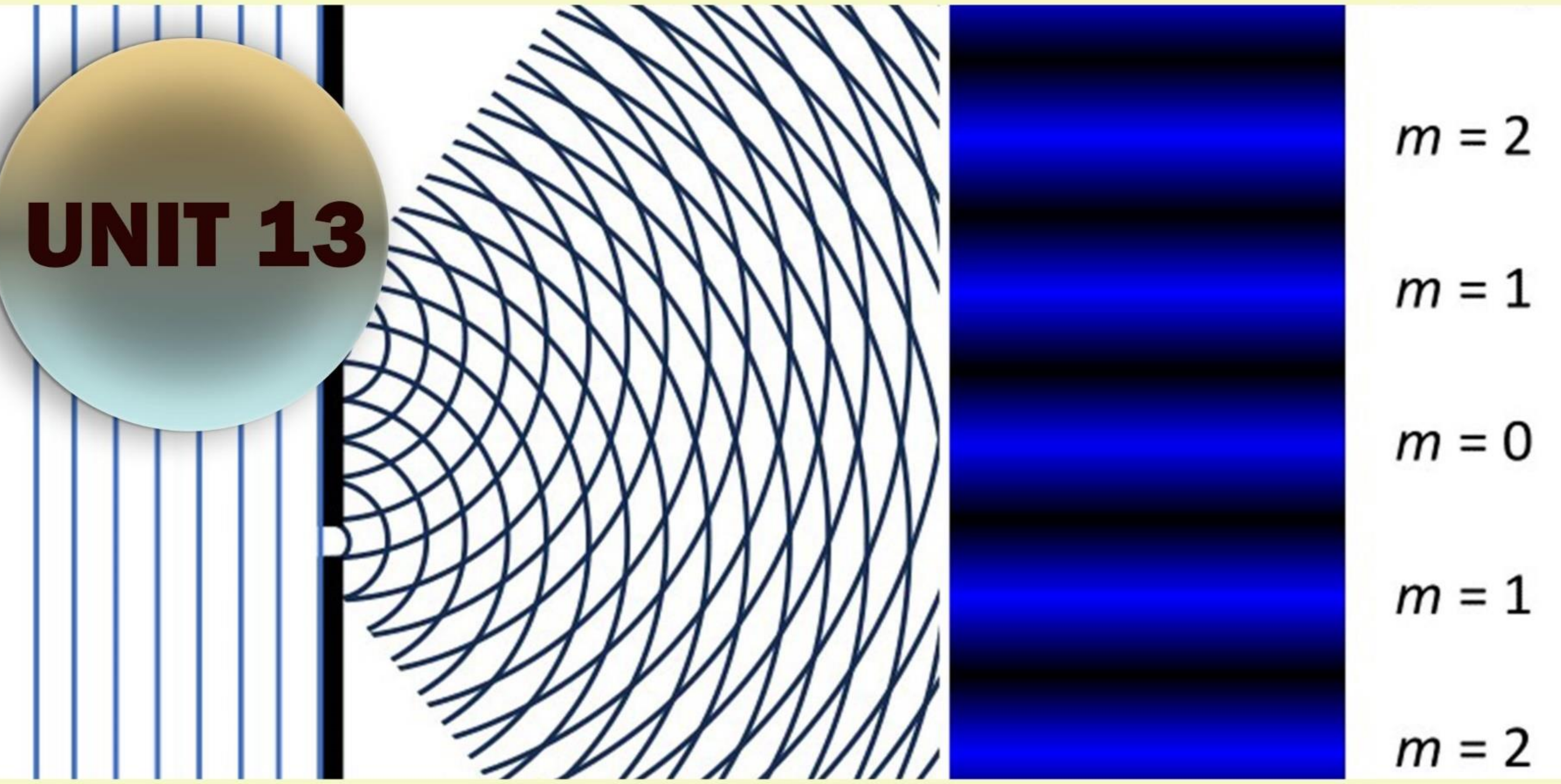
PHYSICS

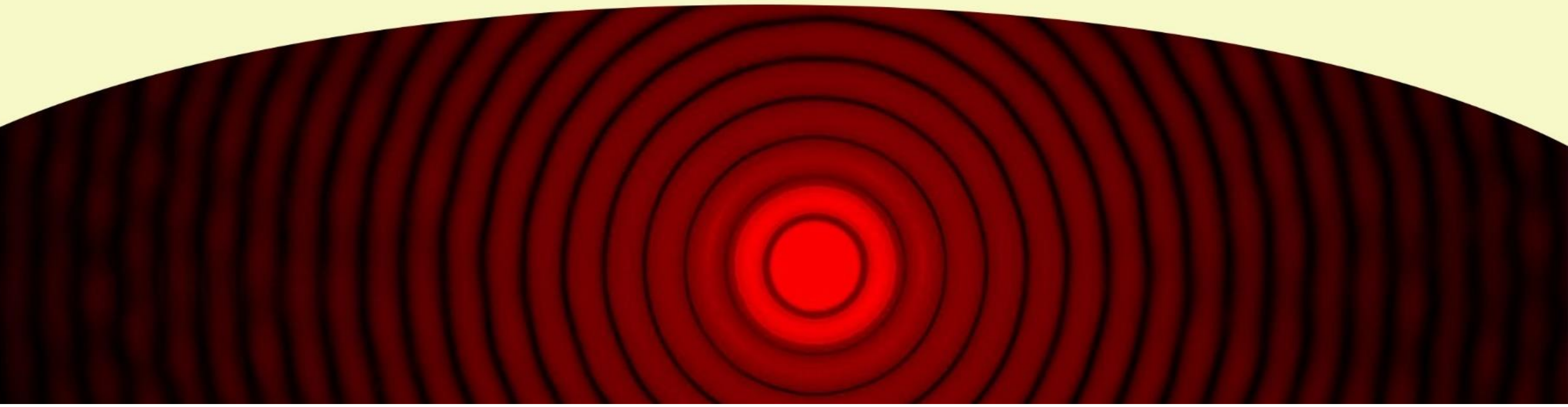
XI

UNIT 13



PHYSICAL OPTICS

PROF:IMRAN HASHMI



NATURE OF LIGHT

Light is everywhere. It extends from the large scale of the universe into our ordinary world. However, the physical understanding of the most common phenomenon, light, has involved significant scientific ideas: classical mechanics, wave theories, quantum particles, and relativity. Some of the greatest physicists made definitive studies on the nature of light.

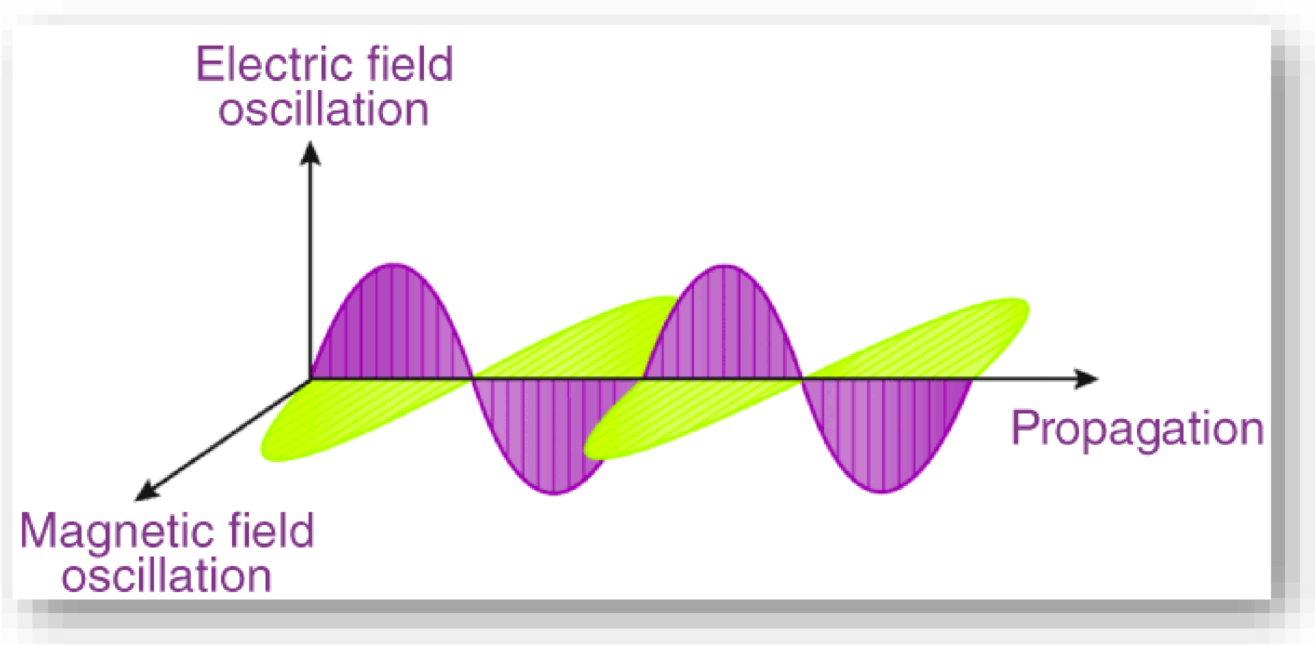
Light has a dual nature that is; particle nature and wave nature. The word "wavelength" expresses the wave or undulating property of light. It is the distance that light travels in one oscillation, and is often described using a unit called a "nanometer". One nanometer is equal to one billionth of a meter. Our eyes can only see light of a wavelength between approximately 400 to 700 nanometers. This range is called the visible light. The light of other wavelengths includes X-rays, ultraviolet rays, and infrared rays. Though we cannot see them directly, these are also members of the light family.

On the other hand, light also has the property of a particle. The intensity of the light varies depending on the number of particles. Bright light has many particles while dark light has fewer particles. These particles of light are called "photons".

Electromagnetic waves

Electromagnetic waves or EM waves are waves that are created as a result of vibrations between an electric field and a magnetic field. In other words, EM waves are composed of oscillating magnetic and electric fields.

Electromagnetic waves are formed when an electric field comes in contact with a magnetic field. They are hence known as 'electromagnetic' waves. The electric field and magnetic field of an electromagnetic wave are perpendicular (at right angles) to each other. They are also perpendicular to the direction of the EM wave.

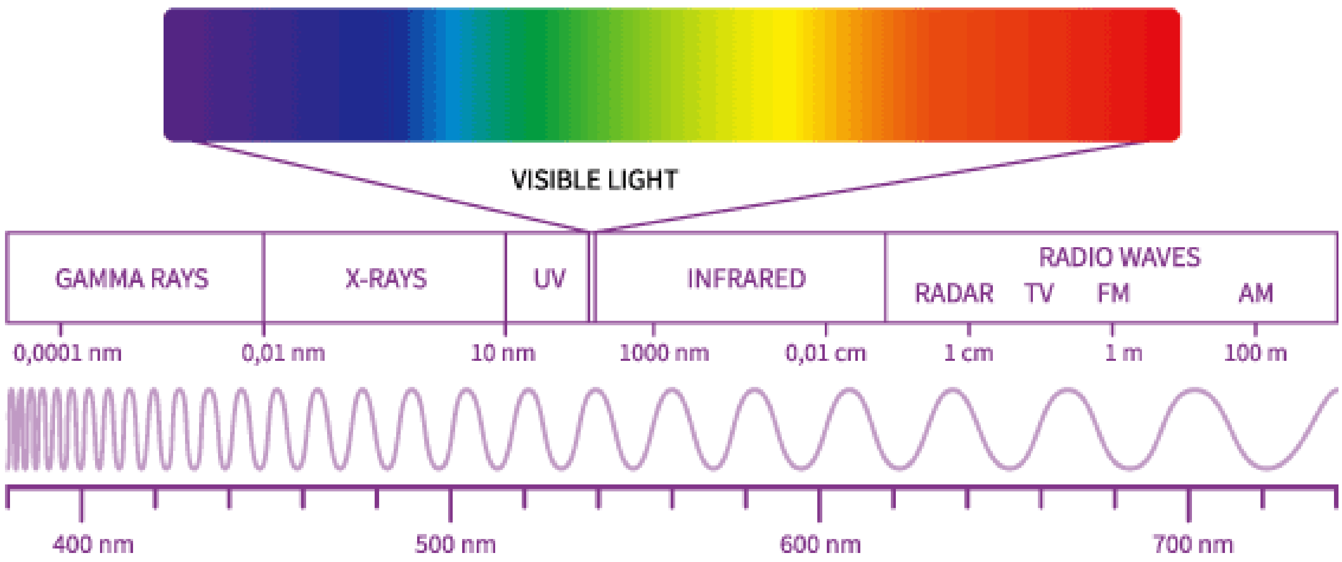


ELECTROMAGNETIC SPECTRUM,

The electromagnetic spectrum, in simple terms, is defined as the range of all types of electromagnetic radiation.

