Refraction through a Prism

Our Objective:

(i) To study the angle of deviation (d) with angle of incidence (i) and to find the angle of minimum deviation (D) from i-d curve.

(ii) To find the refractive index of the material of the prism using A and D.

The Theory:

Prism

A prism is an optical element. It has polished flat surfaces that refract light. The traditional geometric shape of a prism has a triangular base and two rectangular sides. It is called triangular prism.

A prism can be made from materials like glass, plastic and fluorite. It can be used to split light into its components.

How a Prism Works

When light travels from one medium to another medium, it is refracted and enters the new medium at a different angle. The degree of bending of the light's path depends on the angle that the incident beam of light makes with the surface of the prism, and on the ratio between the refractive indices of the two media. This is called Snell's law.

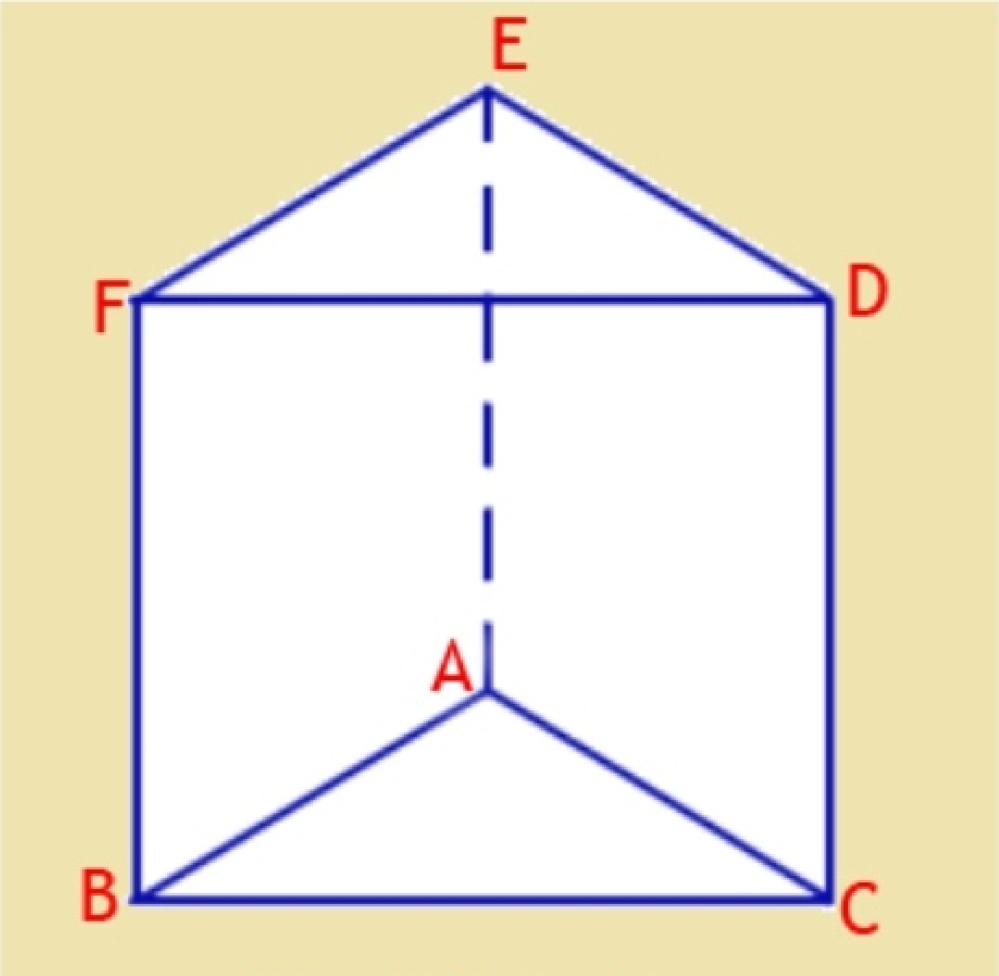
$$i.e, n = \frac{sin\ i}{sin\ r}$$

where, n is the refractive index of the material of the prism.
i is the angle of incidence.
r is the angle of refraction.

The refractive index of many materials varies with the wavelength of the light used. This phenomenon is called dispersion. This causes light of different colors to be refracted differently and to leave the prism at different angles, creating an effect similar to a rainbow. This can be used to separate a beam of white light into its constituent spectrum of colors.

