S3 New Curriculum Physics

Theme: Light

Chapter 3 – Lenses and optical instrument

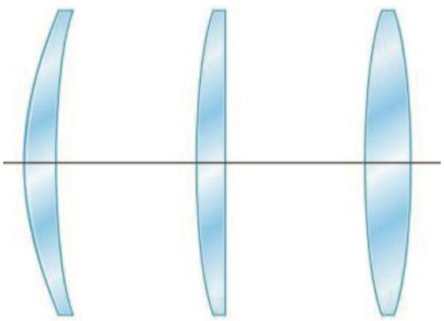
Lenses

Lenses are spherical surfaces of transparent materials. The materials maybe glass, plastics, water and so on.

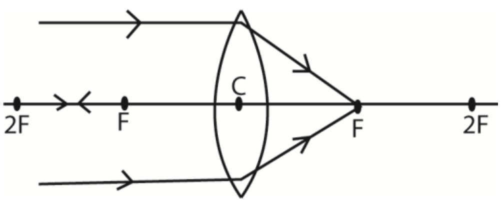
Types of lenses

They are two types namely:
(1) Converging lens (convex lens)
(2) Diverging lens (concave lens)

Converging lens

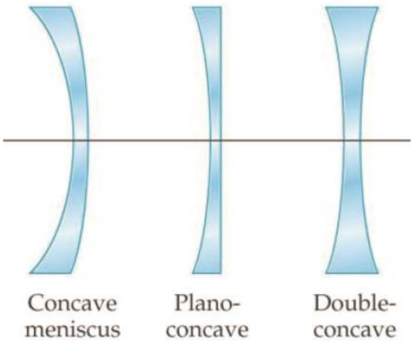


A convex lens is thick in the centre. It is also called converging lens because it bends light rays inwards.

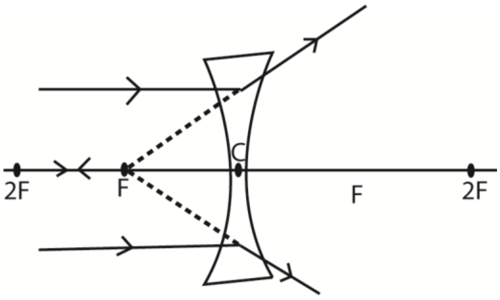


Principal axis is the line through the optical centre "C" of the lens on which the principal focus lies.
Principal focus is the point on the principal axis at which all rays parallel and closed to the principal axis meet after refraction.
Optical Centre: The optical centre is the centre between poles of the lens at which the principal axis passes.
The pole of a lens is the centre point of the surface of **the** lens through which the principal axis passes.

Divergent lenses



A concave lens is thinnest in the central and spreads light out. A concave lens is also called a divergent lens because all rays that are parallel diverge after refraction.



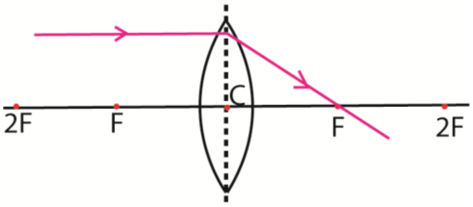
Types of divergent

The principal focus of a converging lens is real while that of the diverging lens is virtual. The refracted ray seems to come from the point after refraction.

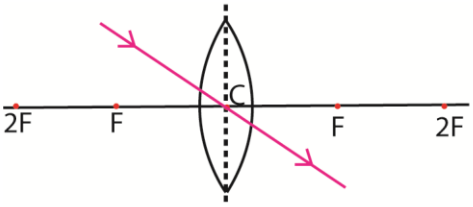
The real principal focus is one at which actual rays meet after refraction.
The focal .length is the distance between the principal focus and the optical centre.

RAY DIAGRAMS
An image can be formed by a lens when two of the following rays undergo refraction and meet at a point. The image will be formed by the meeting of refracted rays. The following are the rays which can be considered when drawing to obtain the image formed by a lens.

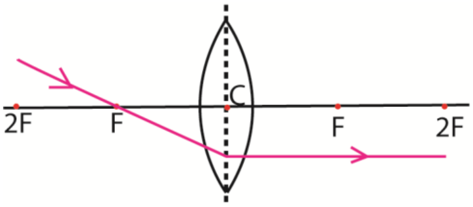
(1) A ray parallel to the principal axis is refracted through the principal focus. This ray can be selected from any point on the object.



(2) A ray through the optical centre (c) is undeviated, for a ray diagram, this ray is a line joining "C" to the point of the object where the parallel ray was selected.

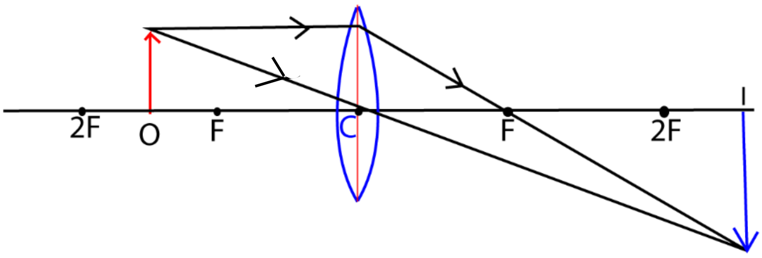


(3) A ray through the principal focus is refracted parallel to the principal axis.



Ray diagram for various positions of the object in a converging lens

(a) **Object at distance between f and 2f from lens.**



The image is real inverted, magnified.