The electromagnetic spectrum is a range of frequencies, wavelengths, and photon energies covering frequencies from below 1 hertz to above 10^{25} Hz, corresponding to wavelengths which are a few kilometers to a fraction of the size of an atomic nucleus in the spectrum of electromagnetic waves.

Type of Radiation	Frequency Range (Hz)	Wavelength Range
Gamma-rays	$10^{20} – 10^{24}$	< 10^{-12} m
X-rays	$10^{17} – 10^{20}$	1 nm – 1 pm
Ultraviolet	$10^{15} – 10^{17}$	400 nm – 1 nm
Visible	$4 \times 10^{14} – 7.5 \times 10^{14}$	750 nm – 400 nm
Near-infrared	$1 \times 10^{14} – 4 \times 10^{14}$	2.5 μm – 750 nm
Infrared	$10^{13} – 10^{14}$	25 μm – 2.5 μm
Microwaves	$3 \times 10^{11} – 10^{13}$	1 mm – 25 μm
Radio waves	< 3×10^{11}	> 1 mm



FORMS OF ELECTROMAGNETIC RADIATION

RADIO WAVES

The term radio waves refers to electromagnetic radiation with wavelengths greater than about 0.1 m. Radio waves are commonly used for audio communications (i.e., for radios), but the term is used for electromagnetic waves in this range regardless of their application.

Radio waves typically result from an alternating current in the wires of a broadcast antenna. They cover a very broad wavelength range and are divided into many subranges, including microwaves, electromagnetic waves used for AM and FM radio, cellular telephones, and TV signals.

The higher the frequency of the radio wave used to carry the data, the greater the detailed variation of the wave that can be carried by modulating it over each time unit, and the more data that can be transmitted per unit of time. The assigned frequencies for AM broadcasting are 540 to 1600 kHz, and for FM are 88 MHz to 108 MHz.

MICROWAVES

Microwaves are the highest-frequency electromagnetic waves that can be produced by currents in macroscopic circuits and devices. Microwave frequencies range from about 10^9 *Hz* to nearly 10^{12} Hz.

Microwaves can also be produced by atoms and molecules. They are, for example, a component of electromagnetic radiation generated by thermal agitation. The thermal motion of atoms and molecules in any object at a temperature above absolute zero causes them to emit and absorb radiation.

Radar is a common application of microwaves that was first developed in World War II. By detecting and timing microwave echoes, radar systems can determine the distance to objects as diverse as clouds and aircraft. A Doppler shift in the radar echo can be used to determine the speed of a car or the intensity of a rainstorm. Sophisticated radar systems are used to map the Earth and other planets.

INFRARED RADIATION

Infrared radiations are also known as thermal or heat waves. The range of wavelength is between 710 mm to 1 mm. The rays are also characterized as near and far-infrared rays. The near-infrared rays have been used in photography and TV remote sensors.

Far infrared rays are thermal. The human body also generates heat or infrared radiation of approximately 800 nm wavelength.

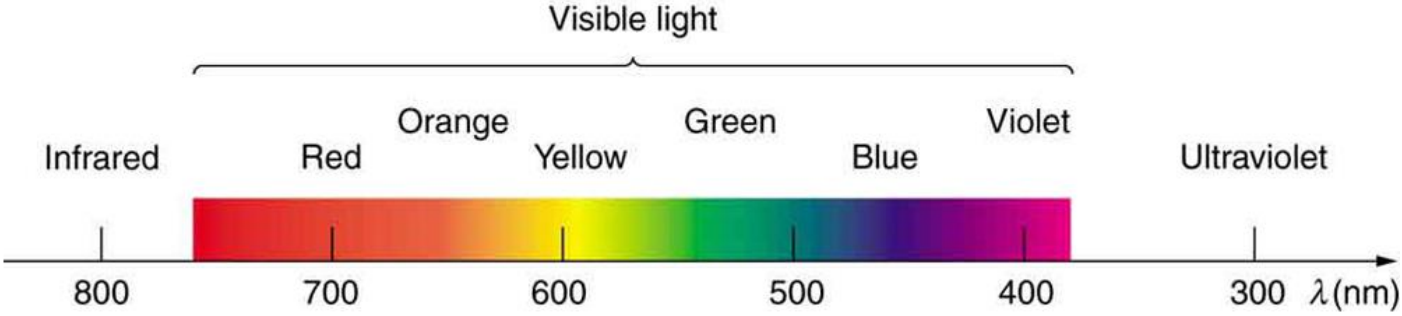
We use this radiation for treating dandruff, skin injuries, blackheads, and smoothing wrinkles. They also improve oxygen supply, blood circulation, and the supply of nutrients to the skin.

VISIBLE LIGHT

Visible radiation, also referred to as visible light or simply "light," is a form of electromagnetic (EM) radiation characterized by electromagnetic waves with wavelengths between 380 nanometers and 740 nanometers.

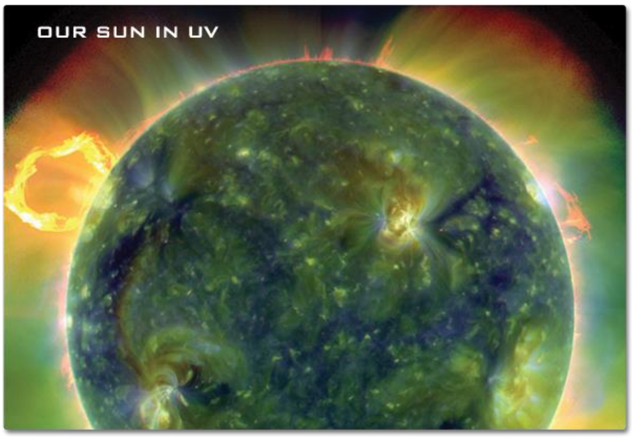
Red light has the lowest frequencies and longest wavelengths, whereas violet has the highest frequencies and shortest wavelengths.

Visible light is the most predominant and we enjoy the beauty of nature through visible light. Plants are more selective. Photosynthesis makes use of parts of the visible spectrum to make sugars.



ULTRAVIOLET RADIATION

Ultraviolet means "above violet." The electromagnetic frequencies of ultraviolet radiation (UV) extend upward from violet, the highest-frequency visible light. The highest-frequency ultraviolet overlaps with the lowest-frequency X-rays. The wavelengths of ultraviolet extend from 400 nm down to about 10 nm at its highest frequencies. Ultraviolet is produced by atomic and molecular motions and electronic transitions.



UV radiation from the Sun is broadly subdivided into three wavelength ranges: UV-A (320–400 nm) is the lowest frequency, then UV-B (290–320 nm) and UV-C (220–290 nm). Most UV-B and all UV-C are absorbed by ozone (O_3) molecules in the upper atmosphere.

Consequently, 99% of the solar UV radiation reaching Earth's surface is UV-A.

Sunburn is caused by large exposures to UV-B and UV-C, and repeated exposure can increase the likelihood of skin cancer.

X-Rays

X-rays have wavelengths from about 10^{-8} m to 10^{-12} m. They have shorter wavelengths, and higher frequencies (2.4×10^{16} Hz to 2.4×10^{19} Hz) , than ultraviolet, so that the energy they transfer at an atomic level is greater. As a result, X-rays have adverse effects on living cells similar to those of

ultraviolet radiation, but they are more penetrating. Cancer and genetic defects can be induced by X-rays. Because of their effect on rapidly dividing cells, X-rays can also be used to treat and even cure cancer. The widest use of X-rays is for imaging objects that are opaque to visible light, such as the human body or aircraft parts. In humans, the risk of cell damage is weighed carefully against the benefit of the diagnostic information obtained.

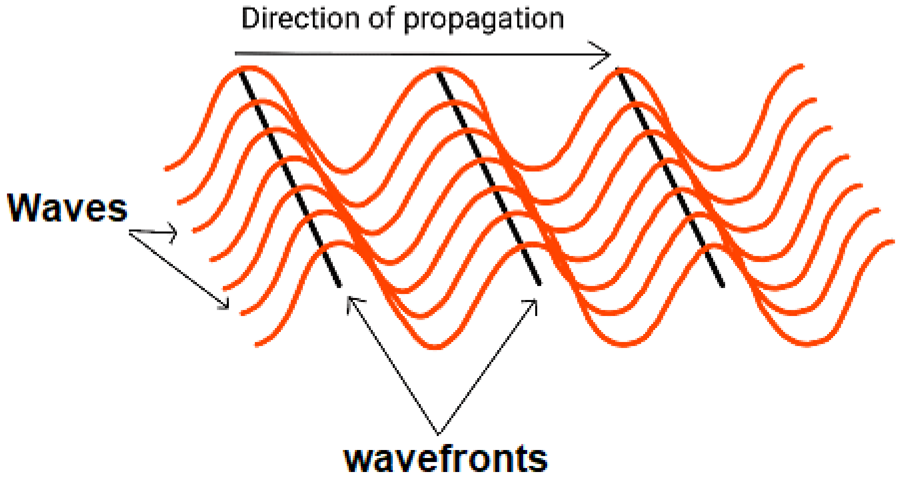
Gamma rays

Gamma rays are a form of electromagnetic radiation (EMR). They are similar to X-rays, distinguished only by the fact that they are emitted from an excited nucleus. Electromagnetic radiation can be described in terms of a stream of photons, which are massless particles each traveling in a wave-like pattern and moving at the speed of light. Each photon contains a certain amount (or bundle) of energy, and all electromagnetic radiation consists of these photons. Gamma-ray photons have the highest energy in the EMR spectrum and their waves have the shortest wavelength.

WAVEFRONT

A wavefront is an imaginary line on a wave that joins all points that have the same phase of vibration

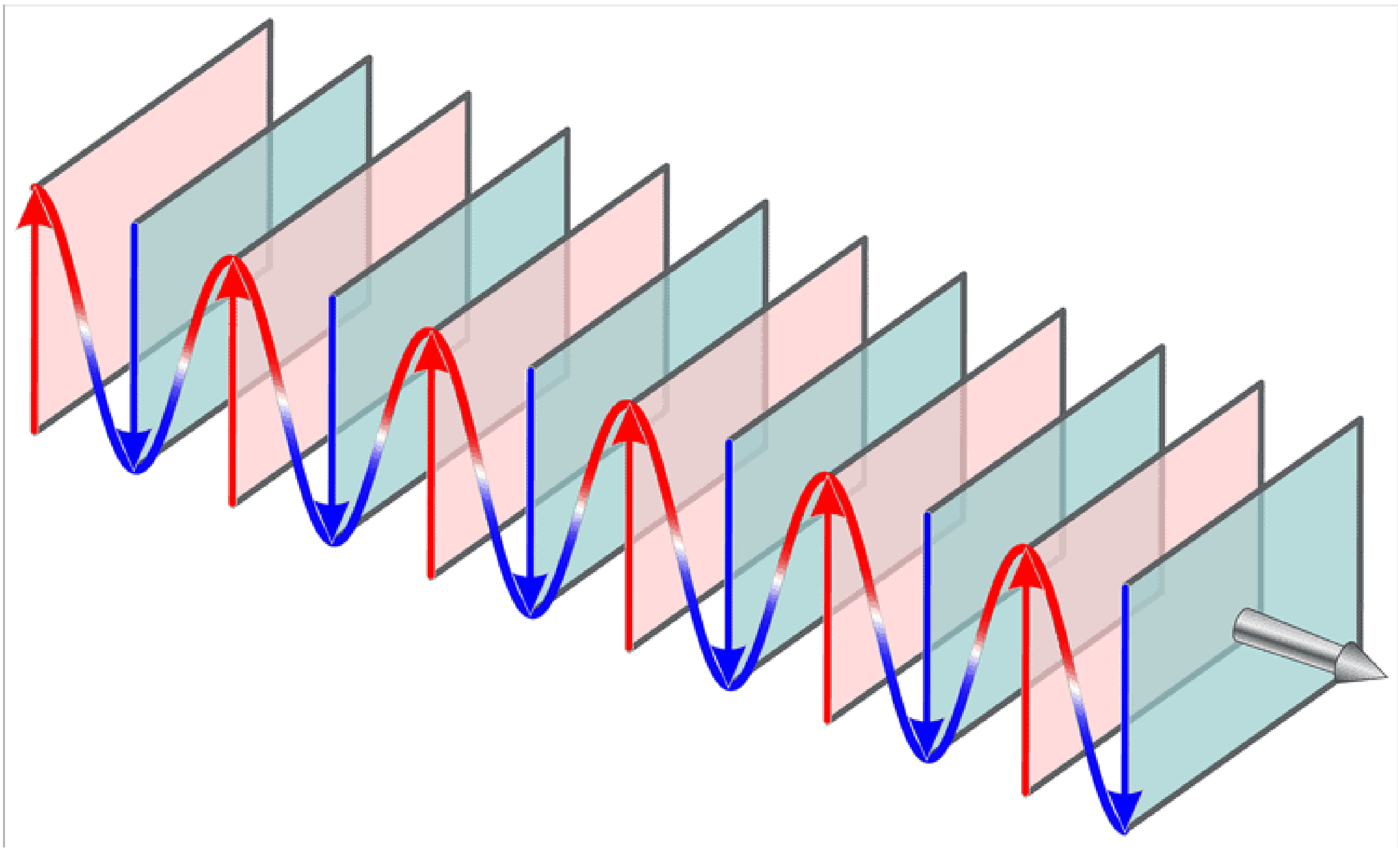
Wavefronts are imaginary surfaces to represent how waves move in two-dimensional space. A wavefront always propagates in the forward direction, as shown in the figure below.



