# Auxiliary Notes

**of the Textbook**

## PHYSICS XI

**A Supplement to the Book**

*“Few Notes”*

Ross Nazir Ullah

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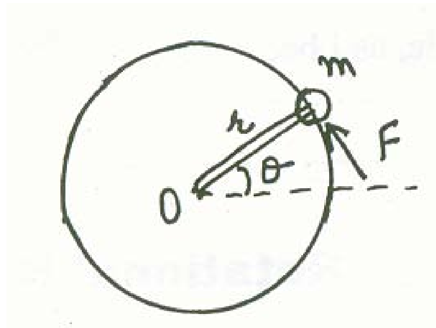
# Moment of Inertia

**Moment of Inertia:** "The rotational analogue of mass in angular motion".

or "The sum of the products of the mass of each particle of the body and the square of its perpendicular distance from the axis".

Mathematically $I = \sum_{i=1}^{n} m_i r_i^2$

## To calculate 'I'




Consider, in a horizontal plane a mass m attached to the end of a mass less rod.

If a force F acts on m, then

$F = ma$ ….. (1)

or $F = mr\alpha$ $[a = r\alpha]$

& the value of torque $\tau$, will be

$\tau = rF = rmr\alpha$

or $\tau = mr^2\alpha$ ….. (2)

comparing equations (1) & (2), we see that

**F** (in linear motion) *corresponds to* $\tau$ (in angular motion)

**a** (in linear motion) *corresponds to* $\alpha$ (in angular motion)

& **m** (in linear motion) *corresponds to* $\mathbf{m\,r^2}$ (in angular motion)

This corresponding quantity in angular motion is known as moment of inertia.

## Calculating 'I' for a rigid body

This rigid body is made up of n small pieces of masses $m_1$, $m_2$, …….
at distances $r_1$, $r_2$, …… from the axis of rotation.

Let

The body be rotating with angular acceleration $\alpha$,

So torque acting on $m_1$ will be


$\tau_1 = m_1 r_1^2 \alpha_1$ [from eq. (2)]

similarly for $m_2$

$\tau_2 = m_2 r_2^2 \alpha_2$

& $\tau_3 = m_3 r_3^2 \alpha_3$

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$\tau_n = m_n r_n^2 \alpha_n$

so $\tau_{total} = m_1 r_1^2 \alpha_1 + m_2 r_2^2 \alpha_2 + \dots\dots + m_n r_n^2 \alpha_n$

since $\alpha_1 = \alpha_2 = \alpha_3 = \dots\dots\dots \alpha_n = \alpha$ all masses are rotating

so $\tau_{total} = m_1 r_1^2 \alpha + m_2 r_2^2 \alpha + \dots\dots + m_n r_n^2 \alpha$ with same $\alpha$

or $\tau_{total} = (m_1 r_1^2 + m_2 r_2^2 + \dots\dots + m_n r_n^2)\alpha$

or $\tau_{total} = \sum_{i=1}^{n} m_i r_i^2 \alpha$

or $\tau = I\alpha$ ….. (3)

where $I = \sum_{i=1}^{n} m_i r_i^2$ ….. (4)

called moment of inertia of the body.

Expression (3) shows that
Moment of inertia depends upon the mass m and the distribution of mass r with respect to axis of rotation. An illustration is given in the figure. Observing the figure and looking equations (3) & (4), we see that the angular acceleration $\alpha$ will be much greater when masses m & m are nearer the axle, as I becomes smaller.

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## Rotational KE of a Disc & a Hoop

**Definitions:**

**Disc:** "A flat circular plate or anything resembling it."

**Hoop:** "A circular band such like a ring; anything curved like a ring."

To prove $v_{disc} > v_{hoop}$

For Disc,

PE at the top = total KE at the bottom

$PE_{top} = KE_{trans} + KE_{rot}$ — for a disc:

i.e. $mgh = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2$ — $I = \frac{1}{2} mr^2$

or $mgh = \frac{1}{2} mv + \frac{1}{2} ( \frac{1}{2} mr^2 ) (v^2 / r^2 )$ — $\omega = v / r$

or $mgh = \frac{1}{2} m v^2 + \frac{1}{4} m v^2$

or $gh = \frac{3}{4} v^2$

or $v^2 = \dfrac{4gh}{3}$ or $\boxed{v_{disc} = \sqrt{\dfrac{4gh}{3}}}$ ….. (1)

For Hoop,

PE at the top = total KE at the bottom

$PE_{top} = KE_{trans} + KE_{rot}$ — for an hoop:

i.e. $mgh = \frac{1}{2} m v^2 + \frac{1}{2} I \omega^2$ — $I = mr^2$

or $mgh = \frac{1}{2} mv + \frac{1}{2} (mr^2 ) (v^2 / r^2 )$ — $\omega = v / r$

or $mgh = \frac{1}{2} m v^2 + \frac{1}{2} m v^2$

or $gh = v^2$

or $v^2 = gh$ or $\boxed{v_{hoop} = \sqrt{gh}}$ ….. (2)

from equations (1) & (2), we conclude

$$\boxed{v_{disc} > v_{hoop}}$$

when rolls down an inclined plane of height h.

# Simple Harmonic Motion

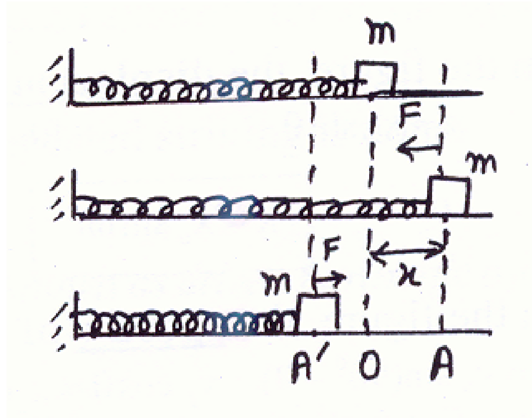
**Definition:**

A particle is said to posses a **simple harmonic motion** if its acceleration is always directed towards the centre and its value is proportional to the displacement of the particle from its central position.

