

UNIT 5

OPTICS

POLARIZATION

- *Waves are basically of two types:*
 - *Longitudinal waves*
 - *Transverse waves*
- *A wave in which particles of the medium oscillate to and fro along the direction of propagation – **Longitudinal** waves*
- *A wave in which every particle of the medium oscillates up and down at right angles to the direction of wave propagation – **Transverse** waves*

● COHERENT SOURCES

The sources of light, which emit continuous light waves of the same wavelength, same frequency and in the same phase difference are called coherent sources.

Conditions to obtain coherent light :

1. Two sources should be single source or by same device.
2. Two sources should give monochromatic light.
3. The path difference b/w light waves from 2 sources should be small.

- Ordinary light (Incoherent light)



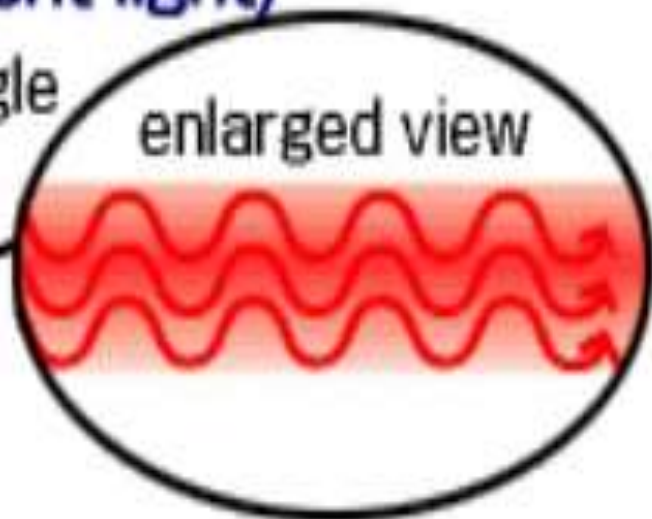
light with unaligned
wavelengths
and phases

- Laser light (Coherent light)

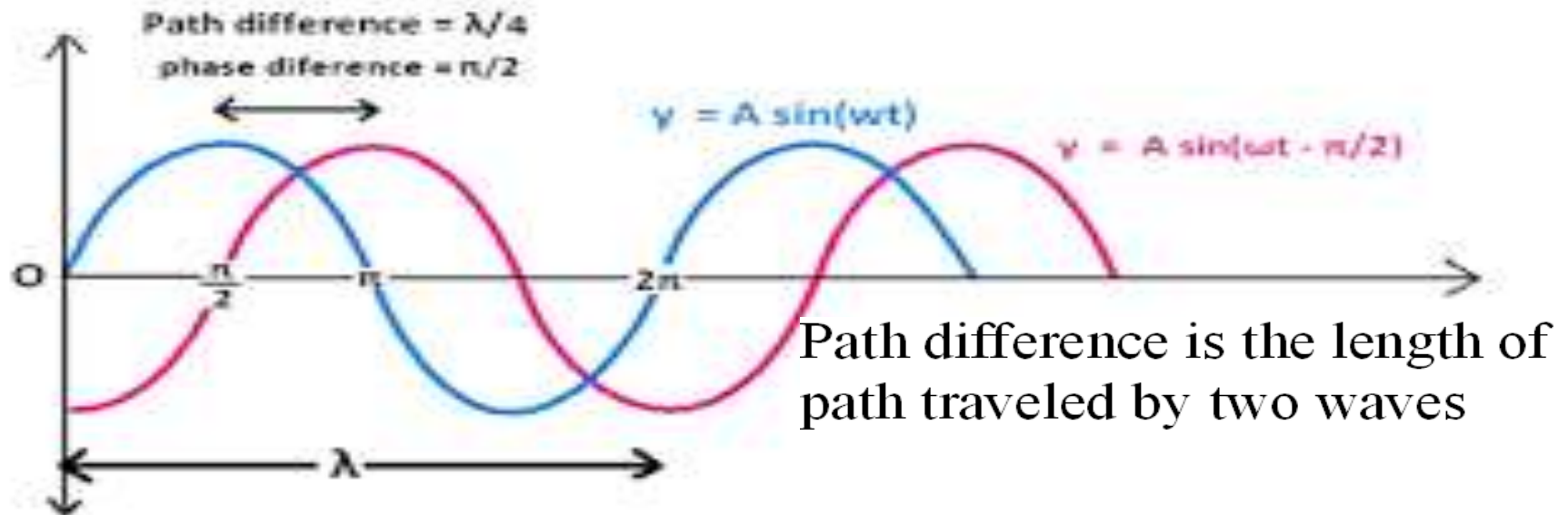
light that has a single
wavelength and
an aligned phase
(rhythm)



enlarged view



Path difference and Phase difference



Phase difference is the difference in phase of two waves of same frequency

Relation between path difference

And phase difference is

The path difference x

Phase difference $2\pi x/\lambda$

INTERFERENCE

- ◉ Interference is an effect that occurs when two or more waves overlap.
- ◉ In general, the individual waves do not affect one another, and the total wave amplitude at any point in space is simply the sum of the amplitudes of the individual waves at that point.
- ◉ Interference is a phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude

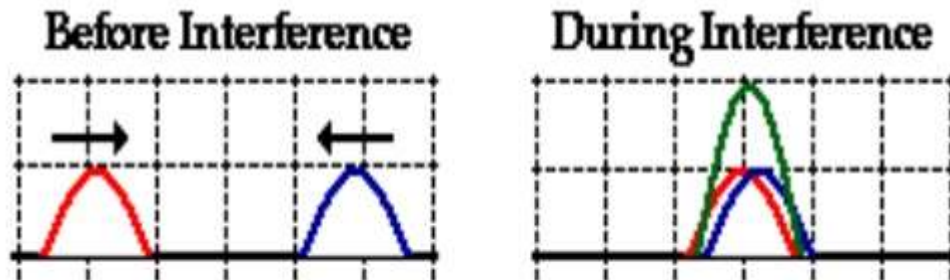
TYPES OF INTERFERENCE

- ◉ Constructive interference
- ◉ Destructive interference

Constructive Interference

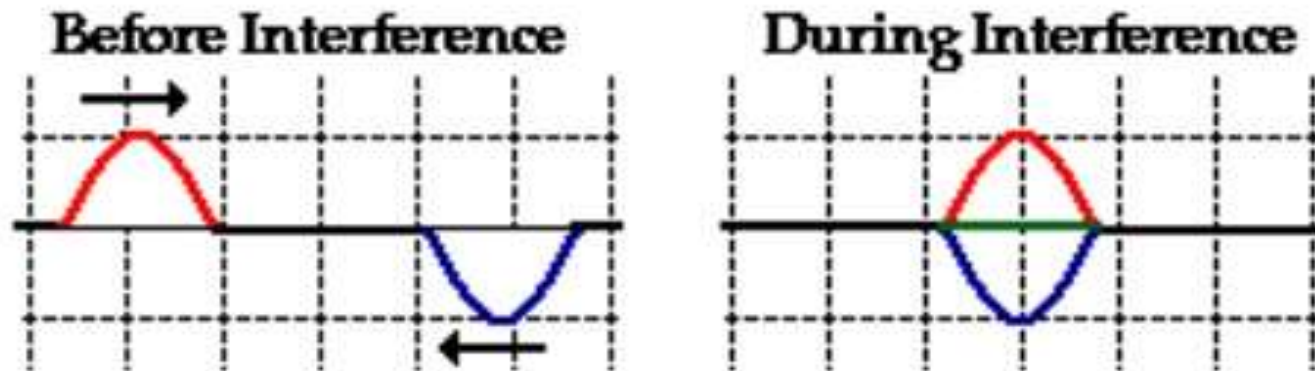
- ◉ It is a type of interference where the two interfering waves have a displacement in the same direction

In *constructive interference* the amplitude of the resultant wave is greater than that of either individual wave