PLANE WAVEFRONT

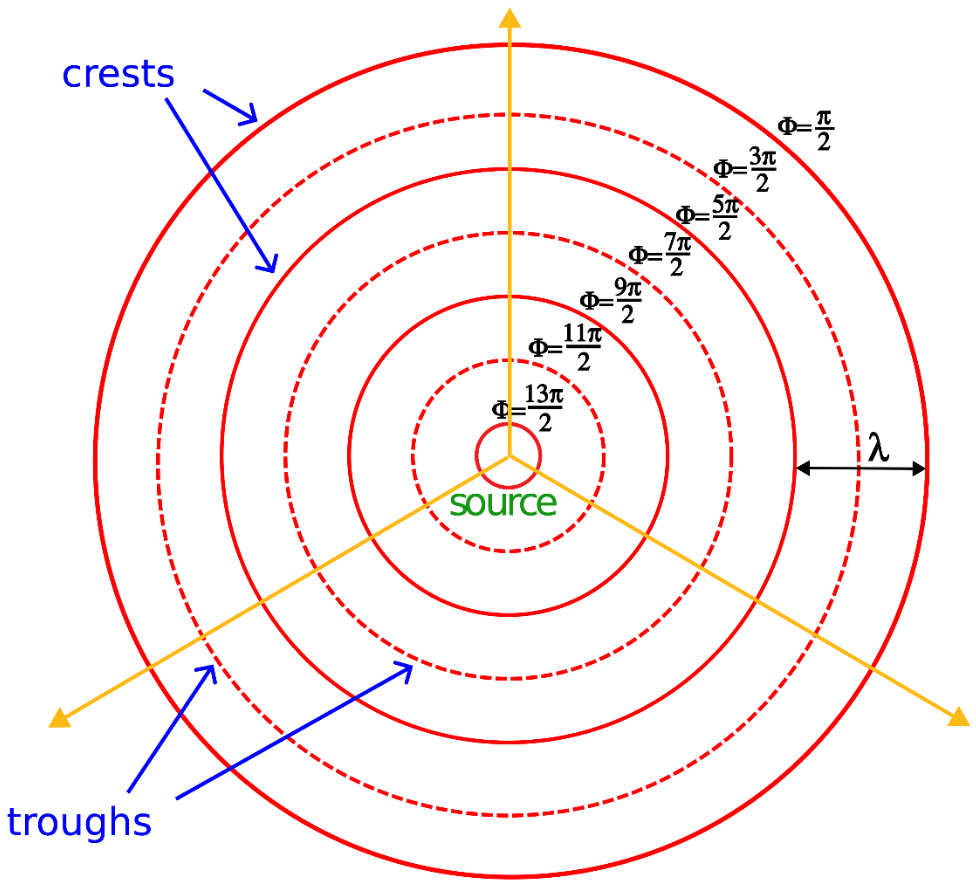
The wavefront will appear as a plane when viewed from a considerable distance from a source of any kind. Such a wavefront is called a plane wavefront.

Plane wavefronts are generated from a very distant source. A common example of the plane wavefront is the rays coming out of the sun.



SPHERICAL WAVEFRONT

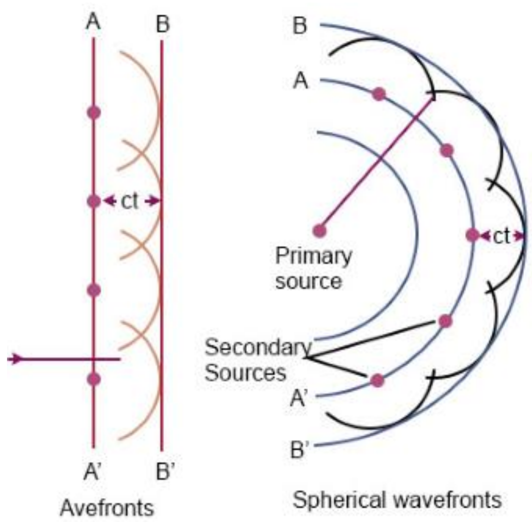
When the point source is an isotropic medium, sending out waves in three dimensions, the wavefronts are spheres centered on the source, as shown in the figure. Such a wavefront is called a spherical wavefront.



HUYGENS'S PRINCIPLE STATES AS,

1 At some time t, consider every point on a wavefront as a source of a new spherical wave. These wavelets move in the forward direction from the source at the same speed as the original speed of the wave. Fig. l3. I .la.

2 At a later time t + Δt, each wave has a radius (distance) cΔt, where c is the speed of the wave (light). The new position of the wavefront after time t+Δt can be found by drawing a plane tangential to all the secondary wavelets.



INTERFERENCE OF LIGHT

DEFINITION

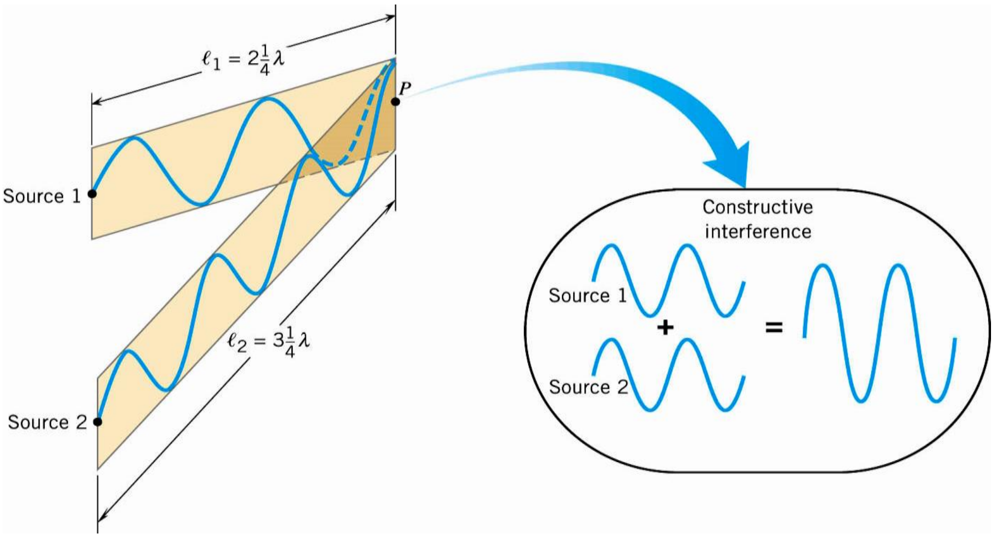
When two waves of light superpose each other, then under suitable conditions, they enhance the effect of each other at some points and cancel their effects at other points. This is called interference.

TYPES OF INTERFERENCE

The interference of light waves can either be constructive interference or destructive interference.

CONSTRUCTIVE INTERFERENCE

If the resultant intensity of interfering waves is greater than the intensity of an individual wave then interference is said to be constructive.



PATH DIFFERENCE

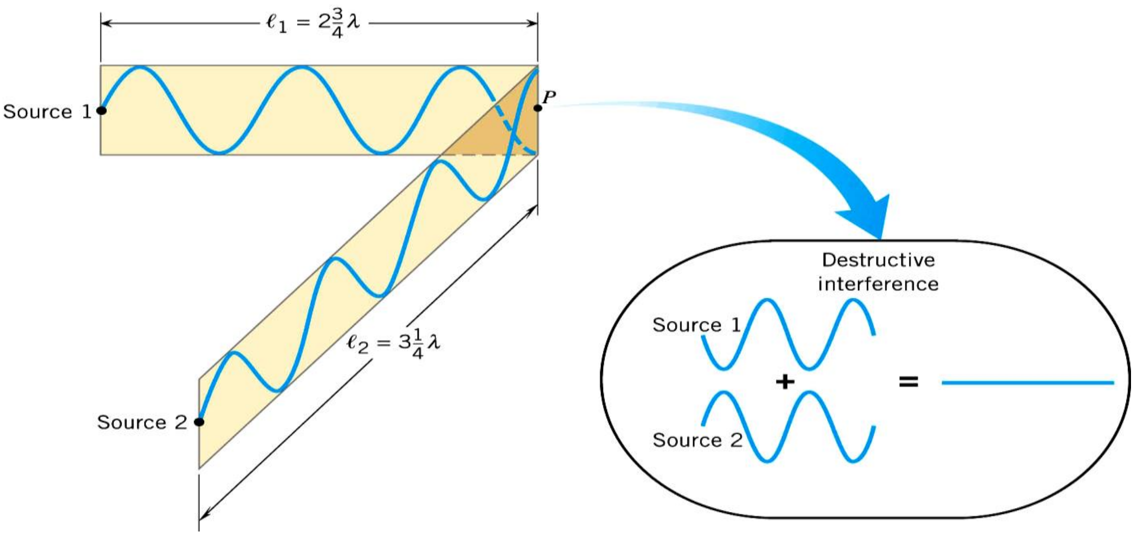
For constructive interference, path difference is an integral multiple of wavelength.

Path difference = m λ

Where m = 0, +, +2, +3 . . . .

DESTRUCTIVE INTERFERENCE

If the resultant intensity of interfering waves is less than the intensity of an individual wave then interference is said to be destructive.



PATH DIFFERENCE

For destructive interference path difference is an odd multiple of half wavelength.
Path difference = (m + 1/2) λ
Where m = 0, + 1, + 2,. . . . . . .

CONDITIONS OF INTERFERENCE

Interference occurs whenever two waves come together, but certain conditions need to be fulfilled to produce an observable interference.

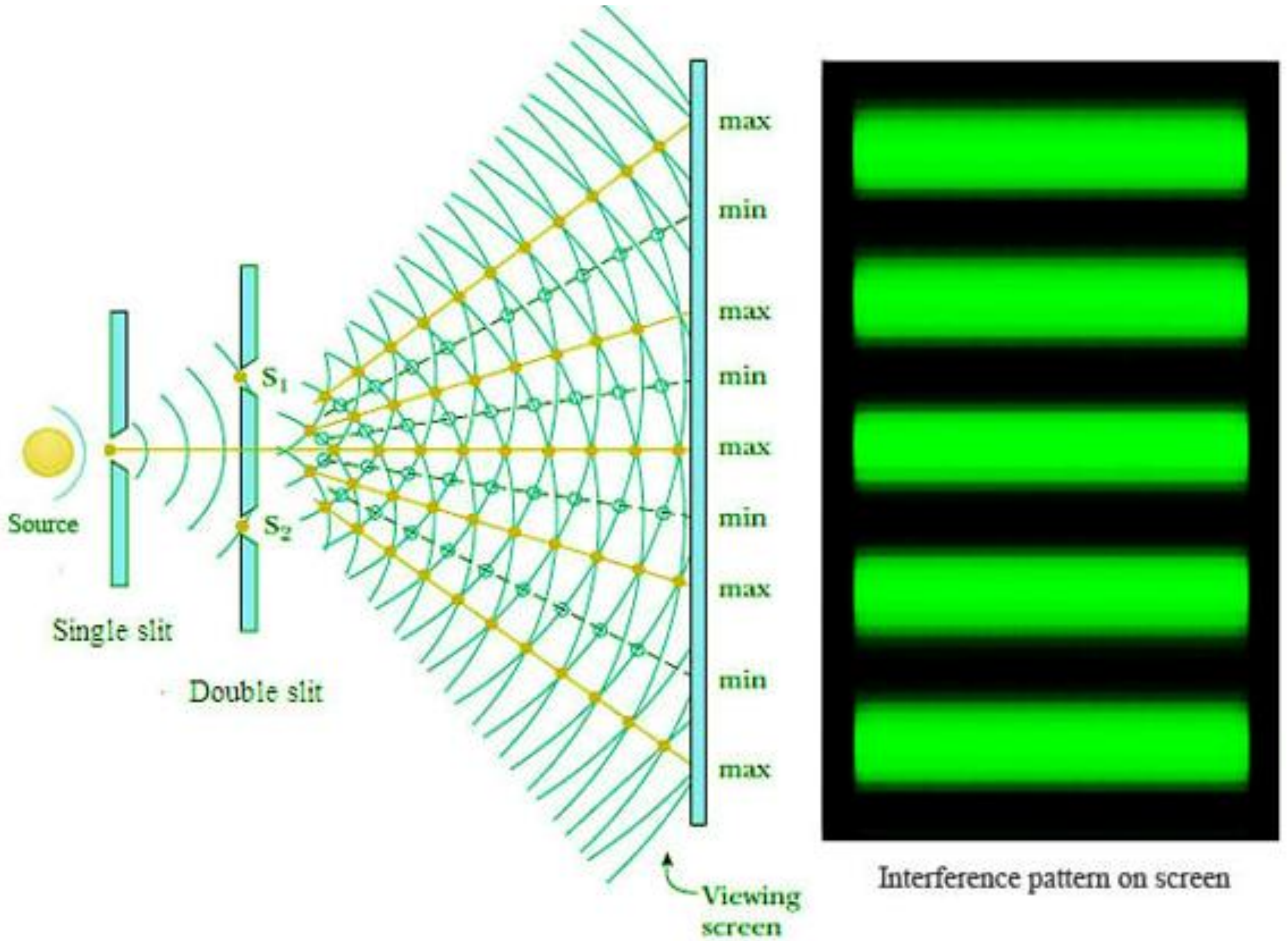
1. **The light waves must have an identical wavelength.**
2. **The distance between the screen and the source must be large.**
3. **The sources must be close enough.**
4. **The sources must be coherent-that is, they must maintain a constant phase** to **each other**.

