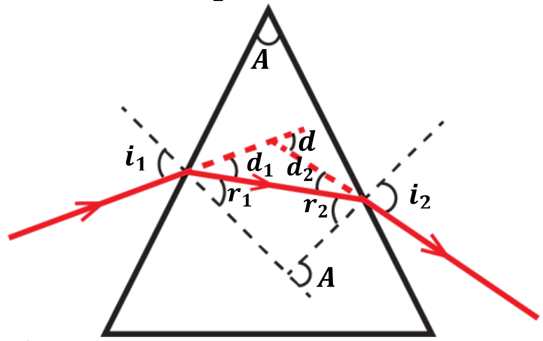
REFRACTION THROUGH PRISMS

A prism has two refracting surfaces. It uses a principle of reversibility of light, therefore light can be incident on either surface.

When a ray of light is incident on the first surface at an angle of incidence i_1, it is refracted at an angle of refraction, r_1 with an angle of deviation, d_1.

The ray then emerges out on the second surface at an angle of emergence i_2, with an angle of refraction, r_2 and angle of deviation, d_2.



$Angle\ of\ deviation,\ \boldsymbol{d_1 = i_1 - r_1}$

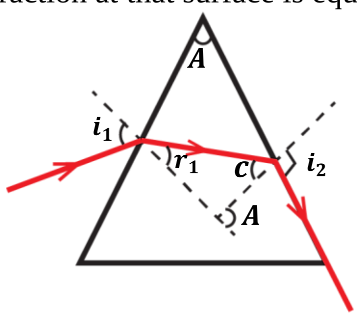
$Angle\ of\ deviation,\ \boldsymbol{d_2 = i_2 - r_2}$

$Total\ angle\ of\ deviation, \boldsymbol{d = d_1 + d_2}$

$$\boldsymbol{d = (i_1 - r_1) + (i_2 - r_2)}$$
$$\boldsymbol{d = i_1 + i_2 - r_1 - r_2}$$
$$\boldsymbol{d = (i_1 + i_2) - (r_1 + r_2)}$$
$$But\ \boldsymbol{A = r_1 + r_2}$$
$$\boldsymbol{d = (i_1 + i_2) - A}$$
$$where\ \boldsymbol{A}\ \boldsymbol{is\ the\ refracting\ angle\ of\ prism}$$

NOTE:

If a ray of light does not emerge out but instead grazes on one surface of the prism, then the angle of refraction at that surface is equal to the critical angle.

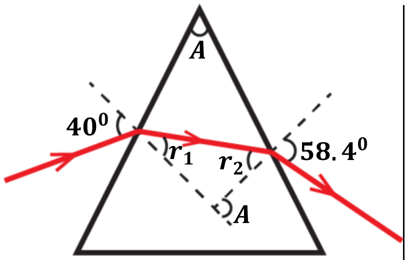


N.B:

For calculations involving prisms, it is easier to consider refractions at each side separately using the law of reversibility of light.

Examples:

1. A ray of light is incident on a glass prism of refractive index 1.5 at an angle of 40^0. Given that the ray emerges out an angle of 58.4^0. Find the;
   i) angle of refraction at both surfaces
   ii) refracting angle of the prism.
   iii) total deviation of the prism.



$\boldsymbol{i_1 = 40^0,\ i_2 = 58.4^0}$

i)

Refraction at first surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_a \sin i_1 = \cap_g \sin r_1$

$1 \times \sin 40^0 = 1.5 \times \sin r_1$

$0.6428 = 1.5 \sin r_1$

$\sin r_1 = \dfrac{0.6428}{1.5}$

$\sin r_1 = 0.4285$

$r_1 = sin^{-1}(0.4285)$

$r_1 = 25.4^0$

Refraction at second surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_a \sin i_2 = \cap_g \sin r_2$

$1 \times \sin 58.4^0 = 1.5 \times \sin r_2$

$0.8517 = 1.5 \sin r_2$

$\sin r_2 = \dfrac{0.8517}{1.5}$

$\sin r_2 = 0.5678$

$r_2 = sin^{-1}(0.5678)$

$r_2 = 34.6^0$

ii)

Refracting angle

$A = r_1 + r_2$

$A = 25.4^0 + 34.6^0$

$A = 60^0$

ii)

Total deviation

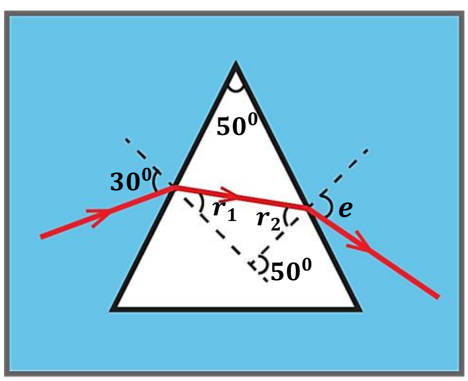
$d = (i_1 + i_2) - A$

$d = (40^0 + 58.4^0) - 60^0$

$d = 98.4^0 - 60^0$

$d = 38.4^0$

2. A ray of light propagating from a liquid is incident on a prism of refracting angle 50^0 and refractive index 1.6 at an angle of 30^0 as shown below.



If the refractive index of the liquid is 1.35. Calculate
i) Angle of refraction, r_1 *and* r_2
ii) Angle of emergency, e
iii) Angle of deviation

i)

Refraction at first surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_l \sin i_1 = \cap_g \sin r_1$

$1.35 \times \sin 30^0 = 1.6 \times \sin r_1$

$0.6750 = 1.6 \sin r_1$

$\sin r_1 = \frac{0.6750}{1.6}$

$\sin r_1 = 0.4219$

$r_1 = sin^{-1}(0.4219)$

$r_1 = 25.0^0$

$A = r_1 + r_2$

$50^0 = 25.0^0 + r_2$

$r_2 = 25.0^0$

ii)

Refraction at second surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_l \sin e = \cap_g \sin r_2$

$1.35 \times \sin e = 1.6 \times \sin 25^0$

$1.35 \sin e = 0.6762$

$\sin e = \frac{0.6762}{1.35}$

$\sin e = 0.5009$

$e = sin^{-1}(0.5009)$

$e = 30.1^0$

iii)

Total deviation

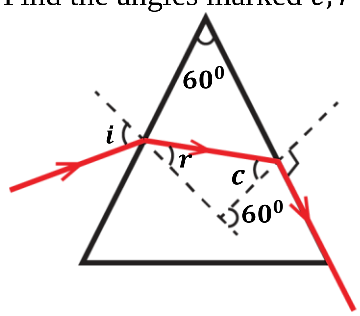
$d = (i_1 + i_2) - A$

$d = (30^0 + 30.1^0) - 50^0$

$d = 60.1^0 - 50^0$

$d = 10.1^0$

3. A ray of light is incident at an angle of incidence, i a triangular prism of refractive index 1.52 as shown below. Find the angles marked c, r and i.



Refraction at second surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_a \sin i_2 = \cap_g \sin r_2$

$1 \times \sin 90^0 = 1.52 \times \sin c$

$1 = 1.52 \sin c$

$\sin c = \frac{1}{1.52}$

$\sin c = 0.6579$

$c = sin^{-1}(0.6579)$

$c = 41.1^0$

$A = r_1 + r_2$

$60^0 = r + c$

$60^0 = r + 41.1^0$

$r = 60^0 - 41.1^0$

$r = 18.9^0$

Refraction at second surface

$\cap_1 \sin i = \cap_2 \sin r$

$\cap_a \sin i_1 = \cap_g \sin r_1$

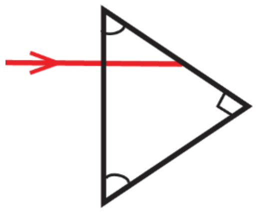
$1 \times \sin i = 1.52 \times \sin 18.9^0$

$\sin i = 0.4924$

$i = sin^{-1}(0.4924)$

$i = 29.5^0$

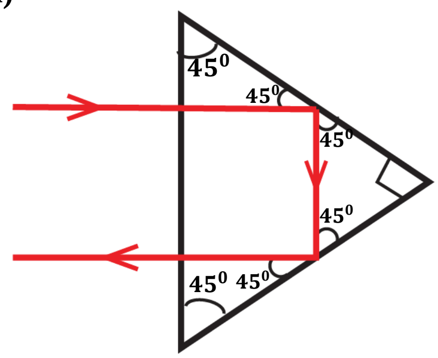
4. The figure below shows light incident normally on a glass prism in air.



a) Copy and complete the diagram.

b) Calculate the refractive index of the prism if the critical angle of glass is 42^0

a)



The ray took that path since the angle of incidence is greater than the critical angle of glass i.e. $45^0 > 42^0$

b)

$$\cap_g = \frac{1}{\sin c}$$

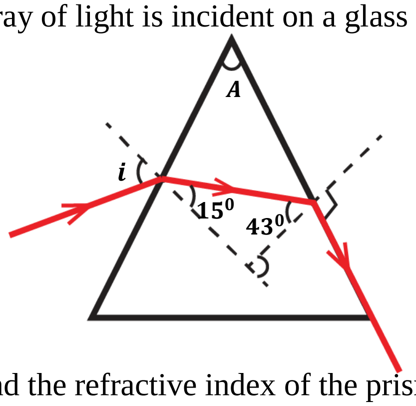
$$\cap_g = \frac{1}{\sin 42^0}$$

$$\cap_g = 1.49$$

EXERCISE

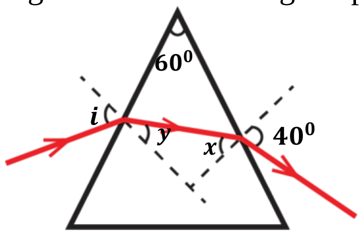
1. A prism of refractive index 1.5 and refracting angle 60^0 has an angle of refraction 28^0 on the first refracting face. Determine;
   i) Angle of incidence (**Ans:** $\mathbf{44.8^0}$)
   ii) Angle of refraction on second refracting surface (**Ans:** $\mathbf{32^0}$)
   iii) Angle of emergency (**Ans:** $\mathbf{52.6^0}$)
   iv) Angle of deviation (**Ans:** $\mathbf{37.4^0}$)

2. A ray of light is incident on a glass prism at an angle, i as shown below.



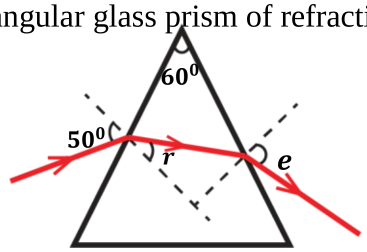
Find the refractive index of the prism, refracting angle and angle of incidence, i.
Ans: $\cap_g = \mathbf{1.47}$, $\boldsymbol{A = 58^0}$, $\boldsymbol{i = 27^0}$

3. A ray of light is incident on a glass prism of an angle, i as shown below.



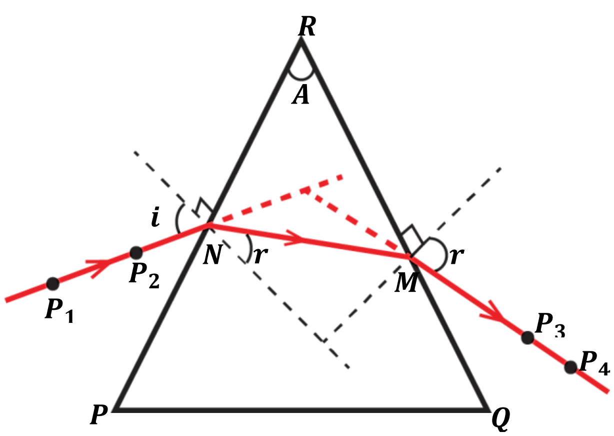
If the refractive index of the prism is 1.5, find the angles marked x, y, and i.
Ans: $\boldsymbol{x = 25.4^0,\ y = 34.6^0,\ i = 59.4^0}$

4. The diagram below shows a ray of yellow light incident at an angle of 50^0 on one side of an equilateral triangular glass prism of refractive index 1.52.