(b) **Object at 2f**

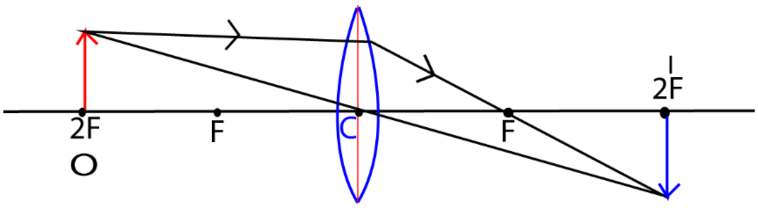
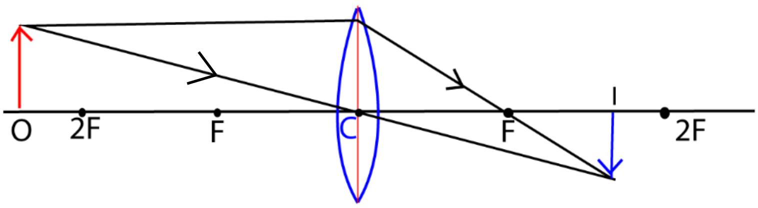


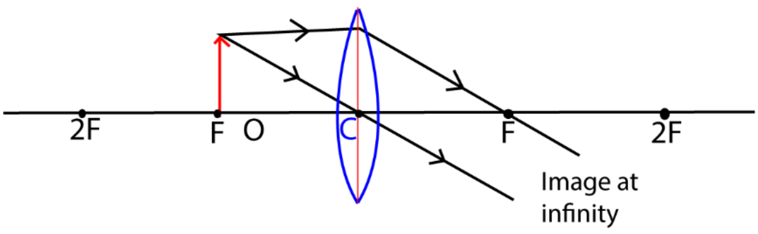
Image is: real, inverted, same size as the object

(c) Object at a distance greater than 2f from the lens

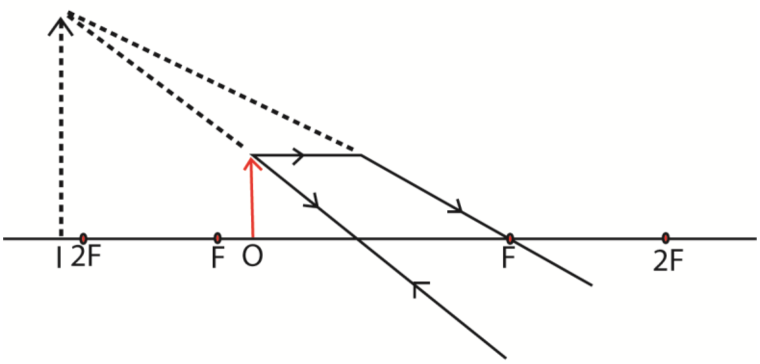


The image is: real, inverted diminished,

(d) Object at f.

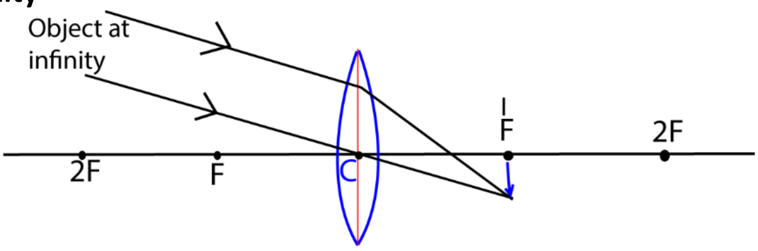


(e) Object at distance less than f from the lens



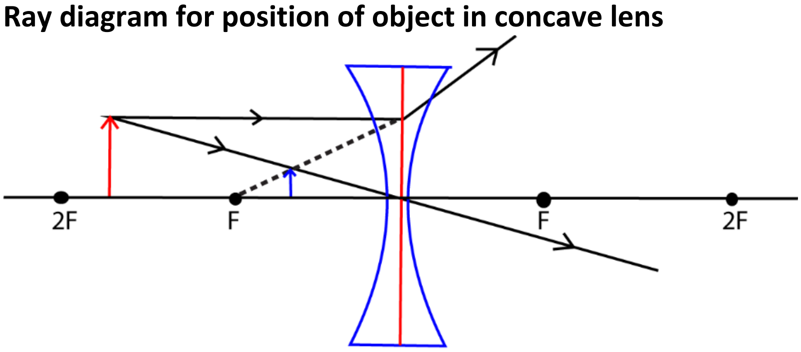
The image is virtual, erect and magnified. A convex lens is used as a magnifying glass when the object is placed between the focal point and' the lens because at this position the image fonned is erect, magnified and virtual,

(f) Object at infinity



The image is: real, inverted and diminished.
A convex lens is used in microscopes magnifying glass, telescopes,

Ray diagram for position of object in concave lens



The image formed in a diverging lens (concave lens) is always erect, virtual and diminished irrespective of the object distance from the lens,

Magnification of lens

Magnification of lens, Mg = $\frac{\text{height of image }(h^1)}{\text{height of object (h)}}$

or Mag = $\frac{\text{image distance from lens (V)}}{\text{object distance from lens (u)}}$

The lens formula

If an object is a distance "u" from the lens and image distance v, then the focal length f is given by

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

This applies to both concave and convex lenses

Sign convention

The convention is that;

(i) distances of real images are positive

(ii) distances of virtual images are negative

For a converging lens the focal length "f" is positive because it real For a diverging lens the focal length f is negative because it virtual.

Example I:

An object of height 10cm is placed at distance 50cn from a converging lens of focal length 20cm. Calculate (i) image position.

