Superposition of Light Waves

Objectives

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

- Correlate general principle of superposition of waves in general to light waves
- Understand Interference as a special case of superposition
- Distinguish between coherent and incoherent sources

Content Outline

- Unit syllabus
- Module-wise distribution of unit syllabus
- Words you must know
- Introduction
- Mechanical wave properties
- Principle of superposition
- Coherence
- Superposition of light from coherent and incoherent sources
- Conditions for constructive and destructive interference
- Summary

Unit Syllabus

UNIT 6: Optics

Chapter–9: Ray Optics and Optical Instruments

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

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

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

Chapter 10 Wave Optics

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

Module Wise Distribution Of Unit Syllabus - 15 Modules

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

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

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

	• Refraction and reflection of plane wavefront using Huygens's principle • Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light • Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or colored fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

Module 11

Words You Must Know

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

- Incident ray: Path of light from a source in any preferred direction of propagation
- Reflected ray: Path of light bounced off from a surface at the point of incidence
- Refracted ray: Path of light when it propagates from one transparent medium to another.
- Normal at the point of incidence: Normal to the surface at the point of incidence. Important when the surface is spherical or uneven
- Converging and diverging rays: Rays of light may converge to or seem to diverge from a point after reflection or refraction such rays are called converging or diverging rays.
- Laws of reflection: Laws followed by light rays whenever reflection takes place
  - The incident ray, reflected ray and the normal at the point of incidence all lie in the same plane
  - The angle of reflection is equal to the angle of incidence
- Snell's law: For oblique incidence of light on a transparent medium surface

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

- The incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
- The angle of refraction is not equal to the angle of incidence.
- A ray of light propagating from a rarer to a denser medium moves towards the normal. This can be observed for obliquely incident rays.
- Plane mirror: A polished surface with infinite radius of curvature
- Spherical mirror- concave and convex: Spherical mirrors are part of spherical surfaces. The polished surface makes them concave or convex.
- Spherical lens- convex and concave: Transparent medium bounded by spherical surfaces, if a thin block of medium has two surfaces bulge out, they form a convex lens
- Prism: A rectangular block cut along its diagonal gives two prisms. Each piece has two refracting surfaces, a base and the angle between the refracting surfaces (in this case $=90^0$) is called angle of prism.
- Light Wave: Light is part of the electromagnetic spectrum. They are transverse waves; origin of light is from electromagnetic transitions of electrons inside the atoms giving out the

radiation. The frequency depends upon the source. Wavelength depends upon the medium in which light is travelling.

- Wavefront: Defined as a surface of constant phase.
- Huygens's principle
  - Each point of the wavefront is a source of a secondary disturbance and the wavelets emanating from these points spread out in all directions with the speed of the wave. These wavelets emanating from the wavefront are usually referred to as secondary wavelets.

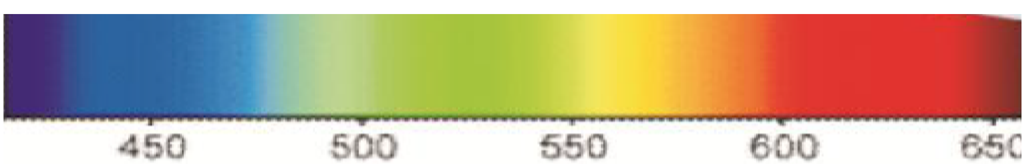
  - If we draw a common tangent (in the forward direction) to all these spheres, we obtain the new position of the wavefront at a later time.
- Huygens's construction: Wavefronts drawn on the basis of Huygens principle

Introduction

The wave theory was not readily accepted primarily because of Newton's authority and also because light could travel through vacuum and it was felt that a wave would always require a medium to propagate from one point to the other.

However, when Thomas Young performed his famous interference experiment in 1801, it was firmly established that light is indeed a wave phenomenon.