The relation between Refractive Index (n), Angle of Prism (A) and Angle of Minimum Deviation (D)

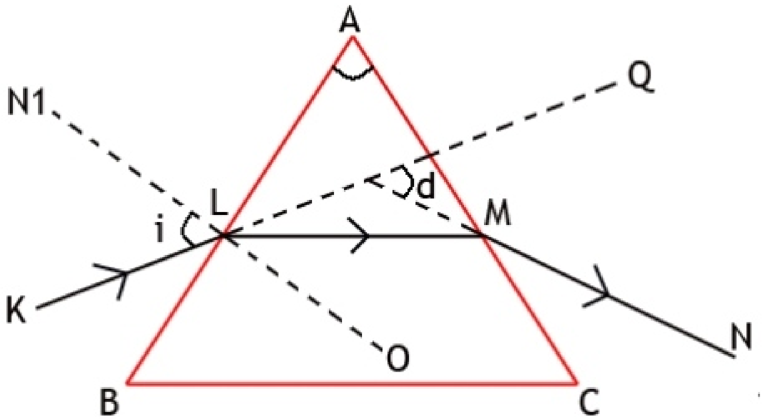
Consider the following triangular prism.



Triangular Prism

The angle A between the two refracting surfaces ABFE and ACDE is called the angle of prism.

A ray of light suffers two refractions on passing through a prism. If KL be a monochromatic light falling on the side AB, it is refracted and travels along LM. It once again suffers refraction at M and emerges out along MN. The angle through which the emergent ray deviates from the direction of incident ray is called angle of deviation 'd'.



As the angle of incidence is increased, angle of deviation 'd' decreases and reaches minimum value. If the angle of incidence is further increased, the angle of deviation is increased.

A graph is drawn between angle of incidence (i) and angle of deviation (d) by taking angle of incidence (i) along X-axis and angle of deviation (d) along Y-axis. It should be a curved graph.

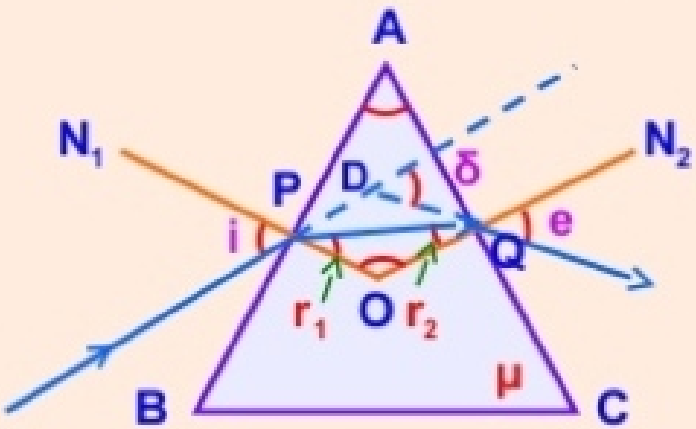
The angle of minimum deviation is obtained from the graph. Let D be the angle of minimum deviation, then the refractive index (n) of the material of the prism is calculated using the formula,

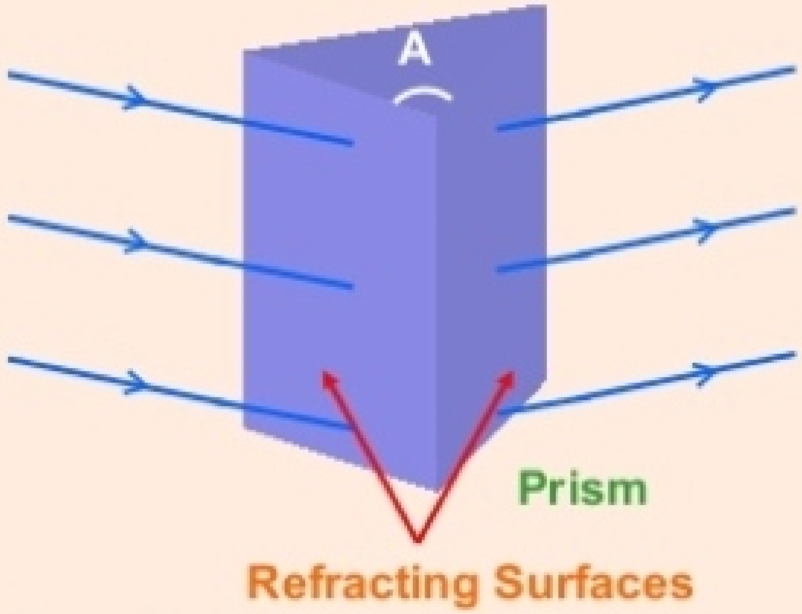
$$n = \frac{sin\frac{(A+D)}{2}}{sin\frac{A}{2}}$$

Learning outcomes:

- Students understand the working of a prism.
- Students will be better able to do the experiment in a real laboratory by understanding the procedure.

