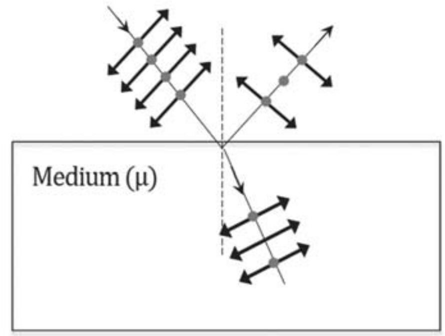
POLARISATION BY REFLECTION AND SCATTERING, BREWSTER LAW AND HUYGENS PRINCIPLE

Polarisation by reflection

The electric field associated with an unpolarised light can be divided in two mutually perpendicular directions:

- Along the incidence plane (the plane of the paper) which is shown by the arrow in the above figure.
- Along the perpendicular direction to the incidence plane which is shown by the blue dot in the figure



In this scenario, the incoming light isn't polarized. When it reflects, more vibrations occur perpendicular to the surface it hits, while when it refracts, more vibrations happen parallel to that surface. Therefore, both the reflected and refracted light become partially polarized. Additionally, the amount of polarization in reflected light shifts as we change the angle of incidence i.

In this situation, the incoming light isn't polarized. Here's what we observe:

- When it reflects, more vibrations occur perpendicular to the surface it hits (or parallel to the reflecting surface). Meanwhile, when it refracts, more vibrations happen parallel to the surface it hits (or perpendicular to the reflecting surface). So, both the reflected and refracted light become partially polarized.
- The amount of polarization in reflected light shifts as we change the angle it hits the surface. At a particular angle, the reflected light becomes completely polarized.

Brewster Law

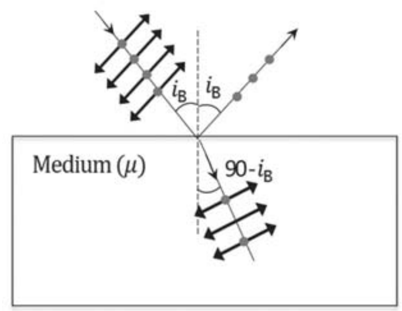
For a particular angle of incidence (B), the reflected light becomes completely plane polarized.

The reflected light has vibration only perpendicular to the plane of incidence for the angle of incidence (i_B).

The required condition for this purpose is

The angle between the reflected ray and refracted ray should be 90°, or in other words, $i_B + r = 90°$.

From Snell's law,



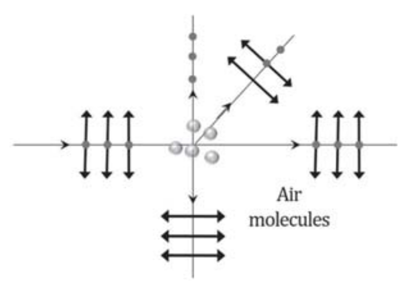
$$1 \times \sin i = \mu \times \sin r \xrightarrow[r=90°-i_B]{i=i_B} \sin i_B = \mu \cdot \text{Sin}(90 - i_B) \Rightarrow \tan i_B = \mu$$

Where, i_B = Brewster angle and μ = Refractive index of medium

If the light ray travels from a medium of R.I. n_1 to another medium of R.I. n_2, then Brewster's law becomes,.

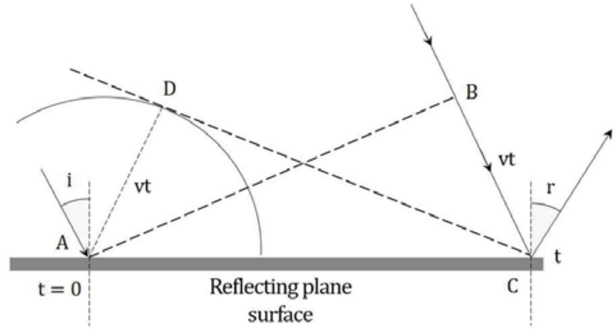
Polarisation by Scattering

- No polarization parallel to original direction of incident light.
- Light perpendicular to original ray is completely plane polarized.



