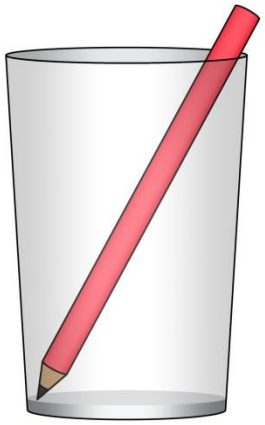
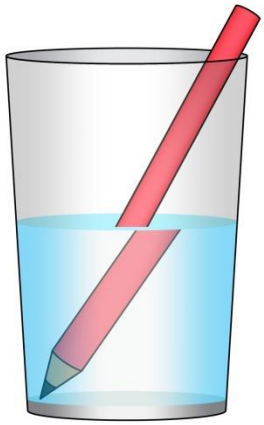
S3 New Curriculum Physics

Theme: Light

Chapter 2 – Refraction, Dispersion and colors



Empty Glass + Pencil



Glass + Water + Pencil

REFRACTION OF LIGHT

Refraction of light is the changing of direction of light rays as they pass from one medium to another of different optical density.

Refraction is due to the change in speed of light between two media of different optical densities, for example when light travels from air to glass, water to glass, glass to air or glass to water, it undergoes refraction because these media have different optical densities.

Refraction can also be defined as the change in the velocity of light when it moves from one medium to another of different optical density.

A ray of light that light is travel from less optically denser medium (air) to more optically denser medium (glass) bends toward the normal. Thus, the angle of incidence in air is greater than angle of refraction in glass as shown in the diagram below

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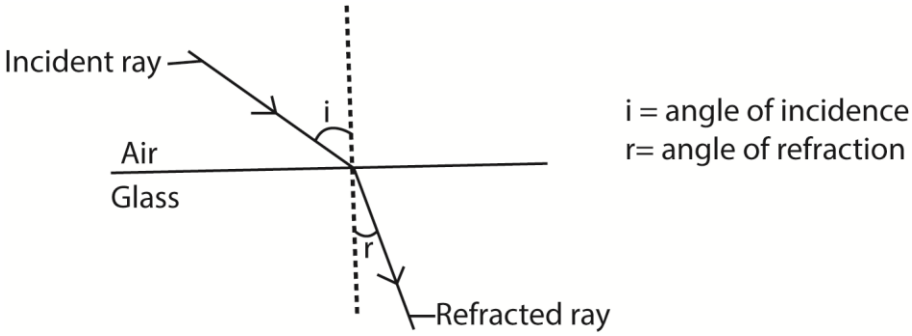
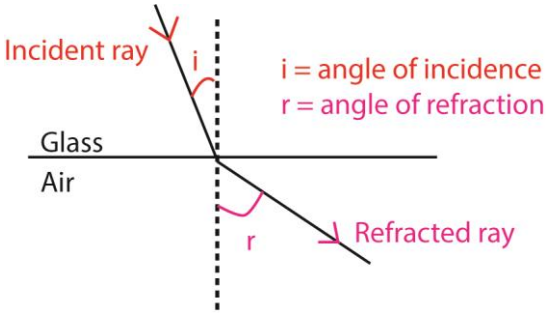
Diagram of light from air to glass



Alternatively, a ray of light that light is travel from optically denser medium (glass) to more optically less dense medium (air) bends away from the normal. Thus, the angle of incidence in glass is less than angle of refraction in air as shown in the diagram below



Causes of refraction of light

Refraction of light is caused by the difference in speed of light as light moves from one medium to another of different optical density.

Laws of refraction

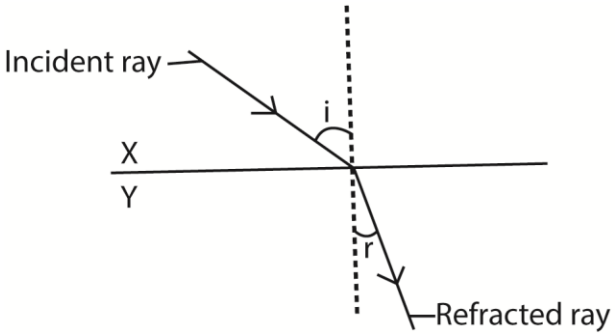
1. The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane

2. The second law which is also called Snell's law states that the ratio of the sine of angle of incidence to the sine of angle of refraction is a constant for two given media.

   I.e. $\frac{\sin i}{\sin r}$ is a constant of two given media.

   Where **i** is the angle of incidence in first medium**, r** is the angle of refraction in the second medium of light.