Refraction of Light through Prism:





In quadrilateral APOQ,

$A + O = 180°$ ....(1)

(since N_1 and N_2 are normal)

In triangle OPQ,

$r_1 + r_2 + O = 180°$ ....(2)

In triangle DPQ,

$\delta = (i - r_1) + (e - r_2)$

$\delta = (i + e) - (r_1 + r_2)$ ....(3)

From (1) and (2),

$A = r_1 + r_2$

From (3),

$\delta = (i + e) - (A)$

or $\boxed{i + e = A + \delta}$

Sum of angle of incidence and angle of emergence is equal to the sum of angle of prism and angle of deviation.

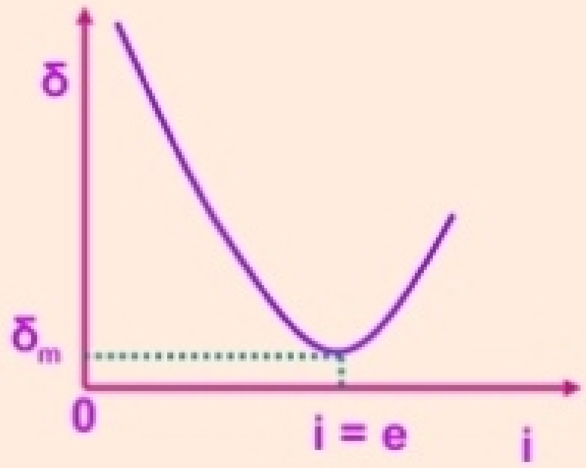
Variation of angle of deviation with angle of incidence:

When angle of incidence increases, the angle of deviation decreases.

At a particular value of angle of incidence the angle of deviation becomes minimum and is called 'angle of minimum deviation'.

At δ_m, $i = e$ and $r_1 = r_2 = r$ (say)

After minimum deviation, angle of deviation increases with angle of incidence.



Refractive Index of Material of Prism:

$A = r_1 + r_2$

$A = 2r$

$r = A / 2$

$i + e = A + \delta$

$2i = A + \delta_m$

$i = (A + \delta_m) / 2$

According to Snell's law,

$$\mu = \frac{\sin i}{\sin r_1} = \frac{\sin i}{\sin r}$$

$$\therefore \quad \mu = \frac{\sin \frac{(A + \delta_m)}{2}}{\sin \frac{A}{2}}$$

Refraction by a Small-angled Prism for Small angle of Incidence:

$$\mu = \frac{\sin i}{\sin r_1} \quad \text{and} \quad \mu = \frac{\sin e}{\sin r_2}$$

If i is assumed to be small, then r_1, r_2 and e will also be very small.
So, replacing sines of the angles by angles themselves, we get