Calculate the angles marked r and e.
Ans: $\boldsymbol{r = 30.3^0,\quad i = 48.9^0}$

<u>Experiment to determine the refractive index of glass using a glass prism</u>:



<u>Procedures</u>;

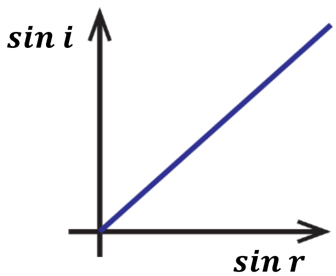
- Fix a white sheet of paper on a soft board using drawing pins.
- Place a glass prism on the white sheet of paper and draw its outline PQR.
- Remove the glass prism and draw a normal at N to meet PQ.
- Using a protractor, measure angle of incidence, i from the normal and fix two pins P_1 and P_2 along it.
- Replace the glass prism back to its outline.
- Look through the glass prism from the opposite side QR and fix pins P_3 and P_4 such that they appear to be in line with the images of pins P_1 and P_2.
- Remove the glass prism and the pins P_3 and P_4.
- Draw a line to join the marks of pins P_3 and P_4 to meet at M and then join N to M.
- Measure the angle of refraction, r.

- Repeat the procedures above for different values of i .
- Tabulate your results including values of $\sin i$ and $\sin r$.

$i(°)$	$r(°)$	$\sin i$	$\sin r$

- Plot a graph of $\sin i$ against $\sin r$.
- Determine the slope of the graph.

<u>Conclusion</u>:
- The graph is a straight line and its slope is equal to the refractive index of the glass prism.

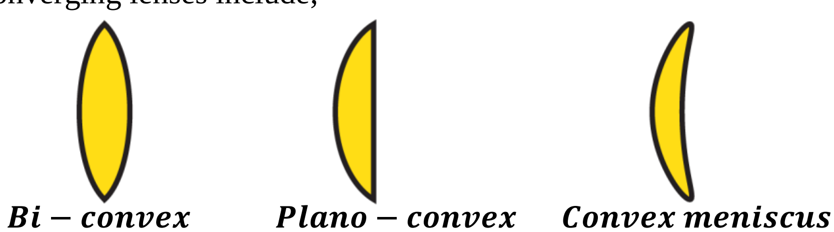


REFRACTION THROUGH LENSES

Lenses are spherical surfaces made from a transparent material.
The materials used to make these lenses may be glass, plastics and water.

<u>Types of lenses</u>;
There are two types of lenses namely;
- Convex (converging) lenses.
- Concave (diverging lenses.

<u>CONVERGING (CONVEX) LENSES</u>:
These are thicker in the middle than at the edges.
A convex lens is called a converging lens because all parallel rays incident to it meet at one point after refraction.
Examples of converging lenses include;

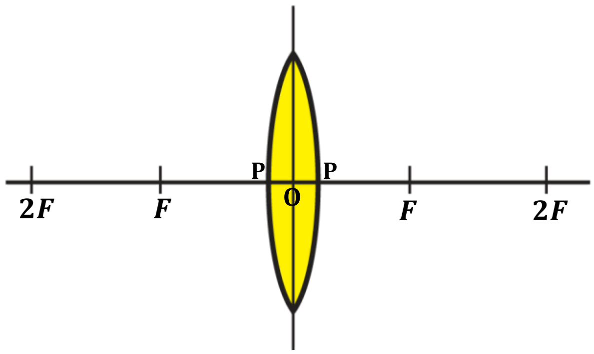


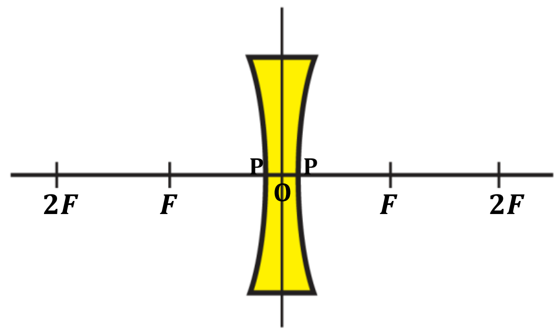
<u>DIVERGING (CONCAVE) LENSES</u>:
These are thicker at the edges than in the middle.
A concave lens is called a diverging lens because all parallel rays incident to it appear to diverge from one point after refraction.

Examples of diverging lenses include;

Bi − concave *concave meniscus* *Plano − concave*

TERMS USED IN LENSES



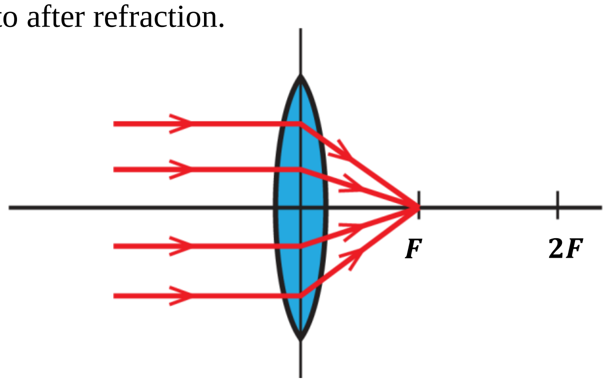


Pole of a lens (P):
This is the mid-point of the surface of the lens.

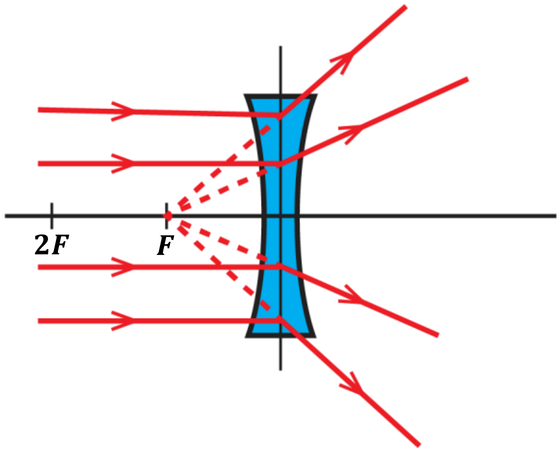
Optical centre (O):
This is the centre of the lens between its poles.

Principal axis:
This is a straight line passing through the optical centre and principal focus of a lens.

Principal focus, F of a converging lens:
This is a point on the principal axis where all rays close and parallel to the principal axis converge to after refraction.

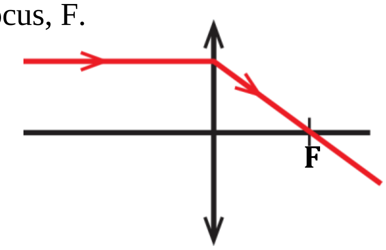
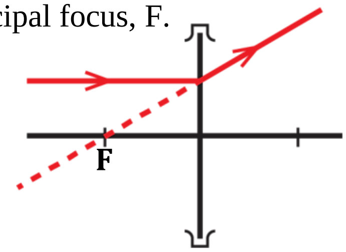
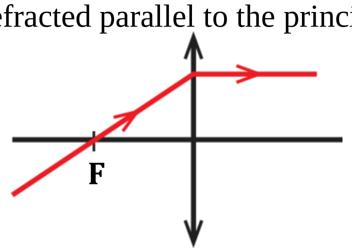
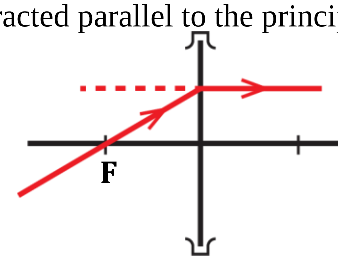
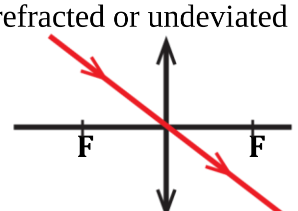
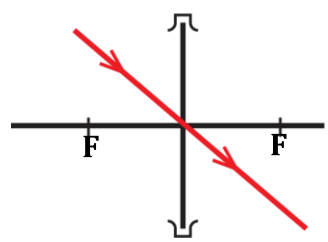


Principal focus, F of a diverging lens:
This is a point on the principal axis where all rays close and parallel to the principal axis appear to diverge from after refraction.



<u>Focal length (f)</u>:
This is the distance between the optical centre and the principal focus of the lens.

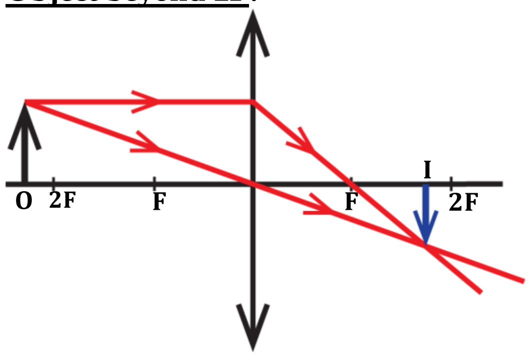
RULES FOR DRAWING RAY DIAGRAMS IN LENSES

<table>
<tr><th>CONVERGING LENS</th><th>DIVERGING LENS</th></tr>
<tr><td>1. A ray parallel to the principal axis is refracted passing through the principal focus, F.

</td><td>A ray parallel to the principal axis is refracted such that it appears to be coming from the principal focus, F.

</td></tr>
<tr><td>2. A ray passing through the principal focus is refracted parallel to the principal axis.

</td><td>A ray that pass through the principal focus is refracted parallel to the principal axis.

</td></tr>
<tr><td>3. A ray passing through the optical centre is not refracted or undeviated

</td><td>A ray passing through the optical centre is not refracted or undeviated

</td></tr>
</table>

IMAGES FORMED BY CONVEX (CONVERGING) LENSES

The nature of the image formed depends on the position of the object from the lens.

