Refraction Through A Prism

Objectives

After going through this module, the learners will be able to:

- Distinguish between refraction through a rectangular glass slab and a glass prism
- Understand the terms related to refraction through a prism
- Derive an expression relating refractive index and angle of minimum deviation
- Find the refractive index of the material of the prism by plotting I - d graph
- Explain dispersion of polychromatic light

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Refraction through a prism,
- Relation between angle of incidence, angle of emergence, angle of prism and angle of deviation OR i + e = A+ **δ**
- Angle of minimum deviation
- Determine the Angle of minimum deviation for a given prism by plotting a graph between angle of incidence and angle of deviation
- Dispersion and spectrum
- Summary

Unit Syllabus

UNIT 6: Optics

Chapter–9: Ray Optics and Optical Instruments

Ray optics Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical; fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification, power of a lens; combination of thin lenses in

contact; refraction and dispersion of light through a prism.

Scattering of light – blue color of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Chapter 10 Wave Optics

Wave optics: wavefront and Huygens's principle, reflection and refraction of plane waves at a plane surface using wave fronts. proof of laws of reflection and refraction using Huygens's principle. Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope. Polarisation, plane polarised light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

Module Wise Distribution Of Unit Syllabus 15 Modules

Module 1	● Introduction ● How we will study optics-plan ● Light facts ● Ray optics, beams ● Light falling on surfaces of any shape texture ● Peculiar observations
Module 2	● Reflection of light ● Laws of reflection ● Reflection of light by plane and spherical surfaces ● Spherical Mirrors aperture, radius of curvature, pole principal axis ● Focus, Focal length, focal plane ● Image – real and virtual ● Sign convention ● The mirror equation, magnification ● To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror ● Application of mirror formula
Module 3	● Refraction of light ● Optical density and mass density ● Incident ray, refracted ray emergent ray

	● Angle of incidence, angle of refraction angle of emergence To study the effect on intensity of light emerging through different colored transparent sheets using an LDR ● Refractive index ● Oblique incidence of light, Snell's law ● Refraction through a parallel sided slab Lateral displacement, factors affecting lateral displacement ● To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab ● Formation of image in a glass slab
Module 4	● Special effects due to refraction ● Real and apparent depth ● To determine the refractive index of a liquid using travelling microscope ● Total internal reflection ● Optical fibers and other applications
Module 5	● Refraction through a prism ● Deviation of light -angle of deviation ● Angle of minimum deviation ● Expression relating refractive index for material of the prism and angle of minimum deviation ● To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation ● Dispersion, spectrum
Module 6	● Refraction at spherical surfaces ● Radius of curvature ● Refraction by a lens ● Foci, focal plane, focal length, optical center, principal axis ● Formation of images real and virtual ● Lens maker's formula

	• Lens formula and magnification • Sign convention • Application of lens formula • Power of lens • Combination of thin lenses in contact

Module 7	• To study the nature and size of image formed by a
	    ○ convex lens
	    ○ concave mirror using a candle and a screen
	• To determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v
	• To determine the focal length of a convex mirror using a convex lens
	• To find the focal length of a concave lens using a convex lens
	• To find the refractive index of a liquid by using a convex lens and a plane mirror

Module 8	• Scattering of light – • blue color of sky • reddish appearance of the sun at sunrise and sunset • dust haze
Module 9	• optical instruments • human eye • microscope • astronomical telescopes reflecting and refracting • magnification • making your own telescope
Module 10	• wave optics • wave front • Huygens's principle shapes of wave front • plane wave front • Refraction and reflection of plane wavefront using Huygens's principle

	• Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light • Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or colored fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

MODULE 5

Words You Must Know

Let us remember the words and the concepts we have been using in the study of this module:

- **Light:** Light is a form of energy which gives the sensation of vision when it falls on the retina of the eye.
- **Ray of light:** The straight line path along which light travels is called a ray of light. Light rays start from each point of a source and travel along a straight line until they strike an object or a surface separating two media.
- **Beam of light:** A group of rays of light is called a beam of light.
- **Parallel beam of light**: If all the rays of light in the group are parallel to each other then the beam is said to be a parallel beam of light.
- **Converging beam of light**: If the rays of light in the group come closer to each other i.e. converge to a point, then the beam is said to be a converging beam of light.
- **Diverging beam of light**: If the rays of light in the group move away from each other i.e. diverge, then the beam is said to be a diverging beam of light.
- **Transparent medium:** A medium through which light can pass freely over a large distance is called a transparent medium. Glass and still water are some examples of transparent objects.
- **Opaque medium:** A medium through which light cannot pass is called an opaque medium. Wood and metals are some examples of opaque objects.
- **Real image:** If the rays of light after reflection from a mirror actually meet at a point i. e. the reflected beam is a converging beam, then the image is said to be a real image.
- **Virtual image:** If the rays of light after reflection from a mirror do not actually meet at a point but meet on producing backwards i.e. the reflected beam is a diverging beam, then the image is said to be a virtual image.
- **Refractive index**: n = speed of light in vacuum / speed of light in the medium
- **Relative refractive index:** Consider light going from medium 1 to medium 2

  Then refractive index of medium 2 with respect to medium 1 is

  $$n_{21} = (n_2/n_1) = v_1 / v_2$$
- **Laws of refraction of light**
  - The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.
  - The ratio of sine of the angle of incidence **i** to the sine of the angle of refraction ***r**, for two media* is constant for a given wavelength of light and is equal to the refractive index of the second medium with respect to the first medium.