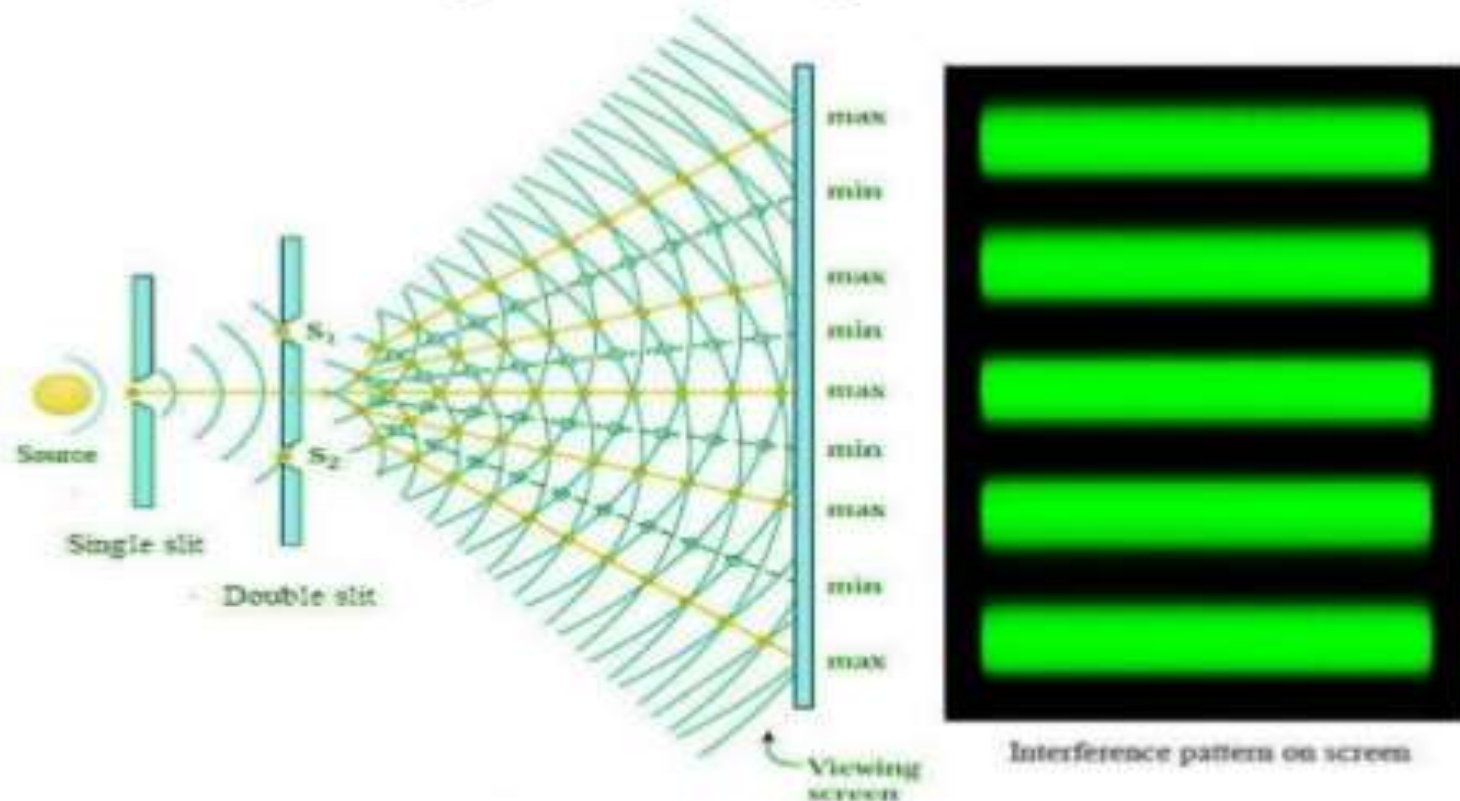
Destructive Interference

- It is a type of interference where the two interfering waves have a displacement in the opposite direction.



In *destructive interference* the amplitude of the resultant wave is less than that of either individual wave.

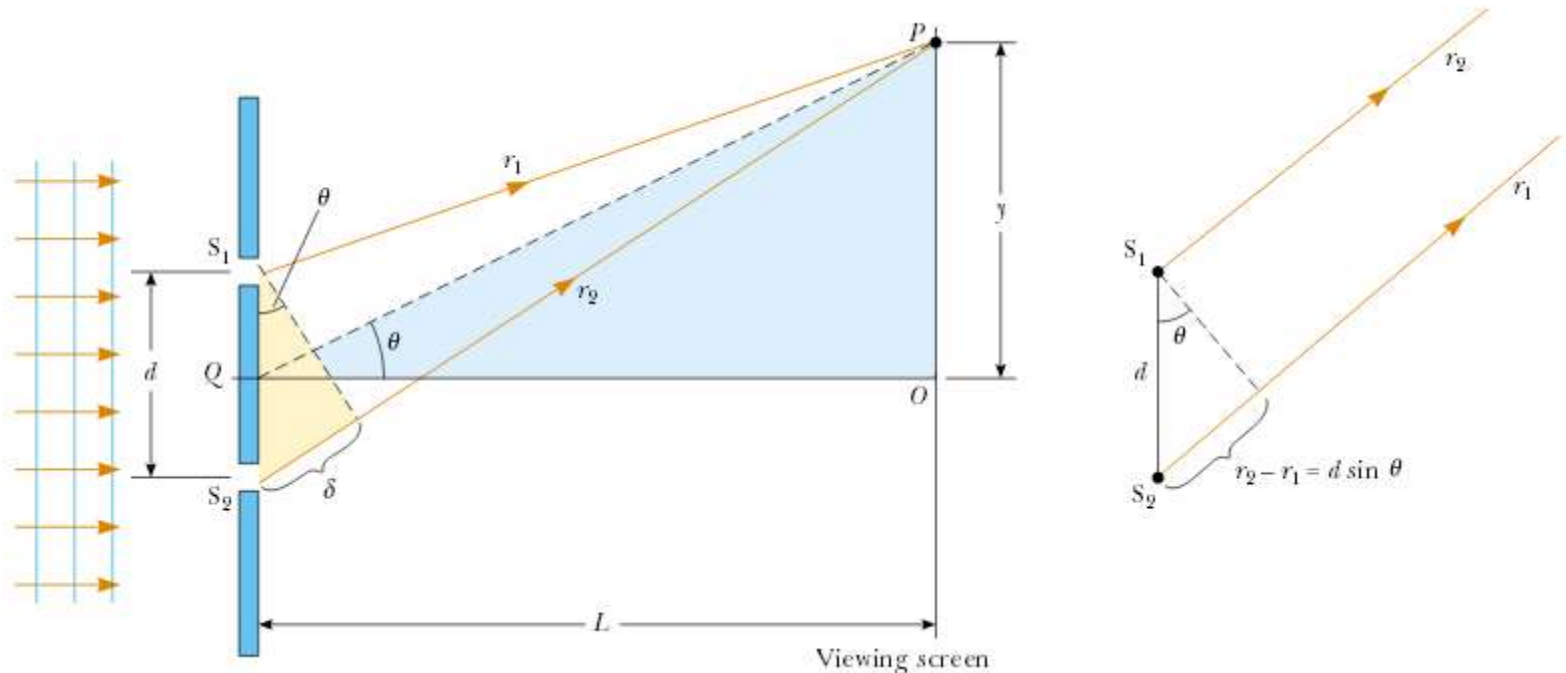
□ The light waves emanating from each slit are superposed on the screen. If the waves are out of phase then *destructive interference* occurs, resulting in a dark patch on the screen. On the other hand, if the waves are completely in phase then *constructive interference* occurs, resulting in a light patch on the screen.



Conditions for Interference

- To observe interference in light waves, the following two conditions must be met:
 - The sources must be **coherent**.
 - They must maintain a constant phase with respect to each other.
 - The sources should be **monochromatic**.
 - Monochromatic means they have a single wavelength.