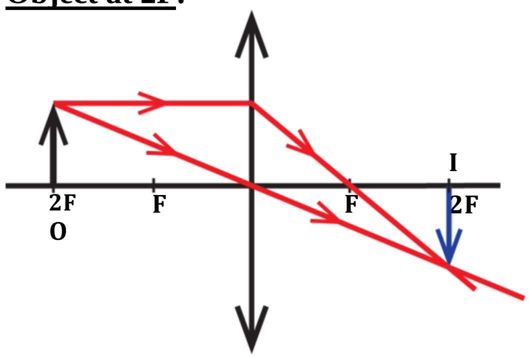
(a) <u>Object beyond 2F</u>:



<u>Nature of image, **I** formed</u>:

- ✓ Between F and 2F.
- ✓ Real
- ✓ Inverted (upside down)
- ✓ Diminished (smaller than object)

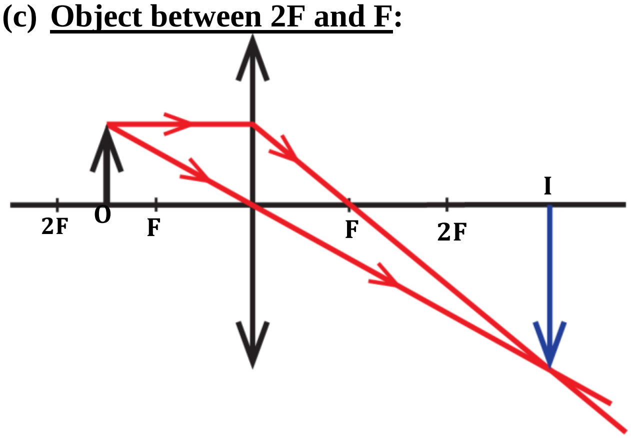
(b) <u>Object at 2F</u>:



<u>Nature of image, **I** formed</u>:

- ✓ Between at 2F.
- ✓ Real
- ✓ Inverted (upside down)
- ✓ Same size as object

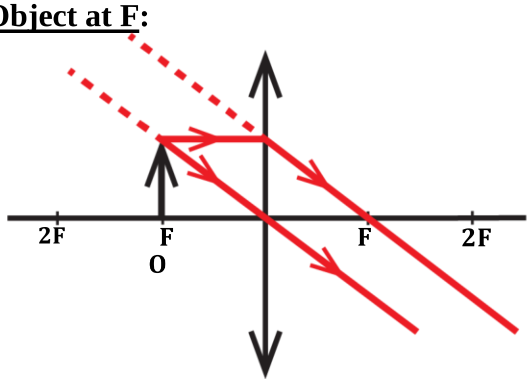
(c) <u>Object between 2F and F</u>:



<u>Nature of image, **I** formed</u>:

- ✓ Beyond 2F.
- ✓ Real
- ✓ Inverted (upside down)
- ✓ Magnified (bigger than object)

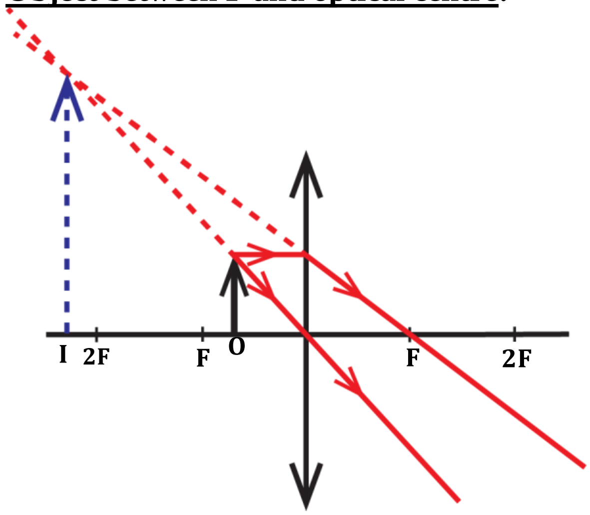
(d) <u>Object at F</u>:



<u>Nature of image, **I** formed</u>:

- ✓ At infinity.
- ✓ Magnified

(e) <u>Object between F and optical centre</u>:

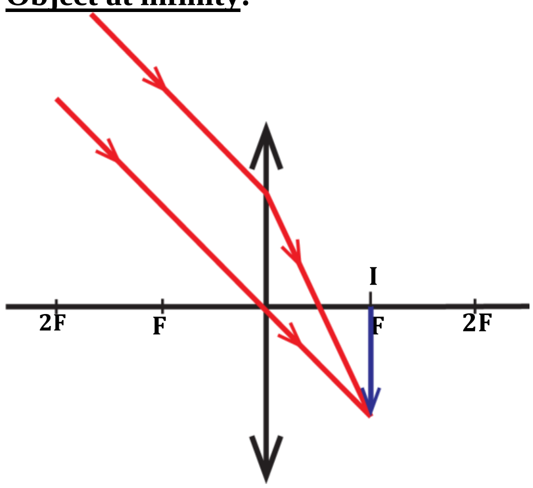


<u>Nature of image, **I** formed</u>:
- ✓ Beyond 2F.
- ✓ Virtual
- ✓ Upright
- ✓ Magnified

NOTE:

A converging lens acts as a magnifying glass when the object is placed between the principal focus and the optical centre.

(f) <u>Object at infinity</u>:

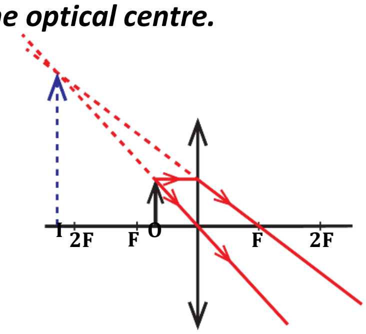


<u>Nature of image, **I** formed</u>:
- ✓ Formed at F.
- ✓ Real
- ✓ Inverted (upside down)
- ✓ Diminished (smaller than object)

QN:

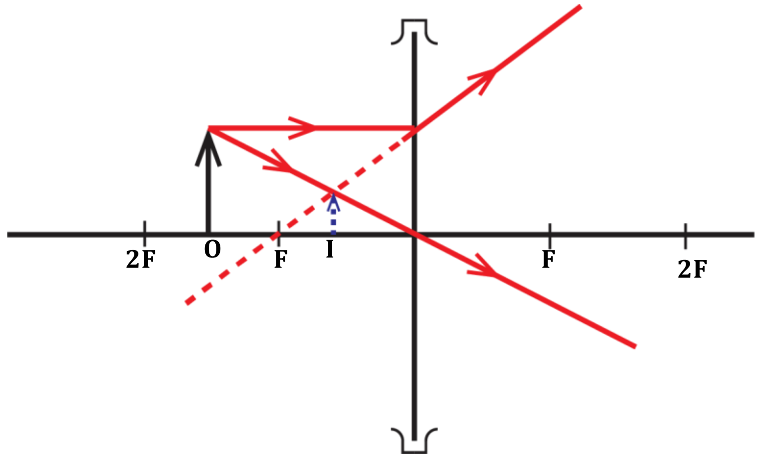
Explain how a converging lens can be used as a magnifying glass.

A converging lens can used as a magnifying glass when the object is placed between the principal focus and the optical centre.



IMAGES FORMED BY CONCAVE (DIVERGING) LENSES

For all positions of the object, the image formed by a concave lens is always virtual, upright and diminished.



CONSTRUCTION OF ACCURATE RAY DIAGRAMS ON A GRAPH PAPER

Steps taken:

- Draw a horizontal line which acts as the principal axis.
- Choose a suitable scale for the object and its position depending on the given distances.
- Measure focal length, f and mark positions F and 2F ($\boldsymbol{Recall}: \mathbf{2F = 2f}$)
- Use any two rules to draw ray diagrams.

Examples:

1. An object of height 4cm is placed at a distance of 60cm from a converging lens of focal length 20cm. Find by scale drawing the position, height and nature of the image.

Axis	Scale	Conversion
Vertical axis	$\mathbf{1: 2cm}$	▪ Height of object, O: $\frac{4}{2} = 2cm$
Horizontal axis	$\mathbf{1: 10cm}$	▪ Focal length, f: $\frac{20}{10} = 2cm$ ▪ Object distance, U: $\frac{60}{10} = 6cm$

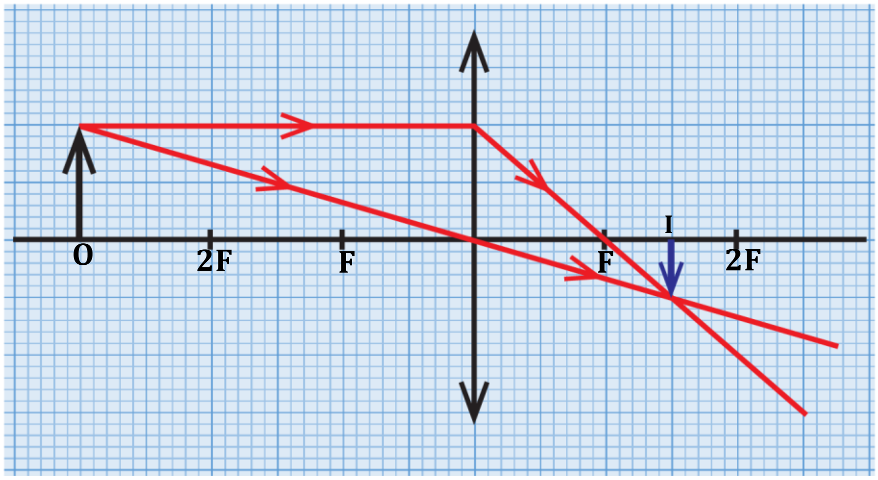


Image position, V

Hint: (3×10)

$\boldsymbol{V = 30cm}$

Nature of image

- *Inverted*
- *Diminished*
- *Real*

Size of image

Hint: (1×2)

$\boldsymbol{h_i = 2cm}$

2. An object of height 2cm is placed at a distance of 10cm from a converging lens of focal length 30cm. Find by scale drawing the position, the height and the nature of the image.

Axis	Scale	Conversion
Vertical axis	$\mathbf{1: 1}\boldsymbol{cm}$	▪ Height of object, O: $\frac{2}{1} = 2cm$
Horizontal axis	$\mathbf{1: 10}\boldsymbol{cm}$	▪ Focal length, f: $\frac{30}{10} = 3cm$ ▪ Object distance, U: $\frac{10}{10} = 1cm$

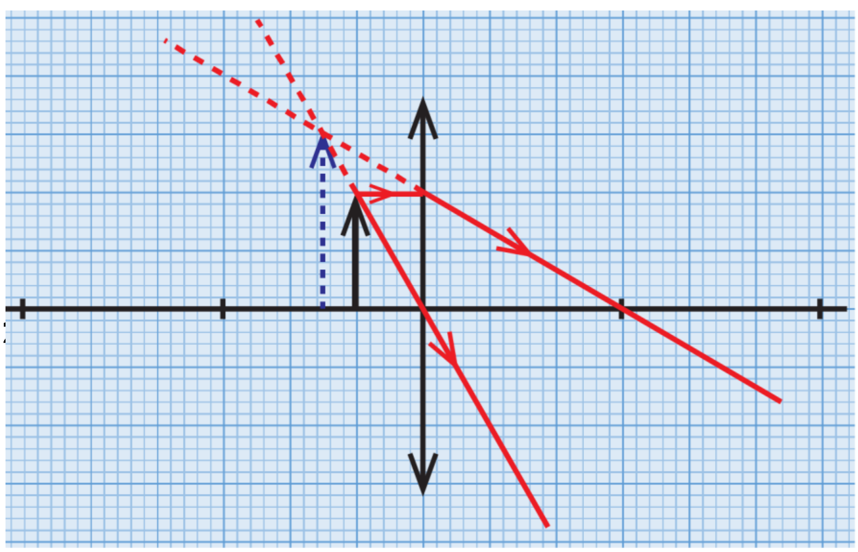


Image position, V

Hint: (1.5×10)

