Wave Optics

Doppler's effect of Light

- Change in frequency of light when there is relative motion between the source of light and the observer.

- The fractional change in the frequency is found by $\frac{\Delta\nu}{\nu} = -\frac{v_{rad}}{c}$
  where v_{rad} is radial velocity that is relative velocity of source with respect to the observer along the line joining them.

Coherent and Incoherent addition of waves

- **Coherent sources:** Two sources of light emitting light waves of same frequency or wavelength and of a stable phase difference

- **Principle of superposition:** When two or more wave trains of light travelling in a medium superpose upon each other, the resultant displacement at any instant is equal to the vector sum of the displacements due to individual waves.

- **Interference of light:**
  Interference of light is the phenomenon of redistribution of light energy in a medium on account of the superposition of light waves from two coherent sources.

  - For constructive interference intensity should be maximum, for which
    $\cos\phi = 1$ = maximum or $\Phi = 2n\pi$ and $x = n\lambda$
    Where, $n = 0, 1, 2$

- **Destructive interference of light:**
  Intensity should be minimum
  $\cos\phi$ = minimum $= -1$
  $\phi = (2n+1)\pi$ and $x = \left(\frac{2n+1}{2}\right)\lambda$
  Where, $n = 1, 2 \ldots \ldots$ and x is the path difference between the two waves, corresponding to phase difference is ϕ.

Huygens principle

- Every point on a given wave front $called the primary wave front$ acts as a fresh source of new disturbances, called secondary wavelets.

- The surface touching these secondary wavelets tangentially in the forward direction at any instant, gives the new wave front at that instant. This is called secondary wave front.

- Using Huygen's principle we can prove the laws of reflection and and laws of refraction.

Young's Double-Slit Experiment

- In Young's Double-Slit Experiment, two slits are illuminated by a monochromatic source of light.

- For the distance d between the slits, alternate bright and dark bands are observed on a screen placed at distance D from the slits.

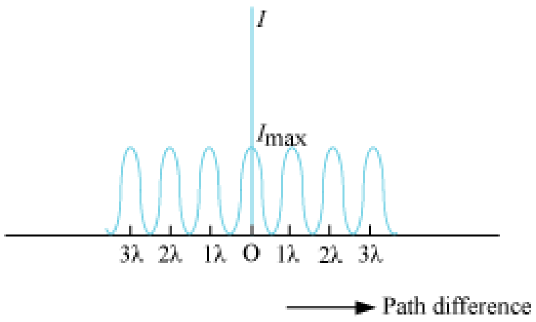
- Conditions for the bright fringes x distance apart from each other:

  - path difference between the light waves for the nth bright fringe = $x\frac{d}{D} = n\lambda$

  - path difference between the light waves for the nth dark fringe = $x\frac{d}{D} = \left(2n-1\right)\frac{\lambda}{2}$

- All the bright and dark fringes are of equal width, as $\beta_1 = \beta_2$.

- Graph of intensity distribution in Young's Double-Slit Experiment:



- **C onditions for producing steady interference pattern:**
  - The sources of light must be coherent.
  - The sources of light must be monochromatic.
  - The two waves that are interfering must have the same state of polarisation.
  - The separation between the sources of light should be very small.
  - The distance of the screen from the two sources of light should be large.

- In a bi-prism experiment, wavelength is calculated using

$\lambda = \frac{Xd}{D}$ and $d = \sqrt{d_1 d_2}$.

Diffraction of light:

- A single slit of width '*a*' gives a diffraction pattern with a central maximum. The intensity reduces to zero at sinθ =$\pm\frac{\lambda}{a}, \pm\frac{2\lambda}{a}$ *etc.* with successively weaker secondary maxima in between.
- **Central Maximum** – The waves from points equidistant from the centre C lying on the upper and lower half reach point O with zero path difference and hence, reinforce each other producing maximum intensity at point O.
- Position of secondary maxima,

$$y'_n = \frac{\left(2n+1\right)D\lambda}{2a}$$

- Position of secondary minima,

$$y_n = \frac{nD\lambda}{a}$$

- Width of secondary maxima,

  $\beta = \frac{D\lambda}{a}$

- Width of secondary minima,

  $\beta' = \frac{D\lambda}{a}$

- Diffraction limits the angular resolution of a telescope to $\frac{\lambda}{D}$, where *D* is the diameter. Two stars closer than this give strongly overlapping images. Similarly, a microscope objective subtending angle 2*b* at the focus, in a medium of refractive index *n*, will just separate two objects spaced at a distance $\frac{\lambda}{2n\sin\beta}$, which is the resolution limit of a microscope.

- A beam of width *a* travels a distance $\frac{a^2}{\lambda} called the Fresnel distance$, before it starts to spread out due to diffraction.
- Diffraction may be classified into two types: Fraunhofer diffraction and Fresnel diffraction.
- According to Rayleigh's Criterion , the image of two point objects are regarded as resolved if the central maximum of one falls on the first minimum of the other.
- Interference patterns are due to the interaction of light from two different wavefronts of two coherent sources, but diffraction pattern is due to the interaction of light coming from different parts of the same wavefront .
- Differences between interference and diffraction :
  - In an interference pattern, all the bright fringes have same intensity. In a diffraction pattern, all the bright fringes are not of the same intensity.
  - In an interference pattern, the dark fringe has zero or very small intensity, and the bright and dark fringes can easily be distinguished. In diffraction, all the dark fringes are not of zero intensity.
  - In intereference, the widths of all the fringes are almost same. In diffraction, fringes are of different widths.

- **Polarisation of light:** The phenomenon of restriction of the vibration of light $electric vector$ in a direction perpendicular to the direction of wave motion, is called polarisation of light. A tourmaline crystal acts as a polariser.

- **Polarisation by reflection**
  - An ordinary beam of light, on reflection from a transparent medium, becomes partially polarised. The degree of polarisation increases as the angle of incidence is increased.
  - At a particular value of angle of incidence, the reflected beam becomes completely polarised. This angle of incidence is called the polarising angle (*p*).

- **Polaroid**

- It is a large sheet of synthetic material packed with tiny crystals of a dichoric substance, oriented parallel to one another.
- It is capable of blocking one of the two planes of vibration of an electromagnetic wave.
- It absorbs the electric field vectors of an electromagnetic wave passing through it.
- When light is passed through a polaroid, it becomes linearly polarised.

- **Uses of polaroid**
    - In three dimensional movie cameras
    - In production and analysis of plane polarised light
    - In the windows of aeroplanes to control the amount of light.
    - In polarising sunglasses to protect the eyes from sunlight.
    - In improving the colour contrast in old oil paintings
- **Brewster's Law**
    - When light is incident at the polarising angle at the interface of a refracting medium, the refractive index of the medium is equal to the tangent of the polarising angle, that is, $\mu = \tan p$.

Law of Malus

When a beam of completely plane polarised light is incident on the analyser, the resultant intensity of light varies directly as the square of the cosine of the angle between the plane of transmission of the analyser and polariser.

That is, $I \propto \cos^2\theta$