- **Critical angle: -** That angle of incidence in denser medium for which the refracted ray just grazes the interface of two media is called the critical angle
- **Total internal reflection: -**

  The phenomenon in which a ray of light travelling from a denser medium to rarer medium at an angle of incidence greater than critical angle is totally reflected back into the same medium is called total internal reflection.
- **Conditions for total internal reflection:**
  - Light must travel from optically denser medium to optically rarer medium.
  - Angle of incidence must be more than critical angle
- **Relation between refractive index and critical angle:**

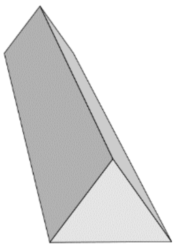
$$n = \frac{1}{\sin i_c}$$

- **Monochromatic light:** Light of single colour or wavelength example sodium light
- **Polychromatic:** Light of multiple colours or wavelengths example white light

Introduction

We have seen that when a ray of light passes through a rectangular glass slab, the emergent ray is parallel to the incident ray but laterally displaced.

The above was a special case of denser medium bounded between parallel sides with uniform optical density.In real life we may have the denser medium enclosed within a geometrical boundary or and irregular boundary.



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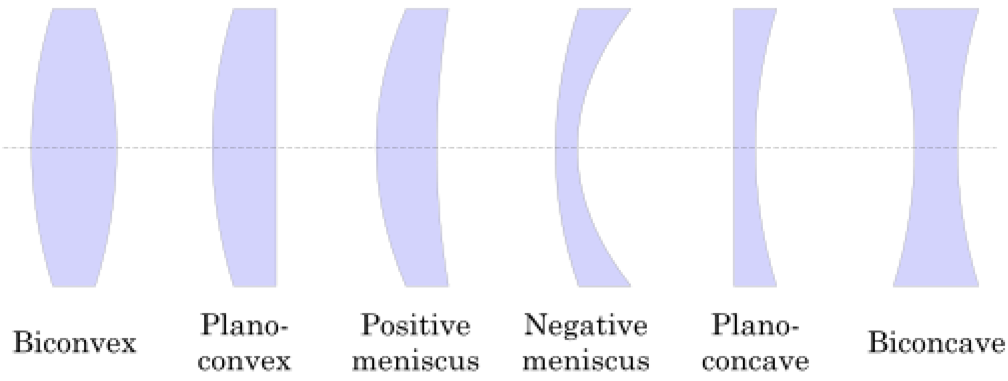

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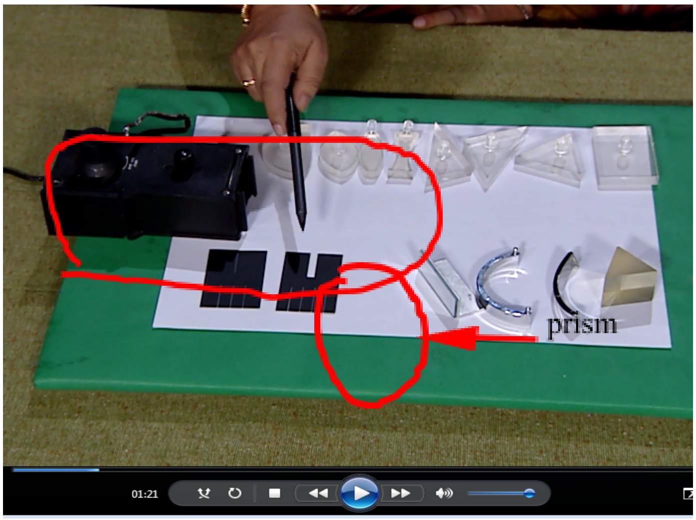
water drop on a leaf

Now let us see the passage of a ray of light through a piece of transparent medium whose refracting surfaces are not parallel to each other, like a glass prism.

So we are considering a geometrical shape where the refracting surfaces are at an angle.



Watch video light box

Also we see objects of different colours around us.

https://c.pxhere.com/photos/42/37/gardens_trees_autumn_pink_red_fall_leaves_green-1141586.jpg!d

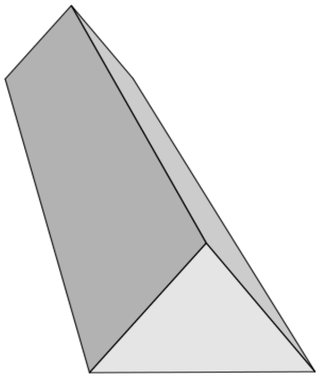
In a garden, leaves are seen as green but some flowers are red, some pink, some violet in the sunlight.

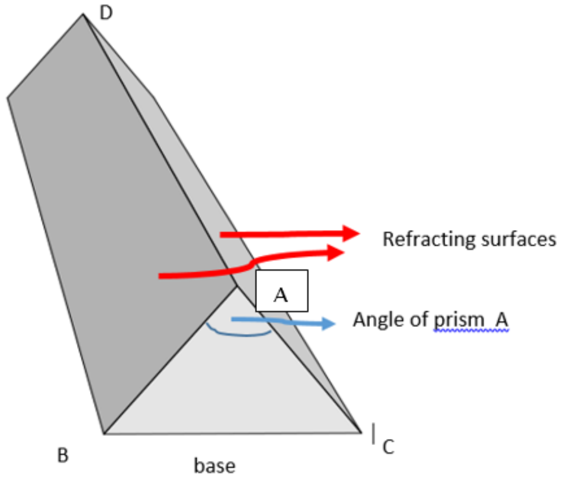
We know that the colour we see depends upon the colour of light entering our eyes from an object or a source of light. In the garden the source of light is Sun, light from the sun as seen appears white. Now let us see, is the sunlight actually white? For that let us study what happens to light when it passes through a piece of transparent medium whose refracting surfaces are not parallel to each other.

Refraction Through A Glass (Transparent Solid Material, Could be Plastic) Prism

Some terms related to a prism

- Prism: A prism is a portion of transparent medium bounded by three plane surfaces inclined to each other at a suitable angle.
- Two plane faces which are inclined to each other are called the **refracting surfaces of the prism**.

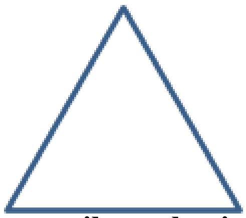




Refracting edge AD

- **Angle of prism:** The angle between the two refracting surfaces i.e. the angle A is called the angle of prism, the value of angle of prism is 60^0 for an equilateral prism.