**To show**

*The acceleration at any instant of a body executing SHM is proportional to displacement and is always directed towards its mean position.*

Consider a mass m attached to one end of an elastic spring which can, move freely on a frictionless horizontal surface.




When the mass is pulled through x, From modified form of Hook's law, the applied force F is

$$F = k\,x \quad \ldots.. \quad (1)$$

Where k is spring constant.

Due to elasticity, the spring opposes the applied force. This opposing force is,

restoring force = F = -k x ….. (2)

In the figure mass m is pulled towards right with some force, the extension gives rise to restoring force.

Some work will be done in displacing from equilibrium against this force. It will be stored as its potential energy. When released this PE changes to KE. At equilibrium all PE converts to KE. Due to inertia it will move towards left.

When compressed whole KE changes to PE. The process is repeated and the mass continues to oscillate between the extreme positions.

To calculate the acceleration a of the mass, we have, F = m a …. (3)

From equations (2) & (3), we get

$$-k\,x = m\,a \text{ or } \quad a = -\frac{k}{m}\,x$$

or $a = -(\text{const.})\,x$ or $a \propto -x$

or or $a \propto -\text{displacement}$

We define, Hook's Law as "Within the limits of perfect elasticity stress is directly proportional to strain".

or stress $\propto$ strain

or $\frac{\text{stress}}{\text{strain}} = \text{constant}$

or $\frac{F/a}{l/L} = E$ or $\frac{FL}{la} = E$

L, a & E are constants, so

$F \propto l$ or $F = k\,l$

or $F = k\,x$

We may call it, the modified form of Hook's law.

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**Stress:** The distorting force per unit area set up inside the body.

**Strain:** The change produced in the dimensions of a body under a system of forces.

Such a motion in which acceleration is proportional to the displacement and is directed towards the center is called **Simple Harmonic Motion**.

# Free & Forced Oscillations

**Free Oscillations:** A body is said to be executing free vibrations (or oscillations) when it oscillates without the interference of an external force.

**Frequency:** It is the number of vibrations executed by a body in one second.
**Natural frequency:** The frequency at which an object or system will vibrate freely.
**Natural period:** The time period of a body or system for free oscillation.

*Example:* Simple pendulum

**Forced Oscillations:**
When a freely oscillating system is subjected to an external force, the vibrations produced are called forced vibrations.

For producing continuous forced vibrations, repeated striking is done.

***Driven Harmonic Oscillator:***
***A physical system undergoing forced vibrations is known as driven harmonic oscillator.***

*Examples:*
1. The vibrations of a factory floor caused by the running of heavy machinery.
2. Loud music produced by sounding wooden boards of strings instruments.

**Damped Oscillator:** The oscillator in which the amplitude decreases steadily with time, are called damped oscillator.

Damping is the process whereby energy is dissipated from the oscillatory system.

**Cause:**
Damping occurs due to energy dissipation caused by viscous drag forces, frictional forces and air resistance.
*Application:* Shock absorber of a car.

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A swinging pendulum or a plucked violin string eventually comes to rest if no further forces act upon it. The force that causes it to stop oscillating is called *damping.* Often the damping forces are frictional, but other damping forces, such as electrical or magnetic, might enter into an oscillating system.

Newer techniques of constructing high buildings include inserting prefabricated units within the skeleton frame; cable hanging; and stacking. Mixing of steel and concrete is becoming more popular. Mass and internal **damping** properties of the concrete assist in minimizing vibration effects, which are potential problems in very tall buildings.

# Resonance

**Definition:**

1. A specific response of a system, which is able to oscillate with a certain period, to external force acting with the same period.
2. The vibratory motion produced in a body by the influence of another body when their time periods are exactly equal.

**Natural period:**

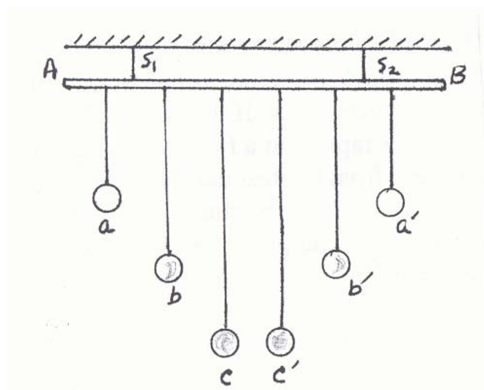
When a body vibrates freely under the action of its own elastic or gravitational force, it always vibrate with the same frequency f, called natural frequency of that body and time period T as its natural period. In case of simple pendulum it is

$$T = 2\pi\sqrt{\frac{\ell}{g}}$$

**Explanation:**

When a periodic force of frequency equal to the natural frequency of a body is applied on the body, it slowly gains in amplitude and finally begins to vibrate with a very large amplitude. This is known as resonance.

**Demonstration:**




An apparatus is shown in the figure. A horizontal rod is AB supported by two strings $S_1$ and $S_2$ . Three pairs of pendulums $aa^/$ , $bb^/$ and $cc^/$ are suspended to this rod.
If one of these pendulums, say c, is displaced in a direction perpendicular to the plane of the paper, then its resultant oscillatory motion causes in rod AB a very slight disturbing motion. Due to it a slight periodic motion will go in each pendulums. But causes the pendulum $c^/$ to oscillate back and forth with steadily increasing amplitude. However, the amplitudes of the other pendulums remain small, because their natural periods are not the same as that of the disturbing force.

**Condition:**

The resonance occurs when the frequency of the applied force is equal to one of the natural frequencies of vibration of the forced or driven harmonic oscillator.

The phenomenon of resonance holds good for all bodies capable of vibrations. It will also occur if the period of the applied force is any integral multiple of the natural period of the body.