Theory of interference



The viewing screen is located a perpendicular distance L from the barrier containing two slits, S_1 and S_2 . These slits are separated by a distance d , and the source is monochromatic. To reach any arbitrary point P in the upper half of the screen, a wave from the lower slit must travel farther than a wave from the upper slit by a distance $d \sin \theta$. This distance is called the **path difference** δ (lowercase Greek delta). If we assume that r_1 and r_2 are parallel, which is approximately true if L is much greater than d , then δ is given by

$$\delta = r_2 - r_1 = d \sin \theta$$

the condition for bright fringes, or **constructive interference**, at point P is

$$\delta = d \sin \theta_{\text{bright}} = m \lambda \quad (m = 0, \pm 1, \pm 2, \dots)$$

The number m is called the **order number**.

the condition for dark

fringes, or **destructive interference**, at point P is

$$d \sin \theta_{\text{dark}} = (m + \frac{1}{2}) \lambda \quad (m = 0, \pm 1, \pm 2, \dots)$$

Then, from triangle OPQ

$$y = L \tan \theta \approx L \sin \theta$$

sin θ and substituting the result

see that the positions of the bright fringes measured from O are given expression

$$y_{\text{bright}} = \frac{\lambda L}{d} m \quad (m = 0, \pm 1, \pm 2, \dots)$$

Using Equations the dark fringes are located at

$$y_{\text{dark}} = \frac{\lambda L}{d} (m + \frac{1}{2}) \quad (m = 0, \pm 1, \pm 2, \dots)$$

Fringes produced by a wedge
shaped films

THEORY

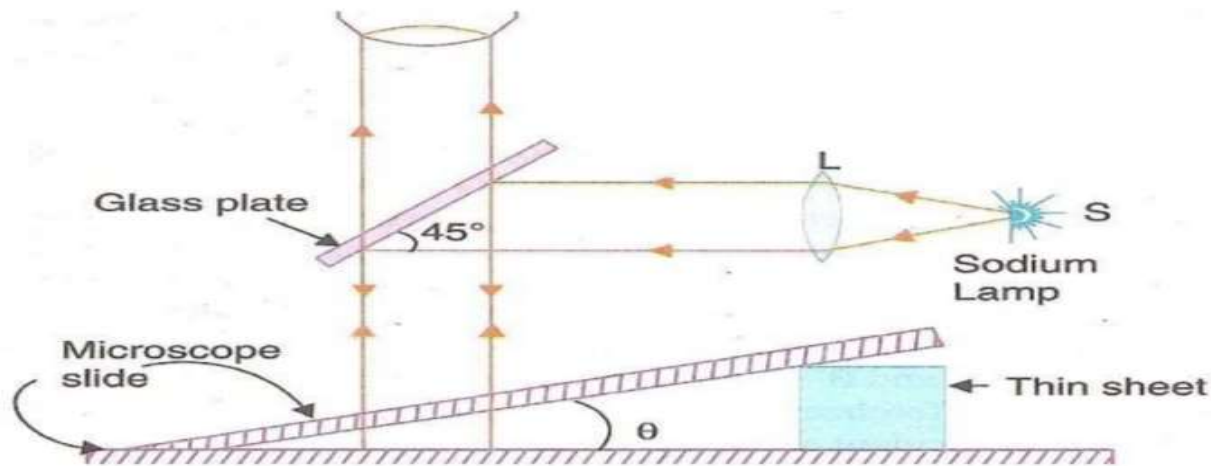


Figure.1a

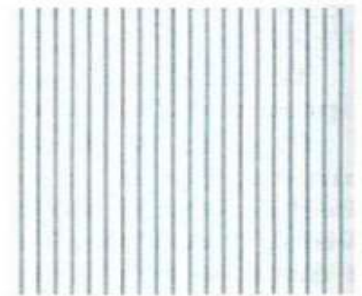


Figure.1b

A thin film having zero thickness at one end and *progressively* increasing to a particular thickness at the other end is called a wedge.

A thin wedge of air film can be formed by two glasses slides on each other at one edge and separated by a thin spacer at the opposite edge.

The arrangement for observing interference of light in a wedge shaped film (shown in Fig.1a) . the wedge angle is usually very small and of the order of a degree. When a parallel beam of monochromatic light illuminates the wedge from above .The rays reflected from the two bounding surfaces of the film are not parallel they appear to diverge from a point near the film .these rays interfere constructively or destructively producing alternate bright and dark fringes (see Fig.1b).

When the light is incident on the wedge from above, it gets partly reflected from the glass-to-air boundary at the top of the air film .

The other Part of the light is transmitted through the air film and gets reflected at the air-to-glass boundary (as shown in fig.2).

The two rays BC and DE reflected from the top and the bottom of the air film have a varying path difference along the length of the film due to variation of the film thickness. Because ray DE travels more distance than BC.

Also ray DE undergoes a phase change of half wave length (π change) occurs at the air to glass boundary due to reflection.