   The constant of $\frac{\sin i}{\sin r}$ is called the refractive index of the medium where light is refracted with respect to the medium where light is incident.



i = angle of incidence
r= angle of refraction

$\frac{\sin i}{\sin r}$ = refractive index of **Y** with respect to **X.** This is written as $_{x}\cap_{y}$

Definition: Refractive index is the constant of the ratio of sine of angle of incidence to the sine of angle refraction for any two given media. Refractive index has no units.

If the first medium is a vacuum or air, then it becomes the refractive index of the second medium and this is called absolute refractive index.

Absolute refractive index of a medium is the constant of ratio of sin **i** to Sin **r** of the medium where **i** is angle of incidence in air or vacuum and **r** is angle of refraction in the medium.

The refractive index of air or vacuum $\cap_a = 1$
The refractive index of water $\cap_w$=1.33 or $\frac{4}{3}$
The refractive index of glass $\cap_g$= 1.5 or $\frac{3}{2}$

Note: Absolute refractive index is also referred to as refractive index of medium

Refractive index of glass is**1.5** means that the constant of the ratio of sine of angle of incidence in air or vacuum to the sine of angle refraction in glass is **1.5**.

For calculations involving sine, cosine, or tan, they should be truncated to 3 decimals.

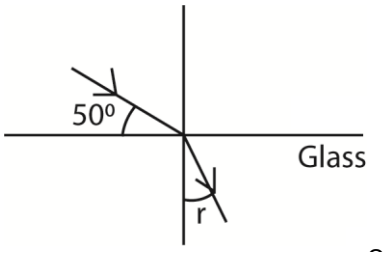
Refractive index can also be in terms of velocities or speeds.

Absolute refractive index = $\frac{\text{velocity of light in vacuum air (c)}}{\text{velocity of light in medium (v)}}$

Commonly velocity of light in vacuum or air is $3x10^{8}ms^{-1}$

Example I

Calculate angle r in the figure below. (Refractive index of glass = 1.5)



Solution

Angle of incidence = 90- 50 = 40^0

From Snell's law

$\frac{Sine\ i}{sine\ r}$= constant

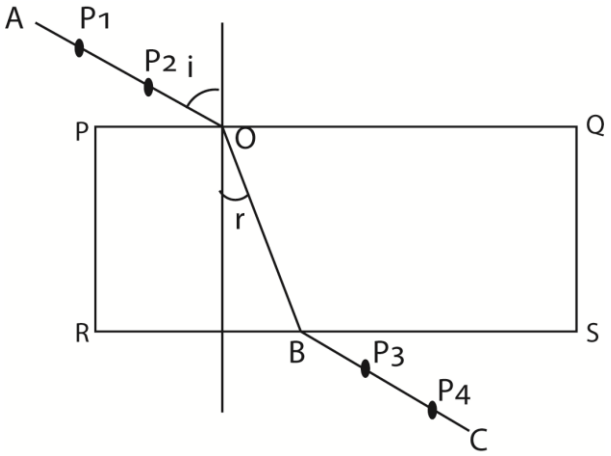
Sine r = $\frac{\sin 40^0}{1.5}$ = 0.428

r = 25^0

Trial 1

1. Draw a diagram to show the direction of a ray of light travelling from a dense to a denser medium.
2. Light travelling in air is incident on a medium at an angle of 60^0. Find the refractive index, if the angle of refraction is 30^0.

Experiment to determine the refractive index of the material of glass



a) Fix a glass block on a plane sheet of paper on soft board.
b) Trace outline PQRS
c) Draw a normal at O
d) Draw a line AO making an angle I = 10^0 with the normal at O

e) Fix pins P_1 and P_2 vertically along AO and replace a glass block

f) From side RS fix pins P_3 and P_4 so as to appear to be in line with the images of pins of P_1 and P_2.

g) Remove P_3 and P_4 and draw a line to join holes of P_3 and P_4 to the block at B

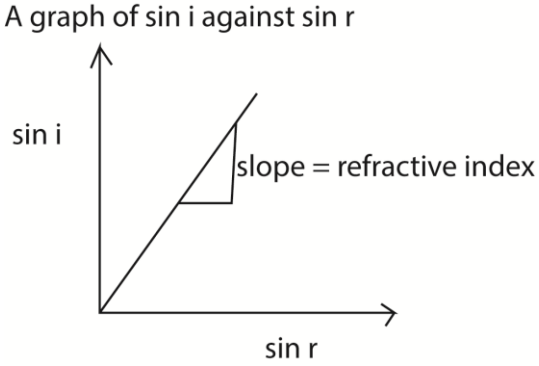
h) Join B to O and measure angle r.

i) Repeat d) to h) for values of i = 25, 30, 35, and 40^0.

j) Tabulate results including values of sine I and sine r.

i (^{0})	Sin i	r(^{0})	Sin r

k) Plot the graph sine I and sine r.



l) The slope of the graph is equal to refractive index of glass.