The white light is made up of seven colors and a spectrum can be seen given below



Light Spectrum showing wavelength in nanometers

The wavelength of visible light was measured and found to be extremely small; for example, the wavelength of yellow light is about 0.5 µm or 550 nm (nanometer).

A **nanometer** is a unit of measurement of length equal to **10^{-9} meter or one billionth of a meter.** It's difficult to imagine just how small that is, so here is an example: A sheet of paper, from your notebook is about 100,000 **nanometers** thick.

Because of the smallness of the wavelength of visible light (in comparison to the dimensions of typical mirrors and lenses) light can be assumed to approximately travel in straight lines. This is the field of ray or geometrical optics, which we had discussed in the previous modules.

Indeed, **the branch of optics in which one completely neglects the finiteness of the wavelength is called ray optics** and is truly a macroscopic view. A ray is defined as the path of light energy propagation in the limit of wavelength tending to zero.

After the **Interference experiment of Young in 1801**, for the next 40 years or so, many experiments were carried out involving the **interference and diffraction of light waves**; these experiments could only be satisfactorily explained by assuming a **wave model of light**.

In module 10 we discussed the original formulation of the Huygens principle and derived the laws of reflection and refraction.

We will now consider the phenomenon of **superposition of light waves**, relate it to our knowledge of superposition of waves in general as considered in Unit 10 Chapter 15 Physics course 2. (Class 11 Book 2)

Mechanical Wave Properties

- Mechanical waves are of two types- transverse and longitudinal
- They need a material medium to propagate. The medium must have three characteristics
  - It should have elasticity.
  - The particles of the medium must have inertia.
  - The medium must offer minimum friction.

- The wave speed is the speed with which the energy moves in the medium. It depends upon elasticity and inertia of particles of the medium

$$v = f \lambda\ f$$

Frequency is the property of the source and

λ The wavelength depends on the medium through which the wave is passing.

- Particle velocity is not the same as wave velocity.

- Energy in the wave depends upon the amplitude of vibration of the source, nature of particles of the medium.
- Mechanical waves can travel through solids, liquids and gases.

Principle of Superposition

This principle states that *(read imagining mechanical waves)*

- The resultant displacement of a particle at any point and at any instant is the algebraic sum of the individual displacements caused to the particle by two or more waves
- The waves continue after the region of overlap in their original direction and wavelength totally disregarding the event of overlap

So,

$y_1 = asin(kx - \omega t)$

represents a wave travelling in the $+\ x$ direction

Where a is amplitude,

$k = \frac{2\pi}{\lambda}$ propagation constant or angular wave number

$\omega = 2\pi f$ angular frequency

And if there is another wave

$y_2 = asin(k'x - \omega t)$

Then the resultant displacement of a particle at any instant is the sum of individual displacements caused to the particle by two or more waves

$Y = y_1 + y_2$

The superposition of waves refers to the state where if two (or more) waves travelling through the same medium at the same time meet, the net displacement of the medium at any time becomes equal to the algebraic sum of the individual displacements.

You will recall sound waves or water waves where we described **trough** and a **crest**

The points where a crest falls on a crest and a trough falls on a trough results in maximum displacement **(constructive interference)** whereas a point where a crest falls on a trough or vice versa represents minimum displacement **(destructive interference).**

To help you visualize -For example, consider a case when two identical stones are dropped into a still pool of water at two close locations.

- Each stone generates a circular wave propagating outwards.
- If the stones were dropped close enough then the waves produced by them will overlap
- The net displacement of the medium at any particular point will be the sum of displacements caused by two individual waves.
- Beyond the region of overlap, the waves continue with their original properties

It is important to note here that the net displacement of the medium at a location refers to the **redistribution of energy**.

As two waves carrying energy superimpose, a redistribution of energy takes place.

The points with **maximum displacement represent the points with maximum energy** whereas the points with **minimum displacement represent the points with minimum energy.**

Thus we can say that the superposition principle obeys the law of conservation of energy.