Solution: f = 20cm. h = 10cm, u = 50cm

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

$\frac{1}{20} = \frac{1}{v} + \frac{1}{50}$

$\frac{1}{v} = \frac{1}{20} - \frac{1}{50} = \frac{3}{100}$

V= 33.3cm

$\frac{1}{v} = \frac{5-2}{100}$

$\frac{1}{v} = \frac{3}{100}$

∴ v= $33\frac{1}{3}$cm

(ii) **Height** of image

$\frac{V}{u} = \frac{h'}{h}$

$\frac{\frac{100}{3}}{50} = \frac{h'}{10}$

$\frac{100}{3} \times \frac{1}{50} \times 10$

$\frac{20}{3} = h^1$

$6\frac{2}{3} = h^1$

Example 2

An object of height 10cm **is** placed at a distance of 60cm from a diverging lens of focal length 20crn. Find

(a) Image position

Solution

h - 10cm, u - 60cm f = -20cm because the focal length for convex lens is virtual so it's negative.

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

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

$$\frac{1}{v} = \frac{-3-1}{60}$$

$$\frac{1}{v} - \frac{-4}{60}$$

V= -15

V= 15

V= 15cm

Finding the position by scale drawing

This will involve two steps:-

i) Select a scale for drawing

ii) Make a sketch of the drawing this should include two major rays from a point on the object. They are:

a) A ray which is parallel and closed to principle axis should refracted through focal point for converging lens while for diverging lens, the ray parallel is refracted in such a way that appears to come from the focal point

b) A ray through the optical centre should be drawn undeviated

iii) Then a diagram is drawn to scale.

Example 3

An object of height 10 cm is placed a distance of 50cm from converging lens of focal length 20cm. Find by, scale drawing

i) Image position ii) height of the image

iii) Nature of the image

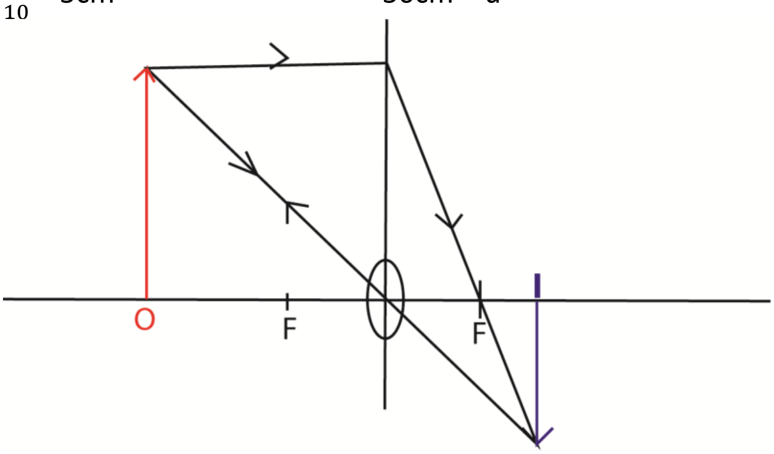
h - 10cm u = 50cm f = 20cm

Scale 1 cm represents 10cm

$\frac{20}{10}$ = 2cm 20cm = f

$\frac{10}{10}$ = 1cm represents 10cm = h

$\frac{50}{10}$ = 5cm 50cm = u



i) image position = 3.3cm x 10 =33cm
ii) Image height = 0.6 x 10 = 6cm
iii) Nature of image is **real**

Example 4

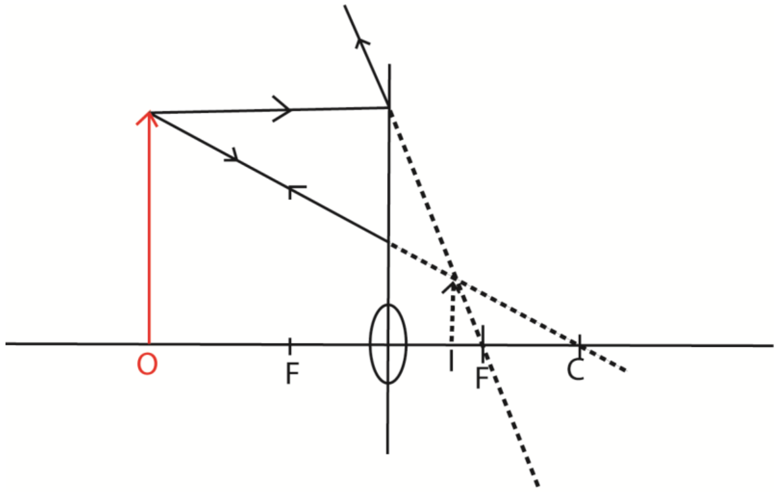
An object of height 10cm is placed at a distance of 60cm from diverging lens of focal length 20cm.

Find by scale drawing the
(i) image position
ii) height of the image
iii) nature of the image
iv) magnification

h = 10cm, u = 60cm f = 20cm
Scale 1cm = 10cm

$\frac{60}{10}$= 6cm = 60cm = u

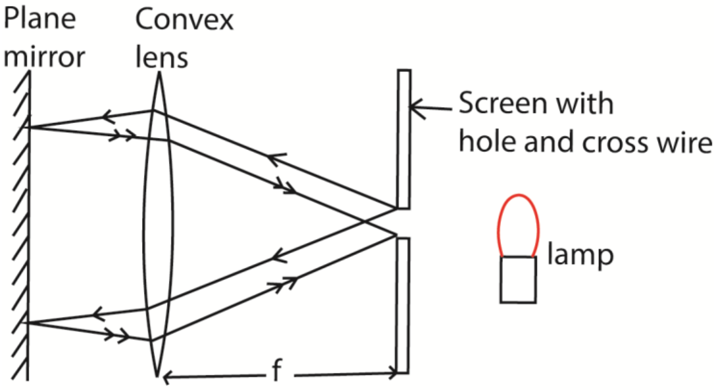
$\frac{20}{10}$ = 2cm = 20cm = f



(i) Image position is 1.5 x 10 = 15cm
(ii) Image height is 0.3 x 10 = 3cm
(iii) Nature of image is **virtual**
(iv) Mg = $\frac{h}{h} = \frac{3}{10}$