Huygens Principle- Reflection, Refraction and Doppler effect

Reflection of Light



- Let the light from infinity falls on the reflecting surface A. Thus, the wavefront will be planar and one of these incident planar wavefront is shown by AB.
- If the velocity of light in the medium is v and the time elapsed for a point on the wavefront to go from point B to point C is t, then, $BC = vt$.
- The 'A' end of the wavefront already touches the reflecting surface when the 'B' end is vt distance away from the reflecting surface. Thus, point A will act as the source of secondary wavelets and in time t, it will generate secondary wavelets of radius vt and the wavefront at this instant will be CD. The wavefront CD is the reflected wavefront at time t
- The angle of incidence, $\angle NAP =$. Let the angle of reflection is, $\angle NAD = r$.
- Since AN is the normal to the reflecting surface, $\angle NAC = 90°$. We have: $\angle NAD =$. Thus, $\angle DAC = \angle NAC - \angle NAD = 90° -$ r
- Since reflected ray and the reflected wavefront CD is perpendicular to each other, $\angle ADC = 90°$.
- Now, CN' is also the normal to the reflecting surface at point C. Thus, $\angle N'CA = 90°$ and the angle of incidence at point C, $\angle BCN' = i$. Thus, $\angle BCA = \angle N'CA - \angle BCN' = 90° - i$
- For triangle ΔADC and ΔABC,

  $AD = vt = B$

  $\angle ADC = \angle ABC = 90°$

  The side AC is common for both the triangles. Thus, these two triangles are congruent of each other.

  Therefore, we can say that:

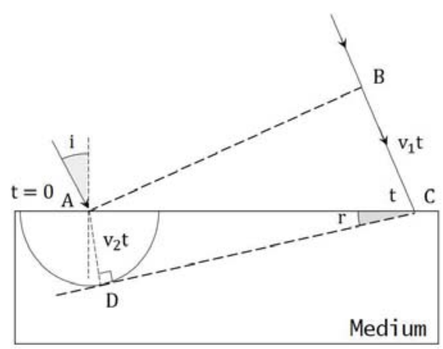
  $\angle BCA = \angle DA$C

  $90° - i = 90° - r$

  $\angle i = \angle$r

  This proves the law of reflection of light.

Refraction of Light



- Let the light from infinity falls on the refracting surface AC. Thus, the wavefront will be planar and one of these incident planar wavefront is shown by AB.
- If the velocity of light in the rarer medium is v_1 and the time elapsed for a point on the wavefront to go from point B to point C is t, then, $BC = v_1t$.
- The 'A' end of the wavefront already touches the refracting surface when the 'B' end is v_1t distance away from the refracting surface. Thus, point A will act as the source of secondary wavelets. If the velocity of light in the denser medium is v_2, then in time t, it will generate secondary wavelets of radius $AD = v_2t$ and the wavefront at this instant will be C. The wavefront CD is the refracted wavefront at time t.
- Let NAN' is the normal on the refracting surface at point . Thus, $\angle N'AC = 90°$. We also assume that the angle of refraction is, $\angle N'AD = r$. Hence, $\angle DAC = 90° - r$.
- Let $N''C$ is the normal on the refracting surface at point . Thus, $\angle N''CA = 90°$. We also assume that the angle of incidence at point C is, $\angle N''CB = i$. Hence, $\angle BCA = 90° - i$.
- For triangle ΔABC:

$$\frac{BC}{AC} = \text{Cos}(90 - i) \Rightarrow \sin i = \frac{v_1 t}{AC} \quad .... (1)$$

- For triangle ΔACD:

$$\frac{AD}{AC} = \text{Cos}(90 - r) \Rightarrow \text{Sin}\, r = \frac{v_2 t}{AC} \quad ....(2)$$

- Dividing equation 1 by equation 2, we get,

$$\frac{\text{Sin } i}{\text{Sin } r} = \frac{v_1}{v_2}$$

- We also know that, $v_1 = \frac{c}{n_1}$ and $v_2 = \frac{c}{n_2}$.