Trial 2

Sample results of an experiment to determine the refractive index of glass are given below

i(^{0})	**Sin i**	**r(^{0})**	**Sin r**
10	0.174	6.7	0.117
20	0.342	13	0.228
30	0.500	10	0.334
40	0.643	25	0.429
50	0.766	31	0.509
60	0.866	35	0.576

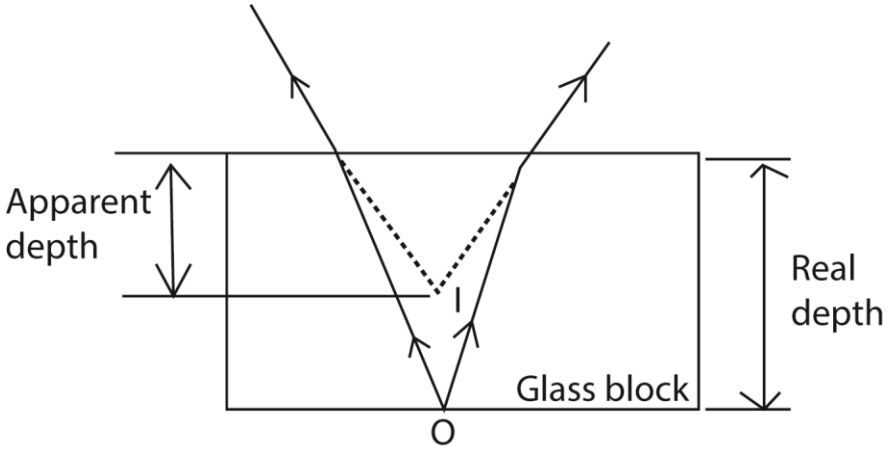
(a) Plot a graph of **sin I** against **sin r**

(b) Find the slope of the graph in (a) and comment.

Real and apparent depth

When a ray of light travels from a more optically denser medium to a less optically dense medium, it bends away from the normal

An object O at the bottom of a glass block, viewed from top the glass block is observed at I



Refractive index = $\frac{Real\ depth}{apparent\ depth}$

Example 2

A pin placed at the bottom of a liquid appears to be at depth of 6cm when viewed from above. Find the refractive index of the liquid of depth 8cm.

Apparent depth = 6cm
Real depth = 8cm.
Refractive index = $\frac{real\ depth}{apparent\ depth}$
= $\frac{8cm}{6cm}$
≅ **1.33**

Example 3

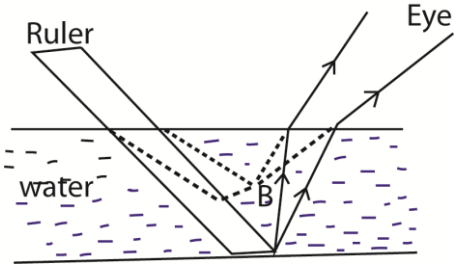
A glass block of thickness 3cm is placed on a pin. To an observe viewing above, the pin is raised by 1cm. find the refractive index of glass block.

Real depth = 3cm
Apparent depth = 3-1 = 2

$\cap = \frac{Real\ depth}{apparent\ depth}$
$\frac{3}{2}$ = 1.5

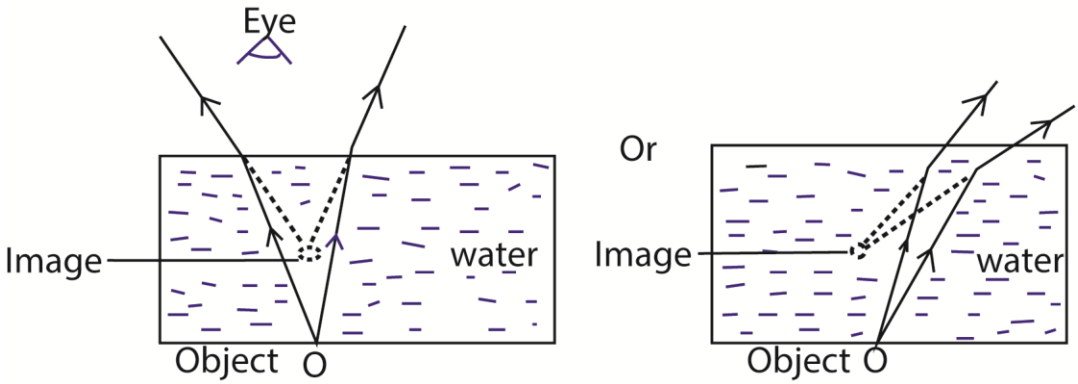
Application of apparent and real depth due to refraction of light