$$\mu = \frac{i}{r_1} \quad \text{and} \quad \mu = \frac{e}{r_2}$$

$$i + e = \mu (r_1 + r_2) = \mu A$$

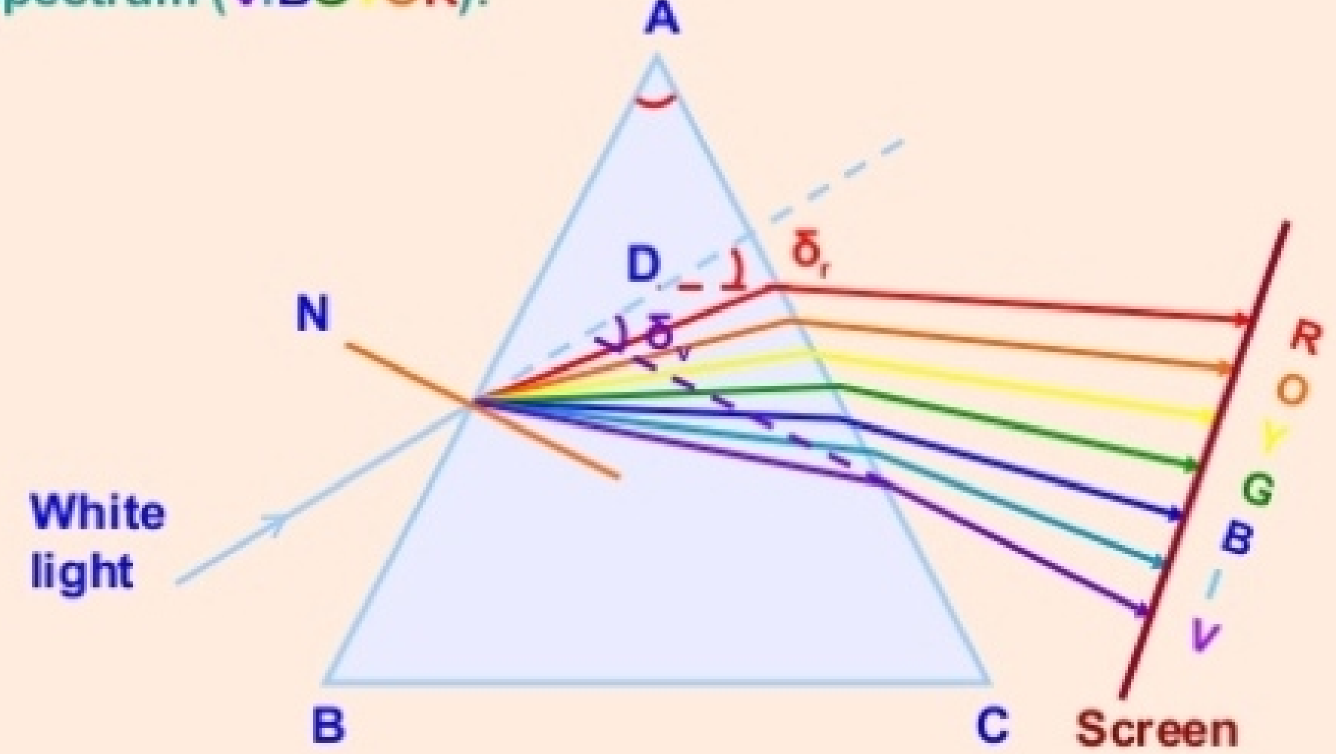
But $i + e = A + \delta$

So, $A + \delta = \mu A$

or $\boxed{\delta = A (\mu - 1)}$

Dispersion of White Light through Prism:

The phenomenon of splitting a ray of white light into its constituent colours (wavelengths) is called dispersion and the band of colours from violet to red is called spectrum (VIBGYOR).



Cause of Dispersion:

$$\mu_v = \frac{\sin i}{\sin r_v} \quad \text{and} \quad \mu_r = \frac{\sin i}{\sin r_r}$$

Since $\mu_v > \mu_r$, $r_r > r_v$

So, the colours are refracted at different angles and hence get separated.

Dispersion can also be explained on the basis of Cauchy's equation.

$$\mu = a + \frac{b}{\lambda^2} + \frac{c}{\lambda^4}$$ (where a, b and c are constants for the material)

Since $\lambda_v < \lambda_r$, $\mu_v > \mu_r$

But $\delta = A(\mu - 1)$

Therefore, $\delta_v > \delta_r$

So, the colours get separated with different angles of deviation.
Violet is most deviated and Red is least deviated.

Angular Dispersion:

1. The difference in the deviations suffered by two colours in passing through a prism gives the angular dispersion for those colours.
2. The angle between the emergent rays of any two colours is called angular dispersion between those colours.
3. It is the rate of change of angle of deviation with wavelength. ($\Phi = d\delta / d\lambda$)

$\Phi = \delta_v - \delta_r$ or $\Phi = (\mu_v - \mu_r) A$

Dispersive Power:

The dispersive power of the material of a prism for any two colours is defined as the ratio of the angular dispersion for those two colours to the mean deviation produced by the prism.

It may also be defined as dispersion per unit deviation.

$$\omega = \frac{\Phi}{\delta}$$ where δ is the mean deviation and $$\delta = \frac{\delta_v + \delta_r}{2}$$

Also $$\omega = \frac{\delta_v - \delta_r}{\delta}$$ or $$\omega = \frac{(\mu_v - \mu_r) A}{(\mu_y - 1) A}$$ or $$\omega = \frac{(\mu_v - \mu_r)}{(\mu_y - 1)}$$

Scattering of Light – Blue colour of the sky and Reddish appearance of the Sun at Sun-rise and Sun-set:

The molecules of the atmosphere and other particles that are smaller than the longest wavelength of visible light are more effective in scattering light of shorter wavelengths than light of longer wavelengths. The amount of scattering is inversely proportional to the fourth power of the wavelength. (Rayleigh Effect)

Light from the Sun near the horizon passes through a greater distance in the Earth's atmosphere than does the light received when the Sun is overhead. The correspondingly greater scattering of short wavelengths accounts for the reddish appearance of the Sun at rising and at setting.

When looking at the sky in a direction away from the Sun, we receive scattered sunlight in which short wavelengths predominate giving the sky its characteristic bluish colour.