Experiment to measure the focal length of converging lens (convex lens) by

a) Illuminating object and plane mirror



Adjust the lens holder

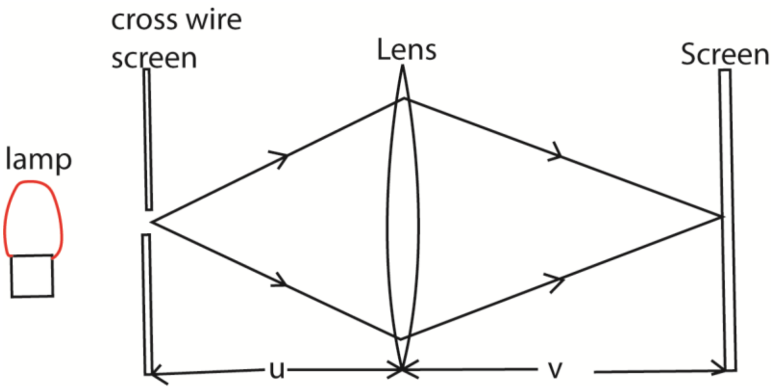
The position of the lens holder is adjusted until a sharp image of the object is formed on the screen alongside the object itself. The object will now be situated at the focal point.

Measuring the focal length

The distance between the screen and the lens is measured and this is the focal length.

Note: At this position, the rays from the lens emerge as parallel rays and strike the mirror at right angle and they are reflected back along their original paths.

b) Measurement of object and Image



Setting the lens

The lens is set up in front of an illuminated object so that a real image is formed on the screen on the opposite side.

Adjusting the lens holder

The position of the lens holder is adjusted until a sharp image of the object is formed on the screen. Several pairs of distance of "u" and "v" are measured and the mean values for focal length f are obtained from

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

Power of a lens

Power of a lens is the reciprocal of its focal length in meters.

Power of lens = $\frac{1}{\text{focal length in metres}}$

The S.I unit of power of lens is **dioptres, D.**

For combined convex lens the power of the combination can be calculated from

Power of the combination = Power of first lens + power of second lens.

Example 5

Two converging lenses of focal lengths 15cm and 20cm are placed in contact. Find the power of the combination

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

$= f_1 = 15\text{m} = \frac{15}{100} = 0.15$

$\therefore$Power $= \frac{1}{1.15}$D

Power of 2nd lens $= \frac{1}{\text{focal length (metre)}}$

$= \frac{29}{109} = 0.2\text{m}$

$\therefore$Power of 2nd lens $= \frac{1}{0.2}$D

So power of combination $= \frac{1}{0.2} + \frac{1}{0.15}$

$= 11.70$

Note:
The focal length of a converging lens is real so it is positive.
The focal length of diverging lens is virtual so it is negative.

Example 6

A converging lens of focal length 20cm is placed in contact with diverging lens of focal length diverging lens focal length 10cm. Find the power of combination focal length of converging lens **f = 20cm**

f $= \frac{20}{100}$
$= 0.2m$

.'. Power of converging $= \frac{1}{f} = \frac{1}{0.2} D = 5D$

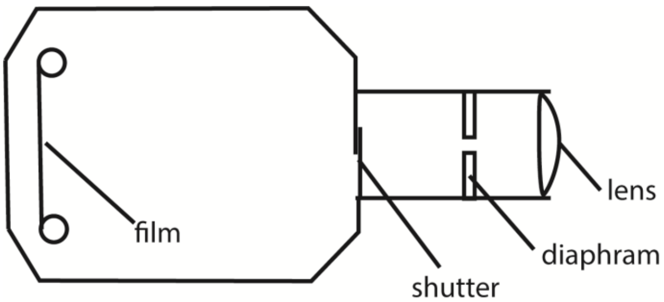
Focal length of diverging lens $= 10cm = \frac{10}{100} m = 0.1m$

Power of the diverging lens $= \frac{1}{-f} = \frac{1}{-0.1}$
$= -10D$

.'. Power of combination = 5 + -10
= -5D

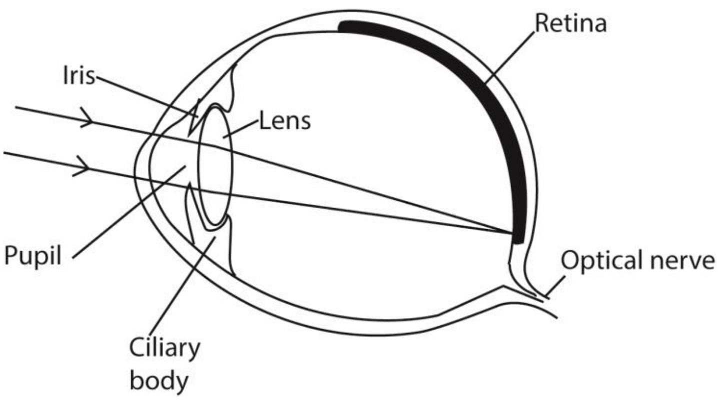
Optical instruments

Lens camera



- The lens focused light from the object on to film
- The diaphragm controls the amount of light reaching the film
- The shutter controls the exposure time of light reaching the film

The Eye



Light enters the eye through the cornea (transparent), the lens and is **focused on the retina.** The retina is sensitive to light and sends messages to the brain through the optic nerve. The iris changes in size to **vary** the amount **of** light that enters through the pupil. The size of the pupil decreases in bright light and increases in dim light.