- **Base of prism:** The third plane surface BCFE of the prism which is opposite to the refracting edge is called the base of the prism.



An equilateral prism

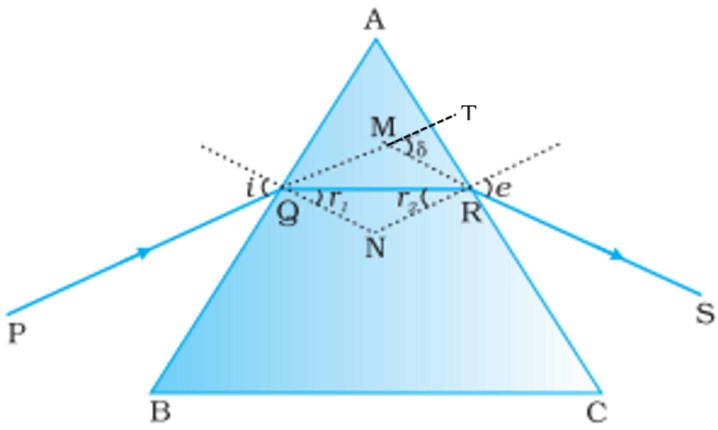
- **Principal section of the prism:** - Any section cut by a plane perpendicular to the refracting edge AD is called its **Principal section.** ABC is the Principal section of the prism.

You may watch

https://www.youtube.com/watch?v=0QyHGM1GMcE

Path of a Monochromatic Ray of Light Through a Prism

- Let ABC be the principal section of prism.
- A ray PQ is incident on the face AB of the prism.
- As light is going from a rarer medium to a denser medium, it will bend towards the normal and go along the path QR.
- The ray QR suffers another deviation at the face AC.
- As now it is going from a denser medium to a rarer medium, so it moves away from the normal and goes along RS.
- We see that the emergent ray here is not parallel to the incident ray, rather it is inclined to the incident ray. The incident ray has finally bent somewhat towards the base of the prism.



Passage of ray PQ through the prism, PQRS.

Let i and r be the angles of incidence and refraction respectively at the face AB.

Let r' and i' be the angle of incidence and refraction respectively at the face AC.

Produce RS backward to meet the produced PQ at M.

The angle between the incident ray and the emergent ray i.e. the angle TMS is the angle of deviation (δ).

Relation Between Angle of Incidence, Angle of Emergence, Angle of Prism and Angle of Deviation

OR to show that $i + e = A + \delta$

Let ABC be the principal section of prism. A ray PQ is incident on the face AB of the prism. As light is going from a rarer medium to a denser medium, it will bend towards the normal and go along the path QR. The ray QR suffers another deviation at the face AC. As now it is going from a denser medium to a rarer medium, so it moves away from the normal and goes along RS. We see that the emergent ray here is not parallel to the incident ray, rather it is inclined to the incident ray. The incident ray has finally bent somewhat towards the base of the prism.

In the triangle QNR

introduce the symbol for angle at all places

$r_1 + r_2 + \angle QNR = 180^0$

In quadrilateral AQNR

$A + \angle QNR = 180^0$

Thus A = $r_1 + r_2$

In triangle MQR

The angle of deviation = $\delta = \angle MQR + \angle MRQ$

$\delta = \left(i - r_1\right) + \left(e - r_2\right)$= deviation at the first face + the deviation at the second face

Or, $\delta = (i + e) - \left(r_1 + r_2\right)$

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

Or **A + δ = i + e**

Thus, when a ray of light passes through a prism the sum of the angle of the prism and angle of deviation is equal to the sum of the angle of incidence and the angle of emergence.

The angle of deviation depends upon

- The angle of incidence
- The angle of the prism
- The material of the prism
- The wavelength of light.

Example: Show that for a light ray to pass through a 60° prism of glass, the angle of incidence shout not be less than 30°.

Solution: Let i and r be the angles of incidence and refraction respectively at the first refracting surface of the prism and r' the angle of incidence at the second surface. By Snell's law, we have

$n = \frac{\sin i}{\sin r}$

If light is incident at 30° (i = 30°), then

$\sin r = \frac{\sin i}{n} = \frac{\sin 30^\circ}{1.5} = \frac{0.5}{1.5} = 0.33$

$r = 0.33 = 19^\circ$

Or

Now $r + r' = A$ (angle of prism)

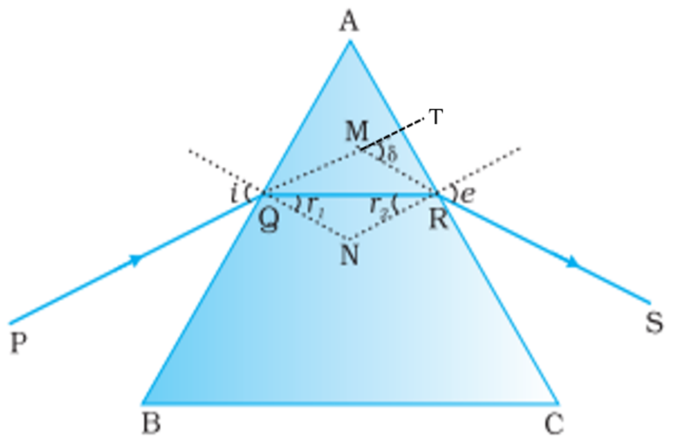
$r' = A - r = 60^\circ - 19^\circ = 41^\circ$

The light is incident at the second surface of prism at 41° which is just a little less than the critical angle 42° for a glass-air interface.

If i becomes less than 30°, then r' will become greater than the critical angle and the light ray will be totally reflected at the second surface, it will not pass out through the prism.

The Angle of Minimum Deviation

The path of a monochromatic ray of light is shown in the figure. We know that for a given prism and a given colour of light, the angle of deviation depends upon the angle of incidence only. As angle i increases, the angle of deviation **δ**, first decreases and reaches a minimum value δ_m and then increases.

