- The light reflected from both surface meet and superpose in air.
- Constructive superposition of colored rays give colored fringes. Hence colored oily surface.



## Newton's ring

It is an example of interference in which a pattern of dark and bright concentric circles are observed when monochromatic light is reflected from a converging lens of large radius of curvature placed on a plane sheet of glass.

Newton's ring experiment



Newton's rings formed by interference between a convex and a flat glass plate

- Air is formed between the lens and the glass plate
- Some light is reflected from the lower surface of the lens while some of that transmitted is reflected from the top side of the glass plate.
- The light reflected from the top side of glass plate undergo a phase difference of  $180^\circ$  equivalent to a phase difference of  $\lambda/2$ . Thus a dark band is formed at B where the phase difference is 0.
- If the thickness of the air is  $t$ ; bright ring is formed when  $2t = (n + \frac{1}{2})\lambda$  and a dark ring is formed when  $2t = n\lambda$ ;  $\lambda$  is the wavelength of light,  $n = 0; 1; 2; 3; \dots$

## Polarization of light

Transverse waves can undergo polarization while longitudinal waves like sound waves do not.

### Definition

Plane polarized light is one whose electrical vectors varies in only one plane perpendicular to the direction of travel of the wave.

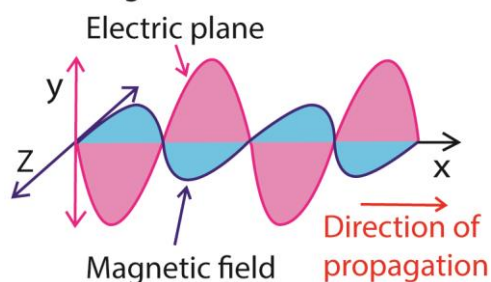
Unpolarized light is whose magnetic and electrical vibrations occur in more than one plane

**Polarization** is the phenomenon where light is absorbed by a medium in such a way that transverse vibrations in a perpendicular direction is allowed to pass through. The emergent light is thus polarized.

Polarization of light can prove that light is transverse and also electromagnetic wave.

Electromagnetic waves are transmitted by varying electric and magnetic fields and the vibrations therefore occur in electric and magnetic vectors. These vectors are always perpendicular to each other and also perpendicular to the direction of propagation of light.

Magnetic and electric Vectors of electromagnetic waves



Experiments show that when light interacts with matter, the vibrations in a magnetic vector are absorbed leaving only vibrations in electric vectors occurring in one plane. This is when light is said to be plane polarized.

### Detection of plane polarized light.

A sheet of Polaroid is held in the path of the plane polarized light and rotated slowly about an axis perpendicular to it. When all light is absorbed in a particular direction, then it is polarized.

A Polaroid is a material which transmits only those vibrations of light occurring in a certain perpendicular direction.

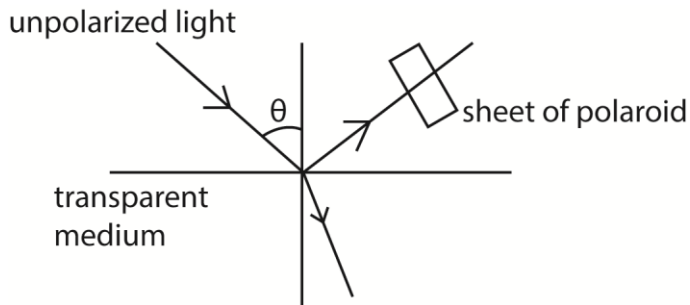
### Method of producing plane polarized light

#### (a) Selective absorption

Unpolarized light is made incident on a plane sheet Polaroid. The transmitted light will be completely polarized.