Accommodation: is the ability of the eyes the focus the images of objects at different distances on the retina.

Similarity between the human eye and camera

(i) The camera consists of a light-proof box which is black inside while the eye has a black pigment inside.
(ii) Both the eye and camera have light sensitive pails. The retina for the eye and film for the camera
(iii) Both the eye and camera have a lens,

(iv) Both have a system which regulates the amount of light entering them, **iris** for the eye and diaphragm for the camera.

Differences between the human eye and the camera

Human eye	Camera
Lens: lens of human eye is biological	Lens: lens of the camera is artificial
Focal length: focal length of lens for the eye is variable	The Focal length: The focal length of lens the for camera is fixed
Distance: The distance between the lens and retina is fixed	Distance: The distance between the lens and film is variable

Defects of vision

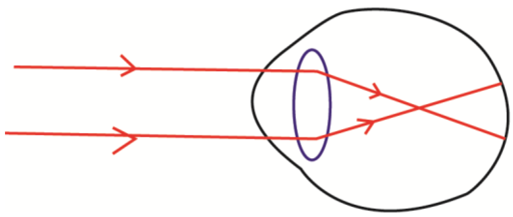
Near point; is the closest point at which one can see an object clearly. For an adult the near point is 25cm

Types of eye defects:

There are two types of eye defects namely: short sightedness and long sightedness.

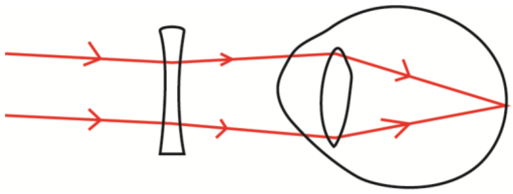
a) **Short sightedness**

Here, a person who can see near objects clearly but cannot focus distant objects. This is because the eye ball is too long or the eye lens is too strong. The lens is too thick even though the ciliary muscles are relaxed.



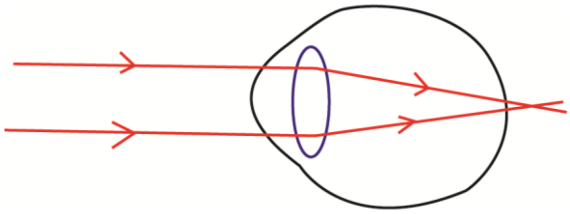
Light rays from a distant object (infinity) are focused in front of the retina.

The defect is corrected by a concave spectacle lens which diverges the light before it enters the eye to give an image on the retina.

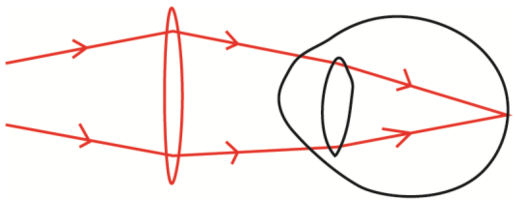


b) Long sightedness

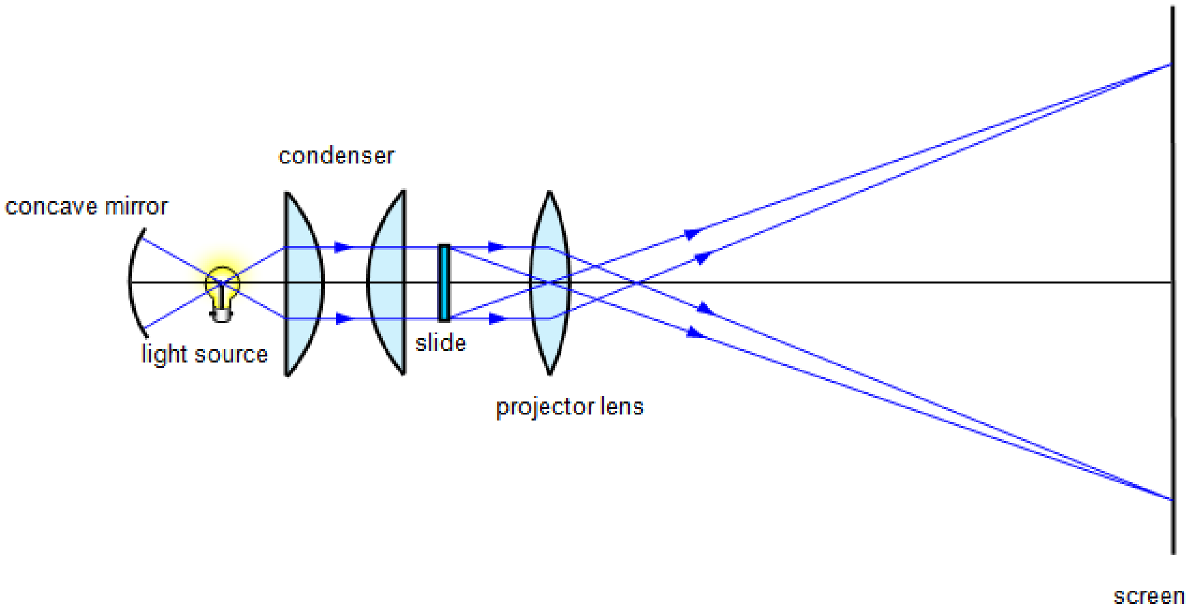
A person can see distant objects clearly but cannot focus near objects. This is because the eye-ball is too short or eye lens is too thin even though the ciliary muscles are fully squeezed. This means that rays of light from the object are focused towards a point behind the retina.



The defect is corrected by a convex spectacle lens which converges the light to give an image on the retina.