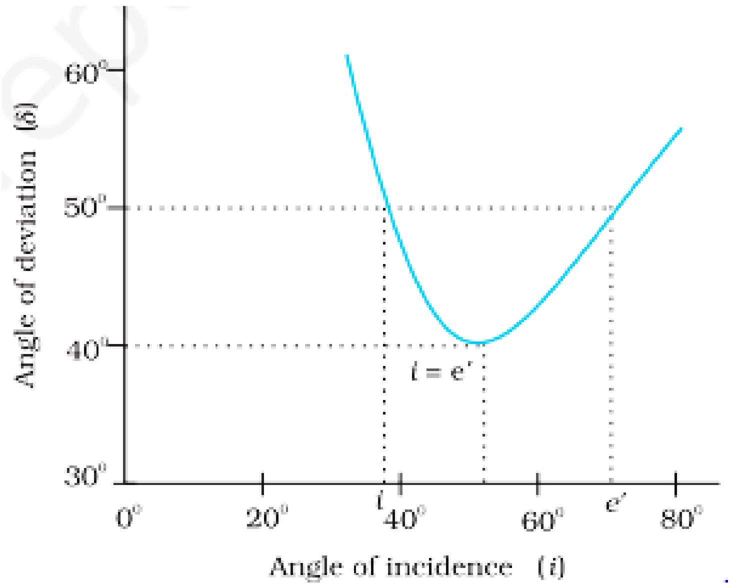


We know that

$\delta = i + e - A$

If the values of i and e are interchanged, the value of **δ** remains the same. Thus any value of **δ** corresponds to the two values of angle of incidence i and e.

A plot between the angle of incidence and the angle of deviation is shown below.



We see that for a given value of δ, except for i = e, there are two values of i and hence also of e.

Thus at minimum deviation δ_m, the refracted ray inside the prism becomes parallel to the base of the prism or we can say that the incident ray and the emergent ray are symmetrically situated w.r.t the prism.

At minimum deviation $\boldsymbol{\delta}_m$

If i = e which means

$r_1 = r_2$

As $\quad r_1 + r_2 = A$, So $r = \frac{A}{2}$

As $\quad \boldsymbol{\delta} = i + e - A$

$\boldsymbol{\delta}_m = i + i - A = 2i - A$

$i = \frac{(A + d_m)}{2}$

The refractive index of the prism

$n_{21} = \frac{n_2}{n_1} = \frac{\sin i}{\sin r}$

$$n_{21} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

This expression can be used to find the refractive index of the material of the prism, if knowing A we can determine the value of δ_m

Example

A monochromatic parallel beam of light strikes a face of an equilateral prism, making an angle of 48^0 with the normal on that face. The light suffers minimum deviation.

Determine the

- the angle of emergence
- angle of refraction at the first refraction
- angle of deviation
- refractive index of the material of the prism.

Solution

- At minimum deviation, e = i

  So angle e = 48^{0}
- at minimum deviation angle r = A/2

  For an equilateral prism, A = 60^{0}, thus r = 30^{0}
- For a prism

$$i + e = A + \boldsymbol{\delta}_m$$

$$48^0 + 48^0 = 60^{0} + d$$

$$\boldsymbol{\delta}_m = 96^{0} - 60^0$$

$$\boldsymbol{\delta}_m = 36^{0}$$

d) $n_{21} = \frac{sin\left(\frac{A+\delta_m}{2}\right)}{sin\left(\frac{A}{2}\right)}$

$= \frac{sin\left(\frac{60+36}{2}\right)}{sin\left(\frac{60}{2}\right)}$

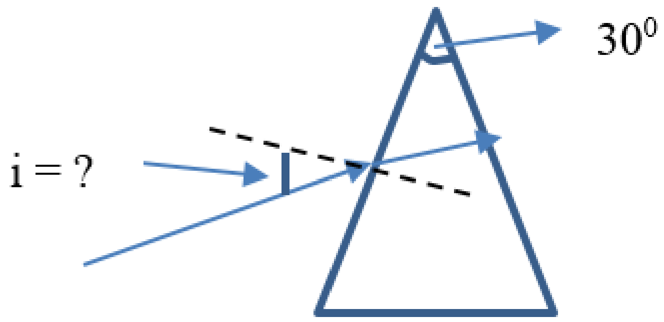
$$= \frac{sin\ 48}{sin\ 30} = 2(0.7431) = 1.4862$$

Example

One face of a prism of refracting angle 30° and refractive index 1.414 is silver. At what angle must a ray of light fall on the unsilvered face so that after refraction into the prism and reflection at the silvered surface, it retraces its path?

Solution

draw a diagram to help you visualize



For the refracted ray incident on the silvered emergent surface, to retrace its pat, the ray should be normally incident on the surface

In the triangle with angle of prism,

The condition

30+90+(90 –r) =180 where r is the angle of refraction at the first incident surface.

Or r = 30^0

Now

$n = \frac{\sin i}{\sin r}$

Substituting $1.414 = \frac{\sin i}{0.5}$ $\quad or\ \sin i = 1.414 \times 0.5 = 0.707$

$i = \sin^{-1} 0.707 = 44.9^0$

Example

- Would the deviation change if a prism is immersed in water?
- Calculate the ratio of deviation in air and water for a thin prism

The deviation produced by a thin prism is given by

$\delta = (n - 1)A$

Where n is the refractive index of the material of the prism with respect to the surrounding and A is the angle of the prism.