YOUNG'S DOUBLE SLIT EXPERIMENT

Thomas Young first demonstrated interference in light waves from two sources in 1801. Figure is a diagram of the apparatus used in this experiment

THEORY

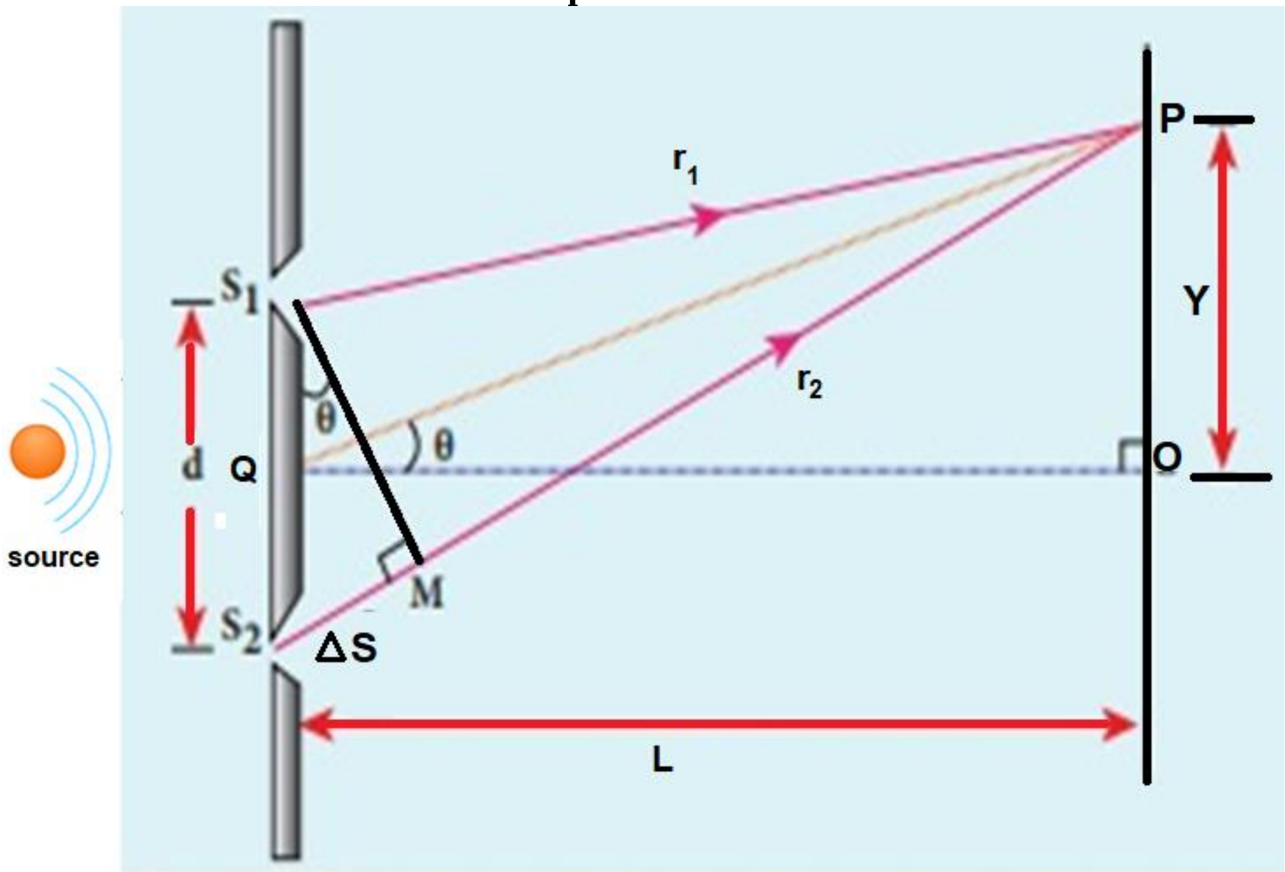
When monochromatic light is allowed to an incident on slits S_1 and S_2, the two slits serve as a pair of coherent light sources because waves emerging from them originate from the same wavefront and therefore are always in phase. The light from the two slits produces a visible pattern on the screen, consisting of a series of bright and dark parallel bands called fringes.



ANALYTICAL TREATMENT OF YOUNG DOUBLE SLITS EXPERIMENT

Consider two narrow slits S_1 and S_2 which are separated by a small distance d. these slits are illuminated by monochromatic light of wavelength λ. Two lights from both slits produce interference at point **P** on the viewing screen which is positioned at a perpendicular distance **L** from the screen.

Note that a wave from the lower slits travels farther than a wave from the upper slit the amount of **dsinθ**. This distance is called the **path difference ΔS.**



Consider triangle ΔS_1S_2R

$$Sin\theta = \frac{Perp}{Hyp}$$

$$Sin\theta = \frac{S_2M}{S_1S_2}$$

$$Sin\theta = \frac{\Delta S}{d}$$

$$d\ Sin\theta = \Delta S \ldots\ldots\ldots(i)$$

The separation of slits (d) is very small as compared to the distance between the slits and screen (L). Under this condition the right angle triangles M S_1 S_2 and PQO are similar,

Again In ΔOPQ

$$\text{Tan}\theta = \frac{\text{Perp}}{\text{base}}$$

$$\text{Tan}\theta = \frac{y}{L}$$

For the small value of θ, we can write

$$\sin\theta \approx \tan\theta$$

$$\text{Sin}\theta = \frac{Y}{L}$$

Substituting the value of sin θ, from above equation in equation.(i), we get

$$d\,\frac{Y}{L} = \Delta S$$

$$d\,\frac{Y}{L} = \text{path difference}$$

$$d\,Y = (\text{path difference})L$$

$$Y = (\text{path difference})\left(\frac{L}{d}\right) \quad \ldots\ldots(ii)$$

POSITIONS OF BRIGHT FRINGES

Constructive interference will occur, and a bright fringe will appear on the screen, when the path difference, ΔS equals a whole number of wavelengths.

$$path\ difference = m\lambda$$

Substituting the value of path difference in the equation (ii), we get

$$Y_{bright} = (m\lambda)\left(\frac{L}{d}\right)$$

$$Y_{bright} = m\left(\frac{\lambda L}{d}\right)$$

The number **m** is called the **order number,** the central bright film at m = 0 is called the *zeroth-order maximum*, and so forth.

POSITIONS OF DARK FRINGES

When the path difference is an odd multiple of λ/2, the two waves arriving at Pare 180^0 are out of phase and give rise to destructive interference. Therefore, the condition for dark fringes at p is

$$pathdifference = \left(m + \frac{1}{2}\right)\lambda$$

Substitute in equation (ii)

$$Y_{dark} = \left(m + \frac{1}{2}\right)\lambda\left(\frac{L}{d}\right)$$

$$Y_{dark} = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$$

Where, ***m = 0, ± 1, ± 2, ...(minima)***

If m = 0 in this equation, the path difference is λ/2, which is the condition for the location of the first dark fringe on either side of the central bright fringe, if m = 1, the path difference is 3(λ/2), which is the condition for the second dark fringe on each side, and so forth.

FRINGE SPACING

The distance between two consecutive bright or dark fringes is called fringe spacing.

For 2[nd] and 3[rd] bright fringes, m = 2 and m = 3

$$\Delta Y = Y_{(bright)3} - Y_{(bright)2}$$

$$\Delta Y = \frac{3\lambda L}{d} - \frac{2\lambda L}{d}$$

$$\Delta Y = \frac{3\lambda L - 2\lambda L}{d}$$

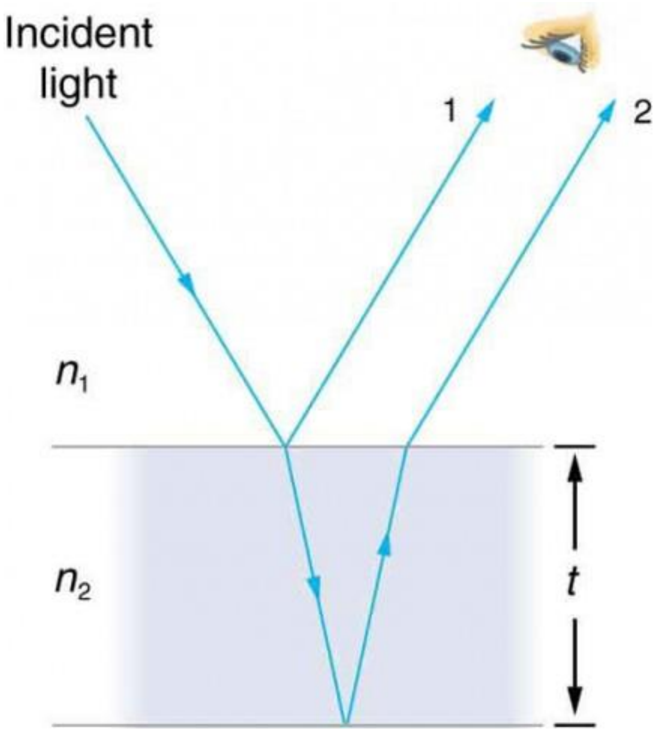
$$\Delta Y = \frac{\lambda L}{d}$$

INTERFERENCE IN THIS FILMS

A soap bubble, a wet surface, or thin layer of oil floating on water, are common examples of thin films. When white light is reflected from such film beautiful colors are observed due to interference. This phenomenon is called interference in thin films.

EXPLANATION

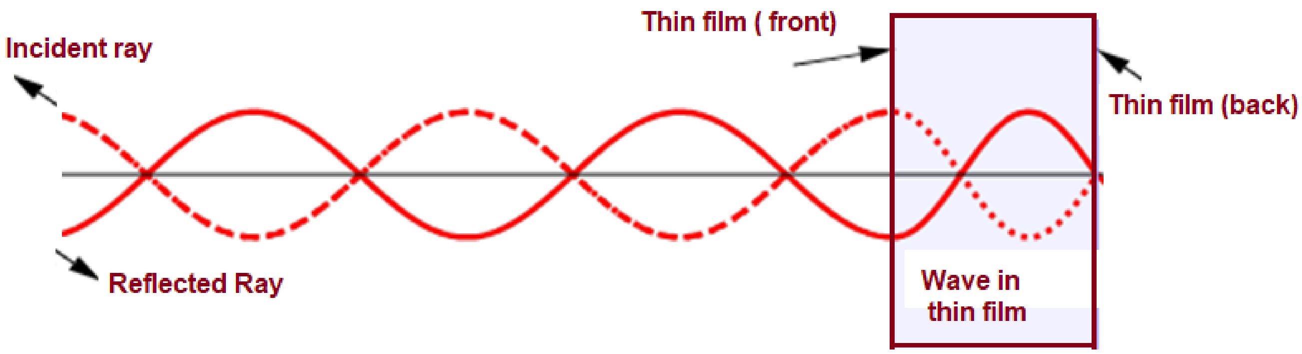
Consider a film of uniform thickness t and index of refraction n, as in Figure. When light coming from an extended monochromatic source is incident on a thin transparent film, interference occurs between the rays reflected from the thin film's upper (B) and lower (D) surfaces.