$\boldsymbol{V = 15cm}$

Nature of image

- *Upright*
- *Magnified*
- *Virtual*

Height of image

Hint: (3×1)

$\boldsymbol{h_i = 3cm}$

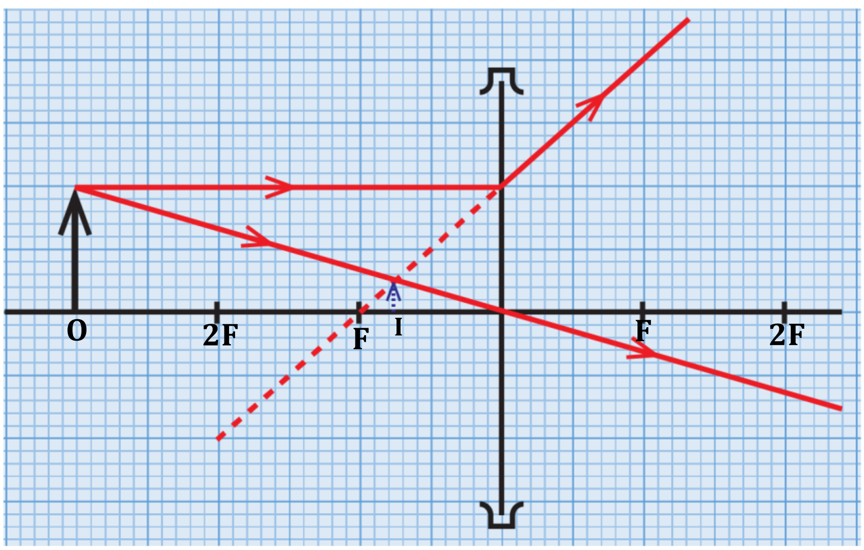
Magnification

$\boldsymbol{M = \frac{v}{u} = \frac{15}{10}}$

$\boldsymbol{M = 1.5}$

3. An object of height 10cm is placed at a distance of 60cm from a diverging lens of focal length 20cm. Find by accurate diagrams, the;
   i) Image position
   ii) Height of image
   iii) Nature of image
   iv) Magnification

Axis	Scale	Conversion
Vertical axis	$\mathbf{1:5cm}$	▪ Height of object, O: $\frac{10}{5} = 2cm$
Horizontal axis	$\mathbf{1:10cm}$	▪ Focal length, f: $\frac{20}{10} = 2cm$ ▪ Object distance, U: $\frac{60}{10} = 6cm$



i) ***Image position, V***
Hint: (1.5×10)
$\boldsymbol{V = 15cm}$

ii) ***Height of image***
Hint: (0.5×5)
$\boldsymbol{h_i = 2.5cm}$

iii) ***Nature of image***
- *Upright*
- *Diminished*
- *Virtual*

iv) ***Magnification***

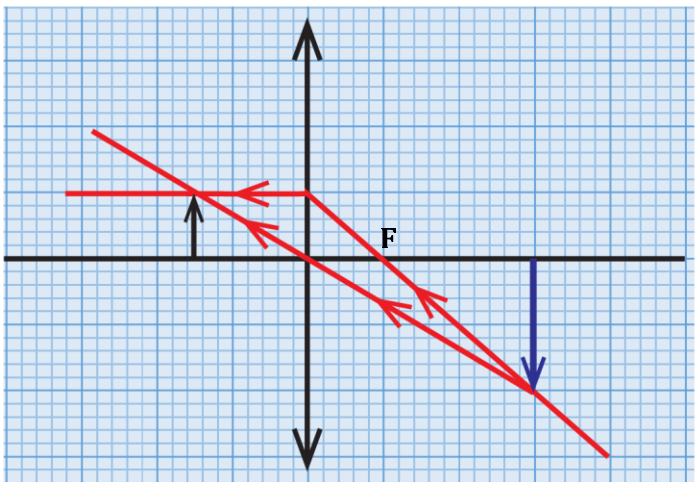
$$\boldsymbol{M = \frac{v}{u}}$$

$$\boldsymbol{M = \frac{15}{60}}$$

$$\boldsymbol{M = 0.25}$$

4. An object 5cm tall placed in front of a converging lens forms an inverted image 10cm tall and 30cm from the lens. By construction, find the position of the object and focal length of the lens.

Axis	Scale	Conversion
Vertical axis	$\mathbf{1:5\boldsymbol{cm}}$	▪ Height of object, O: $\frac{5}{5} = 1cm$ ▪ Height of image, I: $\frac{10}{5} = 2cm$
Horizontal axis	$\mathbf{1:10\boldsymbol{cm}}$	▪ Image distance, V: $\frac{30}{10} = 3cm$



Object position, U

Hint: (1.5×10)

$\boldsymbol{U = 15cm}$

Focal length, f

Hint: (1×10)

$\boldsymbol{f = 10cm}$

Recall: Light rays are reversible

5. An object 32.5cm from a diverging lens of focal length 12cm. By scale drawing and using height of your own choice, find the position and nature of the image.

Let height of object be 10cm

Axis	Scale	Conversion
Vertical axis	$\mathbf{1:5\boldsymbol{cm}}$	▪ Height of object, O: $\frac{10}{5} = 2cm$
Horizontal axis	$\mathbf{1:5\boldsymbol{cm}}$	▪ Focal length, f: $\frac{12}{5} = 2.4cm$ ▪ Object distance, U: $\frac{32.5}{5} = 6.5cm$

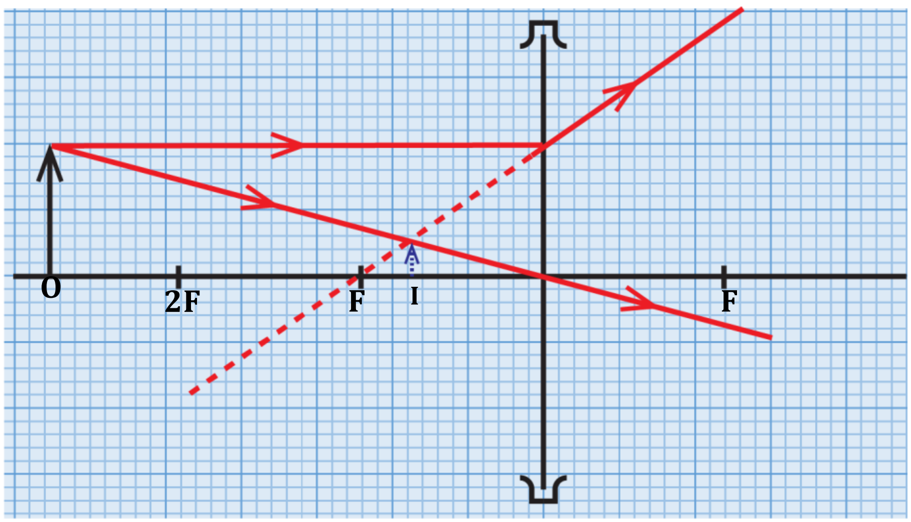


Image position, V

Hint: (1.75×5)

$\boldsymbol{V = 8.75cm}$

Nature of image

- *Upright*
- *Diminished*
- *Virtual*

LENS FORMULA

The both formula for both converging and diverging lenses is given by;

$$\frac{\mathbf{1}}{\boldsymbol{f}} = \frac{\mathbf{1}}{\boldsymbol{u}} + \frac{\mathbf{1}}{\boldsymbol{v}}$$

$$\begin{aligned} where\ \boldsymbol{f} &= focal\ length \\ \boldsymbol{u} &= object\ distance \\ \boldsymbol{v} &= image\ disatnce \end{aligned}$$

Sign convention;

It states that "**real**" is positive and "**virtual**" is negative.

Note:

When calculating using the lens formula;

- The focal length, image distance and object distance of a converging lens are positive.
- The focal length and image distance of a diverging lens are negative but the object distance remains positive.

Examples;

1. An object of height 10cm is placed at a distance of 60cm from a diverging lens of focal length 20cm. Find the position of the image and state its nature.

$\boldsymbol{u = 60cm, v = ?, \ f = -20cm}$

Image position;

$$\frac{\mathbf{1}}{\boldsymbol{f}} = \frac{\mathbf{1}}{\boldsymbol{u}} + \frac{\mathbf{1}}{\boldsymbol{v}}$$

$$\frac{\mathbf{1}}{\mathbf{-20}} = \frac{\mathbf{1}}{\mathbf{60}} + \frac{\mathbf{1}}{\boldsymbol{v}}$$

$$\frac{\mathbf{1}}{\mathbf{-20}} - \frac{\mathbf{1}}{\mathbf{60}} = \frac{\mathbf{1}}{\boldsymbol{v}}$$

$$\frac{\mathbf{1}}{\boldsymbol{v}} = \frac{\mathbf{-1}}{\mathbf{15}}$$

$$\boldsymbol{v = -15cm}$$

The image is;

- Virtual (since V is negative)
- Upright and diminished (it is a diverging lens)

2. An object of height 4cm is placed at a distance of 60cm from a converging lens of focal length 30cm. Find the position and height of the image.

$\boldsymbol{u = 60cm, v = ?, \ f = 30cm, h_o = 4cm}$

Image position;

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{1}{30} = \frac{1}{60} + \frac{1}{v}$$
$$\frac{1}{30} - \frac{1}{60} = \frac{1}{v}$$
$$\frac{1}{v} = \frac{1}{60}$$
$$v = 60cm$$

$$\frac{v}{u} = \frac{h_i}{h_o}$$
$$\frac{60}{60} = \frac{h_i}{4}$$
$$h_i = 4cm$$

POWER OF A LENS

Power of a lens is the reciprocal of its focal length in metres.
Its SI unit is Dioptres (**D).**

$$\text{Power of a lens} = \frac{1}{\text{focal length}(m)}$$

$$P = \frac{1}{f(m)}$$

Examples:

1. Calculate the power of a converging lens of focal length 10mm.

$$f = 10mm = \frac{10}{1000} = 0.01m$$
$$P = \frac{1}{f}$$

$$P = \frac{1}{0.01}$$
$$P = 100D$$

2. Calculate the power of a diverging lens of focal length 10cm.

$$f = -10cm = \frac{-10}{100} = -0.1m$$
$$P = \frac{1}{f}$$

$$P = \frac{1}{-0.1}$$
$$P = -10D$$

NOTE:

If two lenses are combined, we get their total power of combination.

$$\text{Total power of combination} = \text{power of first lens} + \text{power of second lens}$$

3. Two converging lenses of focal length 15cm and 20cm are placed in contact. Calculate the power of combination.

$$f_1 = 15cm = \frac{15}{100} = 0.15m$$
$$f_2 = 20cm = \frac{20}{100} = 0.2m$$

$$P = P_1 + P_2$$
$$P = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P = \frac{1}{0.15} + \frac{1}{0.2}$$
$$P = 11.67D$$

4. A converging lens of focal length 20cm is placed in contact with a diverging lens of focal length 100mm. find the power of the combination.