1. A stick or ruler appears bent when placed in water due to refraction.



Light rays from the bottom of the stick are refracted away from the normal as they pass from water which is more optically denser to air which is less optically denser and the rays appear to be coming from Image point B

2. A swimming pool appear shallow



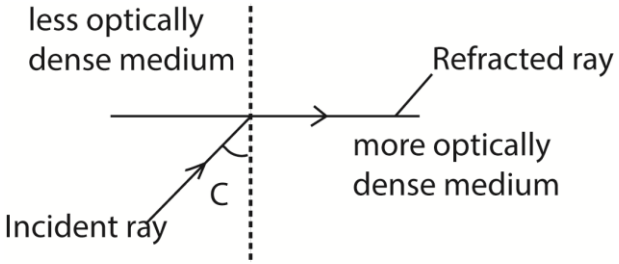
Light rays from an object O at the bottom of the pool are refracted away from the normal as they pass through from water which is more optically dense to air which is less optically dense. So point O which is the bottom will be seen raised to point I as these retracted rays enter the eye.

Critical angle

Is an angle of incidence in a more optically denser medium for which the angle of refraction is 90^0 in a less optically dense medium.

Or:

Critical angle is an angle of incidence for which the angle of refraction is 90^0 for a ray of light moving from a more optically dense medium to a less optically dense medium.



C is critical angle

Conditions for critical angle to occur

1. The angle of refraction is 90^0 in a less optically denser medium
2. The ray of light should be from a more optically denser medium to a less optically denser medium

Calculations involving critical angle, c

From air to glass ang = $\frac{\sin 90}{\sin c}$;

Sin c = $\frac{1}{{}_a n_g}$

Example 4

For each of the following give in refractive index, calculate the critical angle

(a) glass $\cap_g$ = 1.62
(b) Water $\cap_w$ = 1.32
(c) Oil $\cap_0$ = 1.2

Solution

(a) Glass

Sin c = $\frac{1}{1.62}$; c = 38.1^0

(b) For water

Sin c $\frac{1}{1.32}$; c = 49.3^0

(c) For oil

Sin c = $\frac{1}{1.2}$; c = 56.4^0

Trial 3

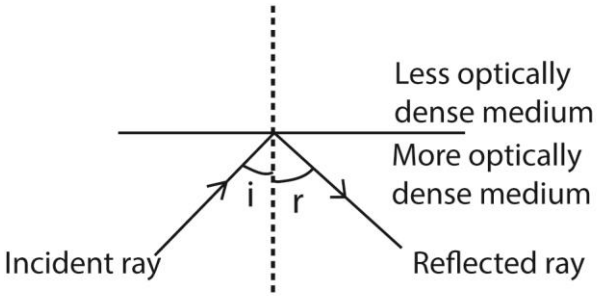
A ray of light travelling from air to water is refracted at an angle of 30^0. Find the angle of incidence if the critical angle of water is 48.6^0. [41.7^0C]

Total internal reflection

Occurs when the angle of incidence in a more optically dense medium is greater than the critical angle

Or.

Total internal reflection occurs when the angle of incidence is greater than the critical angle for a ray of light travelling from a more optically dense medium to a less optically dense medium.



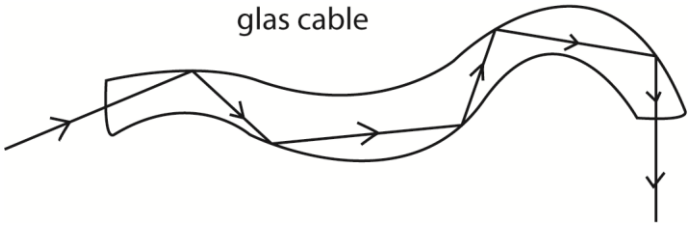
i is angle of incidence greater and critical angle

Conditions for total internal reflection to occur

- The angle of incidence in a denser medium must be greater than the critical angle
- The ray of light should be travelling from a more optically denser medium to a less optically denser medium.