Solution

- yes
- When the prism is in air, then

$n = n_{ag} = \frac{3}{2}$

$\delta_1 = \left(\frac{3}{2} - 1\right)A = \frac{1}{2}A$

When the prism is in water, then

$$n = n_{wg} = \frac{n_{ag}}{n_{aw}} = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8}$$

$$\delta_2 = \left(\frac{9}{8} - 1\right)A = \frac{1}{8}A$$

$$\frac{\delta_2}{\delta_1} = \frac{1}{4}$$

To Determine The Angle of Minimum Deviation For A Given Prism By Plotting A Graph Between Angle of Incidence And of Deviation

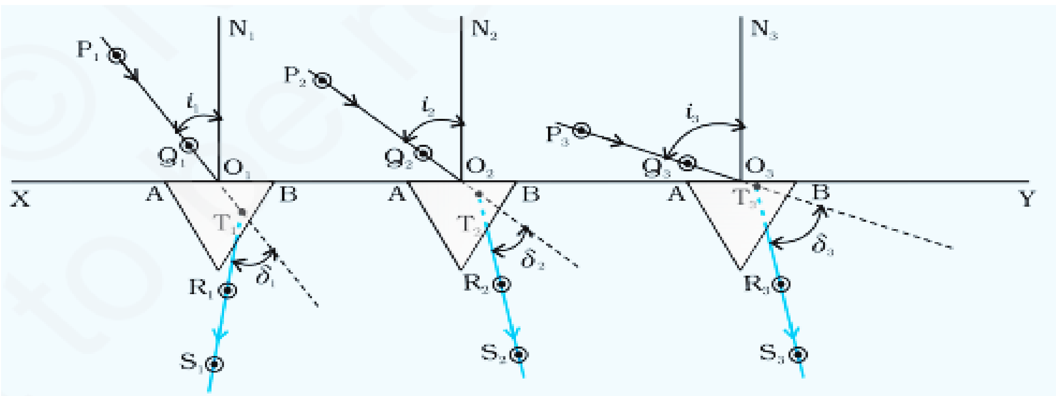
this can be done in the laboratory or even **AT HOME**

Material Required

- Drawing board,
- a white A4 sheet of paper,
- prism,
- Drawing pins, alpins (common pins) pencil, ruler, graph paper and protractor.

Procedure

- Fix a white sheet of paper on a drawing board with the help of cello tape or drawing pins.
- Draw a straight line XY, using a sharp pencil nearly in the middle and parallel to the length of the paper.
- Mark points O_1, O_2, O_3. ., ... on the straight line XY at suitable distances of about 8 to 10 cm and draw normal $N_1 O_1$, $N_2 O_2$, $N_3 O_3$. . . . on these points.



- Draw straight lines $P_1 O_1$, $P_2 O_2$, $P_3 O_3$, . . . corresponding to the incident rays making angles of incidence at 35° , 40° , 45°, 50° , . . . 60° respectively with the normals using a protractor.

The biggest advantage of doing this is

- Your work is organized.
- You will work faster.
- All desired angles of incidence are measured and the corresponding incident rays can be marked.
- Write the values of the angles $\angle P_1 O_1 N_1$, $\angle P_2 O_2 N_2$, …. on the white paper sheet.
- Place the prism with its refracting face AB on the line XY with point O_1 in the middle of AB as shown in the figure.

This will give you enough space to work

- Draw the boundary of the prism with a sharp pencil.

This help in placing the prism in the same position after removing it and help in marking the refracted and emergent rays at the boundaries.

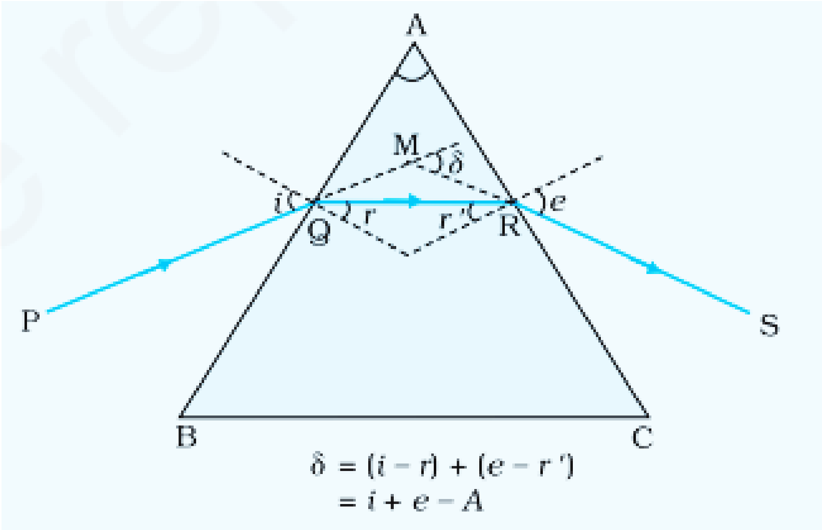
- Fix two alpins (common pins) P_1 and Q_1 with sharp tips vertically about 10 cm apart, on the incident ray line $P_1 Q_1$ such that pin Q_1 is close to point O_1.

Close one eye (say left) and looking through the prism, bring your right eye in line with the images of the pins P_1 and Q_1., as seen through the prism.**You have to close one eye because otherwise the alignment for the pins making up a ray is not possible.**

- Fix alpins R_1 and S_1 about 10 cm apart vertically on the white paper sheet with their tips in line with the tips of the images of pins P_1 and Q_1.

  In this way pins R_1 and S_1 will become collinear with the images of pins P_1 and Q_1.

- Remove the pins R_1 and S_1 and encircle their pin pricks on the white paper sheet with the help of a sharp pencil.
- Remove the pins P_1 and Q_1 and encircle their pin pricks also.
- Join the points (or pin pricks) R_1 and S_1 with the help of a sharp pencil and scale to obtain the emergent ray $R_1 S_1$.
- Produce it backwards to meet the incident ray $P_1 Q_1$ (produced forward) at T_1.
- Draw arrowheads on $P_1 Q_1$ and $R_1 S_1$ to show the direction of the rays.
- Measure the angle of deviation δ_1 and the angle BAC (angle A) of the prism



with a protractor and write the values of these angles indicated in the diagram.