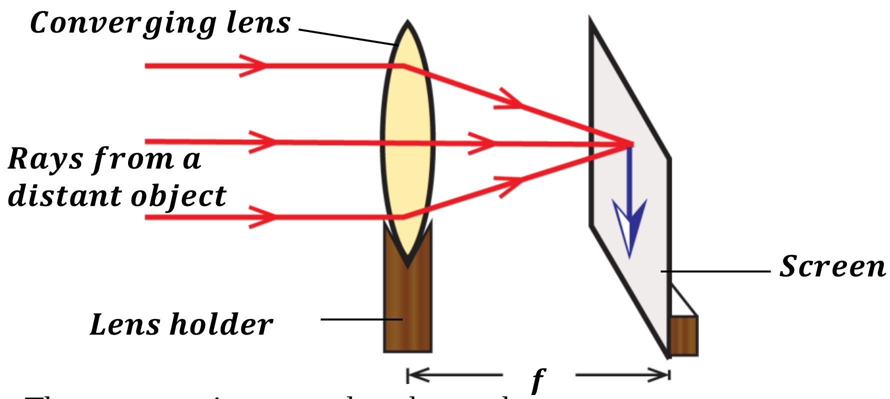
$$f_1 = 20cm = \frac{20}{100} = 0.2m$$
$$f_2 = -100mm = \frac{-100}{1000} = -0.1m$$

$$P = P_1 + P_2$$
$$P = \frac{1}{f_1} + \frac{1}{f_2}$$
$$P = \frac{1}{0.2} + \frac{1}{-0.1}$$
$$P = -5D$$

METHODS OF DETERMINING FOCAL LENGTH OF A CONCAVE MIRROR

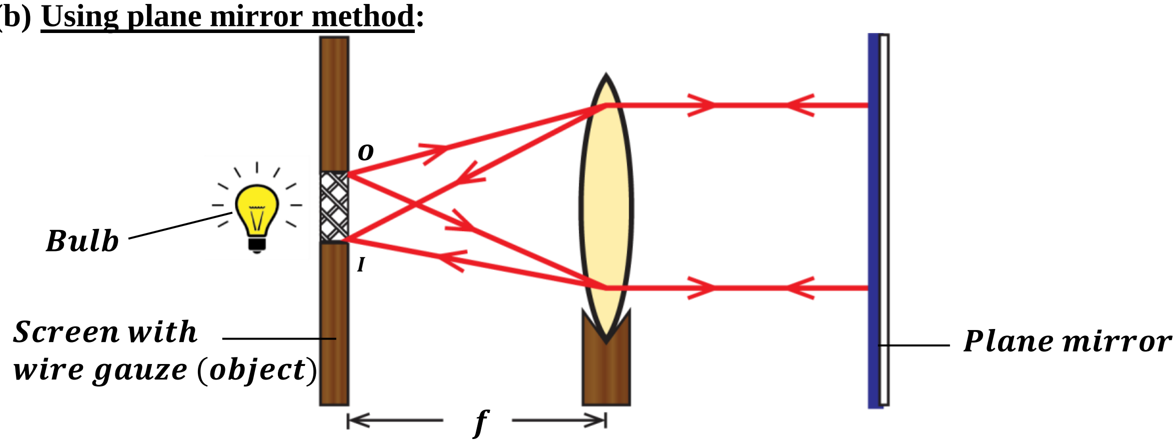
(Methods of determining radius of curvature of a concave mirror)

(a) Using a distant object/approximate/rough method:



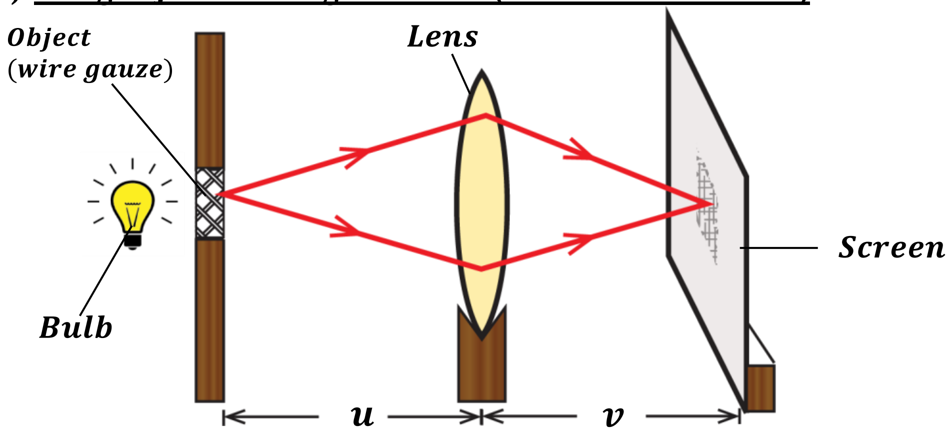
- The apparatus is arranged as shown above.
- Light from a distant object e.g. a window is focused onto the screen.
- The converging lens is moved to and fro until a sharp image of a distant object is obtained on the screen.
- The distance between the sharp image (screen) and the lens is measured and it is approximately equal to the focal length of the lens.

(b) Using plane mirror method:



- An illuminated wire gauze is placed in front of the converging lens.
- A plane mirror is placed behind the lens to reflect back the light that passes through the lens.
- The converging lens is moved to and fro until a sharp image of the wire gauze is formed on the screen near the object. At this point the image and the object will be at the principal focus.
- The distance between the lens and the screen is measured and it is equal to the focal length, f of the converging lens.

(c) Using object and image distances (Lens formula method):



- The apparatus is arranged as shown above with the lens between the screen and the object.
- The lens is placed at a known distance, **u** from the wire gauze.
- The screen is moved to and fro until a clear image of the object is formed on it.
- The image distance, V is then measured and recorded.
- The experiment is repeated for different values of object distance, **u** and the corresponding values of image distance are obtained.
- The results are tabulated including values of $\frac{1}{u}$ and $\frac{1}{v}$.

$\boldsymbol{u}$	$\boldsymbol{v}$	$\boldsymbol{\frac{1}{u}}$	$\boldsymbol{\frac{1}{v}}$

- The focal length for all values is calculated from;

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

- The accurate focal length is obtained by getting the mean value of the calculated focal lengths.

APPLICATIONS OR USES OF LENSES

- The eye uses a lens to focus images on the retina.
- Lenses are used in spectacles to correct eye defects.
- Lenses are used in lens cameras.
- Lenses are used in projectors.
- Lenses are used in microscopes.

OPTICAL INSTRUMENTS

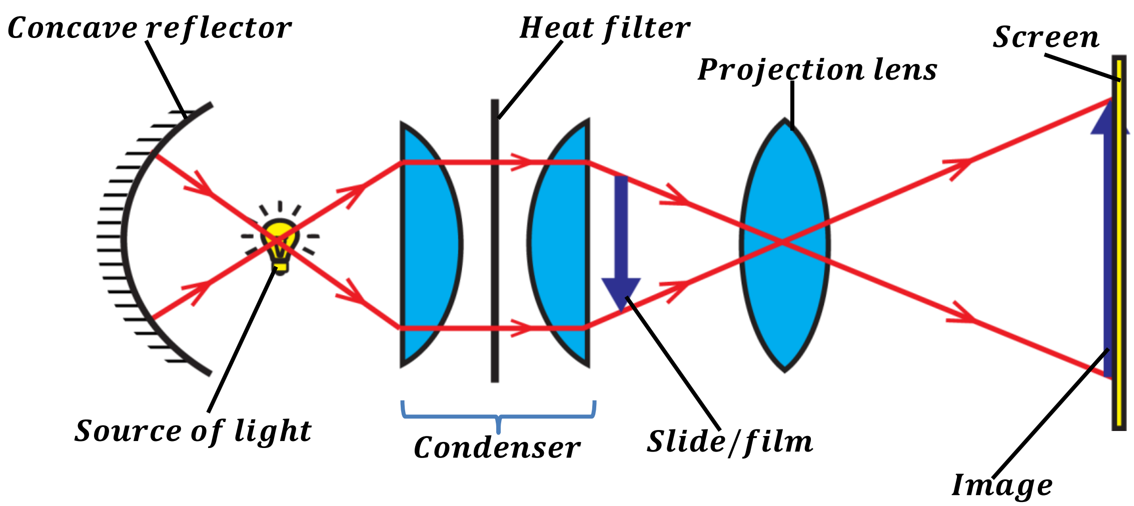
(Applications of lenses)

Optical instruments help us to see near and far objects clearly.
They include;

- Slide projectors
- Lens cameras
- Human eye
- Telescopes
- Periscopes
- Microscopes

SLIDE PROJECTORS

The projector is used to project the image of a slide onto the screen. It forms a real image.



Functions of the parts of the projector:

Source of light:
It provides a powerful beam of light which illuminates the whole system.

Concave reflector:
It reflects back light rays that would have been wasted.

Condenser:
It is made up of two plano-convex lenses which converge and concentrate light onto the slide.

Slide / film:
It acts as the object whose image is to be projected.

Projection lens:
It magnifies the image of the slide on the screen.

Screen:
This is where the real image of the slide is formed.

Heat filter:
It absorbs any heat from the source which would melt the slide.

Examples:

1. A projection lens is used to produce a sharp image of an object when the object and the screen are 160cm apart. If the linear magnification is 7, calculate the focal length of the lens used.

$M = 7,\quad \boldsymbol{u + v = 160cm \Rightarrow v = 160 - u}$

$$\boldsymbol{M = \frac{v}{u}}$$
$$\boldsymbol{7 = \frac{160 - u}{u}}$$
$$\boldsymbol{7u + u = 160}$$
$$\boldsymbol{u = \frac{160}{8}}$$
$$\boldsymbol{u = 20cm}$$
$$\boldsymbol{v = 160 - 20}$$
$$\boldsymbol{v = 140cm}$$

$$\boldsymbol{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$$
$$\boldsymbol{\frac{1}{f} = \frac{1}{20} + \frac{1}{140}}$$
$$\boldsymbol{\frac{1}{f} = \frac{2}{35}}$$
$$\boldsymbol{f = \frac{35}{2}}$$
$$\boldsymbol{f = 17.5cm}$$

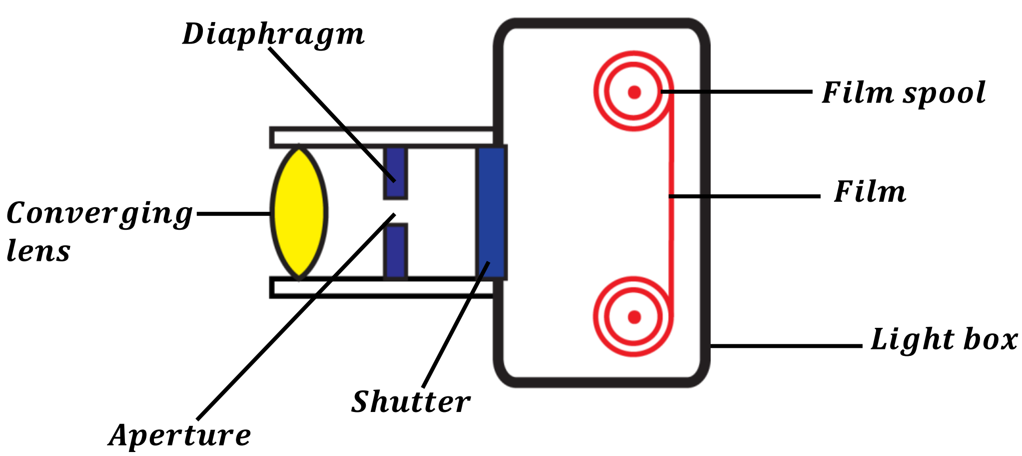
2. A slide projector using slide 5cm by 5cm produces a picture of 3cm by 3cm on the screen at a distance of 24cm from the projection lens. How far from the lens must the slide be?