**Applications:**

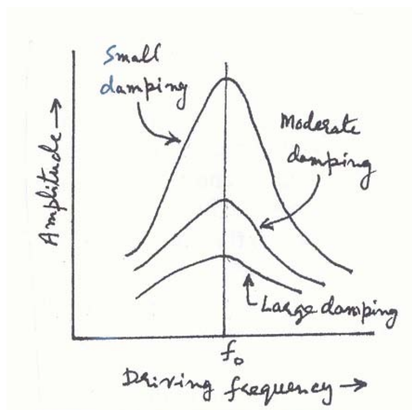
1. The phenomenon of resonance is employed to determine the natural frequencies of many bodies.
2. The art of singing or speaking and the wonderful mechanism of the human ear are excellent natural applications of resonance.

**Examples & Uses:**

1. A swing is an example of mechanical resonance. In it a series of regular pushes are given to the swing, to build large motion.
2. While crossing the bridges the soldiers are ordered to break their steps in order to avoid resonance.
3. Tuning a radio is an example of electrical resonance. By tuning a dial, the natural frequency of AC current in the receiving set is made equal to the frequency of the transmitter.
4. Heating and cooking of food in the microwave oven. The produced microwaves carrying heat energy in the range of $\sim 2450 \times 10^6$ Hz, are absorbed due to resonance by water and fat molecules in the food.
5. Employed in the improvements of the designs of microphones, loudspeakers, studios, etc.

**Sharpness of Resonance:**

At resonance amplitude of the oscillator becomes very large. If the amplitude decreases rapidly at a frequency slightly different from the resonant frequency, the resonance will be sharp. The amplitude as well as its sharpness, both depend upon the damping. Smaller the damping, greater will be the amplitude and more sharp will be the resonance. As it is shown in the figure.




***A heavily damped system has a fairly flat resonance curve.***

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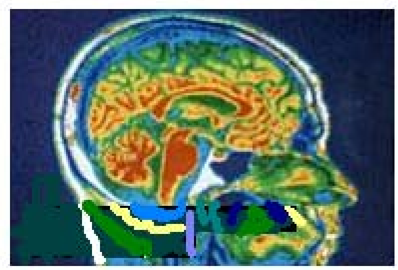
Longitudinal, transverse, and surface seismic waves cause vibrations at points where they reach the earth's surface. Strong tremors can reduce structural edifices to rubble in seconds Seismic instruments have been designed to detect these movements through electromagnetic or optical methods. Engineers consider a variety of quake-related factors in building design.

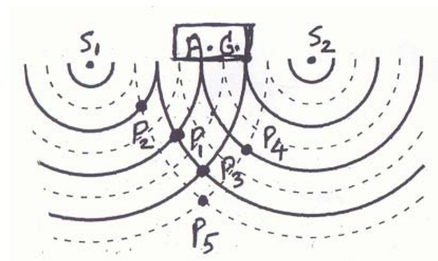
This magnetic resonance imaging (MRI) scan of a normal adult head shows the brain, airways, and soft tissues of the face.



# INTERFERENCE

**Interference:** 1) Superposition of two waves having the same frequency and traveling in the same direction results interference.

2) The phenomenon in which the two waves support each other at some points and cancel at others.

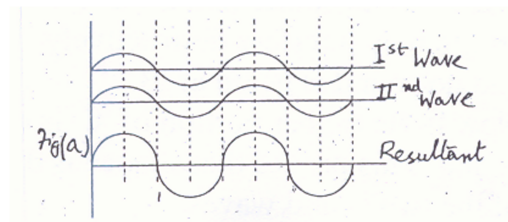



In the figure, compressions and rarefactions are alternately emitted by both sources (speakers). Continuous lines show compression and dotted lines show rarefactions. At points $P_1$, $P_3$ & $P_5$, we find that compression meets with a compression and rarefaction meets a rarefaction. So, the displacement of two waves is added up at these points and a larges resultant displacement is produced.

At points $P_2$ and $P_4$, compression meets with a rarefaction, so they cancel each other's effect. The resultant displacement becomes zero.

**Constructive Interference:**

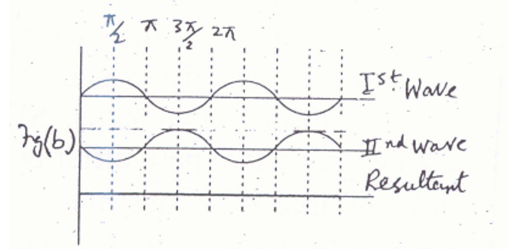
The interference of two waves, so that they reinforce one another.




**Condition for constructive interference:**

The phase difference—or path difference between two waves is zero or an integral multiple of $\lambda$.

or $\Delta S = n\lambda$ , $n = 0, \pm1, \pm2, \pm3, \pm4, \ldots$




**Destructive Interference:**

The interference of two waves, so that they cancel one another.

**Condition for destructive interference:**

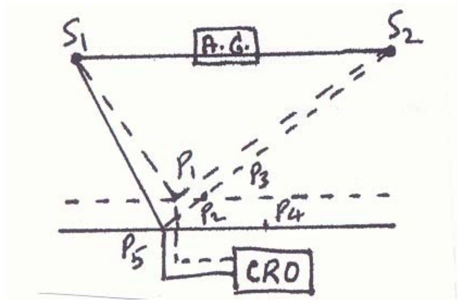
The phase difference or path difference between two waves should be an odd multiple of $\lambda/2$ .

or $\Delta S = (2n+1)\frac{\lambda}{2}$ , $n = 0, \pm1, \pm2, \pm3, \pm4 \ldots$

**Experimental demonstration:**

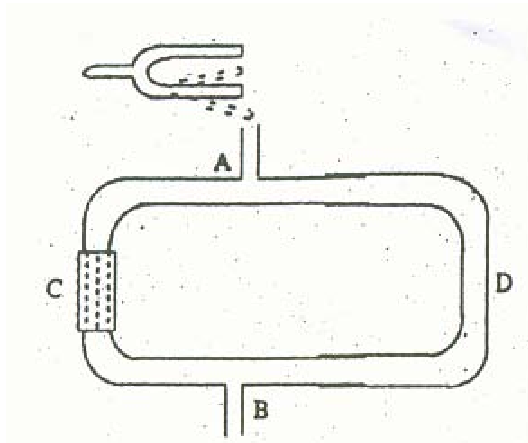
**1. Audio generator:**

Two loud speakers $S_1$ and $S_2$ act as two sources of harmonic sound waves of a fixed frequency produced by an audio generator. A microphone attached to a sensitive CRO act as a detector of sound waves. The microphone is placed at various points, turn by turn, in front of the loud speakers. At points $P_1$ , $P_3$ & $P_5$ , a large signal is seen on the CRO, whereas at points $P_2$ and $P_4$ , no signal is displayed on CRO screen.