Special Cases Of Superposition

The superposition would mean the new particle displacements being different due to individual waves. But can we have conditions for the superposing waves, such that the resultant can be predicted?

You will recall, we studied three such conditions and the result of superposition in each case could be mathematically derived and experimentally verified the same.

We considered these in our modules on superposition of waves class 11 physics 2 course

The three conditions for superposition were

Condition 1

If

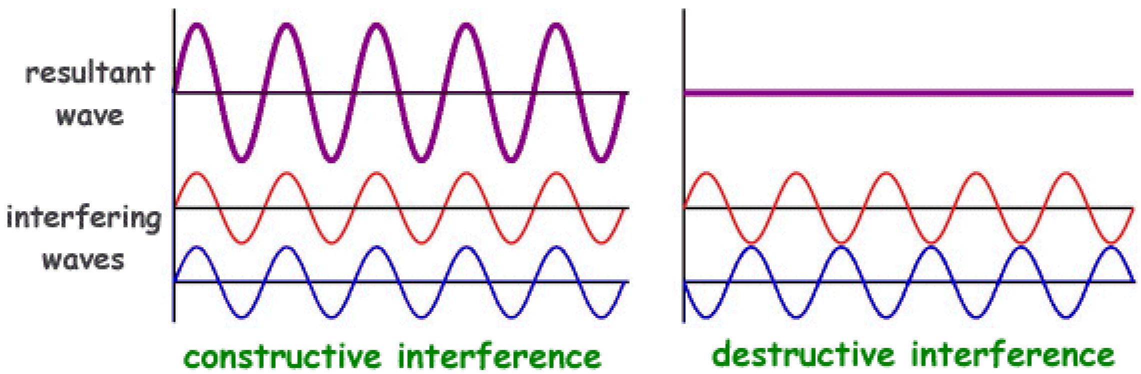
- two waves of same type,
- same frequency
- travelling in the **same** direction and
- of nearly the same amplitude

superposed, **the resultant is called interference**.

Redistribution of energy takes place in the region of overlap. At points there is energy and at other points there is no energy.

Points of increased energy are called constructive interference and of no energy are called destructive interference.

So the region of overlap has patterned energy and no energy points.



https://physics.stackexchange.com/questions/107286/does-interference-take-place-only-in-waves-parallel-to-each-other

Condition 2

If

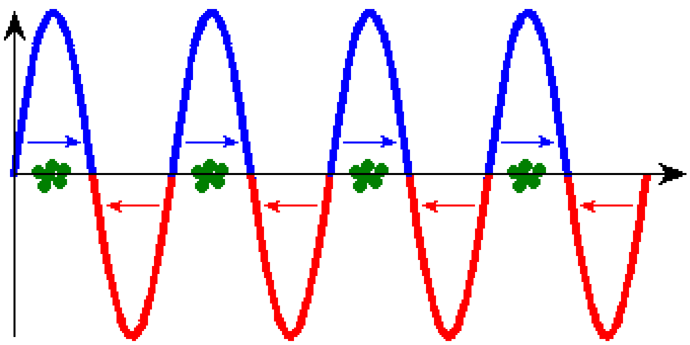
- two waves of same type,
- same frequency
- travelling in the **opposite** direction and
- of nearly the same amplitude

superposed

The resultant is called stationary waves.