The optical phase difference between the two rays BC and DE is given by :

$$\Delta = 2nt + \lambda/2$$

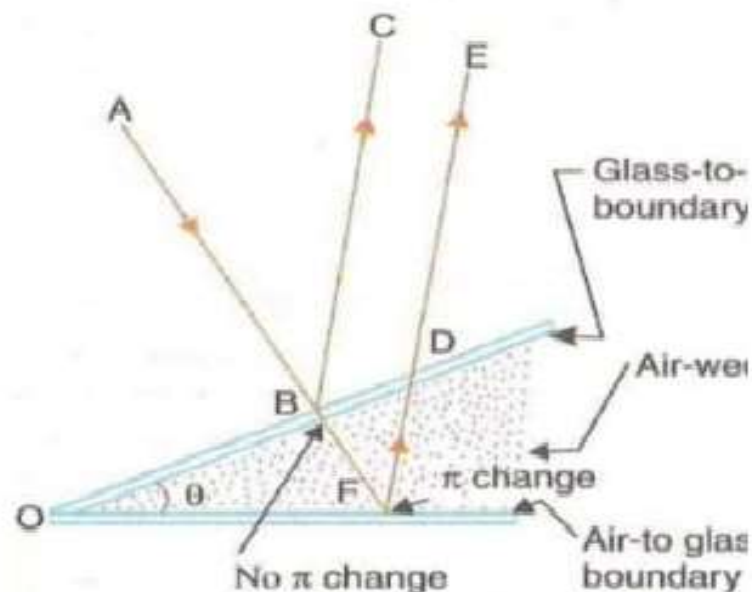


Figure.2

Minima occurs when the phase difference is an *odd* multiple of $\lambda/2$, the two waves arriving are 180° out of phase and give rise to destructive interference. Therefore, the condition for dark fringes, or **destructive interference** is:

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

$$2nt = m\lambda$$

Because the film produced from air $n=1$

$$2t = m\lambda$$

The thickness of the spacer used to form the wedge shaped air film between the glass slices can be determined using a travelling microscope.





Holography

- ✚ Science of producing holograms.
- ✚ Enables 3-D images (holograms) to be made.
- ✚ Involves the use of a **laser**, **interference**, **diffraction**, light **intensity** recording & suitable illumination of the recording.
- ✚ The image changes as the position & orientation of the viewing system changes in exactly the same way as if the object were still present, thus making the image appear **Three-dimensional**.

Working

- 🧑‍🔬 Enables a light field, to be recorded & later reconstructed when the original light field is no longer present, due to the absence of the original objects.
- 🧑‍🔬 Can be thought of as somewhat similar to **sound recording**, whereby a sound field is encoded in such a way that it can be reproduced later, without the presence of the original vibrating matter.

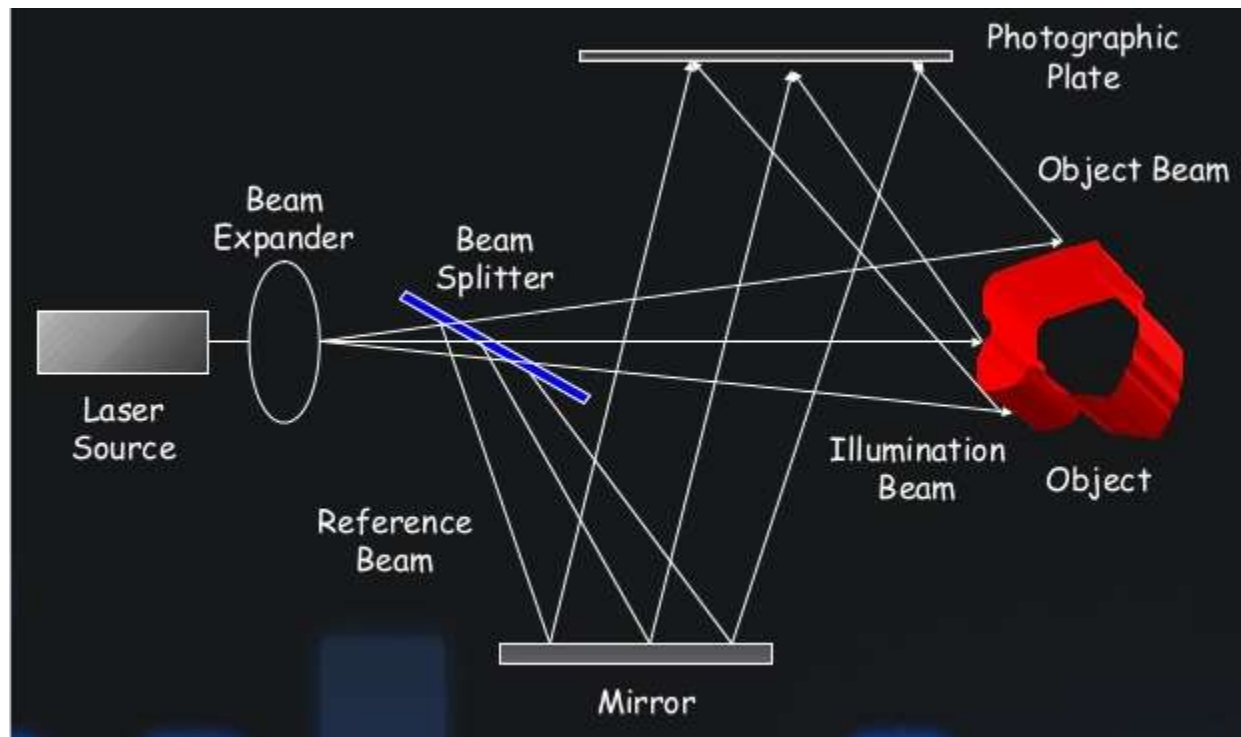


- ✚ Holograms are recorded using a flash of light that illuminates a scene and then imprints on a recording medium, much in the way a photograph is recorded.
 - ✚ However, part of the light (**Reference beam**) beam must be shone directly onto the recording medium.
 - ✚ A hologram requires a **Laser** as the sole light source as it can be precisely controlled and have a fixed **wavelength**.
 - ✚ Usually taken in darkness, or in low level light of a different color from the laser light used in making the hologram to prevent external light from interfering.
- Recording a hologram requires the laser beam to be aimed through a series of elements that change it in different ways. **Beam splitter** divides the beam into two identical beams, each aimed in different directions:
- ✚ Illumination beam
 - ✚ Reference beam