- Repeat last four steps for different values of angle of incidence (40°, 45°, 50° ...) and measure the corresponding angles of deviation δ_1,δ_2, δ_3 ... with the protractor, and indicate them in the respective diagrams.
- Record observations in tabular form with proper units and significant figures.

Observations

Least count of the protractor = ...(degree)

Angle of the prism, A = ...(degree)

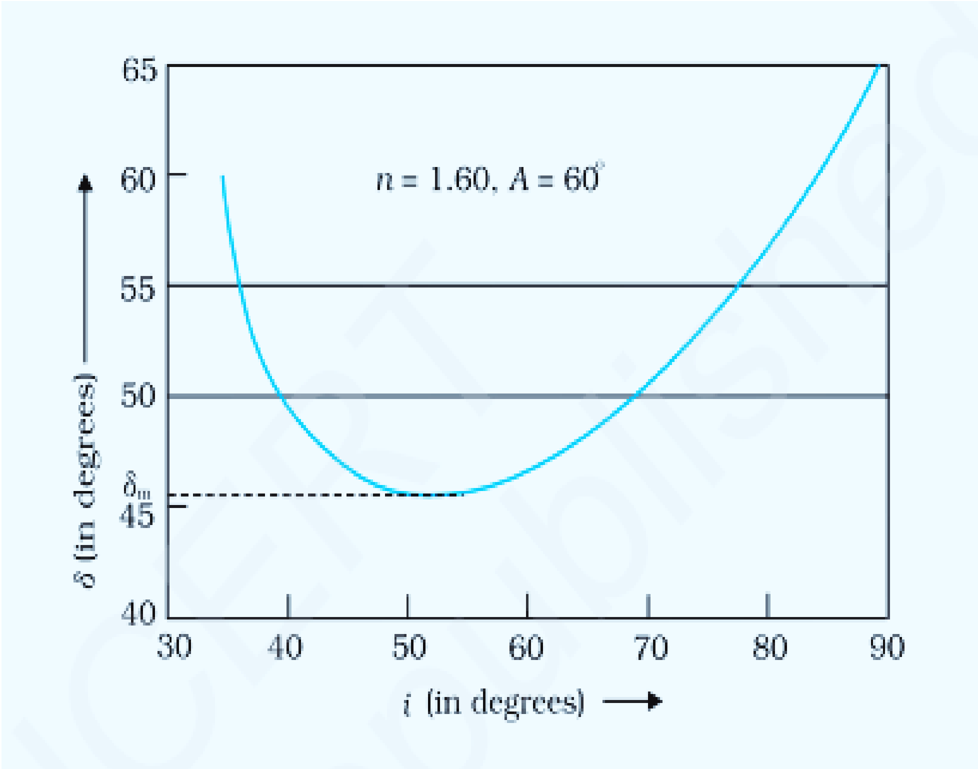
Measuring the angle of incidence, i and angle of deviation δ for a prism

Sl. No.	Angle of incidence, *i* (degrees)	Angle of deviation, *δ* (degrees)
1		
2		
3		
--		
10		

Plotting The Graph Between angle of incidence i **and** angle of deviation δ For The Prism

Take angle of incidence i along x-axis and angle of deviation δ along y-axis, using the observed values, Choose suitable scales on these axes and plot a graph between i and δ.

Take care that you draw a freehand smooth curve passing practically through all the plotted points on the graph



Best way to get the angle of minimum deviation from the graph

- Draw a tangent on the lowest point of the graph parallel to x-axis,
- Read the angle of minimum deviation δm on the y-axis of the graph.
- Express the result with proper significant figures.

Result

Angle of minimum deviation, δ_m = ... ± ... degree

Precautions

Think About These

Why?

- Alpins should be fixed vertically to the plane of paper.
- **Distance PQ and RS should be about 10 cm in order to locate incident and emergent rays with greater accuracy**.
- Same angle of prism should be used for all observations.
- **Position of the prism should not be disturbed for a given set of observations.**
- If the three angles of refraction between adjacent pairs of faces are not equal, then

  $A + \delta \neq i + e$.

- **The angles should be measured accurately.**
- It is suggested that the value of angle of incidence be taken more than 35°. This is required for angles less than 35° as there is a possibility of total internal reflection inside the prism.
- You must check your readings by applying the formula i + e = A + δ.
- **The i-δ curve** that is obtained in this experiment is a non-linear curve. In such situations, more readings should be taken in the minimum deviation region to be able to obtain the value of angle of minimum deviation accurately. For example, if δ readings are taken initially at 35°, 40°, 45° and 50° then a few more readings need to be taken for values of i in the range 45° to 55° say, at a difference of 1° or 2°.
- **Taking more readings in this region will help in drawing a smooth curve. This will enable you to locate the position of the lowest point on the graph more accurately.**
- In the condition of minimum deviation, the refracted ray inside the prism becomes parallel to its base so as to satisfy the condition $r_1 = r_2$
- **The graph does not show a sharp minimum. We have the same deviation for a range of angles of incidence near minimum deviation**.
- Extra care should be taken in drawing tangential lines to the i-δ graph at minimum deviation.
- **What will happen if you go on decreasing the angle of incidence? If you think there is a minimum, try to find its expression theoretically. What happens when it is less than the minimum angle of incidence?**
- What if we draw parallel horizontal lines cutting the i-δ curve, you have drawn, at various values of i and e. Find out the mid points of these horizontal lines and join these mid points. What is the shape of the curve so obtained? If you find that this shape resembles that of a straight line, find its (i) slope (ii) y-intercept and (iii) x-intercept.
- **Can we determine the refractive index of different liquids using a hollow prism by plotting i-δ graph. 5. Measure r and r′ and e from the figures you have drawn. Find the refractive index of the material of the prism from the values of i and r and e and r′.**

Deviation Through A Prism Of Small Angle

Suppose a **monochromatic light** is incident on a small angle prism at small angle then