$\boldsymbol{h_0 = 5cm \quad h_i = 3cm \quad v = 24cm}$

$$\boldsymbol{\frac{h_i}{h_0} = \frac{v}{u}}$$
$$\boldsymbol{\frac{3}{5} = \frac{24}{u}}$$
$$\boldsymbol{u = \frac{24 \times 5}{3}}$$
$$\boldsymbol{u = 40cm}$$

LENS CAMERA

It consists of a light-tight box with a convex lens at the front side.
It has a light sensitive film at the back on which a real, inverted and diminished image.
The inner surface is painted black to prevent the reflection of stray rays of light which would blur the image.



Functions of the parts of the lens camera:

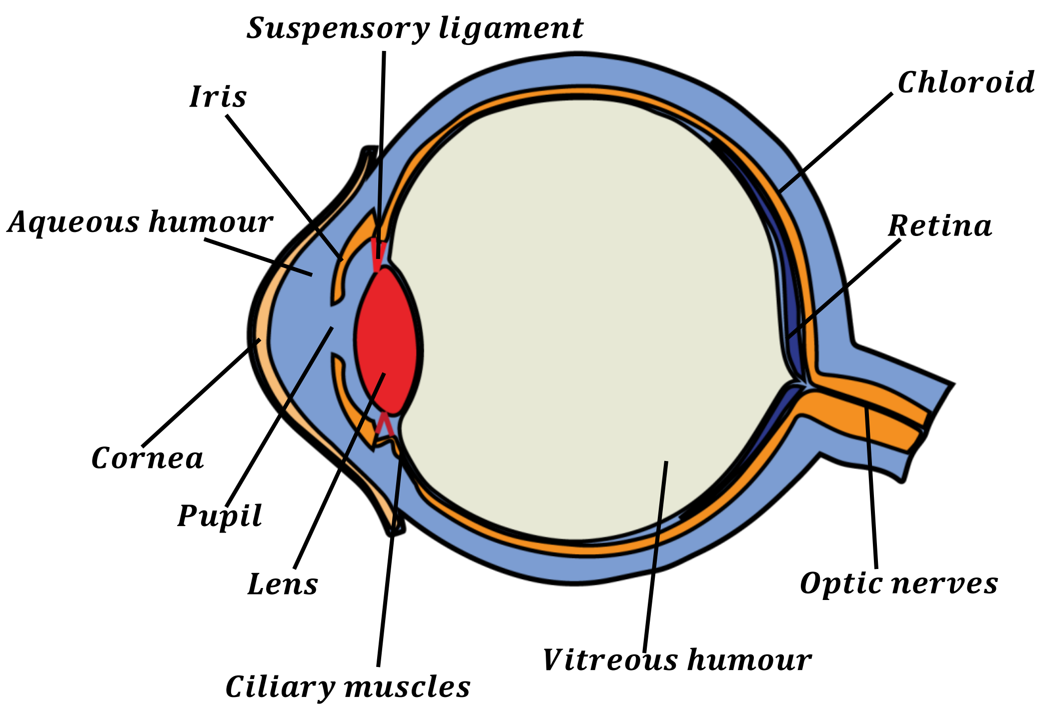
Converging lens:
It focuses the image of the object on the film.

Diaphragm:
It controls the size of the aperture thus controlling the amount of light entering the camera.
The brightness of the image depends on the amount of light entering the camera.

Shutter:
It controls the amount of light reaching the film.

Film:
It is a light-sensitive part where a real, inverted and diminished image is formed.

HUMAN EYE



Light enters the eye through the cornea. The eye lens focusses the image of the object onto the retina.
The retina is sensitive to light and sends messages to the brain through the optic nerves.
Light entering the eye is controlled by the iris.
The lens changes its size so as to focus images of far and near objects on the retina and this is referred to as <u>accommodation</u>.

Functions of the parts of the eye:

Lens:
The convex lens changes in size so as to focus light onto the retina.

Ciliary muscle:
This changes the focal length of the eye lens by changing its size.

Iris:
It controls the amount of light entering the eye by regulating the size of the pupil.

Retina:
This is where the image is formed.

Optic nerves:
They transmit signals of the image from the retina to the brain for interpretation.

NOTE:

- Eye brows stop sweat from running into the eyes.
- Eye lashes help to stop dust blowing into the eye.
- Blinking of the eye prevents dust and other particles from reaching the surface of the cornea.

Important definitions

Accommodation: This is the ability of the eye to change the focal length of its lens so as to focus images of near and far objects on the retina.
OR
This is the ability of the eye to focus images of near and far objects on the retina by changing the size of the eye lens.

Near point: This is the closest or nearest point at which an eye can have a clear vision/image. For a normal eye, the near point is 25cm.

Far point: This is the most distant or furthest point at which the eye can have a clear vision/image.
For a normal eye, the far point is at infinity.

EYE DEFECTS AND THEIR CORRECTIONS

This is a situation where the eye is unable to focus images of near and far objects on the retina.

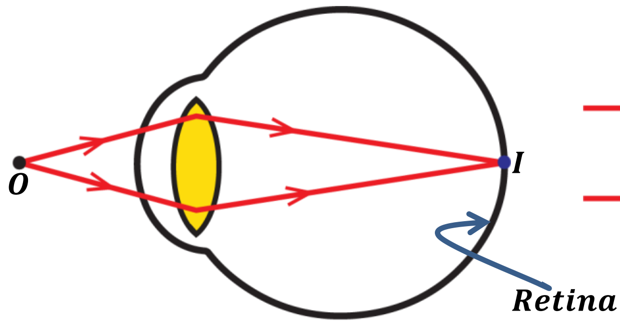
There are two common eye defects namely;

- Short sightedness (Myopia)
- Long sightedness (Hypermetropia)

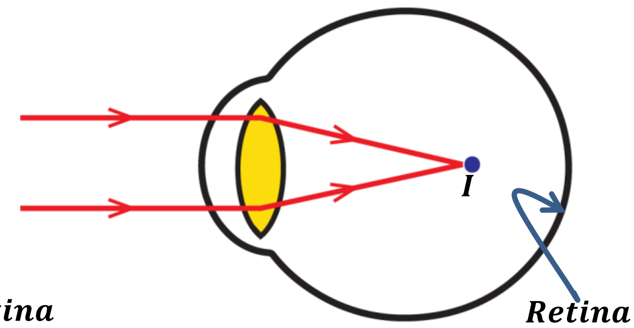
SHORT SIGHTEDNESS (MYOPIA)

A short-sighted person can see nearby objects clearly but cannot see far objects clearly.
The images of the near objects are formed on the retina.
The images of far objects are formed in front of the retina because the eye ball is too long.
This causes a shorter focal length of the eye lens.

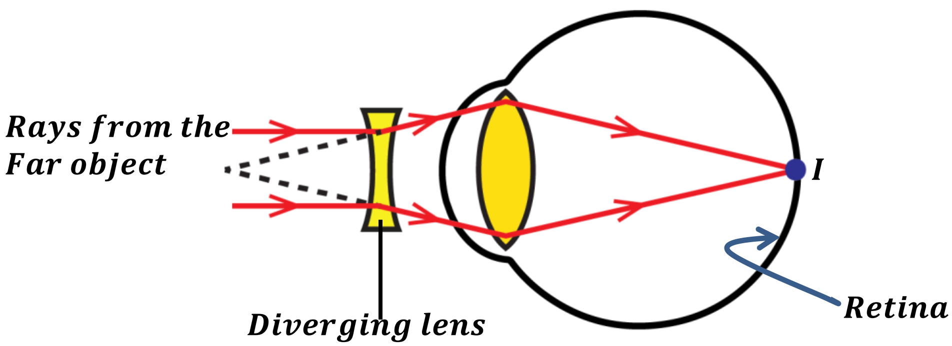
Nearby object



Far object



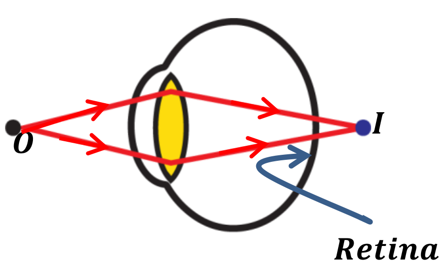
Correction of short sightedness:
It is corrected by wearing spectacles containing a diverging (concave) lens.
The diverging lens diverges the light rays from the far object before entering the eye and the convex lens of the eye converges the diverged rays onto the retina thus forming a clear image.



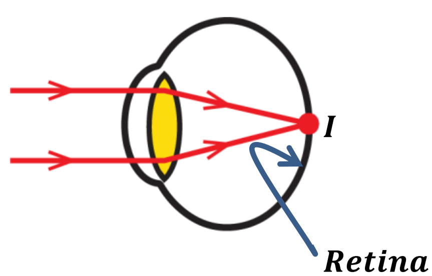
LONG SIGHTEDNESS (HYPERMETROPIA)

A long-sighted person can see far objects clearly but cannot see nearby objects clearly.
The images of the far objects are formed on the retina.
The images of nearby objects are formed behind the retina because the eye ball is too short.
This causes a longer focal length of the eye lens.

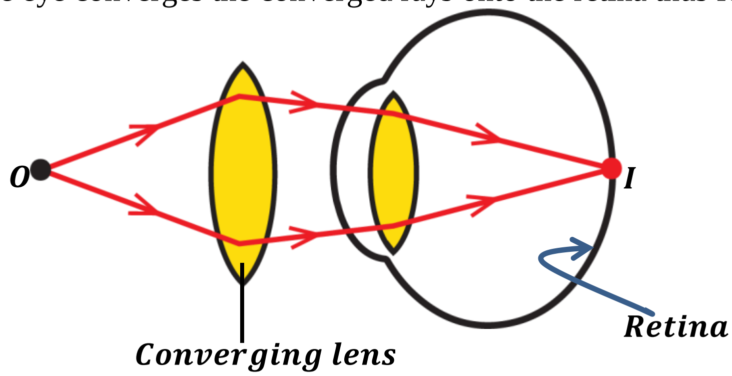
Nearby object



Far object



<u>Correction of long sightedness</u>:
It is corrected by wearing spectacles containing a converging (convex) lens.
The converging lens converges the light rays from the near object before entering the eye and the convex lens of the eye converges the converged rays onto the retina thus forming a clear image.



<u>Astigmatism</u>:
This is where light rays entering the eye fails to come to a single focus point. The person sees a distorted image. A person suffering from astigmatism faces eye strains and headaches after prolonged reading and watching televisions.

<u>SIMILARITIES BETWEEN THE EYE AND THE CAMERA</u>

- Both have a convex lens.
- Both form a real, inverted and diminished image.
- Both have a system which controls the amount of light entering i.e. Iris is to eye and Diaphragm is to camera.
- Both have a light sensitive part where images are formed i.e. retina is to eye and film is to camera.
- The camera is painted black inside and the eye is impregnated with a black pigment called choroid.