Application of total internal reflection

Light pipes

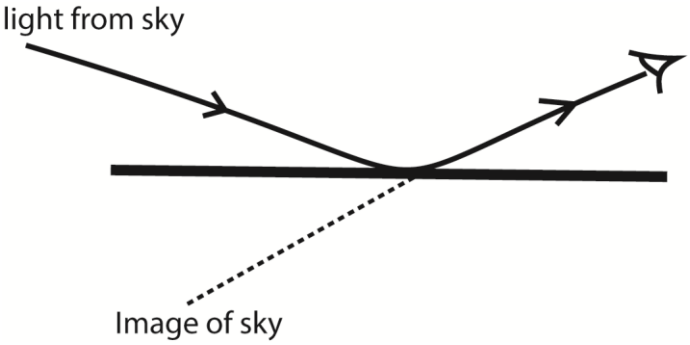


An optical fibre is made of a transparent material coated with another less optically dense material. Light entering the pipe strikes the boundary of the media at an angle of incidence greater than the critical angle. Total internal reflection thus occurs. This takes place repeatedly in the pipe until the light beam emerges from the pipe.

Mirages

Is what is observed as a pool of water on a tarmac road at some distance a head on a hot day.

Explanation of formation of mirage



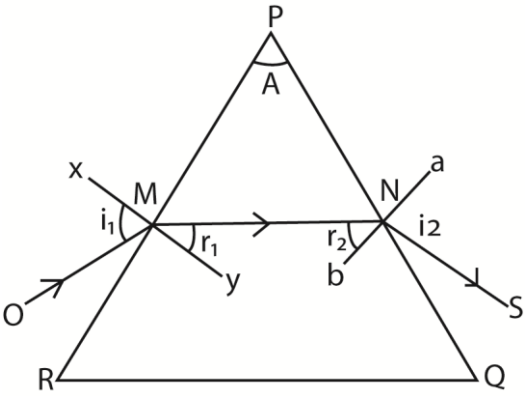
Refractive indices of air layers

Cooler air is more optically dense than warmer air, so warmer air has a low refractive index than cooler air.

Path of light through the glass prism

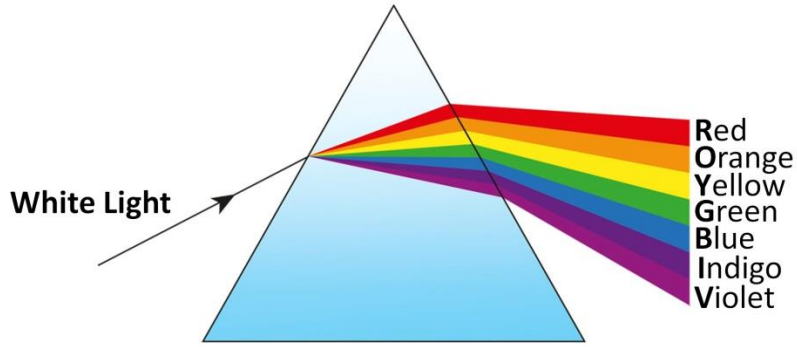
A ray OM making an angle i_1 with the normal at M is refracted towards the normal along MN and away from the normal at N along NS.

Note that light rays from less dense to a denser medium is refracted towards the normal while a light ray from denser to light medium is refracted away from then normal.



Dispersion of white light by a transparent medium

Dispersion of whit light is the separation of white light in to its component colors by a transparent medium due to their speed differences in the medium.



NOTE:

(i) White light is a mixture of various colours. This is called the spectrum of white light.

(ii) The spectrum of white light consists of red, orange, yellow, green, blue, indigo and violet light bands.

(iii) On refraction, violet is the most refracted colour away from the normal (violet is the most deviated colour) while red is least deviated

Colour filters and opaque objects

Filters: A filter is a glass or celluloid transparent colour plate which transmits light of only one colour and absorb all the other light.

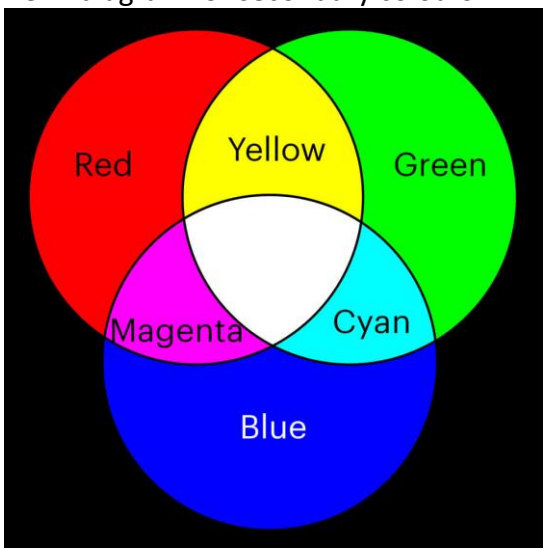
Opaque objects: They do not allow light to pass through. Opaque objects absorb all other colours.