The following important points must be considered to determine the conditions of constructive and destructive interference.

1. CHANGE OF PHASE

An electromagnetic wave traveling from a medium of the index of refraction n_1 towards the medium of the index of refraction n_2 undergoes an 180^0 phase change of reflection when $\mathbf{n_2 > n_1}$

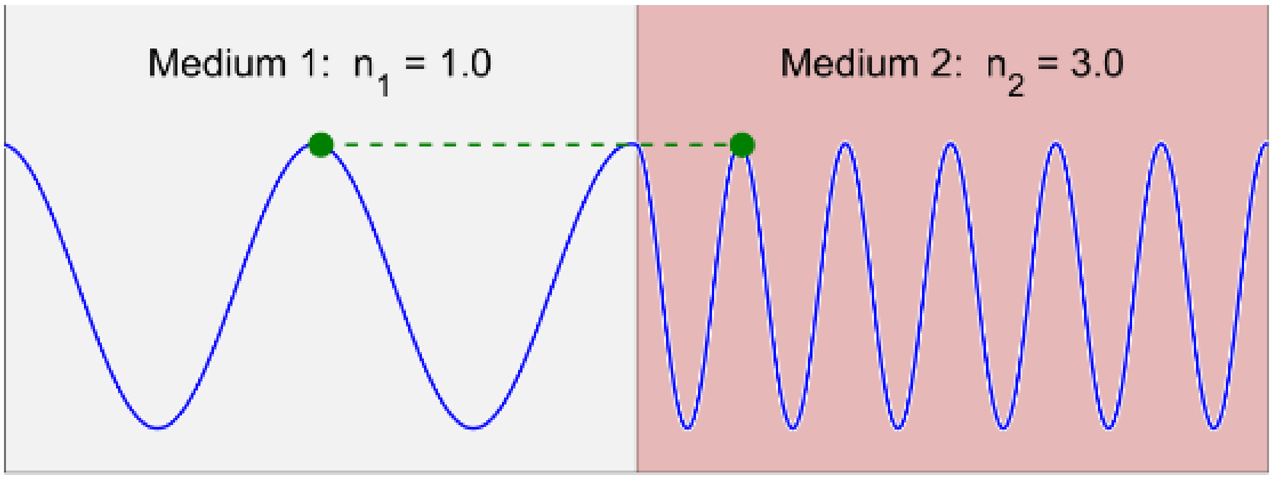


2. CHANGE OF WAVELENGTH

The wavelength of light λ_n in a medium with an index of refraction '**n**' is given by

$$\lambda_n = \frac{\lambda}{n}$$

Where λ is the wavelength of light in a vacuum



CONDITIONS FOR PATH DIFFERENCE

According to the first rule, ray 1, which is reflected from the upper surface **B**, undergoes a phase change of 180^0 to the incident wave, and ray 2, which is reflected from the lower surface **D,** undergoes no phase change to the incident wave. Therefore, ray 1, is 180^0 out of phase to ray 2, a situation that is equivalent to the path difference of $\lambda_n/2$, however, we must also consider that ray 2 travels an extra distance of 2t before the ray recombines.

For constructive interference

The condition for constructive interference is

$$2\,t = \left(m + \frac{1}{2}\right)\lambda_n$$

$$2\,t = \left(m + \frac{1}{2}\right)\frac{\lambda}{n}$$

$$2\,t\,n = \left(m + \frac{1}{2}\right)\lambda$$

where,

m = 0, 1, 2, 3, 4, ...

FOR DESTRUCTIVE INTERFERENCE

The condition for destructive interference is

$$2\,t = (m)\,\lambda_n$$

$$2\,t = (m)\,\frac{\lambda}{n}$$

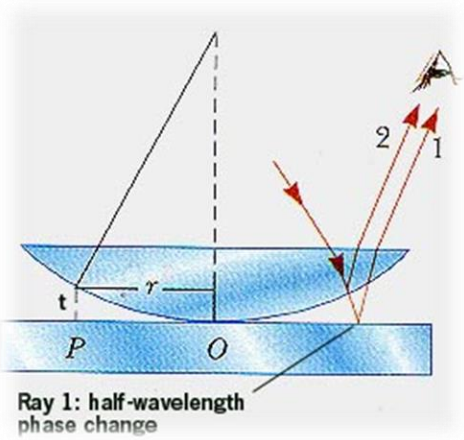
$$2\,t\,n = m\,\lambda$$

NEWTON'S RINGS

Newton rings are circular interference fringes, which can be produced by enclosing a very thin film of air between a plane glass sheet and a Plano-convex of a large radius of curvature.

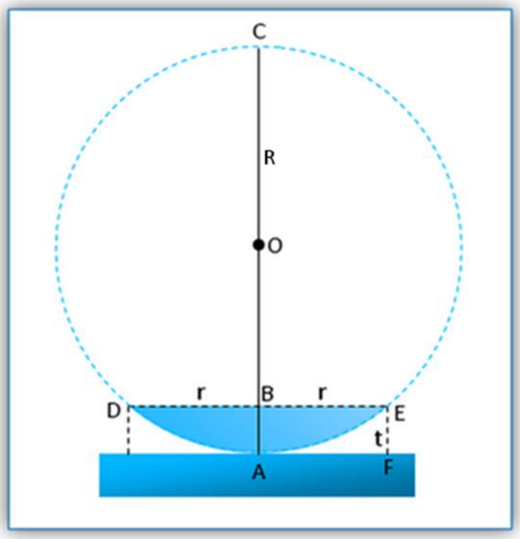
EXPERIMENTAL SET-UP

Parallel light rays from a monochromatic source are made to fall normally on-air film enclosed by a Plano-convex lens and plane glass plate. The rays reflected from the lens's curved surface and the glass plate's upper surface interfere. When viewed with a microscope dark and bright circular fringes are observed. These are called Newton's rings.



THEORY

Let R = radius of curvature of lens
t = thickness of air film
r = radius of interference ring.



According to the geometrical theorem, the product of intercepts of the intersecting chord is equal to the product of sections of diameter then,

$$\overline{DB} \times \overline{BE} = \overline{AB} \times \overline{BC}$$
$$r \times r = t(2R - t)$$
$$r^2 = 2Rt - t^2$$

t^2 can be neglected, being very small

$$r^2 = 2Rt$$
$$r = \sqrt{2tR} \ldots\ldots\ldots (i)$$

RADIUS OF BRIGHT RING

For a bright ring interference must be constructive and the condition for path difference in thin film is

$$2nt = \left(\mathrm{m} + \frac{1}{2}\right)\lambda$$

$$2t = \left(\mathrm{m} + \frac{1}{2}\right)\lambda \qquad \mathrm{n} = 1 \text{ for air}$$

Substituting the value of 2t in equation (1), we get

$$r = \sqrt{\left(\mathrm{m} + \frac{1}{2}\right)\lambda\,\mathrm{R}} \qquad \mathrm{m} = 0,1,2, \ldots\ldots$$

if N is the number of bright rings, then

for 1st bright ring **m = 0** **and** **N = 1**

for 2nd bright ring **m = 1** **and** **N = 2**

for 3rd bright ring **m = 2** **and** **N = 3**

for Nth bright ring **m = (N – 1)**

$$r_n = \sqrt{\left\{N - 1 + \frac{1}{2}\right\} + \lambda R}$$

$$r_n = \sqrt{\left(N - \frac{1}{2}\right) \lambda R}$$

RADIUS OF DARK RINGS

Dark ring interference must be destructive and the condition for path difference in thin film is

$$2t = m\lambda$$

Substituting in equation (1) we get

$$r = \sqrt{m\lambda R}$$

for central dark ring **m = 0**

for 1st dark ring **m = 1**

for 2nd dark ring **m = 2**

for Nth dark ring **m = N**

$$r_n = \sqrt{N\lambda R}$$

MICHELSON'S INTERFEROMETER

An interferometer is a device used to produce and observe interference fringes. It was invented by an American scientist A.A. Michelson in 1881.

PRINCIPLE

This interferometer splits a beam into two parts and then recombines them to form an interference pattern after they have traveled over difference paths.

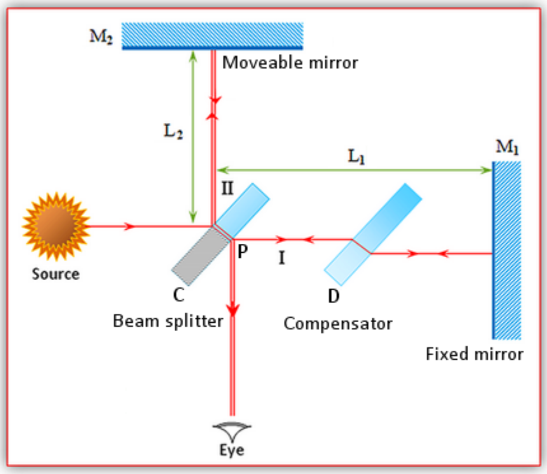
CONSTRUCTION

The main optical parts of this interferometer are:

1. **EXTENDED SOURCE** (S)is a broad, spread source of monochromatic light.
2. **MIRRORS (M_1 & M_2)** are two highly polished plane mirrors. M_1 is fixed whereas M_2 is moveable.
3. **BEAM SPLITTER (C)**is a glass plate having a silver coating just thick enough to transmit half the incident light and to reflect the half.
4. **COMPENSATOR (D)**is a transparent glass plate identical to C but not silvered. Its purpose is to make the path in glass of the two rays equal.

WORKING

A beam of light coming from a source of monochromatic light (s) is split into two rays by a semi-silvered mirror (C). One ray is reflected vertically towards M_2 while the other is transmitted through (D) toward mirror M_1. These two rays travel separate paths L_1 and L_2. After reflection from M_1 and M_2 the two parts recombine between point 'P' and eye to give an interference pattern.



THEORY AND FORMULA

1 The interference condition for the two rays is determined by the difference in their optical path lengths. If M_1 & M_2 are exactly at the same distance from C, the virtual image of M_1 coincides with M_2 and path difference between the two rays is zero. Interference fringes appear.

2. If M_2 is moved, an air film is assumed to be enclosed between M_2 and virtual image of M_1. The thickness of this film can be varied.

Suppose that the center of the circular fringe pattern is bright and that M2 is moved just enough to cause the first bright fringe to move to the center. The path difference between two rays in this case must be one wavelength 'λ', and the distance moved by mirror M_2 is $\frac{\lambda}{2}$ (light passes twice through the equivalent air film).

3 If M_2 is moved slowly and number of fringes 'n' are counted which pass through a reference point then

$$x = m\frac{\lambda}{2}$$

where **λ = wavelength of light**

m = number of fringes

d = distance moved by M_2

$$\lambda = \frac{2x}{m}$$.

USES This interferometer can be used to :

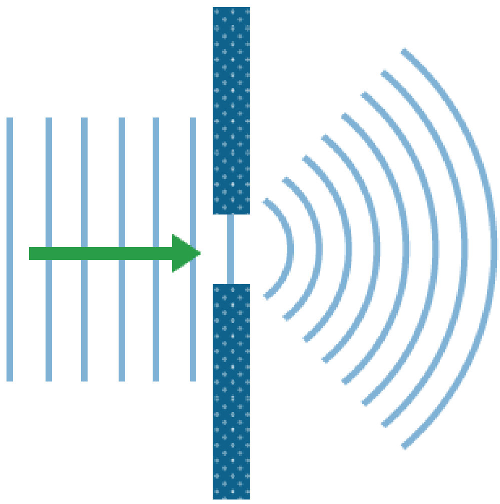
1. determine the wavelength of light.
2. measure the change in length precisely.

DIFFRACTION OF LIGHT

Diffraction was first discovered by an Italian scientist Grimaldi in 1665 and then studied by Newton.

DEFINITION

Diffraction is the spreading out of waves as they pass through an aperture or around objects. It occurs when the size of the aperture or obstacle is of the same order of magnitude as the wavelength of the incident wave.