PROJECTOR



A projector is used for projecting the image of a transparent slide onto the screen. So a projector forms a real image.

Source of light: The powerful source of light is placed at the principal focus of a concave mirror so as to illuminate the slide if the image is to be bright

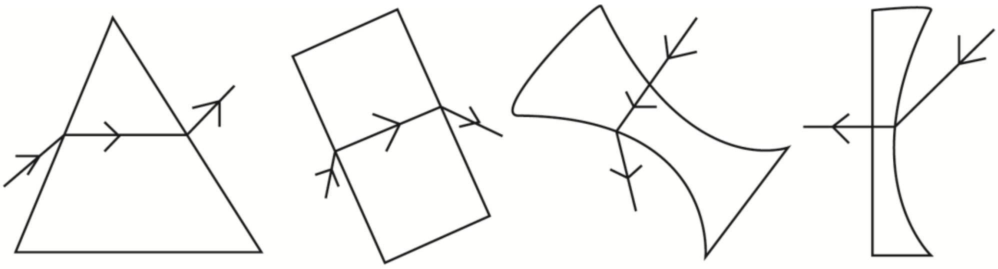
Concave mirror: The concave mirror reflects back light which would otherwise be wasted.

Condenser: This is a combination, of two plane convex lenses. The main function is to collect the rays from the light source and concentrate them onto the slide

The projector lens: The projector lens is mounted in a sliding tube so that it may be moved to and fro to focus a sharp image on the screen.

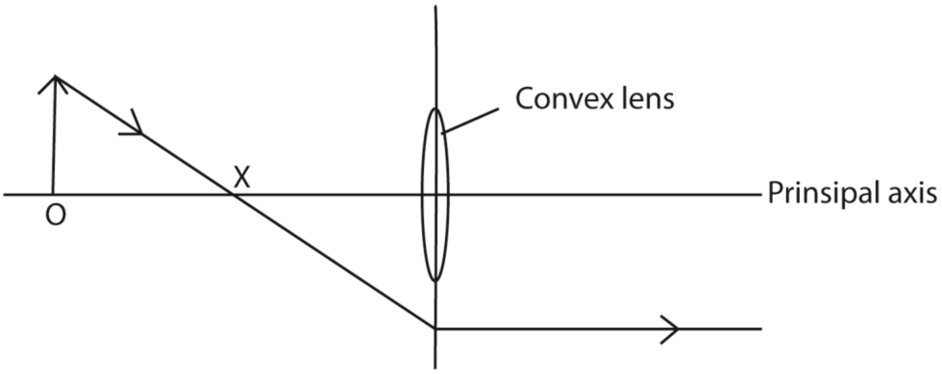
Exercise

1. Which of the following is a correct ray diagram



A B C D

2. An object is placed at a distance of 20cm from a convex lens of focal length 15cm. the type of image formed is
   A. Inverted and magnified
   B. Inverted and diminished
   C. Upright and diminished
   D. Upright and magnified
3. An object is placed between a converging lens and its principal focus. The image formed is
   A. Real, magnified and upright
   B. Real, magnified and inverted
   C. Virtual, diminished, upright
   D. Virtual, magnified, upright
4. A stick with one end immersed in a liquid appear bent at the liquid surface due to
   A. Diffusion
   B. Reflection
   C. Interference
   D. Refraction
5. A pin is placed in front of a convex lens at a distance less than the focal length of the lens. What type of image is formed?
   A. Real, inverted, diminished
   B. Virtual, erect magnified
   C. Real, erect, diminished
   D. Virtual, inverted, magnified
6. A point along the principal axis of a convex lens to which parallel and close to the axis converge after refraction through the lens is
   A. Principal focus
   B. Center of curvature
   C. Optical center
   D. A pole
7. An object of height 1cm is placed 4cm from a convex lens forms an image five times the height of the object. Find the distance of the image from the lens
   A. 0.80cm
   B. 1.25cm
   C. 4.00cm
   D. 20.0cm
8. The image formed by the lens below is



(i) Real (ii) inverted (iii) Upright

A. (i) only
B. (ii) only
C. (iii) only
D. (i) and (ii) only

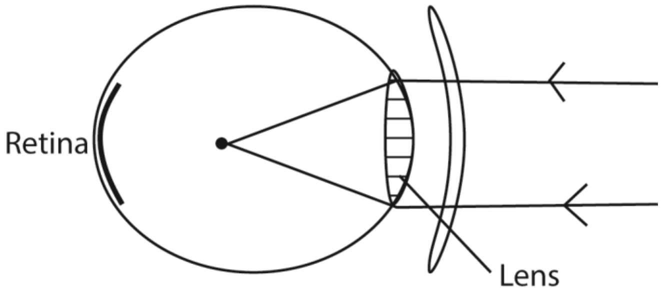
Answers to objective questions

1. D 2. A 3. D 4. D 5. B 6. A 7. D

8. D because the image is formed on opposite side of the lens

Section B

9.

