5 Optics

5.1 Refraction of Light

When considering the effect of lenses or mirrors on the path of light, we draw diagrams using **light rays** and **normals**.

- **Light rays** represent the direction of travel of wavefronts.
- The **normals** is an imaginary line perpendicular to a boundary between two materials or a surface.

Refraction is the change of direction that occur when light **passes at an angle** across a boundary between two **transparent substances**. When entering a glass block from air, the light ray bends

- **Towards the normal** when it passes from air into glass.
- **Away from the normal** when it passes from glass into air.

No refraction takes place if the incident light ray is along the normal.

At a boundary between two transparent substances, the ray bends towards the normal if it passes into a **more dense substance**.

Investigating Refraction by Glass

1. Use a **ray box** to direct a light ray into a **rectangular glass block** at different angles of incident at point P on one of the sides.
2. For each angle of incidence, mark point Q where the light leaves the block.

The **angle of incidence** is the angle between the incident light ray and the **normal** at the point of incident. The **angle of reflection** is the angle between the refracted light ray and the normal at the point of incident.

- The angle of diffraction r is always less than the angle of incident i.
- **Snell's law**: the ratio $\sin i / \sin r$ is the same for each light ray.
  - The ratio is referred to as the **refractive index** n of glass.

$$\text{refractive index of the substance } n = \frac{\sin i}{\sin r}$$

Partial reflection also occur when a light ray in air enters any refractive substance.

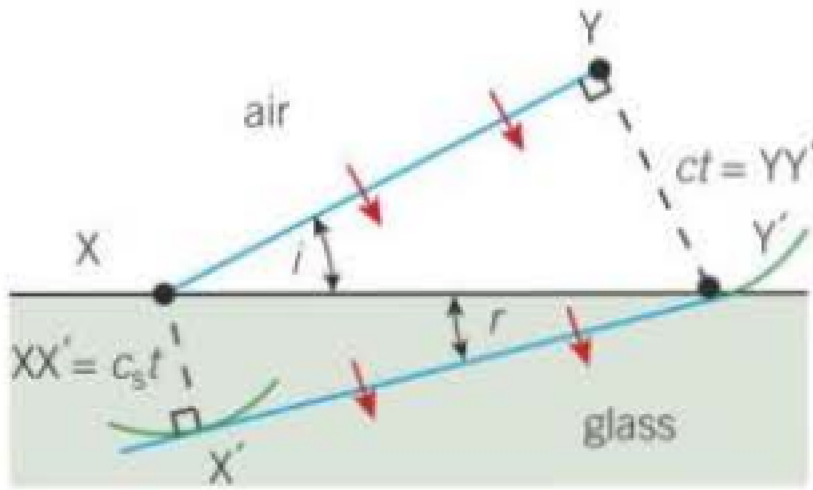
The angle of refraction of the light ray emerging from a rectangular glass block is the same as the **angle of incidence** of the ray entering the block.

- The two side of the block are **parallel to each other**.
- Refractive index when entering the glass is n, when leaving the glass is $1/n$, so the combined effect is $n = 1$.

5.2 More about Refraction

Refraction occurs because the **speed of light waves** is different in each substance. The amount of refraction that takes place depends on the **speed of the waves in each substance**.

Consider a wavefront of light waves when it passes across a **straight boundary** from a vacuum into a transparent substance.



The wave front moves

- A distance ct at speed c in vacuum from Y to Y'.
- A distance $c_s t$ at speed c_s in the substance from X to X'.

This gives us equations

$$\begin{cases} ct & = XY' \sin i \\ c_s t & = XY' \sin r \end{cases}$$

Combining the equations give

$$\frac{\sin i}{\sin r} = \frac{c}{c_s}$$

This shows the **smaller the speed of light** is in a substance, the **greater the refractive index** of the substance.

Since the **frequency does not change** when refraction occurs

$$n_s = \frac{c}{c_s} = \frac{\lambda}{\lambda_s}$$

Refraction at a Boundary between Two Transparent Substances

Consider light crossing a boundary from a substance which the speed of light is c_1 to one that the speed of light is c_2.

$$\begin{aligned}
\frac{\sin i}{\sin r} &= \frac{c_1}{c_2} \\
\frac{1}{c_1}\sin i &= \frac{1}{c_2}\sin r \\
\frac{c}{c_1}\sin i &= \frac{c}{c_2}\sin r \\
n_1 \sin\theta_1 &= n_2 \sin\theta_2
\end{aligned}$$

which is the equation form of **Snell's law**.

Note that the refractive index of air is 1.0003, for most purposes can be assumed to be 1.

White Light Spectrum

A **glass prism** can be used to split a **beam of white light** from a filament lamp into the colours of the spectrum. The dispersion effect occur because the speed of light in glass **depends on wavelength**.

- White light is composed of light with a **continuous range of wavelengths**.
- The shorter the wavelength in air, the greater the amount of diffraction.
- So each colour in the white light beam is **refracted by a different amount**.