#### (b) Reflection

Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website



- A narrow beam of light is made incident on transparent medium.
- The reflected light is observed through a Polaroid.
- The angle of incidence is varied
- At each angle of incidence, the polaroid is rotated about the axis along the light incident on it
- At one angle of incidence, the light gets cut off the observer as the Polaroid is rotated.
- The reflected ray is now completely polarized.
- The angle of incidence  $i_p$  at which all light is polarized is given by  $i_p = \tan^{-1} n$ ; where  $n$  is the refractive index of the material. (Brewster's law)

### Example 20

A parallel beam of Unpolarized light is incident on a transparent medium of refractive index 1.62. It is reflected as plane polarized light. Calculate the angle of incidence in air and angle of refraction in the medium

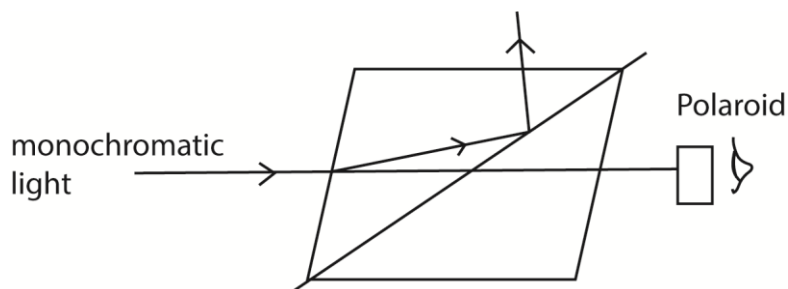
Using Brewster's law;  $n = \tan i_p$

$$i_p = \tan^{-1} 1.62 = 58.3^\circ$$

$$r = 90 - i_p$$

$$= 90 - 58.3 = 31.7^\circ$$

### (c) Double refraction



- A narrow beam of monochromatic light is made incident on nicol prism and viewed from the opposite side as shown above
- The angle of incidence is gradually increased or changed and at each angle, the Polaroid is rotated about an axis through its plane.
- At one point, the emergent light is plane polarized.

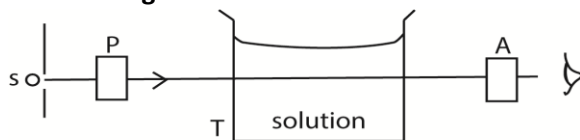
Please find free new curriculum notes, exams and marking guides on [digitlteachers.co.ug](http://digitlteachers.co.ug) website

Note that;

Some crystals such as calcite and Iceland spar exhibit a property known as double refraction where they split unpolarized light into two polarized light rays; ordinary and extraordinary rays.

### Uses of polarized light.

#### (i) Polarized light is used in measurement of the concentration of sugar in a solution



s - source of monochromatic light  
P and A are Nicol prism  
T- glass vessel

The apparatus are arranged as above

First without the solution, the prism A called analyzer is rotated until the emergence light from T is completely extinguished. This orientation is noted.

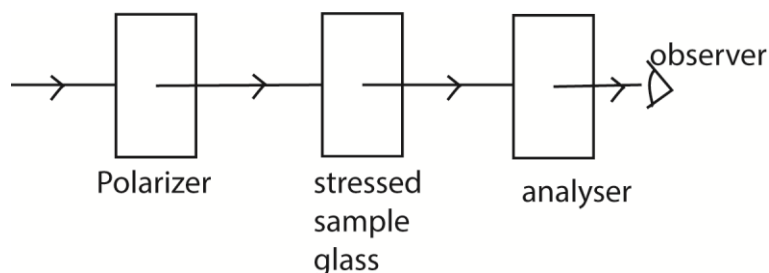
T is filled with sugar solution, on looking through A, light can now be seen.

A is then again rotated until light is extinguished. This point is noted.

The angle  $\theta$  between the two positions is noted.

The angle of rotation  $\theta$  is proportional to the concentration.

#### (ii) It is used in stress analysis



The apparatus is arranged as above

The polarizer and analyzer are Polaroid which are crossed with respect to each other so that light does not pass through.

When a piece of stressed glass is placed between the Polaroids, a pattern of interference fringes can be seen.

The intensity of light depends on the degree of stress and hence the region and degree of stress is determined.

(iii) In film to give illusion of three dimension (orography)

(iv) In liquid crystal display

**Thank you**  
**Dr. Bbosa Science**