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

for small A

$$n = \frac{\left(\frac{A+\delta_m}{2}\right)}{\left(\frac{A}{2}\right)}$$

$$n\,A = A + \delta_m$$

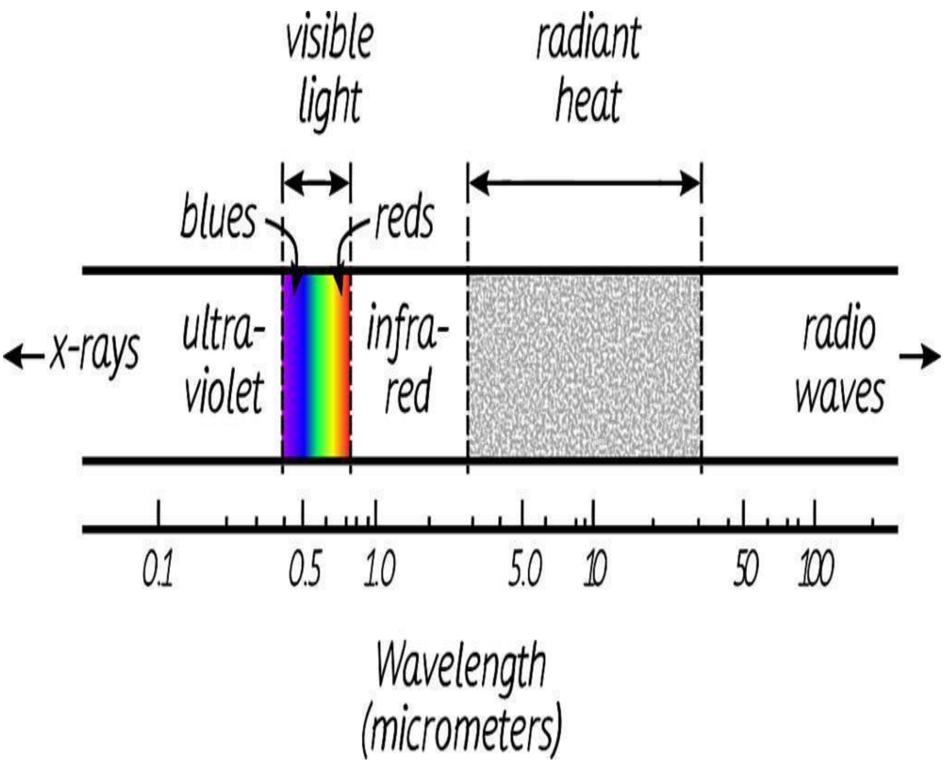
Or $\delta_m = (n - 1)\mathbf{A}$

Dispersion and Spectrum

It has been observed that when a narrow beam of sunlight passes through a prism. The emergent light is found to be consisting of bands of seven colours. These colours always appeared in the sequence of violet, indigo, blue, green, yellow, orange and red. The violet colour has maximum angle of deviation and the red colour has the least angle of deviation. Now the question was, does the prism itself create these colours or it only separates the colours already present in white light. The physicist Issac Newton's experiment with two inverted prisms solved this problem.

The phenomenon of splitting of light into its component colours is known as dispersion. The pattern of colour components of light is called the spectrum of light.

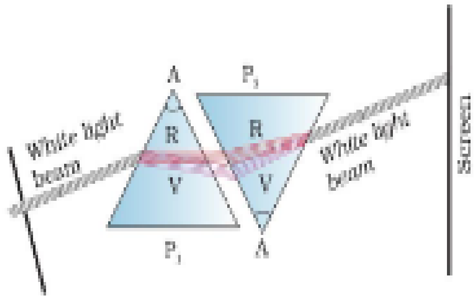
The electromagnetic spectrum over a large range of wavelengths, from γ-rays to radio waves, of which the spectrum of light (visible spectrum) is only a small part.



https://c1.staticflickr.com/1/617/33035188282_8c0b3e5937_b.jpg

Though the reason for the appearance of the spectrum is now common knowledge, it was a matter of much debate in the history of physics. Does the prism itself create colour in some way or does it only separate the colours already present in white light? In a classic experiment known for its simplicity but great significance, Isaac Newton settled the issue once for all. He put another similar prism, but in an inverted position, and let the emergent beam from the first prism fall on the second prism . The resulting emergent beam was found to be white light. The explanation was clear that the first prism splits the white light into its component colours, while the inverted prism recombines them to give white light. Thus, white light itself consists of light of different colours, which are separated by the prism. It must be understood here that a ray of light, as defined mathematically, does not exist. An actual ray is really a beam of many rays of light. Each ray splits into component colours when it enters the glass prism. When those coloured rays come out on the other side, they again produce a white beam. We now know that colour is associated with wavelength of light. In the visible spectrum, red light is at the long wavelength end (~700 nm) while the violet light is at the short wavelength end (~ 400 nm)

He took two similar prisms p_1 and p_2 and put the second prism p_2 in an inverted position with respect to p_1 as shown in the figure. A narrow beam of sunlight was made to fall on the prism p_1, and let the emergent beam from the first prism fall on the prism p_2. It was observed that the resulting emergent beam was found to be white light again. So it was clear that the prism did not produce the colours , rather the first prism splits the white light into its constituent colours and the second prism which is placed inverted with respect to p_1, recombines them back to give white light.



Dispersion takes place because the refractive index of medium for different wavelengths (colours) is different.

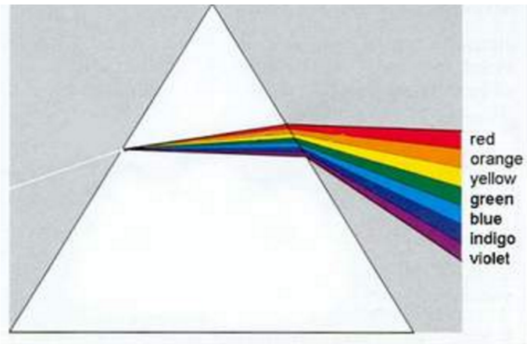
Dispersion: - The phenomenon of splitting of white light(polychromatic light) into its constituent colours on passing through a medium is called dispersion.