Mixing Colours:
Primary colours are those that cannot be obtained by mixing any other colours. These are Red, Green and Blue.

Secondary Colours: A secondary colour is one which is obtained by mixing two primary colours

e.g.	Yellow	= Red + Green
	Magenta	= Red + Blue
	Cyan (Peakcock blue)	= Blue + Green

Venn diagram for secondary colours

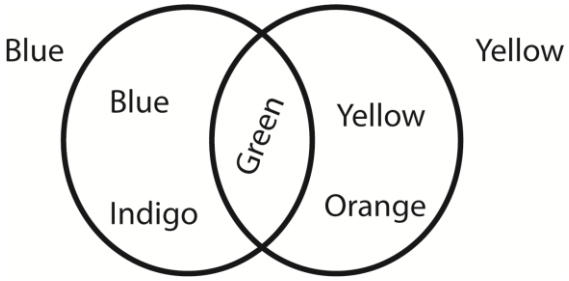


Complimentary Colours These are two colours which give white when mixed

Yellow + Blue	= white
Magenta + Green	= white
Cyan + Red	= white

Mixing pigments
Pigments in dyes are impure and reflect more than one colour light.

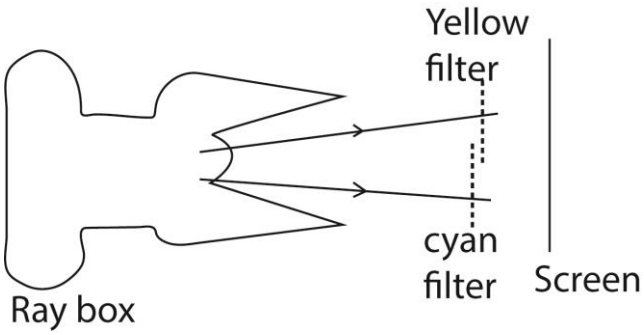
When two pigments are mixed, they reflect the colour which is common to both and absorb all the other, e.g. Yellow paint reflects orange, yellow and green, while blue paint reflects green blue and indigo.
Yellow + blue reflects green, absorbs orange, yellow and blue.



Mixing coloured light is called mixing by addition.

Mixing coloured pigments is called mixing by subtraction.

Mixing of coloured filters and pigments
Example 1



When a yellow filter and cyan filter are placed at some distance from the ray box such that, half of their portions overlap. State and explain what is observed.

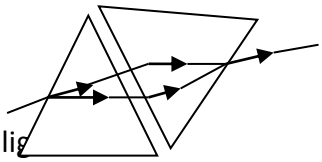
Observation
Green light is seen where white light passes through both filters.

Explanation:
For the overlap of yellow and cyan: Cyan filter absorbs the red light and transmits green and blue, but the yellow filter absorbs blue light and transmit green and red (which absorbed by the cyan filter) so only green is transmitted

Example 2
The overlap of yellow and magenta gives red light because the magenta filter absorbs Green and transmits blue and red light is yellow filter absorbs blue and transmits red and Green so red light is transmitted.

Example 3
The overlap of Cyan and Magenta filter give blue filter because cyan absorbs red light and transmits blue and red light so blue is transmitted.
The process of obtaining colours in this way is called colour mixing by subtraction.

Recombining the spectrum



White lig

White light

The colours of the spectrum can be recombined to form white light by arranging two prisms as above so that the, light is deviated in the opposite direction.

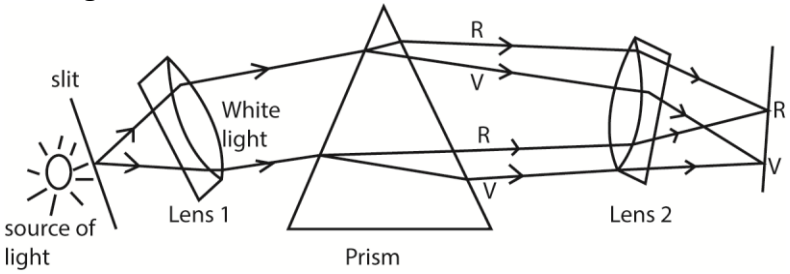
The above experiment shows that:
i) White light is a mixture of seven colours
ii) The prism merely separates the colours of white light by deviating red light least and violet light most and other colours are deviated to varying intermediate extent,

iii) The prism has different refractive index for different colours.