**2. Quincke's Interference tube:**

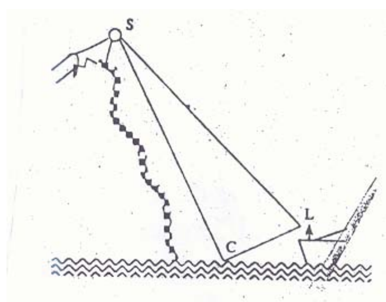
The apparatus is shown in the fig. A vibrating tuning fork is placed in front of the opening A. The sound waves on entering A will split, half the intensity goes through tube C and the other half through tube D. The two waves reunite at B and can be heard.



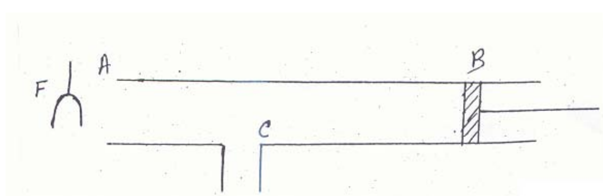

If the sliding tube D is adjusted to make both paths equal, then their path difference is zero and waves interfere constructively. If the tube D is drawn out, so that path ADB becomes longer. When path difference becomes half a wave-length they interfere destructively and no sound is heard at B.
Now if the rubber portion of C is closed, the ear will again hear the sound. This proves that silence is due to the destructive interference of the two sound waves.

**3. Fog Siren:**

If a fog siren is placed on the top of a peak. A ship approaching it may find itself in a silence zone, as it moves the sound again becomes audible. The listener L is receiving sound waves through two paths, SL and SCL. When these two path differ by half integral multiple of λ, destructive interference or silence zone occurs. And when path difference is nλ, the sound is heard.




**4. Seebeck's tube:**




Interference by Seebeck's tube.

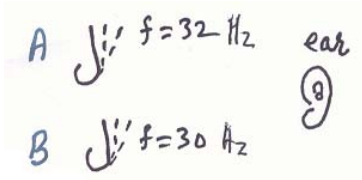
# Beats

**Definition:** 1) The condition whereby two sound waves form an outburst of sound followed by an interval of comparative silence.

2) The periodic alternations of sound between maximum and minimum loudness.

**Explanation:** If two sources of nearly equal frequencies are sounded at the same time, then only a single note is heard. This note rises and falls in loudness alternately.

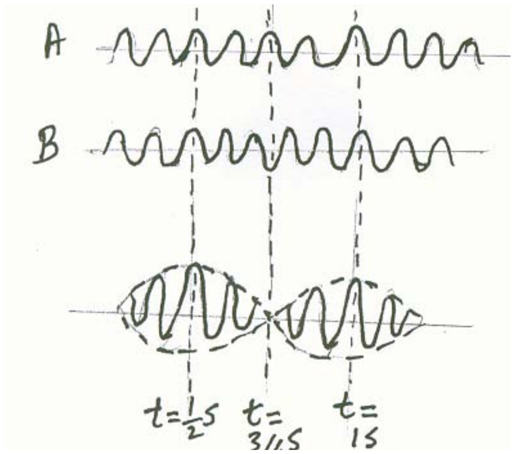
**Illustration:** Consider two tuning forks, having frequencies 30 and 32, be sounded together and placed upon a table. Suppose at a certain instant, at t = ½ seconds, fork A completes 16 vibrations and fork B 15 vibrations. The right hand prongs of both the forks just start moving to the right sending out compressions. These compressions arrive at the ear together and a loud sound is heard. During this interval one beat is heard.




After t = ¾ seconds, the fork A completes 24 vibrations and fork B 22 ½ vibrations. Again compression from A and the rarefaction from B cancel each other and no sound is heard. After t = 1 second, the fork A completes 32 vibrations and fork B 30 vibrations. Both these forks will be sending compressions and again a loud sound will be heard.
During this interval another beat is heard. So the total number of beats heard is 2, which is also equal to the frequency difference of two forks.

**Conclusion: The number of beats per second is equal to the difference between the frequencies of the tuning forks.**

**Displacement curves:**
From the principle of superposition, the resultant displacement of any particle will be the sum of the displacements due to each of the two waves. The resultant wave which is produced from two waves A and B are shown in fig. The variations of amplitude give rise to variations of loudness which is called beats.




**Applications of Beats:**

1. The phenomenon of beats is used in finding the unknown frequencies.
2. It is used in tuning the musical instruments, e.g. pianos, organs.
3. Presence of dangerous gases in mines is sometimes detected by means of beats.
4. It is also made use in the Heterodyne method of radio reception.

[Heterodyne: Having alternating currents of two different frequencies that are combined to produce two new frequencies the sum and difference of the original frequencies, either of which may be used in radio or TV receivers.]

# Dual Nature of Light

## Properties of Light

**Interference:** The phenomenon in which two waves support each other at some points and cancel at others.

**Diffraction:** The bending or spreading of waves around the edge of an opening or obstacle.

**Polarization (of light):** The limiting of the vibrations of light, usually to vibrations in one plane.

**Photoelectric effect:** The emission of electrons by a substance when illuminated by electromagnetic radiation.

**Compton effect:** The phenomenon in which a photon is scattered by an electron and the scattered photon has a frequency less than its original frequency.