Spectrum: - The wavelength wise distribution of components of light is called spectrum.

You must have seen the rainbow and the seven colours

Rainbow in the sky

A prism gives the spectrum as shown



Cause of dispersion

As we know that each colour of light is associated with a wavelength. **According to Cauchy's relation**

We see that the refractive index of a medium is different for different wavelengths of light.

$n = a + \left(\frac{b}{\lambda^2}\right) + \left(\frac{c}{\lambda^4}\right) + ...$

Where a, b, c are constants. For a small angle prism

$$\delta_m = (n - 1) A$$

As $\lambda_{red} > \lambda_{violet}$

So $\mathbf{n_{red} < n_{violet}}$ **thus** $\delta_{red} < \delta_{violet}$t

Thus the red colour is deviated least and the violet colour is deviated maximum Or red light travels faster than the violet light in a prism.

We should note that sunlight while travelling from sun to us does not split into seven colours because in vacuum or in air speed of light is independent of wavelength.

Thus vacuum or air is a non-dispersive medium as all colours travel with the same speed.

You may watch

https://www.khanacademy.org/science/in-in-class-12th-physics-india/in-in-ray-optics-and-optical-instruments#in-in-reflection-and-refraction

Angular Dispersion

When a beam of white light passes through a prism, due to dispersion of light, it breaks up into its constituent colours of VIBGYOR. The violet colour is deviated maximum and the red colour is deviated the least. Let δ_v be the angle of deviation for the violet colour and δ_r be the angle of deviation for the red colour.

$$\delta_v = (n_v - 1) A$$

$$\delta_r = (n_r - 1) A$$

Angular dispersion is the angular separation between the two extreme colours in the spectrum.

Thus

angular dispersion = $\delta_v - \delta_r = (n_v - n_r)A$

The angular dispersion produced by the prism depends upon

- the material of the prism and
- the angle of the prism.

Dispersive Power

It is the measure of the ability of a prism material to cause dispersion.

Dispersive power is defined as the ratio of angular dispersion to the angle of deviation for the mean colour of light (which is yellow colour of light)

$$= (\delta_v - \delta_r) A / (n - 1)A$$

$$= (\delta_v - \delta_r) / (n - 1) = (n_v - n_r) / (n-1)$$

The dispersive power depends only on the nature of material of the prism and not on the angle of the prism.Greater is the dispersive power of the prism, larger is the angle over which the spectrum will be spread.

Further, it is noted that flint glass (with n = 1.66) is usually used for making prism for obtaining greater dispersive power or angular dispersion.

However, crown glass (with n = 1, 5) is generally used for making spherical lenses for obtaining higher focusing power without dispersion.

Example

The refractive indices of a material for red, violet and yellow lights are 1.52, 1.62 and 1.59 respectively. Calculate the dispersive power of the material.If the mean deviation is 40° then what will be the angular dispersion produced by a prism of this material?

Solution

The dispersive power of the material is given by

$$\omega = \frac{n_V - n_R}{n_Y - 1} = \frac{1.62-1.52}{1.59-1} = 0.169$$

If δ_V, δ_R and δ_Y be the deviations produced by the prism in the violet, red and yellow rays respectively, then the dispersive power is

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y}$$

Angular dispersion is

$$\delta_V - \delta_R = \omega \times \delta_Y = 0.169 \times 40^{\circ} = 6.76^{\circ}$$

Summary

- Prism is a portion of transparent medium bounded by three plane surfaces inclined to each other at a suitable angle.
- Two plane faces which are inclined to each other are called the **refracting surfaces of the prism**.
- The line along which the two refracting surfaces meet is called the refracting edge.
- The angle between the two refracting surfaces is called the angle of prism
- The third plane surface of the prism which is opposite to the refracting edge is called the base of the prism.
- A section cut by a plane perpendicular to the refracting edge is called its **Principal section.**
- A monochromatic ray of light on passing through a prism bends towards the base of the prism. The angle which the emergent ray forms with the incident ray is called the angle of emergence
- When a ray of light passes through a prism, the sum of the angle of the prism and angle of deviation is equal to the sum of the angle of incidence and the angle of emergence. $i + e = A + \delta$
- The angle of deviation depends upon
    - The angle of incidence

- The angle of the prism
- The material of the prism
- The wavelength of light used.

- As angle i increases, the angle of deviation δ , first decreases and reaches a minimum value δ_m and then increases.

  Thus at minimum deviation δ_m, the refracted ray inside the prism becomes parallel to the base of the prism or we can say that the incident ray and the emergent ray are symmetrically situated w.r.t the prism.

- At minimum deviation δ , i = e , which means the ray travels parallel to the base inside the prism and angle A/2 = r

$$n = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- The phenomenon of splitting of white light into its constituent colours on passing through a medium is called **dispersion.**
- The wavelength wise distribution of components of light is called **spectrum.**
- For a small angle prism and refraction at small angles

$$\delta = (n - 1) A$$

- Cauchy's formula for dependence of the refractive index of a material on the wavelength of light is

  $n = a + (b/\lambda^2) + (c/\lambda^4) + \ldots\ldots\ldots$

- When sunlight passes through a prism, the red colour is deviated least and the violet colour is deviated maximum. Or red light travels faster than the violet light in a prism.
- Angular dispersion is the angular separation between the two extreme colours in the spectrum.

  angular dispersion = $\delta_v - \delta_r = (n_v - n_r)A$

- The angular dispersion produced by the prism depends upon i) the material of the prism and ii) the angle of the prism.
- Dispersive power is defined as the ratio of angular dispersion to the angle of deviation for the mean colour of light (which is yellow colour of light)

  $\omega = (\delta_v - \delta_r)/(n - 1) = (n_v - n_r)/(n - 1)$

- dispersive power depends only on the nature of material of the prism