Note;
White light is separated into seven colours by a prism because (he prism has different refractive index for the different colours of white, light

Production of pure spectrum

Placing an illuminated slit



- An illuminated slit is placed at the principal focus of a converging lens, so that a parallel beam of light emerges from it.

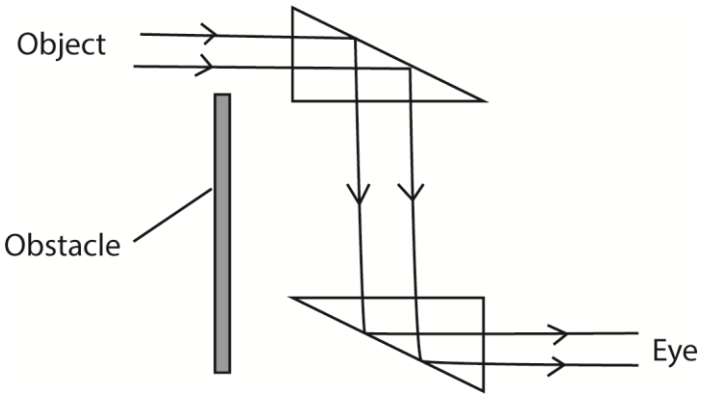
- This beam then falls into prism where dispersion of white light occurs.

- The spectrum is then directed to the screen by lens 2.

Uses of prisms

1. They enable the refractive index of a glass material to be measured accurately.
2. They are used in the dispersion of light emitted by glowing objects.
3. They are used as reflecting surfaces with minimal energy loss.
4. They are used in prism binoculars and periscopes

Transmission of light rays through the periscope



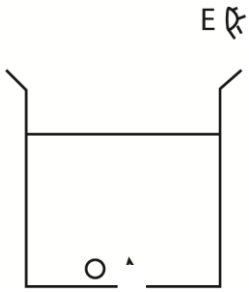
Rays from object are totally reflected until they enter the eye.

Use of prisms is preferable to a plane mirrors in a periscope because prisms give you **brighter, clearer, and longer-lasting reflections**

- **Brighter reflection**: Prisms reflect nearly 100% of the light internally, while plane mirrors reflect less because some light is absorbed or scattered by the reflective coating.
- **No need for coating**: Plane mirrors rely on a metallic coating (like silver or aluminum) that can tarnish or degrade over time. Prisms don't need this—they reflect light purely through geometry and physics.
- **More durable and stable**: Prisms are solid glass blocks, so they're sturdier and less likely to warp or lose alignment compared to thin mirrors.
- **Consistent image quality**: Because of their precision and durability, prisms maintain sharp, bright images over time—ideal for optical instruments like periscopes and binoculars.

Revision questions

1. (a) What is meant by refraction of light
   (b) State the laws of refraction of light.
   (c)



   In the diagram above an object O is placed at the bottom of clear pond. Draw rays diagram to show how it appears to an observer at E.

   (d) The refractive index of glass is 1.62. Calculate critical angle[38.1^0]

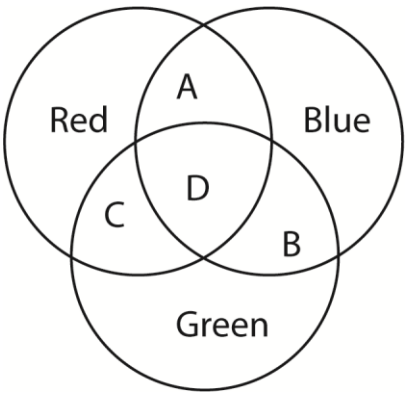
2. With the aid of a diagram why a pond appears shallower than it actually is.

3. (a) Explain the causes of refraction of light.
   (b) Describe an experiment you would use to measure the refractive index of glass using a glass block.
4. (a) Explain dispersion as applied to light

   (b) Describe how you can produce pure spectrum.

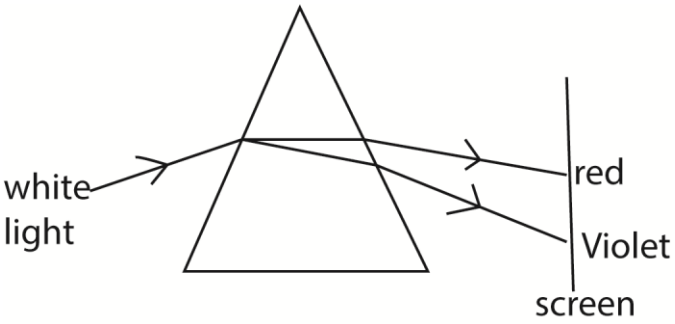
   (c) (i) Distinguish between primary and secondary colours.