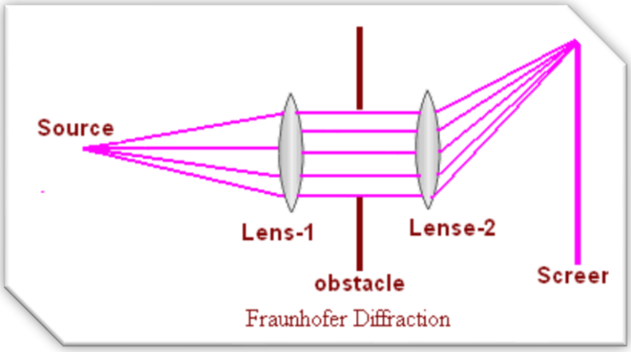


TYPES

Diffraction phenomena are divided into two classes known for historical reasons as :
Fraunhofer diffraction
Fresnel diffraction

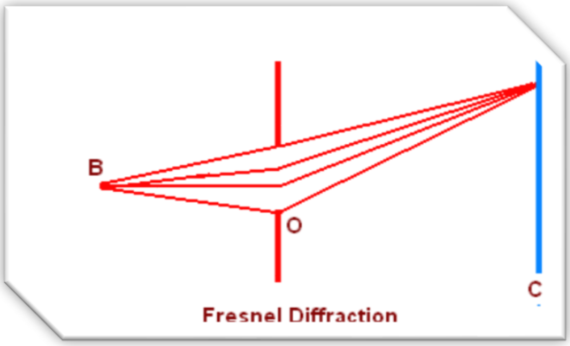
FRAUNHOFER DIFFRACTION

When the source of light and the screen are effectively at an infinite distance from the obstacle causing the diffraction, the corresponding rays are parallel to each other. This is known as Fraunhofer diffraction.



FRESNEL DIFFRACTION

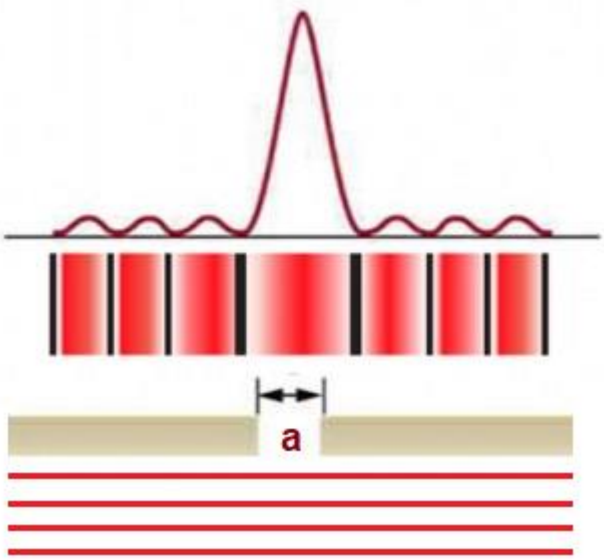
When the source of light or screen or both are at finite distances from the obstacle causing the diffraction so that the corresponding rays are not parallel to each other. This is known as Fresnel diffraction.



SINGLE SLITS DIFFRACTION

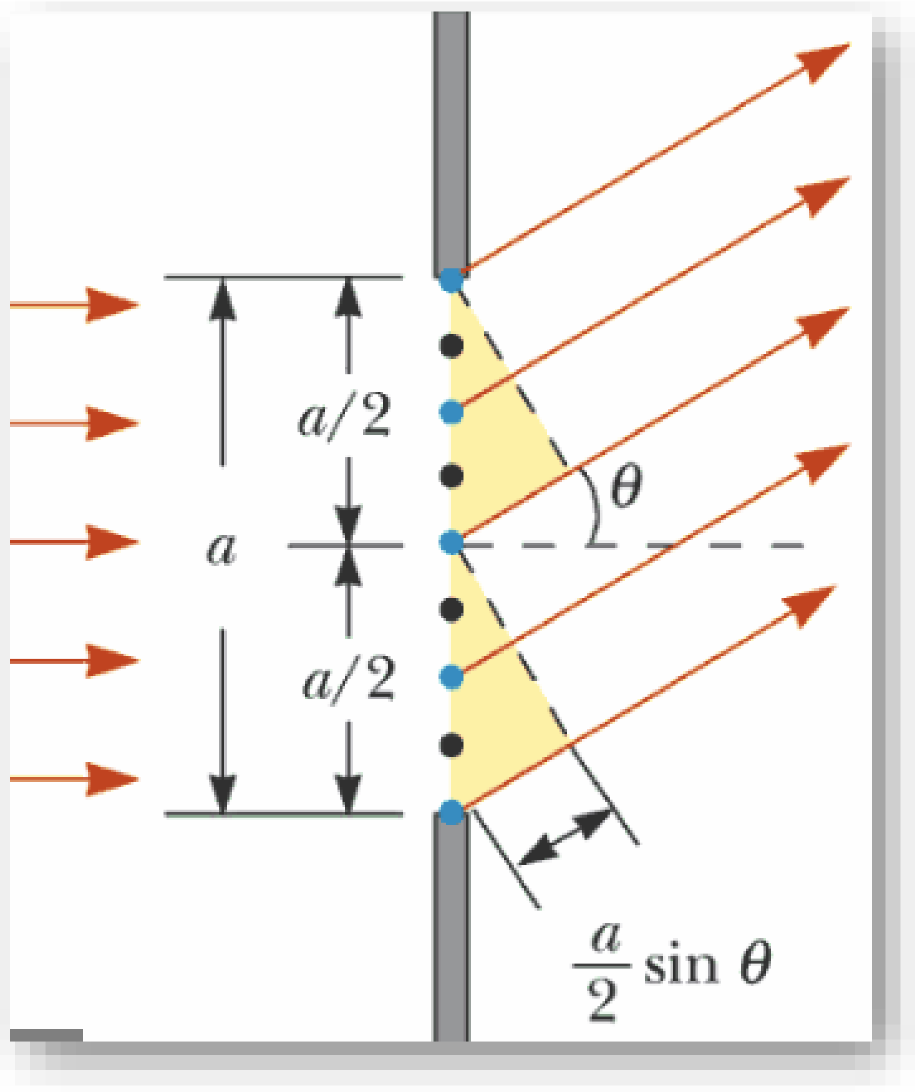
When light passes through a single slit whose width **a** is on the order of the wavelength of the light, then we can observe a single slit diffraction pattern on a screen that is a distance L >> d away from the slit. The intensity is a function of angle. Huygens' principle tells us that each part of the slit can be thought of as an emitter of waves. All these waves interfere to produce the diffraction pattern. Where crest meets crest we have constructive interference and where crest meets trough we have destructive interference.

Single slit diffraction pattern. Monochromatic light passing through a single slit has a central maximum and many smaller and dimmer maxima on either side, as shown in figure.



FORMULA FOR SINGLE SLITS DIFFRACTION

Figure, shows two rays that represent the propagation of two wavelets: ray 1 from the top edge of the slit and ray 2 from exactly half way down. The rays are off at the same angle θ to reach the same point on a distant screen. The lower one travels an extra distance $\left(\frac{1}{2}\, a \,\sin\theta\right)$ to reach the screen. If this extra distance is equal to $\left(\frac{1}{2}\,\lambda\right)$ then these two wavelets interfere destructively. Now let's look at two other wavelets, shifted down distance ΔS so that they are still separated by half the slit width $\left(\frac{1}{2}\,a\right)$. The path difference between these two rays must be $\left(\frac{1}{2}\,\lambda\right)$ so that these two interfere destructively. All the wavelets can be paired off; since each pair interferes destructively, no light reaches the screen at that angle. Therefore, the first diffraction minimum occurs where;



$$\frac{1}{2}\ a\ \sin\theta\ = \frac{1}{2}\ \lambda$$

$$a\ \sin\theta\ = \ \lambda$$

The other minima are found in similar way, by pairing off wavelets separated by a distacne of $\frac{1}{4}\,a,\ \ \frac{1}{6}\,a,\ \ \frac{1}{8}\,a,\ \ \ldots\ldots\ldots\ldots\ \ \frac{1}{2m}\,a,$ where m is an integral other than zero. The diffraction minima are given by

$$\frac{1}{2\mathrm{m}}\ a\ \sin\theta\ = \frac{1}{2}\ \lambda\ \ (m = \pm 1,\ \ \pm 2,\ \ \pm 3 \ldots\ldots..)$$

$$\frac{1}{\mathrm{m}}\ a\ \sin\theta\ = \ \lambda$$

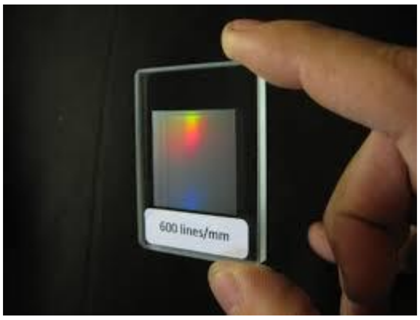
$$a\ \sin\theta\ = m\ \lambda$$

DIFFRACTION GRATING

A German Physicist, Joseph Von Fraunhofer invented a simple way of measuring the wavelength of light. The device he used is called a diffraction grating.

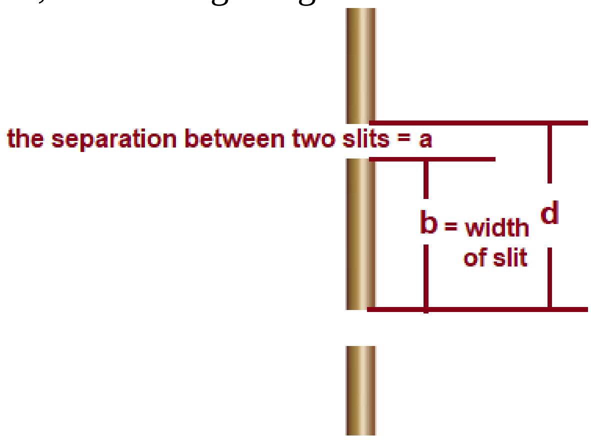
DEFINITION

A grating is a glass plate upon which is ruled several equally spaced opaque lines, usually several thousand per centimeter.



GRATING ELEMENT

Let us consider a grating having **'a'** as the separation between two consecutive slits and **'b'** as the width of each slit such that **a + b =d**; called the grating element

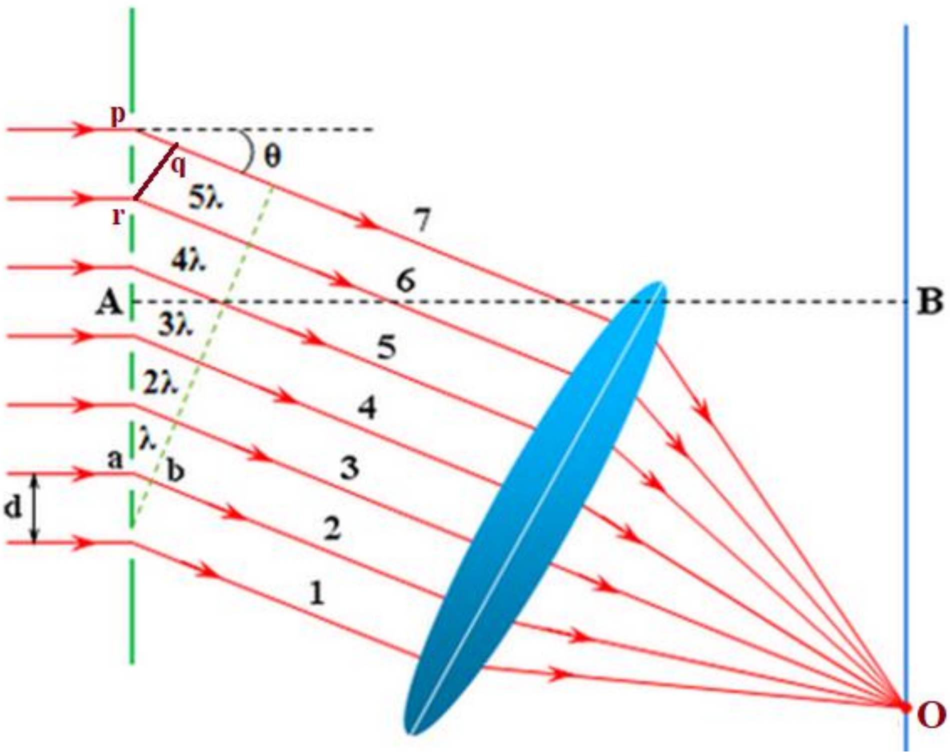


$$d = \frac{length\ of\ grating}{total\ number\ of\ lines\ or\ slits}$$

$$\boldsymbol{d = \frac{L}{N}}$$

DETERMINATION OF WAVELENGTH

consider a parallel beam of monochromatic light illuminating the grating at normal incidence. A few of the equally spaced narrow slits are shown in the figure given below



consider the parallel rays which after diffraction through the grating make an angle **θ** with **AB**, the normal to the grating. They are then brought to focus on the screen at **O** by a convex lens. If the path difference between ray **1** and **2** is one wavelength **λ**, they will reinforce each other at **O**

In Δpqr :

$$Sin\theta = \frac{Perp}{Hyp}$$

$$Sin\theta = \frac{pq}{pr}$$

$$Sin\theta = \frac{path\ difference}{d}$$

$$d\ Sin\theta = path\ difference.............(i)$$

At the rays from adjacent slits interfere constructively, if the path difference is:

$$path\ difference\ =\ m\,\lambda\ \dots\dots\dots..(ii)$$

Comparing equation (i) and (ii), we get:

$$d\ Sin\theta\ =\ m\,\lambda$$

Where d = grating element

m = order of diffraction

λ = wavelength of light used

θ = angle of diffraction, which can be measured using spectrometer.