<u>DIFFERENCES BETWEEN THE EYE AND CAMERA</u>

Human eye	Lens camera
• The eye lens is biological (natural). • The eye lens has a changing focal length. • The distance between the eye lens and retina is fixed. • Forms an image on the retina. • Amount of light entering the eye is controlled by the iris.	• The camera lens is artificial. • The camera lens has a fixed focal length. • The distance between the camera lens is adjustable. • Forms an image on the film. • Amount of light entering the camera is controlled by the diaphragm.

COLOURS AND DISPERSION OF LIGHT

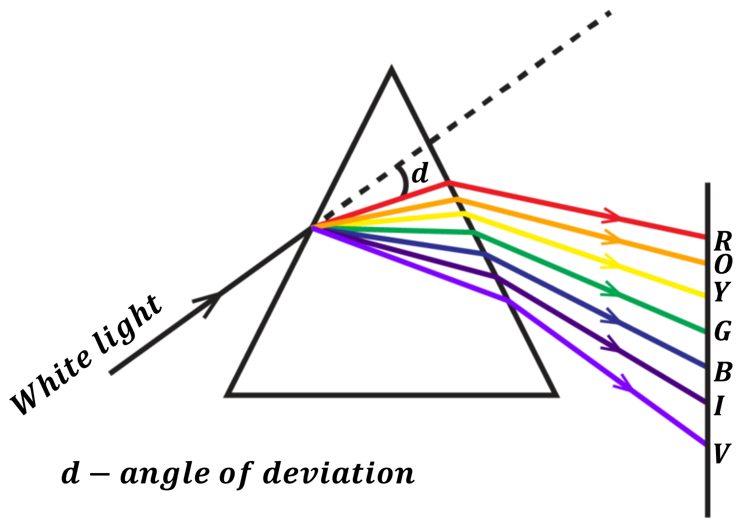
Colours of objects depend on the colour of light which reaches our eyes.
It is proved that white light is made up of a mixture (band) of seven colours i.e. Red, Orange, Yellow, Green , Blue, Indigo and Violet. (ROYGBIV)
This band of colours in white light is referred to as a **spectrum**.
Definition;

A **spectrum** is a band of seven colours that form white light.

DISPERSION OF WHITE LIGHT:

- **Dispersion** is the splitting of white light into its constituent colours.

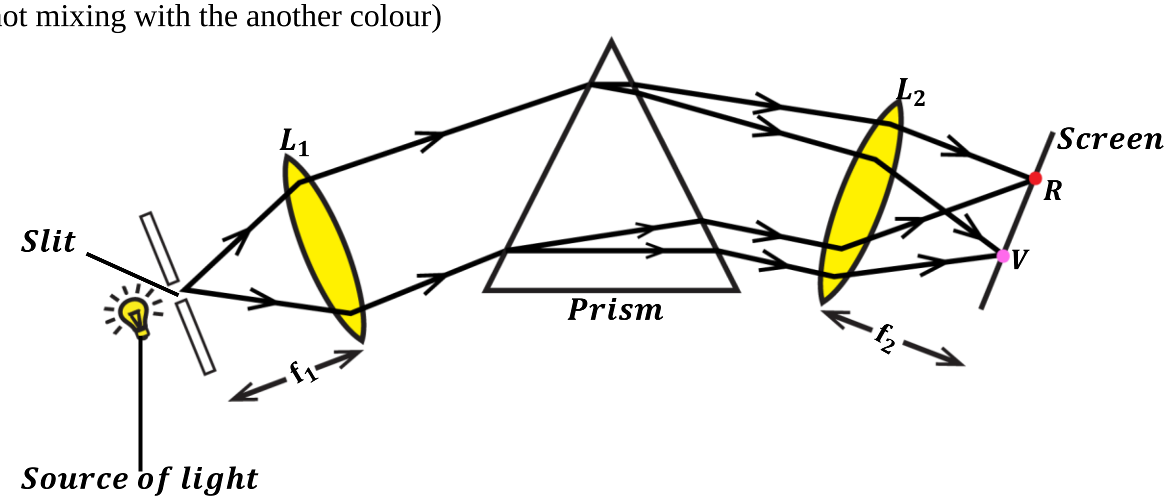
When white light is passed into a prism, it is deviated and separated into seven colours. This is because the refractive index for a prism is different for each colour.
Therefore, each colour moves at a different speed.



- Red colour which has the least refractive index is deviated least.
- Violet colour which has the highest refractive index is deviated most.

PURE SPECTRUM

A **pure spectrum** is a spectrum is a spectrum in which the colours do not overlap (i.e. one colour not mixing with the another colour)



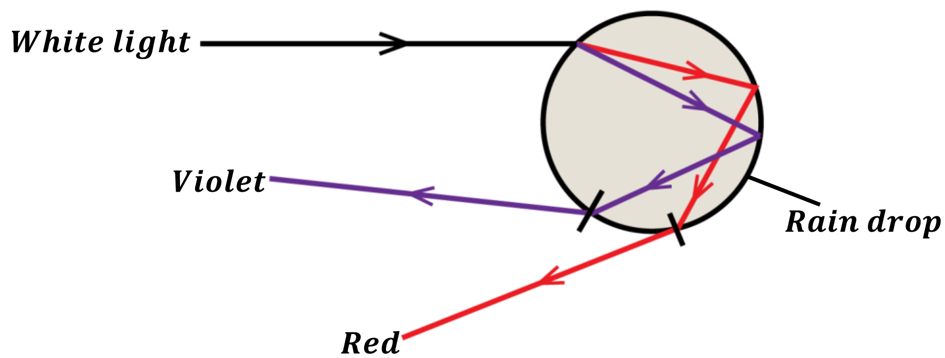
- An illuminated slit is placed at the principle focus of the first converging lens, L_1.
- The converging lens, L_1 converges a parallel beam of light onto the prism.
- Dispersion of light occurs at the prism thus separating the light into different colours.
- A second converging lens, L_2 is placed at the other side of the prism.
- A screen is then placed at the principle focus of the second converging lens, L_2.
- The second converging lens, L_2 focus each constituent colour of white light onto the screen at different points without overlapping hence forming a pure spectrum.

NOTE:

- ❖ The first lens, L_1 helps to produce a parallel beam of light from the source of light (i.e. rays from the principal focus are refracted as parallel)
- ❖ The slit should be made narrow to reduce the overlapping of colours.
- ❖ The combination of the slit and first lens is called a collimator (to collimate means to make it parallel)

FORMATION OF A RAIN BOW

- When white light from the sun is incident on a rain drop in the atmosphere, it undergoes refraction and then dispersed into different colours of the spectrum.
- The spectrum is internally reflected back in the opposite direction from where it came from.
- The spectrum finally emerges out (refracts out) and this is viewed as a rain bow.



COLOURS

The colour of an object depends on the colour falling on it and the colour the object reflects. Therefore, an object absorbs all other colours and reflects the colour we see.

Examples

- ❖ A green leaf appears green in white light (day light) because the leaf absorbs all other colours in white light and reflects only green.
- ❖ White object appears white in white light because it absorbs no colour and reflects all the colours in white light.
- ❖ A blue shirt appear black in a dark room because there is no light falling on it in a dark hence it reflects nothing.

TYPES OF COLOURS:
There are three types of colours namely;
- Primary colours
- Secondary colours
- Complementary colours

Primary colours:
These are colours which cannot be obtained by mixing any other colours.
Examples include; Red, Blue, and Green (**RGB)**

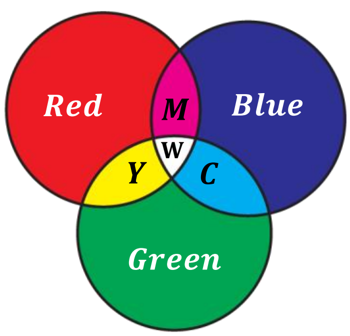
Secondary colours:
These are colours which are obtained by mixing any two primary colours.
Examples include;

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

Complementary colours:
These are colours which produce white light when mixed together.
Examples include;

$$Blue + Yellow = White$$
$$Red + Cyan = White$$
$$Green + Magenta = White$$

Note: When all the three primary colours are mixed together, white light is produced.



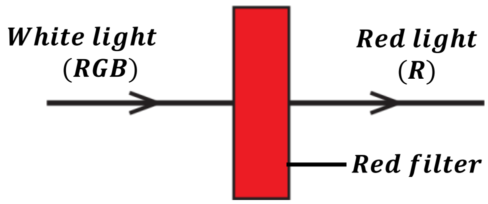
$\boldsymbol{Y - Yellow}$
$\boldsymbol{M - Magenta}$
$\boldsymbol{C - Cyan}$
$\boldsymbol{W - White}$

COLOUR FILTERS:
A colour filter is a transparent coloured material which allows light of its own colour type to pass through it and absorbs other colours.
That's to say;
- Green filter allows only green light to pass through it.
- White filter allows red, green and blue light to pass through it.
- Cyan filter allows only blue and green light to pass through it.
- Magenta filter allows only red and blue light to pass through it

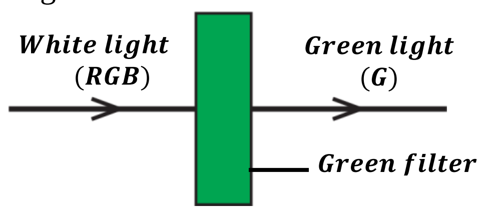
ETC

Examples:

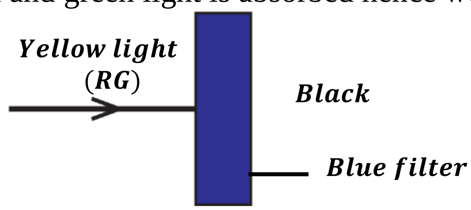
- When white light is incident on a red filter, it allows only red light to pass through it (transmits) and absorbs blue and green light.



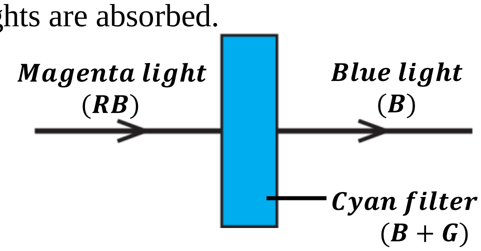
- A green filter allows only green light to pass through it and absorbs other colours when placed in white light.



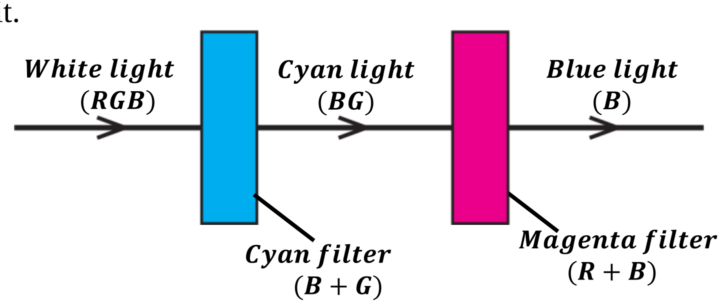
- When yellow light is incident on a blue filter, no colour is allowed to pass through it. Therefore, red and green light is absorbed hence we see black.



- When magenta light is incident on a cyan filter, only blue light will pass through it but red and green lights are absorbed.