See animation

https://www.google.co.in/search?dcr=0&site=imghp&tbs=sur%3Afmc&tbm=isch&sa=1&ei=RnU7WprbOMSHvQSgwqXACw&q=station



Transverse Stationary waves are produced in vibrating strings of musical instruments, and longitudinal stationary waves are produced or in closed and open organ pipes

Condition 3

If

- two waves of same type,
- nearly the same frequency
- travelling in the **same** direction and
- of nearly the same amplitude

  superposed

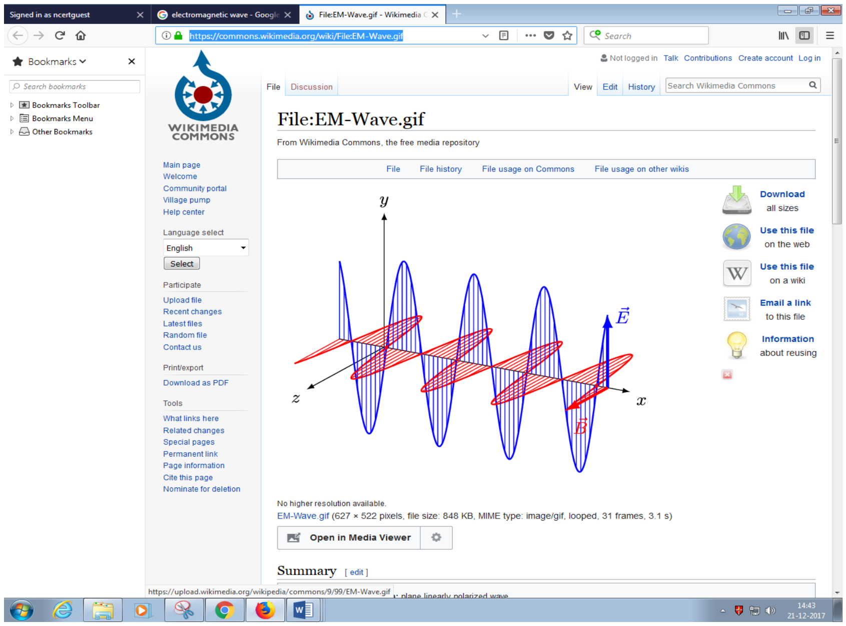
The resultant produces beats. In superposition of sound waves, beats are due to redistribution of energy in time. So we hear a loud sound followed by a low sound. The waxing and vanning of sound takes place. The beat frequency is an average of the two frequencies and the frequency of beat is the difference of the two frequencies of the waves superposing.

We use these 3 conditions for superposition, because we can predict the outcome.

Superposition Of Light Waves Producing Interference

Light waves are electromagnetic in nature. They are transverse waves with electrical and magnetic field components

https://commons.wikimedia.org/wiki/File:EM-Wave.gif



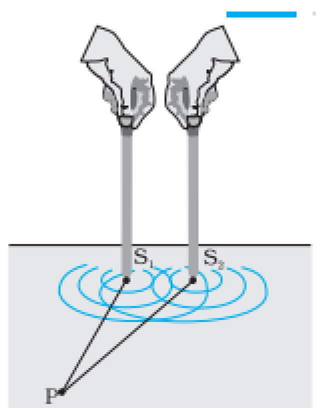
Vector E/B = velocity of light

$$\frac{E}{B} = c$$

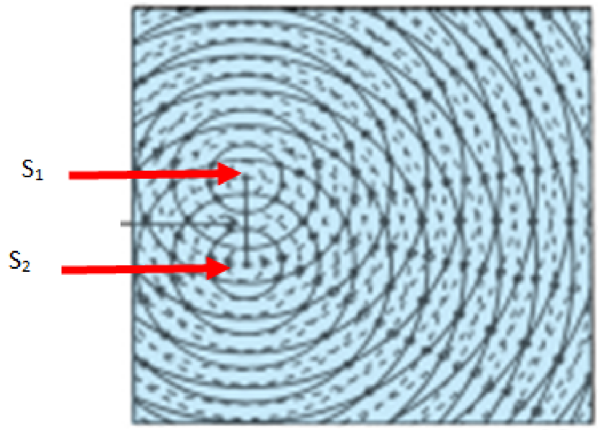
as E >>>B so we prefer to consider the electric vector

We will now discuss the interference pattern produced by the superposition of two waves.

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



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



The diagram shows the position of crests (solid circles) and troughs (dashed circles) at a given instant of time.