**Theories of light:**

*Several theories have been given to explain the properties of light. We will consider the following four theories.*

1. **Newton's Corpuscular theory:**
   According to it light consists of streams of minute particles in motion.

2. **Huygen's wave theory:**
   According to it light travels from one place to another in the form of waves.

3. **Maxwell's Electromagnetic wave theory:**
   According to it light waves are electromagnetic in nature and they consist of an oscillating electric field and an oscillating magnetic field, both are perpendicular to each other and have the same frequency and phase.

4. **Quantum theory of light:**
   According to it light is carried from one place to another in wave packets called 'quanta' or 'photons', each having a definite energy and momentum.

**Dual nature of light:**

*Our present view about the nature of light is that light possesses both wave and particle properties. Sometimes it behaves like waves and sometimes it behave like particles. However, both these behaviors cannot be studied simultaneously.*

*i) Interference, diffraction and polarization shows its wave nature and can be explained by classical wave theory.*

*ii) Photoelectric effect and Compton effect exhibit its particle nature and can be explained by quantum theory.*

# Interference in thin films

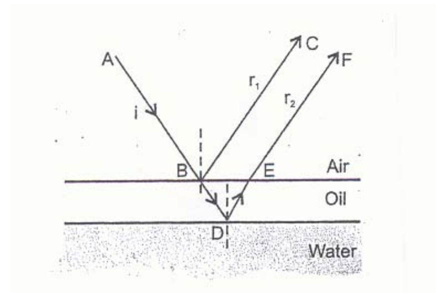
***Thin film:*** The transparent medium whose thickness is comparable with the wavelength of light.

***Principle of reflection:*** When reflection takes place from a denser medium, then reflected rays suffers a phase change of $180^{o}$ or a path difference of $\lambda/2$. When reflection takes place from a rarer medium, there is no change of phase.

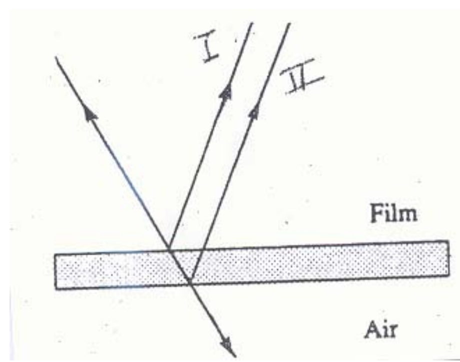
**Introduction:**

*The multiple reflection of light between the surfaces of transparent medium gives rise to beautiful effects of interference.*

**Illustration:**




Consider a thin film of a refracting medium. Let a monochromatic light of wavelength $\lambda$ be incident on the upper surface. A part of ray AB is reflected as ray BC and the rest of it is transmitted as ray BD. At D a part of it is again reflected , which emerges as ray EF. The rays BC and EF are superimposed to produce interference fringes. The monochromatic light will look bright or dark depending upon their path difference to make constructive or destructive interference.




Looking figure (b), part I of this beam is reflected from the upper surface and the remaining portion refracted into the film, after reflection from the second face, it emerges out as part II. As the film is thin, so the separation between part I and II is very small and they superimpose on each other. The portions I and II, being the parts of same beam, will have phase coherence. So the effect of their interference can be detected. This results in the formation of circular rings.

**Depending upon path difference:**

1) Thickness of the film. 2) Angle of incidence.
3) Nature depending upon index of refraction, n.

**Examples:**

1. Coloured fringes formed in soap bubbles.
2. Formation of colours in thin layer of oil on water.
3. Formation of colours on metal sheets during welding.

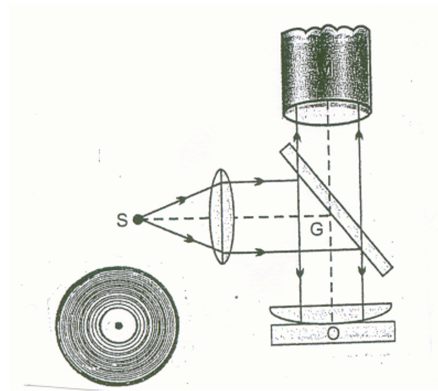
Fringe pattern for <u>transmitted rays</u> is just opposite to the reflected rays due to no phase change.

# Newton's Rings

**Definition:** Coloured rings produced by the interference of light waves.

**Explanation:**
If a convex lens is placed upon a flat glass plate, we enclose an air film between the lens and the glass plate. If such a film is illuminated by a parallel beam of monochromatic light from the top falling normally on the film and also viewed from the same direction, we will see dark and bright circular rings. Such rings were first studied by Newton and are known as Newton's rings.

**Experimental arrangement:**
A plano convex lens is placed in contact with a plane glass surface, shown in the fig. When this arrangement is illuminated from above by a parallel beam of mono-chromatic light, a series of concentric rings are observed. They are formed due to the interference between rays reflected by the top and bottom surfaces of air gap between the convex lens and the plane glass.




The air gap, equivalent to a thin film, increases in width from the central contact point out to the edges, corresponds to constructive and destructive interference and results in series of bright and dark rings, shown in the fig.

For dark rings, we have the formula,

$r = \sqrt{m\lambda R}$ ; r = distance between central spot and the dark fringe
m = number of order & R = radius of curvature of the lens

We can calculate the **wavelength** $\lambda$, from the above formula.

**Circular rings:**
The fringes are circular because the air film is symmetrical about the points of contact of the lens and the glass plate. That is , it will have the same thickness at all points which lie on the circumference of a circle drawn with centre O and a radius. The whole circle will therefore appear dark. These alternate bright and dark circular fringes can be observed by a low power travelling microscope.

**Black central spot:**
The point of contact between the two glass surfaces is dark. It is because of the fact that the two reflected parts of the incident wave ( although air gap is zero) at central spot are in opposite phase which is equivalent to a path difference of $\lambda /2$ .