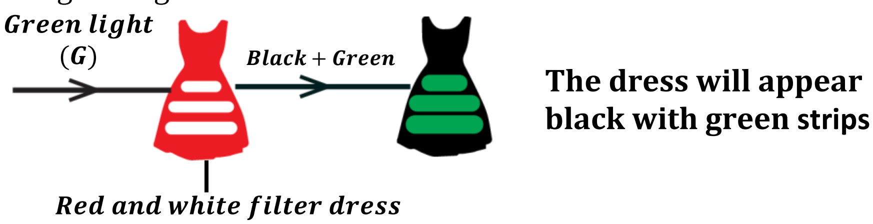


- When white light is incident on the cyan filter and then magenta filter; cyan filter allows only green and blue light to pass through it and then the magenta filter allows only blue light to pass through it.

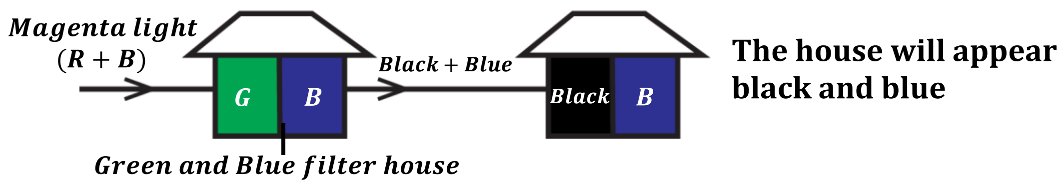


<u>Further examples</u>:

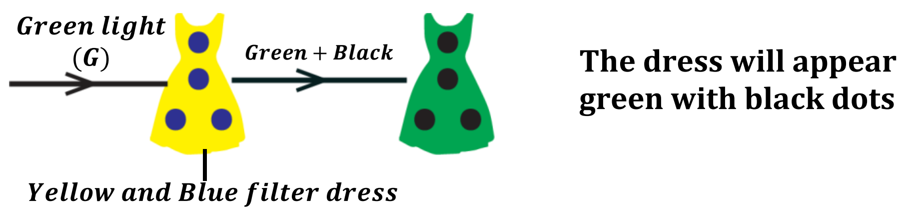
1. A girl wearing a red dress with white strips passes under green light. What will be the colour of her dress under green light?



2. A house is painted green and blue. What will be the colour of the house when viewed under magenta light?

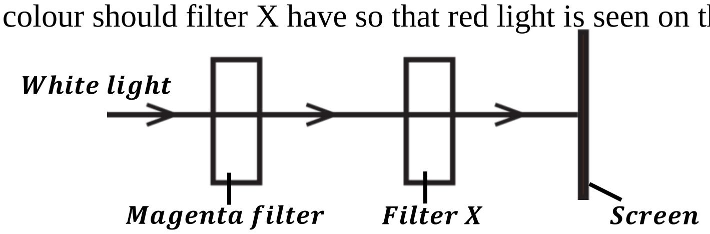


3. What colour will be observed when a girl wearing yellow dress with blue dots dances in a disco hall with green light?



EXERCISE:

1. What colour should filter X have so that red light is seen on the screen.



2. Explain the appearance of a student wearing a green sweater in a disco hall with yellow light.
3. Explain why an object why an object illuminated by white light appears black.
4. State why most car registration numbers plates are printed black on a yellow background.

EXAMINATION QUESTIONS

1.a) What is meant by focal length of a lens

b) Where should an object be placed in front of a converging lens in order to obtain

i) Diminished real image

ii) A real image, same size as the object

iii) A magnified real image

iv) A magnified virtual image

c) An object 4cm high is placed perpendicularly on the principal axis 10cm away from a converging lens of focal length 15cm. With the aid of a ray diagram, determine nature, position and magnification of the image formed

Ans: 30cm, 3

d) Mention two applications of the image formed

2.a) Define the following

i) Critical angle ii) Total internal reflection

b) Explain briefly why the sky appears blue

c) State two applications of a concave mirror

d) i) An object 8cm high is placed perpendicularly on the axis and 12cm away from a concave mirror. With the aid of a ray diagram, find the focal length of the mirror if the height of the image formed is 2cm

Ans: 2.4cm

ii) State the nature of the image formed in (i) above

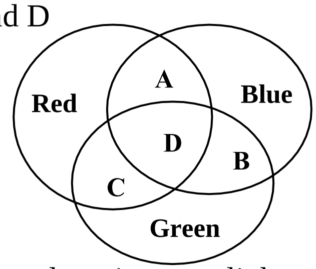
3.a) Explain dispersion as applied to light

b) i) What is a pure spectrum

ii) With the aid of a labeled diagram, describe briefly how a pure spectrum is produced

c) i) Distinguish between a primary and a secondary colour

ii) The figure below shows colours mixed by addition. Name the colours represented by letters labeled A, B, C and D



d) State the colour of a yellow dress in green light

4.a) Define the following as applied to a concave mirror

i) Centre of curvature

ii) Principal axis

b) State and explain one application of

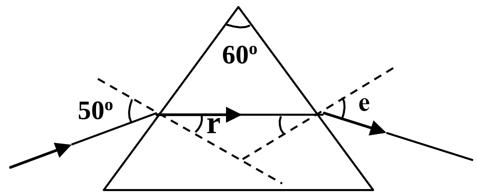
i) Concave mirror ii) Convex mirror

c) Describe an experiment to measure the focal length of a concave mirror

d) An object of height 1cm is placed 15cm in front of a concave mirror of focal length 10cm. If the object is perpendicular to the principal axis, find by construction the position, the size and nature of the image.

Ans: 30cm, 2cm

5. a) The diagram below shows a ray of yellow light incident at an angle of 50o on one side of an equilateral triangular glass prism of refractive index 1.52



i) Calculate the angles marked r and e

Ans: r = 30.3^0, e = 48.9^0

ii) State and explain what would be observed if the ray above were of white light

b) Explain, with the aid of a diagram, why the writing on a piece of paper placed under a glass block appears raised when observed from above

c) State

i) The conditions necessary for total internal reflection to occur

ii) One application of total internal reflection

6. a) i) State the laws of refraction of light

ii) Describe an experiment to verify the laws of refraction of light

b) An object 5cm tall placed in front of a converging lens, forms an inverted image twice as tall as the object and 30cm from the lens. By construction, find the position of the object, the focal length and power of the lens

Ans: 15cm, 10cm, 10D

c) A ray of light is incident on glass from air at an angle of 42o. If the refractive index of glass is 1.41, find the angle of refraction

Ans: 28.3^0

7. a) i) State the laws of reflection of light

ii) Describe an experiment to verify the laws of reflection of light

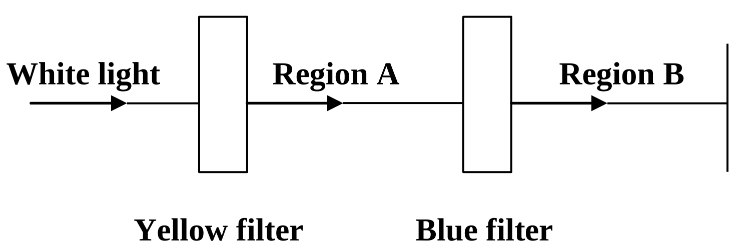
b) i) Define the term critical angle

ii) A ray of light moving from water to air at an angle of incidence of 48.6^0 has the angle of refraction of 90^0. Calculate the refractive index of water

Ans: 1.33

c) Distinguish between primary and secondary colours

d) White light is incident on two colour filters in the diagram below



i) State the colours that will be observed in regions A and B

ii) Explain the observation in (d) (i) above

8. a) Explain the term virtual image as applied to optics

b) With aid of a ray diagram, explain why a convex mirror is used as a driving mirror

c) An object is placed 15cm in front of a concave mirror. An upright image of magnification four is produced. By graphical method, determine the

i) Nature of the image
ii) Focal length of the mirror
iii) Distance of the image from the mirror

Ans: ii) 12cm iii) 60cm

d) Name two applications of a concave mirror

9. a) Explain the following terms as applied to a thin converging lens
   i) Principal focus
   ii) Focal length
   iii) Power

   b) An object is placed at right angles to the principal axis of a thin converging lens of focal length 10cm. A real image of height 5cm is formed at 30cm from the lens. Find by construction the position and height of the object.

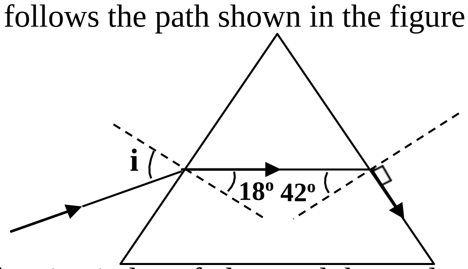
Ans: 15cm, 2.5cm

   c) With the aid of a ray diagram show how a converging lens can be used as a magnifying glass

10. a) With the aid of a diagram, explain briefly how a pure spectrum may be produced
   b) i) What are primary colours? Name them
   ii) Explain briefly what happens when white light falls on a green body
   c) With the aid of a labeled diagram, describe how a lens camera works

11. a) Explain the phenomenon of dispersion as applied to white light
   b) Draw a ray diagram to show the dispersion of white light by a glass prism
   c) Distinguish between secondary and primary colours. Give one example of each
   d) Name the colour that would be obtained when the following coloured lights are mixed
   i) Green and red ii) Cyan and red
   e) Explain why an object illuminated by white light appears
   i) Coloured
   ii) Black

12. a) Describe a simple method of measuring the refractive index of glass in form a block
   b) i) Explain, with the aid of a diagram, the term critical angle
   ii) Light of the same wave length is incident at an angle i on glass prism. The light is refracted and follows the path shown in the figure below



Find the refractive index of glass and the angle of incidence, i

Ans: n = 1.49, i = 27.4^0

13. a) Define
   i) The principal focus of a converging lens
   ii) A virtual image
   b) With the aid of a labeled diagram, describe a simple to determine the focal length of a

converging lens

c) An object of height 4cm is placed perpendicularly on the principal axis at a distance of 45cm from a converging lens of focal length 15cm. By graphical construction, determine

i) The position of the image

ii) The magnification

Ans: i) 22.5cm, 0.5

d) Give one use of converging lenses

14. a) i) Describe a simple experiment to show that light travels in a straight line

ii) An object 3cm high is placed at right angle to the principal axis of a concave mirror of focal length 7.5cm. If the object is 30cm from the pole of the mirror, construct a ray diagram to obtain the position and size of the image formed

iii) State two applications of a concave mirror

Ans: ii) 10cm, 1cm

b) i) State laws of refraction of light

ii) Light of the same wavelength is incident from air on glass of refractive index 1.5. If the angle of incidence is 60^0, find the angle of refraction

Ans: ii) 35.3^0

15. a) Describe an experiment to demonstrate the laws of reflection of light

b) With the aid of a diagram illustrate how shadows are formed when an opaque object is placed between an extended source of light and the screen

c) An object 10cm high is placed at a distance of 15cm from a convex mirror of focal length 30cm

i) Draw a ray diagram to locate the position of the image

ii) Calculate the magnification

Ans: i) 10cm **ii) 0.67**

d) Give reasons for use of convex mirrors in vehicles