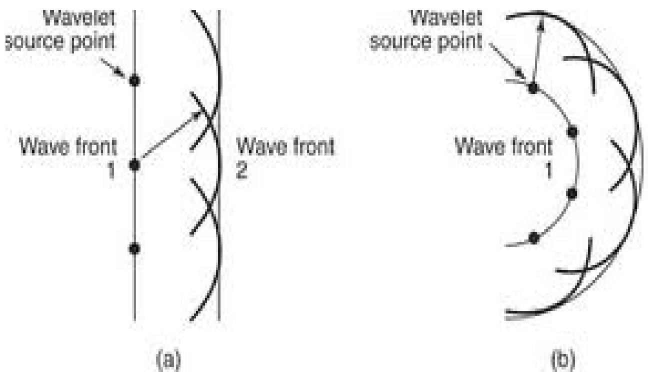
Wave Optics

- A wavefront is defined as a surface of constant phase.
- Huygens' principle tells us that each point on a wavefront is a sourceof secondary waves, which add up to give the wavefront at a later time.

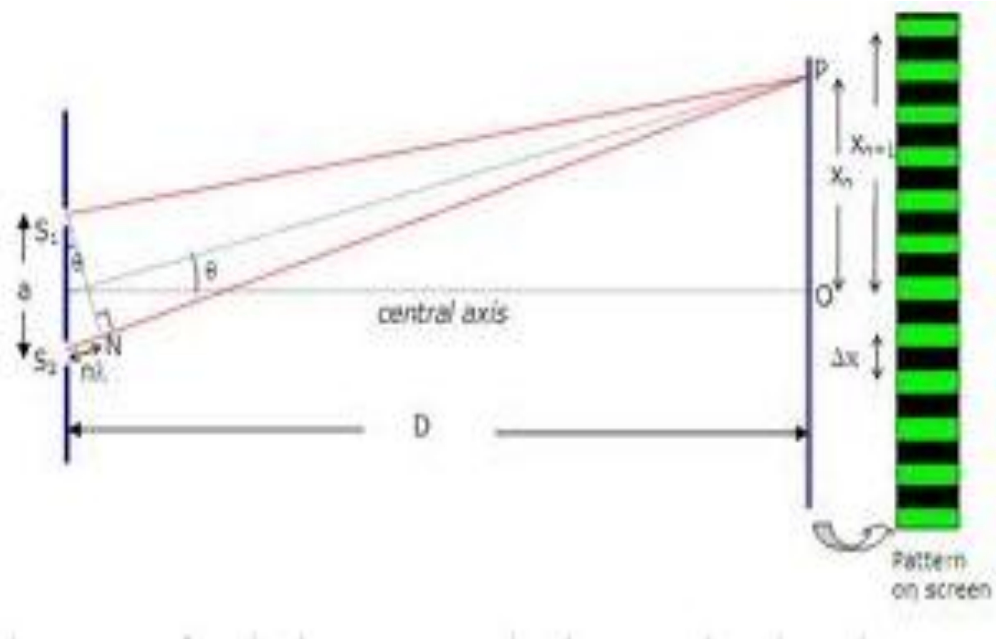


- Huygens' construction tells us that the new wavefront is the forwardenvelope of the secondary waves. When the speed of light isindependent of direction, the secondary waves are spherical. The raysare then perpendicular to both the wavefronts and the time of travelis the same measured along any ray. This principle leads to the wellknown laws of reflection and refraction.

- **DopplerEffect**
  - When the source moves away from the observer the frequency as measured by the source will be smaller. This is known asthe *Doppler effect*.
  - The fractional change in frequency $\Delta\nu/\nu$ is given by $-v_{radial}/c$, where v_{radial} is the component of the source velocity along the line joining the observer to the source relative to the observer; v_{radial} is considered positive when the source moves away from the observer.

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

- Young's double slit of separation d gives equally spaced fringes ofangular separation λ/d. The source, mid-point of the slits, and centralbright fringe lie in a straight line. An extended source will destroythe fringes if it subtends angle more than λ/d at the slits.