WAVELENGTH OF LIGHT

We know that

$$d\ Sin\theta\ =\ m\,\lambda$$

$$\lambda\ =\ \frac{d\ Sin\theta}{m}$$

X- RAY DIFFRACTION AND BRAGG'S LAW

When X-rays of sufficiently small wavelength are incident upon a crystal lattice, they diffract from the lattice points. At certain angles of incidence, the diffracted parallel waves constructively interfere and create detectable peaks in intensity.

DERIVATION OF BRAGG'S LAW

Consider two x-rays 1 and 2, of wavelength λ which are incident on the crystal salt. These x-rays are reflected from atoms A and D of a crystal with a separation distance (d) between its atomic planes.

Let θ be the angle made by x-rays with the layers, as shown in figure. It can be seen in the figure that the second x-ray covers more distance as compared to the first x-ray, the total path difference will be

Path difference = BD + DC ………(i)

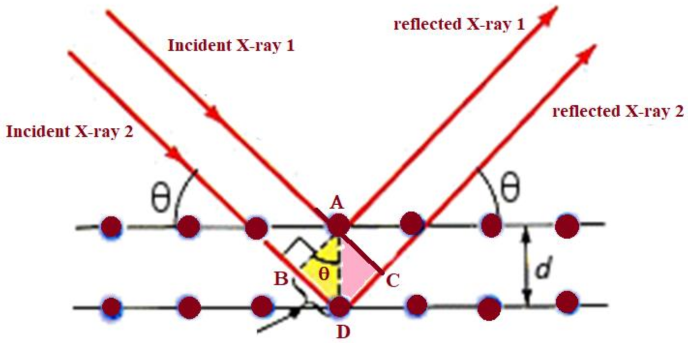
Consider a triangle DAB,

$$Sin\theta = \frac{perp}{hyp}$$

$$Sin\theta = \frac{BD}{AD}$$

$$Sin\theta = \frac{BD}{d}$$

$$BD = d\ Sin\theta$$



Similarly, Consider another triangle DAC,

$$Sin\theta = \frac{perp}{hyp}$$

$$Sin\theta = \frac{BC}{AD}$$

$$Sin\theta = \frac{BC}{d}$$

$$BC = d\ Sin\theta$$

Substituting the expression for BD and BC in equation(i), we get

Path difference = $d\ Sin\theta + d\ Sin\theta$

Path difference = $2\ d\ Sin\theta \quad \dots\dots\dots\dots (ii)$

We know that the condition for constructive interference

Path difference = m λ ……………(iii)

Comparing equation (ii) and (iii)

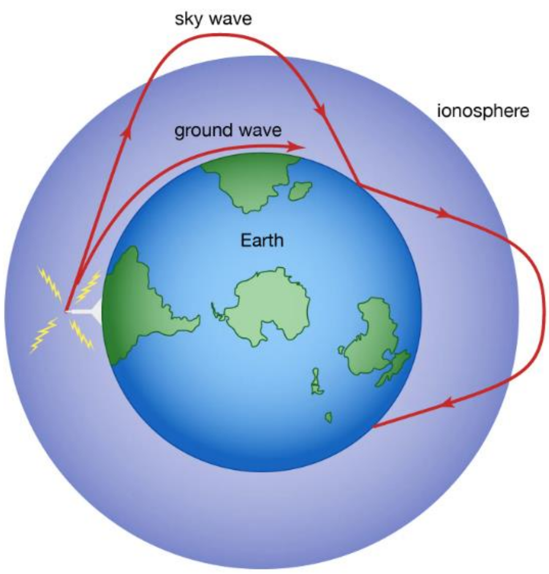
$$\mathbf{2\ d\ Sin\theta = m\ \lambda}$$

SHORT RESONING QUESTIONS

1 In every day experience, visible light seem to travel in straight lines while radio waves do not, Explain.

Ans *Light appears to travel in a straight line because diffraction (or deviation from the path) is least in light. Diffraction is least because -of small wavelength of light. So small wave length of light causes the light to travel almost in straight line.*

Radio waves transmitted by antennas in certain directions are bent or even reflected back to Earth by the ionosphere, as illustrated in Figure 5. They may bounce off Earth and be reflected by the ionosphere repeatedly, making radio transmission around the globe possible.



2 Explain why two waves of significantly different frequencies cannot be coherent?

Ans Two waves of significantly different frequencies cannot be coherent because their differing rates of oscillation prevent them from maintaining a constant phase relationship over time.

For example, let's say wave one is frequency f and wave two is frequency 2f The wavelength of the 2f-wave will be half of the wavelength of the f-wave because frequency and wavelength are inversely proportional. They will both travel at the same speed, but their paths will be different. This is because they have different frequencies and therefore different wavelengths, so even if they start at the same point, they will eventually drift out of phase with each other. This is what causes them to fall out of sequence and become incoherent.

3 In a Young's double slit experiment, how the interference phenomenon is affected by changing the slits separation and the distance between the slits and screen?

Ans if the slit separation increases then the Intensity of light emitted by the slits increases. Thus, more brighter fringes are formed at the screen on increasing the separation of the slits.

When the distance between double slits and the screen are further apart, the optical path difference between the light waves from the two slits increases and the waves' frequencies don't line up as well. This means the crests and troughs get more separated, resulting in lower fringe contrast.

4 Explain how the double-slit experiment provides evidence for the wave nature of light.

Ans The double slit experiment better serves to demonstrate the wavelike property of light because of the intense diffraction pattern caused by destructive and constructive interference from the two slits. The single slit experiment does also have a diffraction pattern but it is much less obvious

5 Discuss the concept of monochromatic light in the context of Newton's rings

Ans

1. The intrusion pattern connecting two surfaces created by light reflecting between them is said to form Newton's Rings.
2. On respective sides of the spherical, there are two flat surfaces. When observed in monochromatic light, Newton's Rings appear as changing bright and dark circles at the position of interaction joining the two surfaces.
3. When viewed in white light, the distinct wavelengths of light collide at a very discrete extent of thickness in the surface of air between the two surfaces. As a consequence, a coaxial circle of a band of colors, a rainbow emerges.

6 Explain why monochromatic light is preferred for obtaining clear and well-defined interference patterns in the experiment

Ans Monochromatic light, which is light of a single wavelength or color, is used in interference experiments for a few key reasons:

1. Coherence - Monochromatic light exhibits high spatial and temporal coherence, meaning the waves are well-aligned and can interfere constructively or destructively. This is necessary for interference patterns to form.
2. Wavelength Specificity - The wavelength of monochromatic light is precisely defined, which allows the interference patterns to be clearly observed and analyzed. Different wavelengths would create different interference fringe patterns.
3. Contrast - The uniform color of monochromatic light results in high-contrast interference fringes that are easy to observe and measure. white light would create lower-contrast, overlapping patterns.

7 Discuss how the interference of light waves leads to the formation of bright and dark rings in the experiment

Ans The rings occur because of a thin layer of air that exists between the curved convex and flat glass surfaces. Light reflected from the top and bottom surfaces of the glass is superimposed (combined) and produces interference patterns that appear as the colored rings.

8. If young double slits experiments were submerge in water, how would the fringe patern be changed?

Ans The wavelength of light in a medium such as water is decreased when compared to the wavelength in air. Thus, $d\sin\theta = m\lambda$ says that θ is decreased for a particular *m* and *d*. This means that the bright spots on the screen are more closely packed together in water than in air.

9. Monochromatic red light is incident on a double slits the interference pattern is viewed on a screen some distance away. Explain how the fringe pattern would change if the red light source is replaced by a blue light source.

Ans As red light is switched to blue light, the wavelength of the light is decreased. Thus, $x = \frac{\lambda L}{d}$ fringe spacing decreases *or* $d\sin\theta = m\lambda$ says that θ is decreased for a particular *m* and *d*. This means that the bright spots on the screen are more closely packed together with blue light than with red light.

10. For a diffraction grating, what is the advantage of (a) many slits (b) closely spaced slits

Ans . (*a*) The advantage of having many slits in a diffraction grating is that this makes the bright maxima in the interference pattern more sharply defined, brighter, and narrower.

(*b*) The advantage of having closely spaced slits in a diffraction grating is that this spreads out the bright maxima in the interference pattern and makes them easier to measure

11. What would be the color of the sky if the Earth had no atmosphere?

Ans If Earth had no atmosphere, the "color" of the sky would be black (and dotted with stars and planets) at all times. This is the condition of the sky that the astronauts found on the Moon, which has no atmosphere. The reason the sky is blue for Earth, is that the air molecules scatter light from the Sun in all directions, and preferentially scatter blue light down to the surface. If there were no air molecules to scatter the light from the Sun, the only light we would see would be from the stars/planets and directly from the Sun and the rest would be black.

12 Why are X-rays not diffracted by diffraction grating or thin film?

Ans. When the ordinary light is disturbed in its path by placing an obstacle or slits in its path whose dimension is nearly equal to the wavelength of light then light bends around the edges of the obstacle or slits called diffraction of light. A diffraction grating is used to diffract an ordinary monochromatic light, as spacing of grating (d) is set at 100 nm, which is much closed to the wavelength of ordinary monochromatic light wavelength. The range of the X-rays falls within the 0.5×10^{-10} m to 10×10^{-10} m. it is quite evident that spacing of grating is 1000 times greater than maximum wavelength of X-rays.

That is why, X-rays passes through the grating without showing any phenomenon of diffraction

SELF-ASSESSMENT QUESTIONS

1 Name the type of electromagnetic radiation corresponding to each of the given wavelengths,

a) 500 nm b) 10000 Km c) I cm

Ans A 500 nm corresponds to visible light

A 10000 km corresponds to an extremely low-frequency radio wave

A 1 cm corresponds to a microwave.

2 State two main properties of electromagnetic waves.

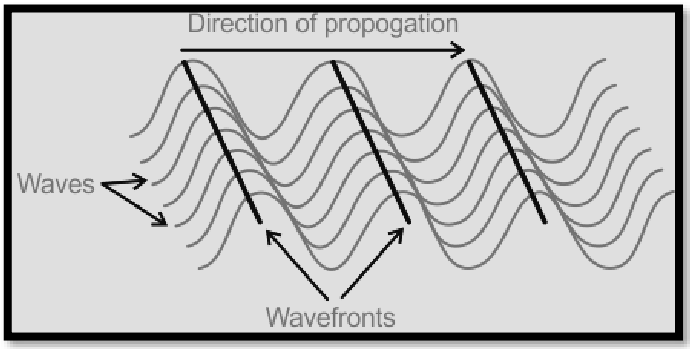
Ans **Property 1:** They propagate by varying electric and magnetic fields, such that these two fields are at right angles to each other and a right angle with the wave's propagation direction.

Property 2: Electromagnetic waves travel with a constant velocity in a vacuum. The speed of the waves is 3×10^8 m/s.

3 Describe a wavefront. How do plane wavefronts emerge out of spherical wavefronts?

Ans **A wavefront is an imaginary line on a wave that joins all points that have the same phase of vibration**

Wavefronts are imaginary surfaces to represent how waves move in 2-dimensional space. A wavefront always propagates in the forward direction, as shown in the figure below.



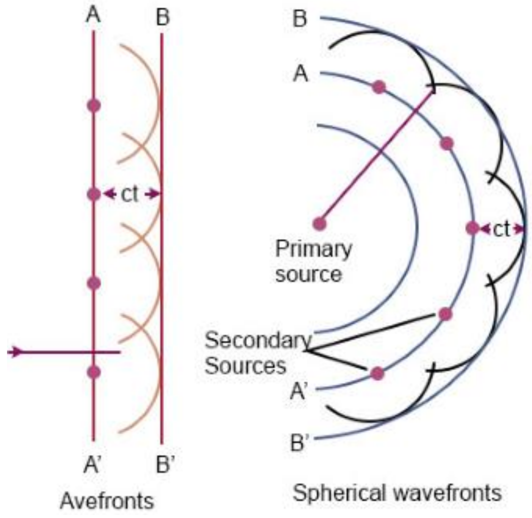
Spherical wavefronts emerge as a result of a point source emitting waves uniformly in all directions. As these waves spread outward, they form concentric spherical wavefronts around the source. When these spherical wavefronts become very large in comparison to the distance from the source, they appear flat or planar because, at large distances, the curvature of the spheres becomes less noticeable, and the wavefronts appear nearly, flat or planar.