Consider a point P for

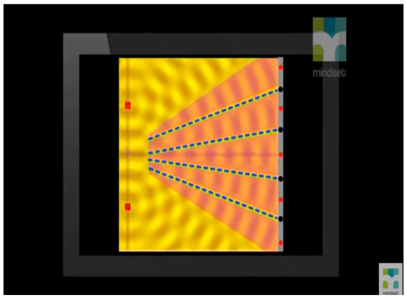
$$S_1 P = S_2 P$$

Since the distances S_1 P = S_2 P are equal, waves from S_1 and S_2 will take the same time to travel to the point P

Think About These

- Our common experience is that when two light bulbs shine simultaneously on the same wall, the intensities add.
  Why are we then considering displacements and not intensity?
- How can we get the two waves to start with no phase difference or with constant phase difference?
- If the waves that emanate from S_1 and S_2 are in phase, they will also arrive at the point P, in phase?
  If yes, how can we ensure that the required condition for interference is satisfied.
- Would prediction of maxima and minima be possible if no phase relationship of the two superposing waves at a location is known?

Applying Huygens principle every point on a wave front is in phase and is a source of secondary wavelets replicating the source waves in every way (frequency, wavelength and speed are same if the medium is homogeneous).



https://www.youtube.com/watch?v=vqa4L0DuWbM

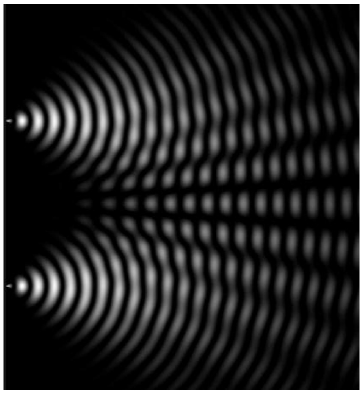
This video explains Huygens's Principle that each point in a wave is a source of secondary waves of the same frequency and wavelength and these secondary waves form a new wave front that advances through the medium

Coherence

After superposition, two waves can add together to create a wave of greater amplitude than either one (constructive interference) or create a wave of lesser amplitude than either one (destructive interference), depending on their **relative phase**.

Two waves are said to be **coherent if they have a constant relative phase.**

Spatial coherence describes the correlation (or predictable relationship) between waves at different points in three dimensional space.



In order to obtain the **phenomenon of interference** by superposition of waves it is necessary that the two sources producing waves must be coherent.

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

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

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

(c) **The waves produced by the two sources must have either the same phase or a constant phase difference**.

Key Points about Coherent sources and interference of light

- **Coherent sources of light are those sources which continuously emit waves of same wavelength, same frequency and are in same phase or constant phase difference.**
- Coherent sources are a must to observe the phenomenon of interference.
- **Light waves emitted by two sources can remain coherent if the initial phase difference between waves is maintained or else they would be incoherent sources.**
- **Two independent sources of light cannot be coherent and cannot produce interference, the light from the sources can superpose but no interference pattern can be observed, because the light beam is emitted by millions of atoms radiating independently so the phase difference between waves from sources fluctuates randomly several million times per second. Conventional light sources are incoherent sources. The transitions between energy levels in an atom is a completely random process and so we have no control over when an atom is going to lose energy in the form of radiation.**
- **Coherent sources are obtained by choosing two points on the same wavefront.**
- **Coherent sources produce coherent waves. Coherent waves are the waves with constant phase relationship with one another. Phase relationship between two waves can only be kept constant only when their frequencies are the same.**
- **Coherent sources have same frequency and constant phase difference or zero phase difference**

Are Waves From The Same Monochromatic Source Coherent?

Coherent light needs to have a fixed phase relation. Typically, light sources are a superimposition of a large number of atomic level micro sources. Light from a source is emitted as a random event with no synchronization between those atomic sources. So there is no fixed phase relation.

i.e. Not coherent. Lasers employ a specific mechanism with a resonating cavity that synchronizes the constituent atomic sources. The light that comes from a laser, however, is coherent, parallel, monochromatic and continuous.