- A single slit of width a gives a diffraction pattern with a centralmaximum. The intensity falls to zero at angles of ± λ/a, ± 2λ/a..etc..with successively weaker secondary maxima in between. Diffractionlimits the angular resolution of a telescope to λ/D where D is thediameter. Two stars closer than this give strongly overlapping images.Similarly, a microscope objective subtending angle 2β at the focus,in a medium of refractive index n, will just separate two objects spacedat a distance $\lambda/(2n \sin \beta)$, which is the resolution limit of amicroscope. Diffraction determines the limitations of the concept oflight rays. A beam of width a travels a distance a^2/λ, called the Fresneldistance, before it starts to spread out due to diffraction.

- Natural light, e.g., from the sun is unpolarised. This means the electricvector takes all possible directions in the transverse plane, rapidlyand randomly, during a measurement. A polaroid transmits only onecomponent (parallel to a special axis). The resulting light is calledlinearly polarised or plane polarised. When this kind of light is viewedthrough a second polaroid whose axis turns through 2π, two maximaand minima of intensity are seen. Polarised light can also be producedby reflection at a special angle (called the Brewster angle) and byscattering through π/2 in the earth’s atmosphere.

Sample Examples

- What speed should a galaxy move with respectto us so that the sodium line at 589.0 nm is observedat 589.6 nm?

  Solution

  Since $\nu\lambda = c$,

  $\Delta\nu/\nu = -(\Delta\lambda/\lambda)$

  $\Delta\lambda = 589.6 - 589.0 = +0.6$ nm

  $\Delta\nu/\nu = -(\Delta\lambda/\lambda) = -(v_{radial}/c)$

  $= c(0.6/589) = 306$ km/s

  $v_{radial} = 306$ km/s

- What is the effect on the interference fringes in aYoung's double-slit experiment due to each of the following operations:

  (a) The screen is moved away from the plane of the slits;

  (b) The (monochromatic) source is replaced by another(monochromatic) source of shorter wavelength;

  (c) The separation between the two slits is increased;

  (d) The source slit is moved closer to the double-slit plane;

  (e) The width of the source slit is increased;

  (f)The monochromatic source is replaced by a source of whitelight?

  Solution

  (a)Angular separation of the fringes remains constant(= λ/d). The actual separation of the fringes increases in proportion to the distance of the screen from the plane of thetwo slits.

  (b) The separation of the fringes (and also angular separation)decreases. See, however, the condition mentioned in (d) below.

(c) The separation of the fringes (and also angular separation)decreases. See, however, the condition mentioned in (d) below.

(d) Let *s*be the size of the source and *S* its distance from the plane ofthe two slits. For interference fringes to be seen, the condition$s/S < \lambda/d$ should be satisfied; otherwise, interference patternsproduced by different parts of the source overlap and no fringesare seen. Thus, as *S* decreases (i.e., the source slit is broughtcloser), the interference pattern gets less and less sharp, andwhen the source is brought too close for this condition to be valid,the fringes disappear. Till this happens, the fringe separationremains fixed.

(e)Same as in (d). As the source slit width increases, fringe patterngets less and less sharp. When the source slit is so wide that thecondition $s/S \leq \lambda/d$ is not satisfied, the interference patterndisappears.

(f) The interference patterns due to different component colours ofwhite light overlap (incoherently). The central bright fringes fordifferent colours are at the same position. Therefore, the centralfringe is white. For a point P for which $S_2P - S_1P = \lambda b/2$, where λb(≈ 4000 Å) represents the wavelength for the blue colour, the blue component will be absent and the fringe will appear red in colour.Slightly farther away where $S_2Q - S_1Q = \lambda b = \lambda r/2$ where λr (≈ 8000 Å)is the wavelength for the red colour, the fringe will be predominantly blue.Thus, the fringe closest on either side of the central white fringeis red and the farthest will appear blue. After a few fringes, noclear fringe pattern is seen.