4 What is meant by Huygens's Principle?

Huygens's Principle states as,

1 At some time t, consider every point on a wavefront as a source of a new spherical wave. These wavelets move in the forward direction from the source at the same speed as the original speed of the wave. Fig. l3. I .la.

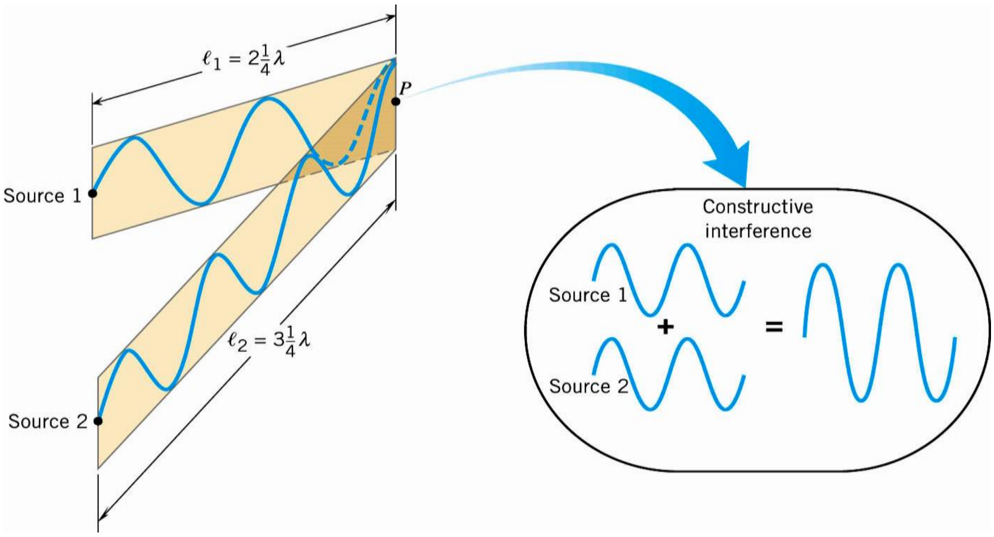
2 At a later time t + Δt, each wave has a radius (distance) cΔt, where c is the speed of the wave (light). The new position of the wavefront after time t+Δt can be found by drawing a plane tangential to all the secondary wavelets.



5 Describe the conditions for constructive and destructive interference

Ans. **CONSTRUCTIVE INTERFERENCE**

If interfering waves' resultant intensity is greater than an individual wave's, then interference is said to be constructive.



CONDITION FOR CONSTRUCTIVE INTERFERENCE

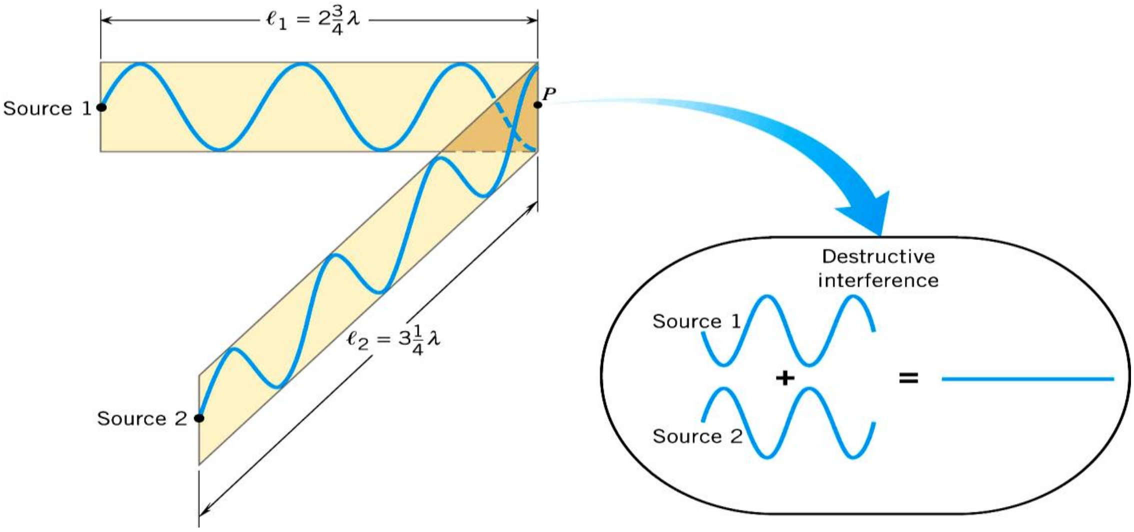
For constructive interference, path difference is an integral multiple of wavelength.

Path difference = m λ

Where m = 0, +, +2, +3 . . . .

DESTRUCTIVE INTERFERENCE

If the resultant intensity of interfering waves is less than that of an individual wave then interference is said to be destructive.



CONDITION FOR DESTRUCTIVE INTERFERENCE

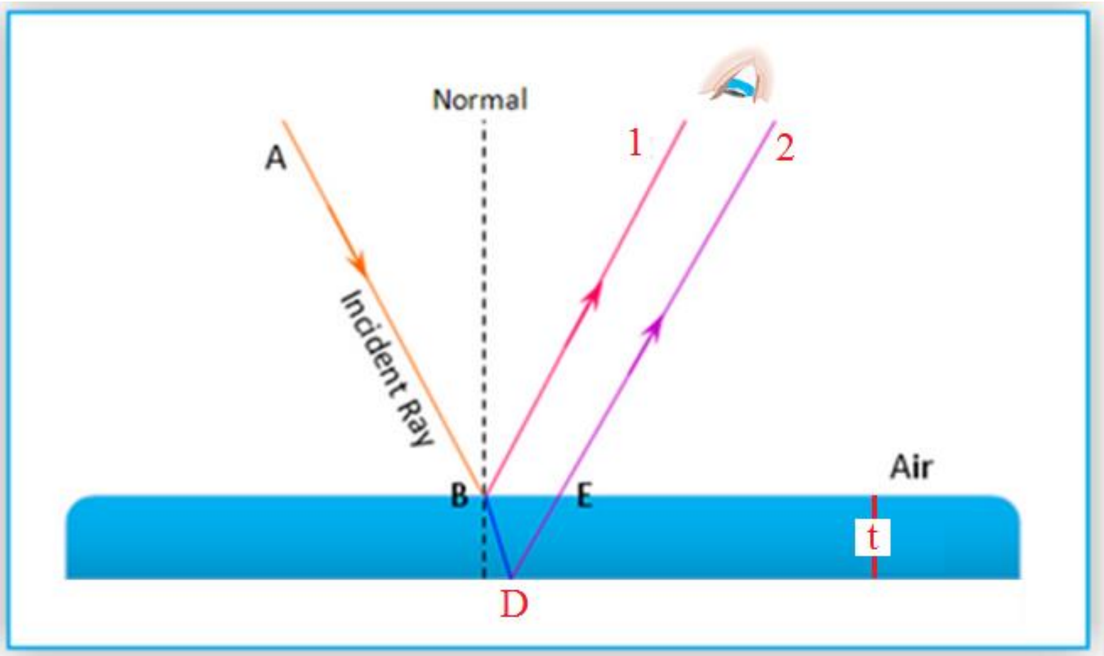
For destructive interference path difference is an odd multiple of half wavelength.

Path difference = (m + 1/2) λ

Where m = 0, + 1, + 2,. . . . . . .

6 What caused the change of interference condition in thin films?

Ans. Consider a film of uniform thickness t and index of refraction n, as in Figure. When light coming from an extended monochromatic source is incident on a thin transparent film, interference occurs between the rays reflected from the upper (B) and lower (D) surfaces of thin film.



The following important points must be considered to determine the conditions of constructive and destructive interference.

1. <u>CHANGE OF PHASE</u>

An electromagnetic wave traveling from a medium of the index of refraction n_1 towards the medium of the index of refraction n_2 undergoes an 180^0 phase change of reflection when $\mathbf{n_2 > n_1}$

2. CHANGE OF WAVELENGTH

The wavelength of light λ_n in a medium with an index of refraction '**n**' is given by

$$\lambda_n = \frac{\lambda}{n}$$

Where λ is the wavelength of light in a vacuum

CONDITIONS FOR PATH DIFFERENCES

According to the first rule, ray 1, which is reflected from the upper surface **B**, undergoes a phase change of 180^0 with respect to the incident wave, and ray 2, which is reflected from the lower surface **D,** undergoes no phase change with respect to the incident wave. Therefore, ray 1, is 180^0 out of phase with respect to ray 2, a situation that is equivalent to the path difference of $\lambda_n/2$, however, we must also consider that ray 2 travels an extra distance of 2t before the ray recombines.

For constructive interference

The condition for constructive interference is

$$2t = (m + 1/2)\, \lambda_n$$

$$2t = (m + \frac{1}{2})\frac{\lambda}{n} \qquad [\ \lambda_n = \frac{\lambda}{n}\ ]$$

$$2\,n\,t = (m + 1/2)\,\lambda$$

where,

$$m = 0, 1, 2, 3, 4, \ldots\ldots\ldots$$

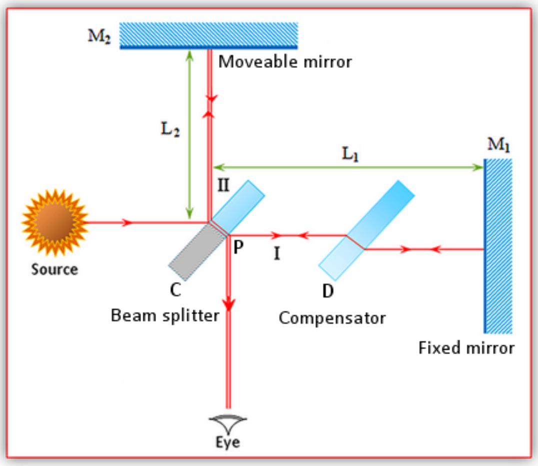
For Destructive Interference

The condition for destructive interference is

$$2\,n\,t = m\,\lambda$$

7 Why compensator plate is important in the Michelson interferometer

Ans We will see a simple Michelson Interferometer. The light source comes from the left and hits a beam splitter. The beam splitter is AR-coated on the front side and has a 50/50 reflective coating on the second side. This is where the light splits into the two paths



But you notice that the light going up to the test mirror must pass through the beam splitter two times. Once after the 1st reflection, and another one on its way back to the detector (below). The reference arm only passes through the beam once. Therefore, a compensator plate is inserted in the test beam so that the light effectively passes through the beam splitter the same number of times as the test beam.

8 Why do you think the diffraction of light is an interference phenomenon?

Ans Diffraction is a phenomenon that occurs when waves encounter an obstacle or aperture that disrupts the wavefront. When a wave passes through a narrow slit or around an obstacle, it spreads out and interferes with itself, leading to the phenomenon of diffraction. Diffraction can be understood in terms of interference because it involves the superposition of waves that have been diffracted by the obstacle or aperture.

When a wave passes through a slit or around an obstacle, different parts of the wavefront experience different path lengths, leading to constructive and destructive interference among the diffracted waves. This interference pattern results in the bending and spreading of the wave around the edges of the obstacle or aperture.

9 What are the factors which determine the number of order of diffraction obtainable when light incident normally on a diffraction grating?

Ans The number of diffraction orders can be determined by using the equation,

$$\boldsymbol{m = \frac{2\,d\,\sin\theta}{\lambda}}$$

The above equation shows that the number of diffraction orders obtained when light is incident normally to the diffraction grating depends on the grating element (d), the diffracted angle(θ), and the wavelength of monochromatic light.

10 Why do X-rays are used to obtain a diffraction pattern through a crystal?

Ans X-ray diffraction patterns, which are used to determine the crystalline arrangements of the atoms inside a solid, are only possible if the wavelengths of the radiation are comparable to or smaller than the separations of the atoms themselves. Visible wavelengths are a thousand times longer than the separations of atoms in solids. So diffraction of visible light cannot occur.

X-rays satisfy Bragg's Law for constructive interference in crystal lattices. When X-rays strike a crystal lattice at a specific angle, they undergo constructive interference, leading to the formation of diffraction peaks that can be measured and analyzed to determine the crystal structure.