Why There Is No Coherent Wave Source In Nature?

The conditions for **two coherent waves are two coherent sources** with:

- Same frequency
- Constant or zero phase difference
- Same Amplitude

Which is not possible to obtain from two different light sources. So two car headlamps are not coherent sources of light

Superposition Of Light From Coherent And Incoherent Sources

Let us **analyze mathematically** the need for coherent sources to observe interference of light.

Since light is an electromagnetic wave, the optical effects arise mainly due to the oscillating electric field vector.

Let the displacement of the electric field vector from two coherent sources S_1 and S_2 be

$$\mathbf{y_1 = a \cos \omega t}$$

and

$$\mathbf{y_2 = a \cos (\omega t} + \theta) \quad \text{respectively,}$$

Where the 'a' is the amplitude of the two interacting waves and θ is the constant phase difference by which the second wave leads the first wave.

The resultant displacement due to both the waves can be obtained by using the Superposition principle.

$$y = y_1 + y_2$$

$$y = a[\cos \omega t + \cos(\omega t + \theta)]$$

$$y = 2a\cos\left(\frac{\theta}{2}\right)\cos\left(\omega t + \frac{\theta}{2}\right)$$

$2a\cos\left(\frac{\theta}{2}\right)$ in the above expression represents the **amplitude of the resultant wave**.

For waves, the intensity is proportional to the square of the amplitude

$$\mathbf{I \propto (Amplitude)^2}$$

Or

$$I \propto 4a^2 \cos^2 \left(\frac{\theta}{2}\right)$$

$$I = 4Io \cos^2 \left(\frac{\theta}{2}\right)$$

where Io represents the intensity produced by each source.

If $\theta = 0, \pm 2\pi, \pm 4\pi$…... then **the intensity of the resultant wave is maximum or we have constructive interference**

i.e. $\mathbf{I_{max} = 4Io.}$

If $\theta = \pm\pi, \pm 3\pi, \pm 5\pi$….. then the intensity of the resultant wave is minimum **or we have destructive interference**

i.e. $\mathbf{I_{min} = 0}$

After having an understanding of superposition of waves and coherent sources, we can now define the term interference for waves

Interference refers to the superposition of waves produced by two coherent sources.

In other words we can say that the interference refers to the redistribution of energy obtained by the superposition of two or more waves that are coherent with each other.

Interference effects can be observed with all types of waves, for example, light, radio, acoustic and surface water waves.

In case the **two waves do not maintain a constant phase relation**

we will observe an average intensity that will be given by

$$\langle I \rangle = 4I_0 \langle cos^2\left(\frac{\theta}{2}\right) \rangle$$

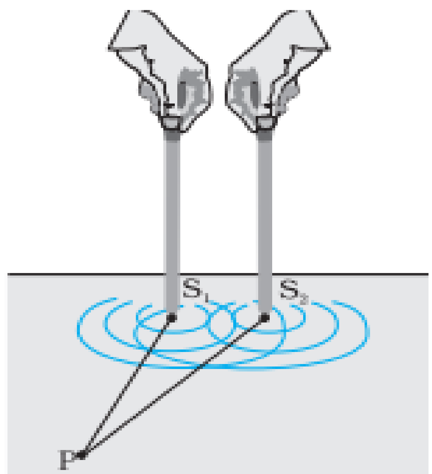
the time-averaged quantity < $cos^2\left(\frac{\theta}{2}\right)$ > will be ½ . This is because the function $cos^2\left(\frac{\theta}{2}\right)$ will randomly vary between 0 and 1 and the average value will be ½ . The resultant intensity will be given by $I = 2\ I_0$ at all points.