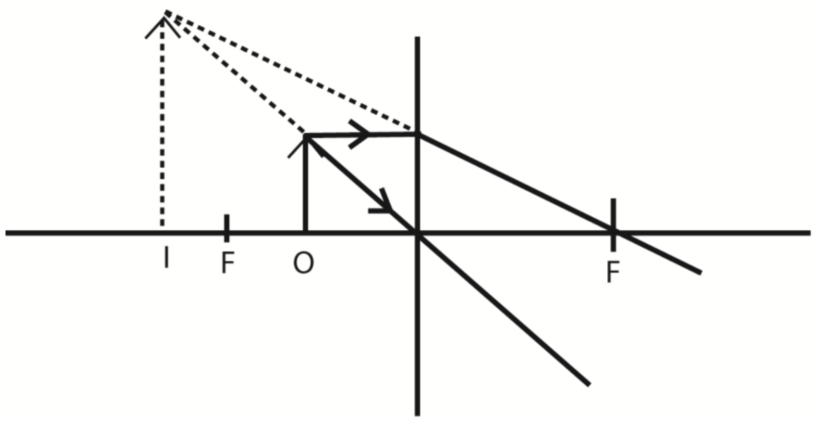


The figure above shows refraction of light from a distant object by a human eye

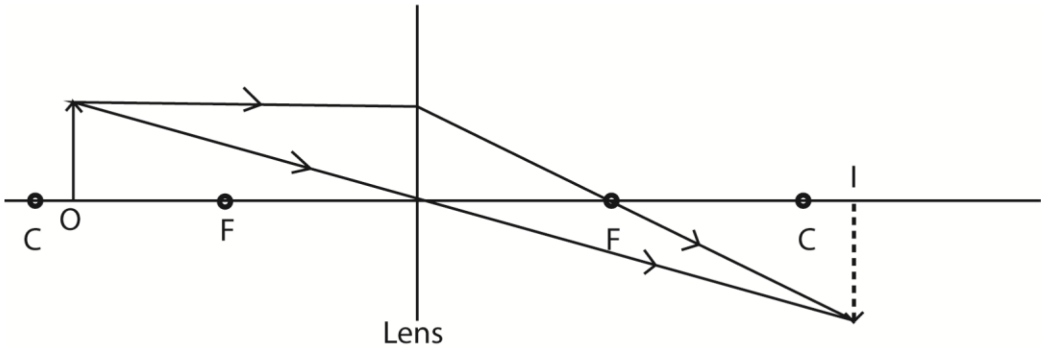
(a) Explain why the eye is not able to see the object clearly
The image is formed in front of the retina because the lens is strong

(b) What is accommodation?
This is the ability of the eye lens to adjust its focal length to focus images of objects at varying distances.

10. (a) By using a ray diagram, show how a virtual image can be formed in converging lens.
Solution
A lens form a virtual image when the object is between the center of the lens and principal focus.



(b) A converging lens of focal length 20cm forms a real image 4cm high of an object which is 5cm high. If the image is 36cm away from the lens, determine by a graphical method the position of the object.
Vertical scale 1cm represent 1cm
Horizontal scale 1cm represent 5cm
Object position is 45cm



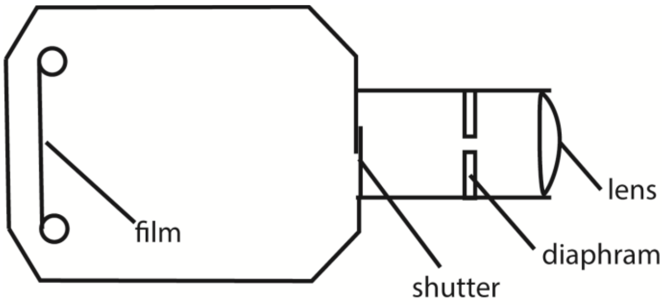
(c) Give two differences between a pin-hole and a lens camera.
- In a pinhole camera the image is always in focus while in lens camera the image is brought to focus by adjusting position of the lens
- In pinhole camera the intensity of light entering is fixed while in a lens camera the intensity of light entering is controlled by the shutter or diaphragm
- In pin hole camera the image distance is fixed while in the lens camera it is not.

11. (a) Define focal length of a converging lens.
It is the distance between the center of the lens and principal focus.
(b) Focal length of a converging lens is 10cm. what is its power
Power of the lens = $\frac{1}{f}$; f in meters
f = 10cm = 0.1m
power = 1/0/0.1 = 10 diopters

(c) State two properties of an image of a real object formed by diverging lens
- Virtual
- diminished
- Upright

(d) Explain how a lens camera works.

Lens camera



- The lens focused light from the object on to film
- The diaphragm controls the amount of light reaching the film
- The shutter controls the exposure time of light reaching the film

12. (a) What is meant by refractive index? (01mark)

    Refractive index is the ratio of sine of the angle incidence to the sine of angle of refraction.

    (b) Define focal length of a converging lens (1marks)

    Focal length of a converging lens is the distance between the optical center and the principle focus.

13. (a) Define the following

    (i) Aperture of a lens

    This is the width of the lens.

    (ii) Virtual image: it is an image formed by apparent intersection of rays when their directions have been produced backwards.

    (b) A converging lens has a focal length of 10cm. calculate the power of this lens

    Power = $\frac{1}{f}$, f = 10cm = 0.1m

    Power = $\frac{1}{0.1}$ = 10D

    (c) Describe an experiment to determine the focal length of convex lens using an illuminated object and plane mirror.

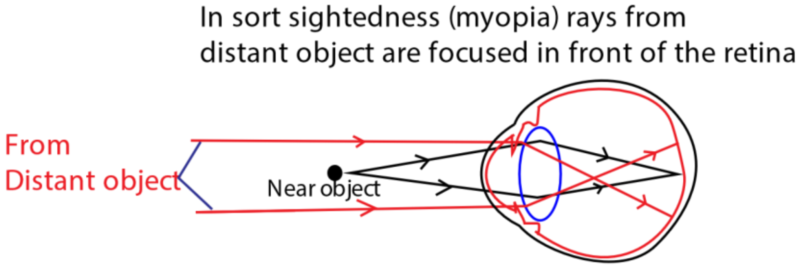
    - A lit bulb is placed behind a screen with a hole having cross wires.
    - A convex lens is placed in front of the screen
    - Then a plane mirror is placed behind the lens.
    - The screen (or lens) is moved to and fro along the principal axis until a sharp image of cross wire is formed on it besides the wire gauze.
    - The distance between the lens and screen is equal to focal length.