**Transmitted light:**
If the fringes are seen with the help of transmitted light central spot will look bright. Because the path difference between the two paths of the wave is zero at the centre and they are in the same phase.

# Diffraction of Light

**Diffraction:** i) The property of bending of light around obstacles and spreading of light waves into the geometrical shadow of an obstacle.

ii) The bending or spreading of light waves around the edge of an opening or obstacle.

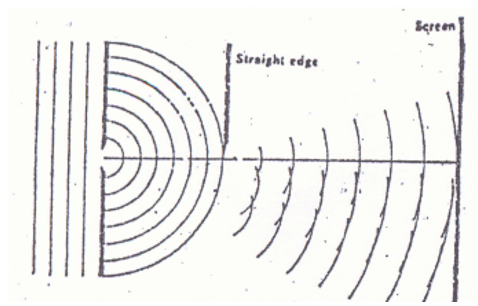
**Introduction:**

When light is incident over a sharp edge, it bends towards the geometrical shadow. The condition for diffraction is that the size of the obstructing object or slit must be comparable with the wavelength of the incident light.

The minute study or careful inspection of light shadow shows a series of bright and dark bands with the shadow which is due to diffraction.

**Illustration:**

Consider the light passing through a slit S and spherical wave fronts crossing a straight edge. Applying Huygen's principle, if we draw secondary wavelets, some of their portion will pass to the geometrical shadow. And interference give rise to fringes.




**Common factor between interference & diffraction:**

In both interference and diffraction superposition of waves occur.

**Difference between interference & diffraction:**

| | |
|---|---|
| 1.Interference is the superposition of few secondary wavelets. | 1. Diffraction is the superposition of very large number of secondary waves. |
| 2. Interference fringes are equally spaced. | 2. Diffraction fringes are wide near the obstacle and go on becoming narrow towards the shadow region. |
| 3. Interference is the result of interaction of two different wave fronts originating from the same source. | 3. Diffraction is the result of interaction from different parts of the same wave front. |
| 4. Points of minimum intensity are perfectly dark. | 4. Points of minimum intensity are not perfectly dark. |
| 5. All bright bands are of uniform intensity. | 5. All bright bands are not of the same intensity. |

**Difference between deviation & diffraction:**

**Deviation:** The turning of a ray during reflection or refraction.

**Diffraction:** The bending or spreading of light waves around the edge of an opening or obstacle.

In deviation two mediums viz. denser and rarer are required.

In diffraction no change of medium is involved.

One more term:

**Scattering:** The deflection of light by fine particles from the main direction of a beam.

# Diffraction Grating

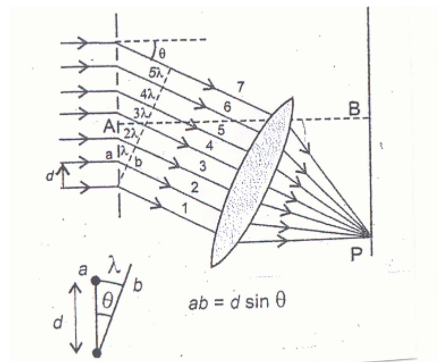
**Diffraction grating:**

A diffraction grating is a glass plate having a large number of close parallel equidistant slits mechanically ruled on it.

**Grating element:**

Distance of the width of slit and the separation between two consecutive slits, which is equal to length of grating divided by number of ruled lines.

**Experimental arrangement:**




To understand how a grating diffracts light.

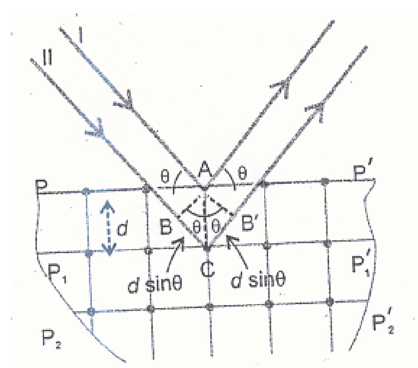
Consider, a parallel beam of light illuminating grating at normal incidence. The parallel rays of the diffraction through the grating make an angle θ with AB. They are brought to focus on the screen at P by a convex lens. For P to be bright point, the path difference will be integral multiple of λ to make constructive interference. We have

$$d \sin\theta = n\lambda, \quad n = 0, \pm 1, \pm 2, \pm 3, \ldots$$ where n is number of order of image.

For θ = 0 corresponding to n = 0 gives zero order image. As θ increases we get second, third order bright images corresponding to 2λ, 3λ, etc.

Diffraction of X-Rays by Crystals

**X-rays** is a type of electromagnetic radiation of much shorter wavelength of the order of $10^{-10}$ m.




To observe the effects of diffraction, the grating spacing must be of the order of the wavelength of the radiation used. The regular array of atoms in a crystal forms a natural grating with spacing $\sim 10^{-10}$ m. In the figure, a series of atomic planes of constant inter-planar spacing are shown.

If an X-ray beam is incident at an angle θ on one of the planes, the beam will be reflected from both upper and lower planes. The path difference for reinforcement of two reflected beams is $2d\sin\theta$, i.e.,

$$2d\sin\theta = n\lambda$$ where n is the order of reflection.

The above equation is known as Bragg equation.

It can be used to determine inter-planar spacing between similar parallel planes of a crystal if known wavelength of X-rays is used.

X-ray diffraction has been useful determining the structure of biologically important molecules such as hemoglobin and double helix structure of DNA. It is also used in the field of X-ray crystallography in which structure of crystals is investigated.