When the phase difference between the two vibrating sources changes rapidly with time, we say that the two sources are incoherent and when this happens the intensities just add up.

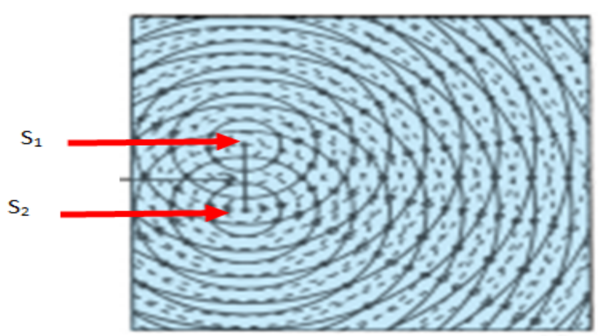
This is indeed what happens when two separate light sources illuminate a wall.

Conditions For Constructive And Destructive Interference

Let us recall our experience with water waves.



Top view

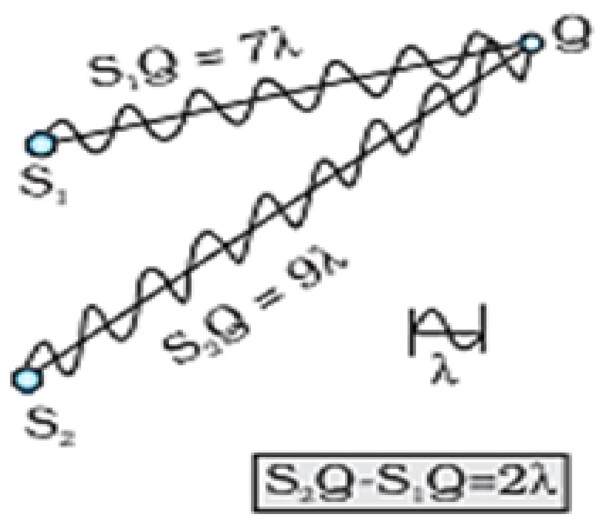


At any point on the perpendicular bisector of S_1S_2, the intensity will be $4I_0$, because intensity is proportional to square of the amplitude.

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

We next consider a point Q in the Figure for which $S_2Q - S_1Q = 2\lambda$

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



Thus, if the displacement produced by S_1 is given by

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

then the displacement produced by S_2 will be given by

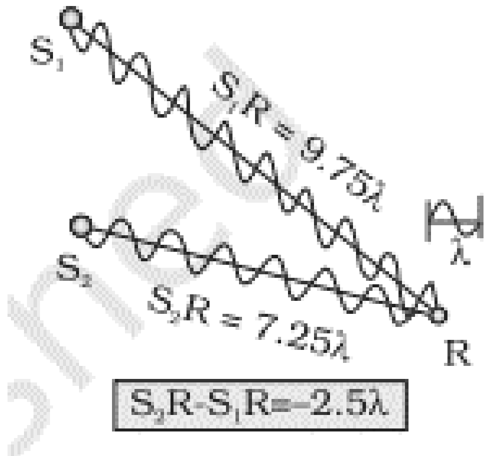
$$y_2 = a \cos (\omega t - 4\pi) = a \cos \omega t$$

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

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

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

We next consider a point R



(b)

Figure (b) for which $S_2R - S_1R = -2.5\lambda$

The waves emanating from S_1 will arrive exactly two and a half cycles later than the waves from S_2Thus if the displacement produced by S_1 is given by

$$\mathbf{y_1 = a\cos\omega t}$$

then the displacement produced by S_2 will be given by

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

Where we have used the fact that a path difference of 2.5λ corresponds to a phase difference of 5π

The two displacements are now **out of phase** and the two displacements will **cancel out** to give **zero intensity**. This is the explanation for destructive interference.

Now can you understand why the interference results in a spatial –light and no light pattern?