To make a Hologram following items are required :

- ✚ A suitable object or set of objects.
- ✚ A suitable laser beam
- ✚ Part of the laser beam to be directed so that it illuminates the object (the object beam) and another part so that it illuminates the recording medium directly (the reference beam), enabling the reference beam and the light which is scattered from the object onto the recording medium to form an interference pattern

- ✚ A recording medium which converts this interference pattern into an optical element which modifies either the amplitude or the phase of an incident light beam according to the intensity of the interference pattern.
- ✚ An environment which provides sufficient mechanical and thermal stability that the interference pattern is stable during the time in which the interference pattern is recorded



Process

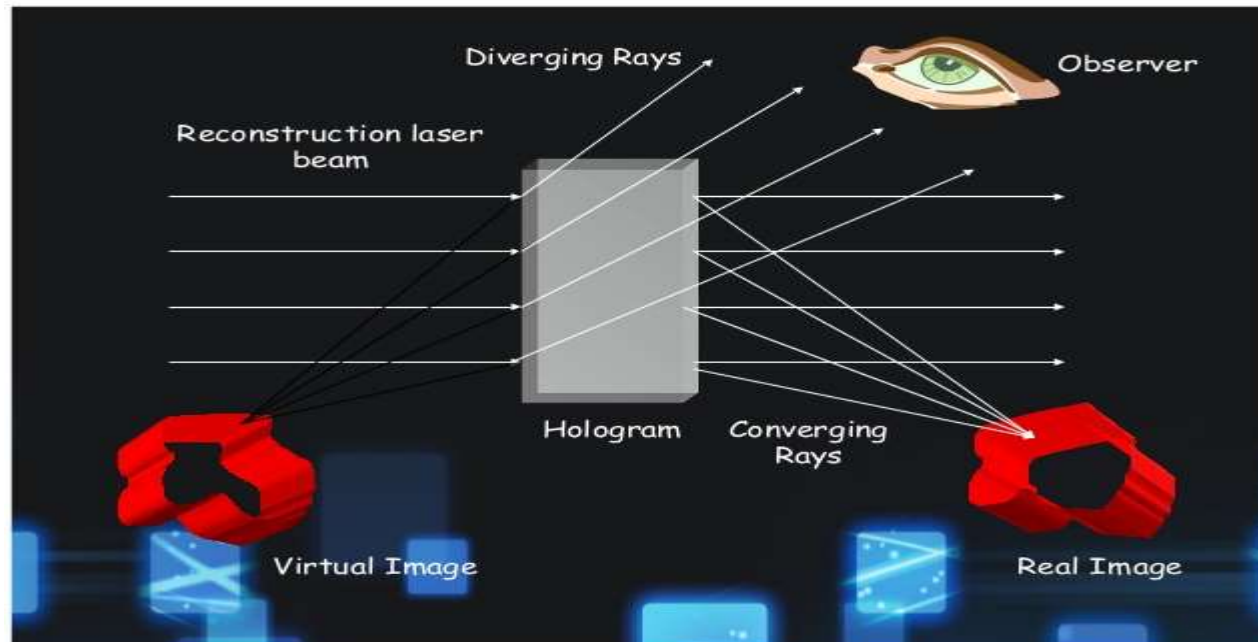
It is this interference pattern that is imprinted on the recording medium.

The interference pattern can be considered an **Encoded** version of the scene.

This missing key is provided later by shining a laser, identical to the one used to record the hologram, onto the developed film.

When this beam illuminates the hologram, it is diffracted by the hologram's surface pattern. This produces a light field identical to the one originally produced by the scene and scattered onto the hologram.

The image this effect produces in a person's **retina** is known as a **Virtual image**.