   (ii) Name the colours represented by letters A, B, C and D, in the following colours mixed by addition

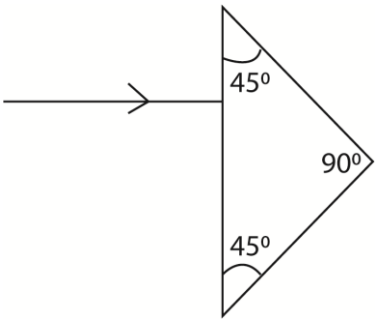


   (d) What is the colour of a yellow dress in green light?: [green]

   (e) With the aid of, show dispersion of white light by a prism

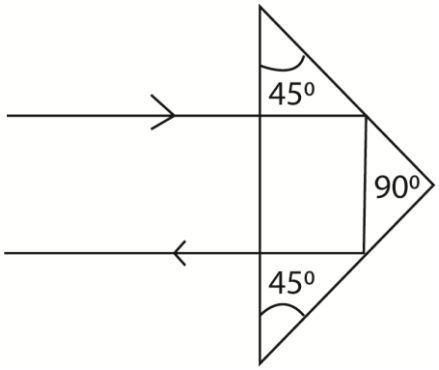


5.



The figure above shows a ray of light incident normally on a glass prism in air. The critical angle of the prism is 42^0.

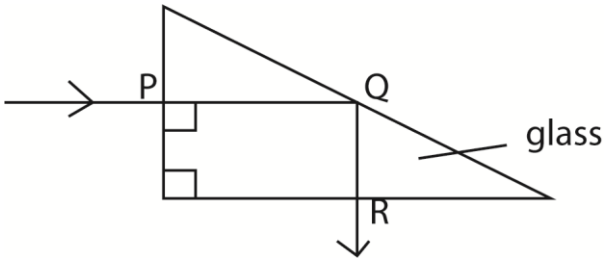
(a) Complete the ray diagram to show the path of light as it emerges from the prism (2marks)



(b) Calculate the refractive index of the prism (02marks)

$n = \frac{1}{\sin c} = \frac{1}{\sin 42} = 1.50$

(c) The figure shows a ray incident on a right angled prism of refractive index 1.5. Explain why the ray of light follows the path shown.

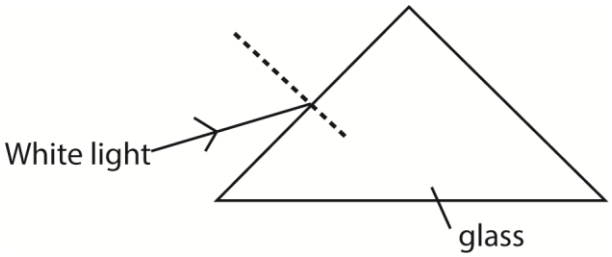


At P, a ray strikes the glass at 90^0 thus passes into the prism without refraction

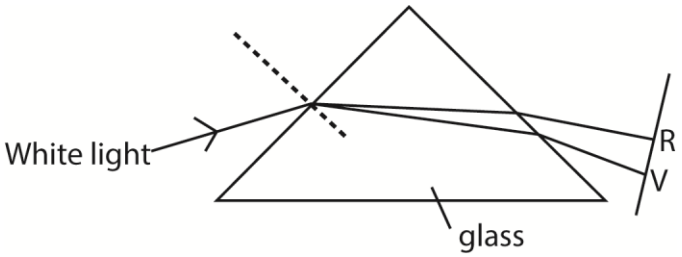
At Q, the ray PQ strikes the glass air boundary at an angle greater than the critical angle and is totally internally reflected to R.

At R, QR strikes the glass air boundary at 90^0 and thus pass without refraction.

6. A ray of white light is incident on a glass prism as shown above. Complete the diagram to show the effect of the glass prism on the ray.



Solution



(b) Find the critical angle for the glass in air if the refractive index of the glass is 1.5

Sinc = $\frac{1}{n} = \frac{1}{1.5}$

c = 41.8^0

7. (a) (i) What is meant by refraction?

This is the bending of light rays as they move from one medium to another of different optical densities.

(ii) When does total internal reflection occur (2marks)

Total internal reflection occurs when:

- light is moving from a denser optical medium to less dense optical medium
- the angle of incidence is greater than the critical angle