14. (a) What is meant by the term principal focus of diverging mirror?

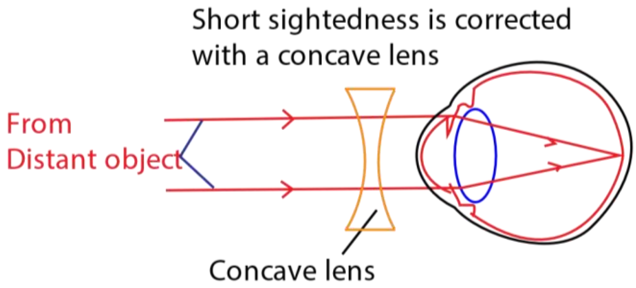
    It is a point on principal axis to which all rays originally parallel and close to the axis appears to diverge from after refraction through the lens.

    (b) What is meant by shortsightedness?

    Is defect where an eye can see only near objects clearly? Or is a condition where rays from distant objects are focused in front of the retina



(c) Draw a ray diagram to show how shortsighted may corrected by suitable lens.



15. (a) (i) What is meant by focal length of a lens?

Focal length of a lens is the distance between the optical center and principal focus.

(ii) Calculate the power of a concave lens of focal length 20cm

Power = $\frac{1}{f\ (metres)} = \frac{1}{0.2} = 5D$

(b) An object of height 7.5cm is placed at a distance of 15cm from a convex lens of focal length 20cm. by scale drawing determine the

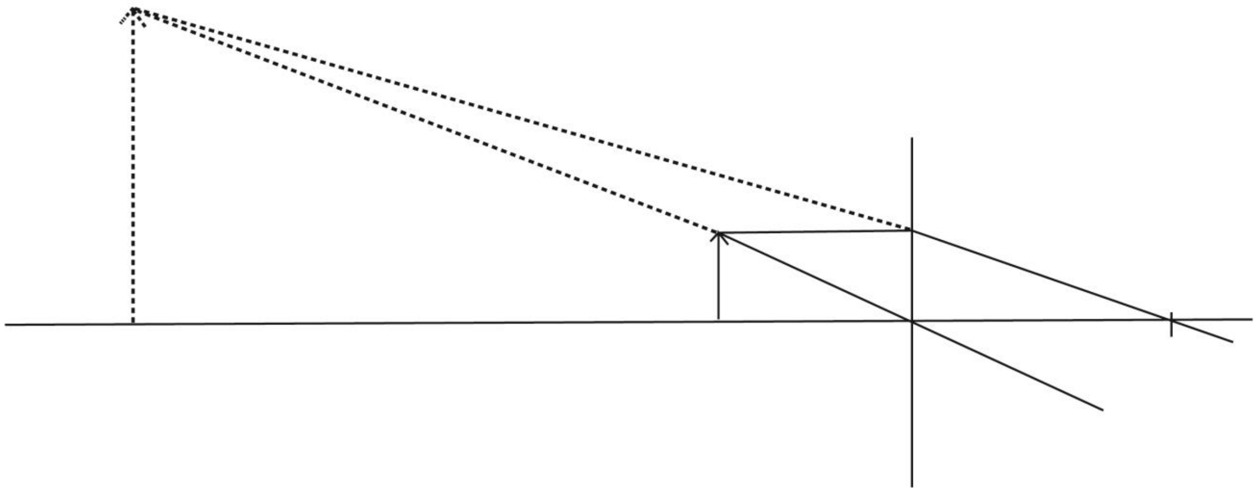
Solution

From lens formula image distance = -60cm, i.e. image is virtual on the same side as object

From magnification, image height = $\frac{60}{15}\ x\ 7.5$ =30cm

Horizontal scale 1cm rep 2.5 cm

Vertical scale 2cm rep 7.5cm



(i) Height of the image = 4cm x 7.5 = 30cm

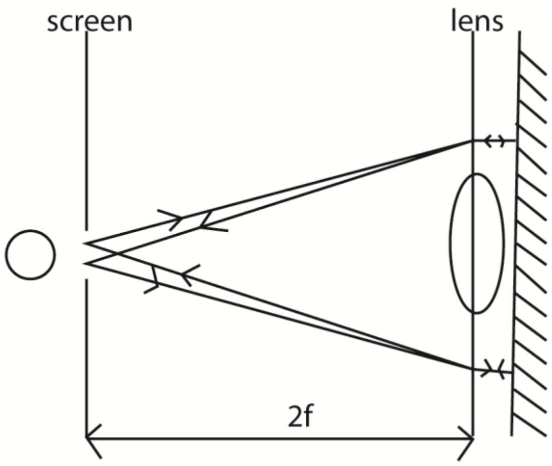
(ii) Image distance =24 x 2.5cm = 60cm

(iii) Linear magnification = $\frac{image\ distance}{object\ distance} = \frac{60}{15} = 4$

(c) Describe an experiment to determine the focal length of a convex lens using an illuminated object and plane mirror.

Solution

- A bulb is placed behind a screen with a hole having cross wires
- A convex lens is placed in front of the screen
- A plane mirror is placed behind the lens
- The lens is moved to and fro along the principal axis until a sharp image of the cross wires is formed on the screen besides the wire guaze.
- The distance between the screen and the lens = 2f



(d) What is the main differences between the operation of a lens camera and the eyes

- Eye lens has variable focal length, lens for a camera has fixed focal length
- Eye has fixed image distance, lens camera has variable object distance

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Thanks

Dr. Bbosa Science