# Polarization

**Polarization (of light):**

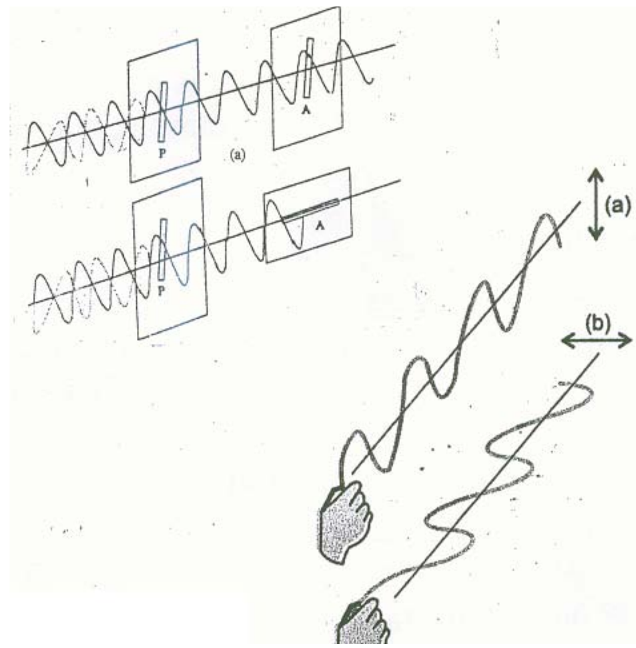
*The limiting of the vibrations of light, usually to vibrations in one plane.*

**Introduction:**

*The phenomenon of interference and diffraction proves the wave nature of light, but polarization shows that light moves as transverse waves.*

**A mechanical experiment:**

To distinguish between a transverse wave and longitudinal wave, a mechanical experiment can be performed as shown in the figure. Transverse wave on a string passed through a wooden piece with a slit P. If the slit is at right angles, the wave is not passed. If the wave was longitudinal, the slit position does not count.




**Production:**

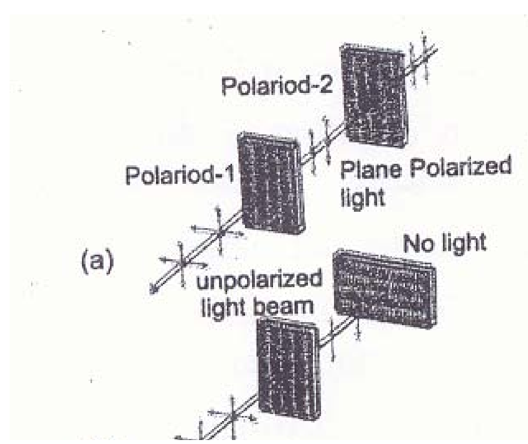
In transverse mechanical waves, the vibration can be oriented along vertical, horizontal or any other direction as shown in the figure.

A light emitted by a bulb or Sun is unpolarized. It is produced by oscillating charge consists of a periodic variation of electric field vector accompanied by the magnetic field vector at right angle to each other.

**Detection & Obtaining Polarized Light:**

The selective absorption method is the most common method to obtain plane polarized light by using certain types of materials called dichroic substances, e.g., a polaroid.

When two polaroids placed with their crystal axes parallel, a beam of light falls on them is transmitted. If one of them is rotated, the intensity of the transmitted light decreases and finally cut off when the axes of two crystals become perpendiculars to each other, as shown in the figure. On further rotation the light reappears.




This transmitted light is called plane polarized, which is defined as a beam of light in which all the vibrations are in one direction.

**Factors:**

According to electromagnetic theory, light consists of electric and magnetic components perpendicular to each other. When light passes through certain crystals, the electric vibrations are confined in a particular plane are moved in a single direction.

In general polarization depends upon,

1) Selective absorption of light.
2) Reflection of light.
3) Refraction of light.
4) Scattering of light.

**Optical Rotation:**

When a plane polarized light is passed through certain crystals, they rotate the plane of polarization. For example, quartz and sodium chlorate are termed as optically active crystals.

**Applications:**

1. Polaroid filters
   It's a transparent plastic sheet in which needle like crystals are embedded. These filters are used in many fields for polarization of light.
2. Optical activity
   Concentration of sugar in blood or urine is determined through polarized light.
3. Curtain-less window
   An outer polarizing disc is fixed and inner one is rotated to adjust the amount of light.
4. Head lights
   At night head-light glare can be controlled through polarizing headlights and light polarizing viewer.
5. Photography
   Polarizing discs are used in front of camera lens to enhance the effect of sky.

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**Few Definitions:**

**Optical activity:** The property of rotating the plane of polarization of light.

**Incandescent:** Glowing with heat; white-hot.

**Absorption:** In radiation. Reduction in the intensity of electromagnetic radiation, or other ionizing radiation, on passage through a medium.

**Reflection:** The turning back of a wave from the boundary of a medium.

**Refraction:** The bending of a wave disturbance at it passes obliquely from one medium into another of different density.

**Scattering:** The deflection of light by fine particles from the main direction of a beam.

**Dichroic substances:** The substances (or crystals) such as tourmaline having property of selectively absorbing light vibrations in one plane while allowing light vibrations at right angles to this plane to pass through.

**Polaroid:** A doubly refracting material that plane-polarizes unpolarized light passed through it.

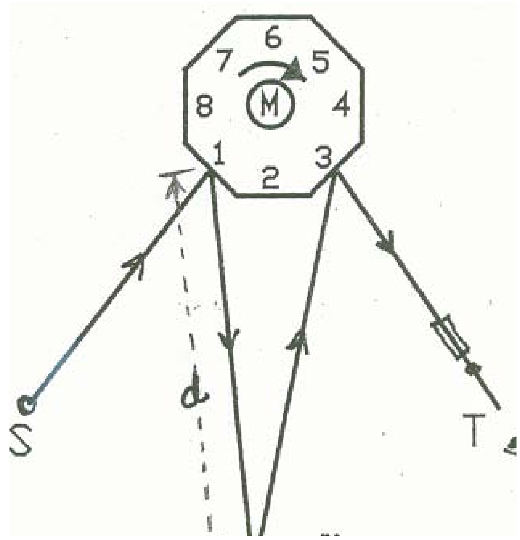
# Spectrometer

**Spectrum:** A band of seven colours formed by the dispersion of the components of white light, when it is passed through a prism.
**Spectrometer:** Optical instrument used for the study of spectra from different sources of light. It consists of collimator, turntable and telescope.
**Collimator:** It consists of a fixed metallic tube with a convex lens at one end and an adjustable slit, that can slide in and out of the tube, at the other end.
**Turn-table:** The part of the spectrometer between collimator and telescope. This turn-table is provided with three leveling screws. It is used for supporting the prism or the diffraction grating.
**Telescope:** A device for collecting and producing an image of distant objects. It is attached with a vernier scale and is rotatable about the same vertical axis as the turn table.