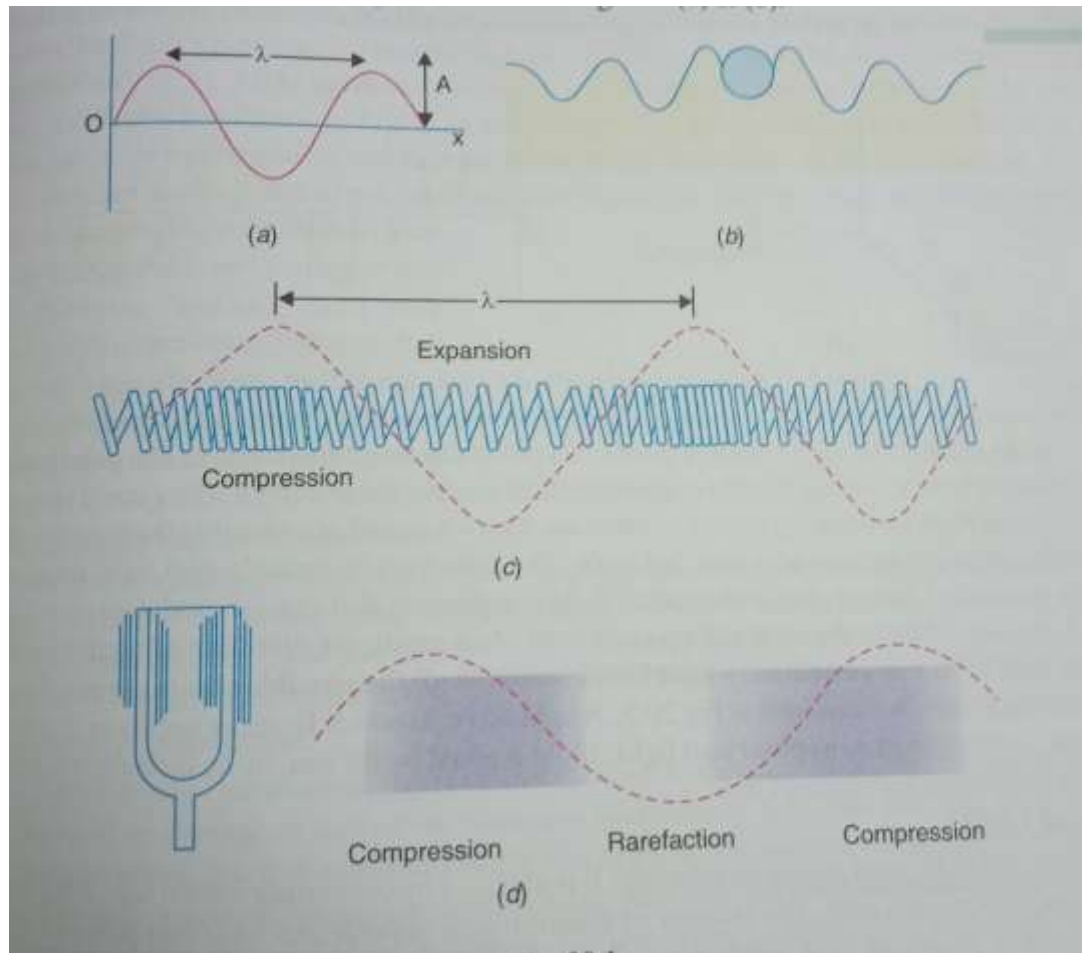
Reconstructing and viewing the holographic image

- ✦ When the hologram plate is illuminated by the laser beam, an exact reconstruction of the original object wave front is obtained.
- ✦ An imaging system (an eye or a camera) located in the reconstructed beam 'sees' exactly the same scene as it would have done when viewing the original.
- ✦ When the lens is moved, the image changes in the same way as it would have done when the object was in place.
- ✦ If several objects were present when the hologram was recorded, the reconstructed objects exhibit **Parallax**.

Applications

- Art
- Data Storage
- Dynamic Holography
- Hobbyist use
- Holographic interferometry
- Interferometric microscopy
- Sensors and Biosensors
- Security

POLARIZATION



POLARIZATION

- *In a longitudinal wave, all directions perpendicular to the wave propagation are equivalent*
- *In a transverse wave, a preferential direction normal to the wave propagation exists*
- *The existence of this direction in transverse wave leads to the characteristic phenomenon known as **polarization***
- *Polarization is specific to transverse waves*

POLARIZATION

- *In an ideal light wave, the vibrations of electric vector are confined to a single plane*
- *In practice, light sources emit a mixture of light waves whose planes of vibration are randomly oriented about the direction of propagation*
- *Such random orientation of vibration planes gives rise to symmetry*
- *The process of removing the symmetry and bringing in one-sidedness in the light wave is called **polarization***

OPTICAL ACTIVITY

- *Certain crystals and solutions possess a natural ability to rotate the plane of polarization about the direction of propagation – **optical activity***
- *In liquids and solutions, the optical activity is due to certain structural symmetry in their molecules*
- *Substances, which have the ability to rotate the plane of the polarized light passing through them, are called **optically active substances***
- *Quartz and cinnabar – examples of optically active crystals; aqueous solutions of sugar, tartaric acid – optically active solutions*

OPTICAL ACTIVITY

- *Optically active substances are classified into two types:*
 - *Dextrorotatory* substances – which rotate the plane of polarization of the light toward the right – known as right handed or dextrorotatory
 - *Laevorotatory* substances – which rotate the plane of polarization of the light toward the left – known as left handed or laevorotatory

SPECIFIC ROTATION

- *A measure of the optical activity of a sample is the rotation produced for a 1 mm slab for a solid, or a 100 mm path length of a liquid – **specific rotation***
- *If an optically active material is kept between two crossed polarizers, the field of view becomes bright*
- *In order to get darkness again, the analyzer has to be rotated through an angle*
- *The angle through which the analyzer is rotated equals the angle through which the plane of polarization is rotated by the optically active substance*

SPECIFIC ROTATION

- *The angle of rotation depends on*
 - *The **thickness** of the substance*
 - ***Density** of the material or concentration of the solution*
 - ***Wavelength** of light*
 - *The **temperature***
- *The amount of rotation θ caused by crystalline materials is given by, $\theta = \alpha l$, where α is called the **rotational constant***

SPECIFIC ROTATION...