To Summarize

- If we have two coherent sources S_1 and S_2 vibrating in phase or with constant phase difference, then for an arbitrary point P whenever **the path difference**,

  $\mathbf{S_1P \sim S_2P = n\lambda}$ **(n = 0, 1, 2, 3 ...)**

  Or

  Path difference equal to an integral multiple of wavelength

We will have **constructive interference and the resultant intensity will be 4I $_0$**

The sign ~ between S_1 P and S_2 P represents the difference between S_1 P and S_2 P

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

  $S_1 P \sim S_2 P = (2n + 1) \lambda/2$ (n = 0, 1, 2, 3 …)

  Or

  Path difference equal to odd multiple of half wavelength

  We will have **destructive interference and the resultant intensity will be zero.**

Example

Two waves of amplitudes 3 m and 2 m reach a point in the same phase, what is the resultant amplitude?

Solution

$$3m + 2\,m = 5m$$

Example

The phase difference between two waves reaching a point is /2 . What is the resultant amplitude if individual amplitudes are 3 mm and 4 mm?

Solution

Resultant amplitude= $a = \sqrt{a_1^2 + a_2^2 + 2a_1 a_2 cos\frac{\pi}{2}}$

$$= \sqrt{3^2 + 4^2} = 5mm$$

Example

In an interference pattern two waves arriving at a point P have a phase difference of $\pi/3$. What is the intensity at P expressed as a fraction of maximum intensity I_0?

Solution

The resultant intensity at any point of an interference pattern is given by

$$I = 4I_0 \cos^2 \left(\frac{\theta}{2}\right)$$

Where $4I_0$ is the maximum intensity and θ is the phase difference between the two waves

Substituting the given values

$I = I_0 cos^2 \frac{\pi}{6} = I_0 \left(\frac{\sqrt{3}}{2}\right)^2 = \frac{3}{4} I_0$

Example

Two coherent sources emit waves of amplitudes a and$2a$. They meet at a point P equidistant from the two sources. If the intensity of the first is I, what is the resultant intensity at point P?

Solution

Resultant amplitude at point P = a + 2a= 3a

Intensity ∝ $(amplitude)^2 = 9I$

Try These

- What is meant by the term interference of light?
- Why does interference produce a pattern?
- Write two conditions necessary for obtaining well defined and sustained interference pattern.
- Can two independent sources of light produce superposition? Which requisite conditions for interference are not fulfilled?
- Why can two identical bulbs not produce interference.
- Two coherent sources produce interference. If one of the sources flickers at a high frequency, what changes will be observed in the interference pattern?

Summary

You have learnt

- The principle of superposition of waves applies whenever two or more sources of light illuminate the same point.
- When we consider the intensity of light due to these sources at the given point, there is an interference term in addition to the sum of the individual intensities. But this term is important only if it has a non-zero average, which occurs only if the sources have the same frequency and a stable phase difference.

- Coherent sources of light are those sources which continuously emit waves of same wavelength, same frequency and are in same phase or constant phase difference.
- Coherent sources are a must to observe the phenomenon of interference.
- Coherent sources can be obtained from a single wavefront by suitably selecting two close points. According to Huygens principle these two would be giving secondary wavelets identical to the source and would be in phase.
- An interference pattern as a result of superposition can be obtained on a screen.
- Condition for constructive and destructive interference

  Phase difference $\theta = 0, \pm 2\pi, \pm 4\pi$…... then **the intensity of the resultant wave is maximum or we have constructive interference i.e. $I_{max} = 4I_o$.**

  Path difference equal to an integral multiple of wavelength

  We will have **constructive interference and the resultant intensity will be $4I_0$,**

  if Phase difference $\theta = \pm\pi, \pm 3\pi, \pm 5\pi$….. then the intensity of the resultant wave is minimum **or we have destructive interference**

  i.e. $I_{min} = 0$

  Path difference equal to odd multiple of half wavelength

  We will have **destructive interference and the resultant intensity will be zero.**