# Speed of Light

## Michelson's experiment

The speed of light was determined by measuring time it took to cover a round trip between two mountains. Figure shows experimental set up.
The eight-sided mirror M can be rotated clockwise.
The source S becomes visible when time taken by light for round trip between M and m is equal to moving the mirror M from face 2 to face 1.




Time taken by light for round trip = $t_1 = \frac{2d}{c}$

Time of moving face 2 to face 1 = $t_2 = \frac{1}{2\pi f} \times \frac{2\pi}{8} = \frac{1}{8f}$

$S = v\,t$

or $t = \frac{S}{v}$

The above two times are equal for the source S to be visible.
So

$$\frac{2d}{c} = \frac{1}{8f} \quad \text{or} \quad c = 16\,f\,d$$

Time T for one vibration i.e. for $2\pi$ angle

$T = \frac{1}{f} = \frac{1}{2\pi f} \times 2\pi$

time t for rotating $2\pi / 8$ angle

$t = \frac{1}{2\pi f} \times \frac{2\pi}{8}$

The above equation was used to determine the speed of light.
Presently accepted value for the speed of light in vacuum is

$$c = 2.99792458 \times 10^8 \text{ms}^{-1} \quad \text{rounded to} \quad 3.00 \times 10^8 \text{ms}^{-1}$$

The speed of light in other materials is always less than c.
The speed of light in air is generally taken as that of speed in vacuum.

## Thermodynamic Scale

"The fraction 1/273.16 of the thermodynamic temperature of the triple point of water".

It is the SI base unit of thermodynamic temperature.

Zero Kelvin (0 K) is absolute zero. One Kelvin is the same as one degree on the Celsius scale of temperature.

In this scale, absolute zero is at -273.16° C, which is zero K, and the degree intervals are identical to those measured on the Celsius scale

The unknown temperature T in Kelvin is, $T = 273.16\frac{Q}{Q_3}$

where Q is heat absorbed or rejected by the system at T

& $Q_3$ is heat absorbed or rejected by the system at the triple point

**Triple point:** The only point at which the gas, solid, and liquid phases of a substance can coexist in equilibrium. The temperature of the triple point of water is defined to be 273.16 Kelvin.

**Petrol engine:**

An engine based on the principle of Carnot cycle. It undergoes 4 processes;

i) Intake of petrol air mixture into the cylinder with a outward piston.
ii) Adiabatic compression of the mixture with the inward piston.
iii) A spark fires the mixture causing its adiabatic expansion that forces the piston to move outward which delivers power to crank shaft to derive the flywheel.
iv) The residual gases are expelled from the outlet valves and piston moves inward.

**Carburetor:**
A device used to charge air with gas from petrol for producing light or power. It mixes liquid fuel and air in the correct proportions, vaporizes them, and transfers the mixture to the cylinders.

**Diesel (or diesel fuel):** Fuel used for diesel (compression ignition) engines. The composition varies but is near that of gas oil.

**Petrol (or gasoline):** A light hydrocarbon liquid fuel for spark-ignition engines; a complex mixture consisting mainly of hydrocarbons such as hexane, heptane and octane.

**Diesel engine:**

Its like a petrol engine but without sparkplug. It undergoes four processes;

i) The diesel is sprayed into the cylinder with a outward piston,
ii) Adiabatic compression of the mixture with the inward piston,
iii) Fuel mixture ignites on contact with air due to high temperature causing its adiabatic expansion that forces the piston to move outward which delivers power to crank shaft to derive the flywheel,
iv) The residual gases are expelled from the outlet valves and piston moves inward.

# Entropy & Second Law of Thermodynamics

Entropy: "The physical quantity which describes the ability of a system to do work and it also describes disorder of a system". Mathematically

$$\Delta S = \frac{\Delta Q}{T}$$

Entropy is a state variable. It is a measure of disorder. The more disordered the state of a system, the larger will be its entropy.

Change in entropy is positive when heat is added and negative when heat is removed from the system.

Another form of Second Law of Thermodynamics

If a system undergoes a natural process, it will go in the direction that causes the entropy of the system plus the environment to increase.

*Only those processes are probable for which entropy of the system increases or remains constant. The process for which entropy remains constant is a reversible process; whereas for all irreversible processes, entropy of the system increases.*
Increase in entropy means degradation of energy from a higher level where more work can be extracted to a lower level at which less or no useful work can be done. The energy in a sense is degraded, going from more orderly form to less orderly form, eventually ending up as thermal energy.
In all real processes where heat transfer occurs, the energy available for doing useful work decreases. In other words the entropy increases.

## Relating the both

In the definition and application of the Second Law of Thermodynamics, Clausius was the first to introduce a new physical quantity, called entropy, which has proved to be of great importance not only in the further development of thermodynamics but also in the recognition of a fundamental law of Nature. The problem of continuous conversion of heat into work, with which the second law deals, is largely dependent on the direction rather than the actual amount of energy change in a system. We find that the new concept, entropy, can cover that additional factor. In the application of the second law, the change of the thermal state of the working substance is more important than the general idea of more convertibility of heat in work, since it is the working substance alone which undergo a thermo-dynamical change in the process, so entropy can efficiently define the thermo-dynamical state of any working substance. Also entropy deals with the physical property of a substance that can remain constant in adiabatic change.
The above arguments lead us to restate second law of thermodynamics in terms of entropy. That is, the entropy of the Universe during any process either remains constant or increases.