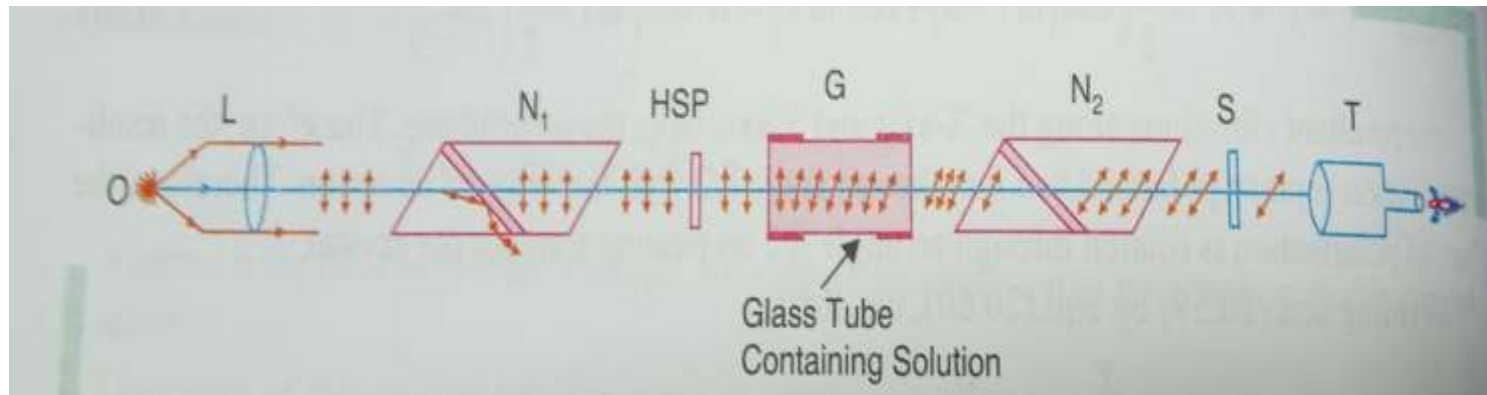
- In solutions the amount of rotation θ is given by $\theta = s c l$*

where c is the concentration and s is called the specific rotation

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

LAURENT'S HALF SHADE POLARIMETER

- A *polarimeter* is an instrument used for determining the optical rotation of solutions
- When used for determining the optical rotation of sugar, it is called a *saccharimeter*



LAURENT'S HALF SHADE POLARIMETER...

- *Construction:*

- *glass tube for holding the solution between Nicol prisms*
- *monochromatic light incidents on the polarizer N_1*
- *light transmitted is plane polarized*
- *polarized beam passes through the half-shade plate and glass tube G containing the solution*

LAURENT'S HALF SHADE POLARIMETER...

- Light emerging from the solution incidents on the analyzer N_2*
- Light is observed through the telescope T*
- Analyzing Nicol N_2 can be rotated about the axis of the tube and the rotation can be measured*

Working:

- Analyzer is first adjusted – field of view is completely dark*
- Glass tube is filled with solution*
- Field now becomes illuminated*

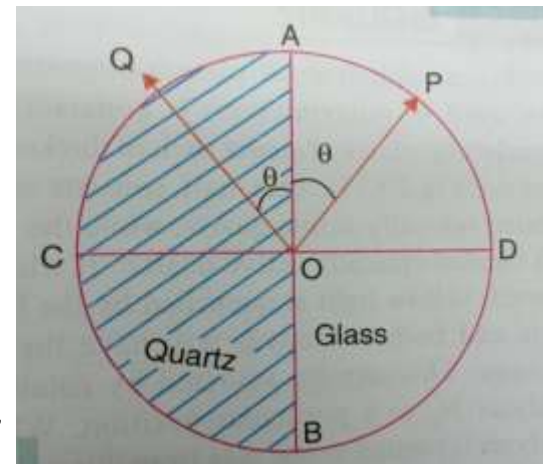
LAURENT'S HALF SHADE POLARIMETER...

- *Field of view is made dark by rotating the analyzer through a certain angle – optical rotation of the solution*
- *Practical difficulty is to determine the exact position for which complete darkness is achieved*
- *This can be overcome by Laurent's half – shade device*

LAURENT'S HALF SHADE POLARIMETER...

- It consists of a semicircular half wave plate ACB of quartz cemented to a semicircular plate ADB of glass
- The optic axis of the wave plate is parallel to the line of separation AB

The half wave plate introduces difference of 180° between e-ray and o-ray passing through it



LAURENT'S HALF SHADE POLARIMETER...

- *One half of the incident light passes through the quartz plate ACB and the other half through ADB*
- *On passing through the glass, half the vibrations will remain along OP*
- *On passing through the quartz half, the vibrations split into e- and o- rays*
- *O – vibrations are along OD and e-vibrations are along OA*

LAURENT'S HALF SHADE POLARIMETER...

- The half wave plate introduces a phase difference of π rad between the two vibrations*
- The resultant vibration will be along OQ whereas the vibrations of the beam emerging from glass plate will be along OP*
- The half wave plate turns the plane of polarization of the incident light through an angle 2θ*

DETERMINATION OF SPECIFIC ROTATION OF SOLUTION

- *The analyzer is first in the position for equal darkness without the solution in the tube G*
- *Reading on the circular scale is noted*
- *Tube is filled with optically active solution*
- *Field of view is partially illuminated*
- *Analyzer is rotated till the field of view becomes equally dark*
- *Reading on the scale is noted again*
- *Difference between the two scale readings gives the angle of rotation of the plane of polarization caused by the solution*

DETERMINATION OF SPECIFIC ROTATION OF SOLUTION...

- Knowing θ , l and C , the specific rotation is obtained using the formula, $S = \theta / l \times C$
- In the actual experiment, different concentrations of solutions are taken and the corresponding angles of rotation are determined
- A graph is plotted between the concentration C and the angle of rotation θ
- The graph is a straight line
- Using the value of slope, specific rotation is calculated