Thus, we can write,

$$\frac{\text{Sin } i}{\text{Sin } r} = \frac{v_1}{v_2}$$

$$n \sin i = n_2 \text{ Sinr}$$

Doppler Effect

From our understanding of the Doppler effect in sound waves, we know that when a sound source and a listener are moving relative to each other, the frequency of the sound heard by the listener isn't the same as the frequency of the source. Instead, the perceived frequency is determined by,

$$f' = \frac{v \pm u_o}{v \pm u_s} f$$

f = frequency of stationary source

v = speed of sound in air

u_o = speed of the observer

u_s = speed of the source

When the source and the observer relatively comes closer, the apparent frequency should increase.

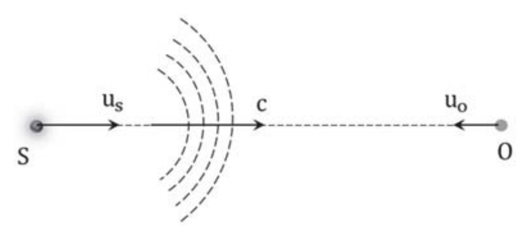
$$f' = \frac{v + u_o}{v - u_c} f$$

When the source and the observer are relatively going away, the apparent frequency should d ecrease.

$$f' = \frac{v - u_o}{v + u_s} f$$

In the case of light waves, when a light source and an observer move closer to each other, the apparent frequency of light observed by the observer changes to:

$$f' = \frac{v+u_o}{v-u_s} f \xrightarrow[\text{In case of light}]{v = c} f' = \frac{c+u_o}{c-u_s} f$$



Therefore, the change in frequency is given by,

$$\Delta f = f' - f = f\left[\frac{c+u_o}{c-u_s} - 1\right] = f\left[\frac{u_o+u_s}{c-u_s}\right]$$

When the speed of the source (u_s) is small compared to that of light (c), the above equation can be written as,

$$\frac{\Delta f}{f} = \frac{v_{radial}}{c}$$

Where, $v_{radial} \to u_o + u_s$ = Relative speed of the source with respect to the observer

When relative speed of the source with respect to the observer i.e., v_{radial} is comparable to the speed of light, then the formula of apparent frequency is given by,

If the source and the observer relatively comes closer, then,

$$f' = f\sqrt{\frac{1+(v/c)}{1-(v/c)}}$$

If the source and the observer are moving away from each other, then,

$$f' = f\sqrt{\frac{1-(v/c)}{1+(v/c)}}$$

Validity of ray optics

- For the experiment of diffraction:
  When the size of the slit is equivalent to its size of image on the screen, i.e., when $d \cong$,it can be said that the ray optics is valid in this case.
  When $d \neq a$ rather the size of slit's image on the screen slit is greater than the size of slit itself i.e., $b > d$, it can be said that the wave optics is valid in this case.
- Consider a diffraction experiment set up having following parameters:
  Wavelength of light used $= \lambda$
  Slit width $= a$
  Distance b/w slit and screen $=$ z
  For diffraction to happen, we should have,
  $$\theta = \frac{\lambda}{a}$$
  Therefore, the width of diffracted beam,
  $$y = z \times \theta = \frac{\lambda z}{a}.$$
- Now, the threshold distance b/w slit and screen, known as "Fresnel's distance", after which diffraction is observed, can be derived as follows:
  $y \approx$ a
  $$z \cdot \frac{\lambda}{a} \approx a \Rightarrow z \approx \frac{a^2}{\lambda} = z_F$$
  Z_F, known as the "Fresnel distance," represents the minimum distance that a light beam must travel before it starts noticeably veering off its straight path. This distance essentially equals the separation between the slit and the screen.
- If $z < z_F$, the ray optics is valid.
- If $z > z_F$, the wave optics is valid and diffraction will be taken place