14 LENSES AND OPTICAL INSTRUMENTS

LENSES

Lenses are made of a transparent materials (glass or plastic) with at least one curved surface. The operation of lenses is based on refraction of light through a triangular prism. They change the direction of light passing through them.

OBJECTIVES

At the end of this topic, students should be able to:

- identify and distinguish between a convex and concave lenses;
- draw ray diagrams to show the formation of images by lenses;
- state the characteristics of images formed by curved lenses;
- determine the focal length of lenses;
- derive and use the lens formula to perform simple calculations on lenses;
- state the uses of lenses.

Convex and concave lenses

Two types of lenses are the **convex** and **concave** lenses.

Convex lenses

A **convex lens** is thicker at the centre than at the edges. It converges parallel rays of light to a focus after refraction and are called **converging lens**. A convex lens sometimes forms an enlarged, erect and virtual image and some other times, they form an inverted real images. Figure 14.1 shows three kinds of convex lenses. The **biconvex lens** has two smooth curved surfaces {Figure 14.1(a)}, **Plano convex lens** {Figure 14.1(b)} has one plane surface and one curved convex surface and the **converging meniscus** Figure 14.1(c).

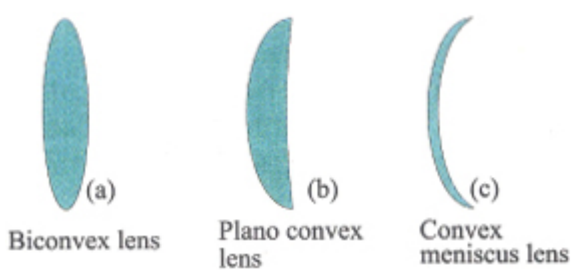


Figure 14.1: Types of convex lenses

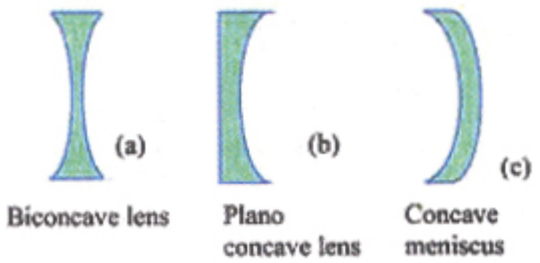


Figure 14.2: Types of concave lenses

Concave lenses

Concave lenses are thicker at the edges than at the centre. They diverge (spread) parallel rays of light as if they are coming from the focus, therefore, they are called **diverging lens**. Concave or diverging lenses always produce **erect, virtual** and **diminished images** irrespective of the position of the object. Figure 14.2 shows three types of concave or diverging lenses. The **biconcave lens** has two smooth spherical surfaces curved inwards Figure 14.2(a). **Piano concave lens** has one smooth plane surface and one smooth curved surface Figure 14.2(b) and the **diverging meniscus** Figure 14.2(c).

Action of lenses on parallel rays of light

(a) Refraction of light through convex lenses

Convex or **converging lenses** refract parallel rays of light converging them to the focus F of the lens. Convex lenses refract light the same way triangular prism refracts light. A convex lens is made up many prisms of different gradients as shown in Figure 14.3 (b), each prism bends light rays towards its base. The deviation or bending is more at the sections where the prism slopes most. The prism at the centre is rectangular; therefore, a ray passing normally through it is not deviated.

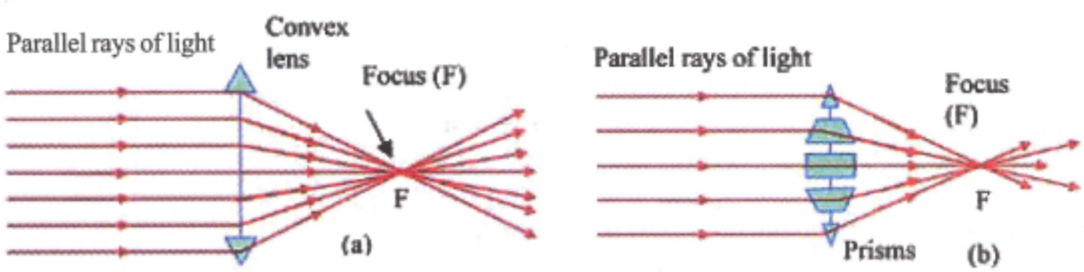


Figure 14.3 Action of convex lens on parallel rays of light

(b) Refraction of light through concave lenses

Concave or **diverging lenses** refract parallel rays of light in such a way that they seem to spread or diverge from the focus F. The refraction of light by concave lens is likened to many prisms arranged as shown in figure 14.4 (b). Rays of light parallel to the principal axis is refracted or deviated towards the base, thus, spreading the light rays.

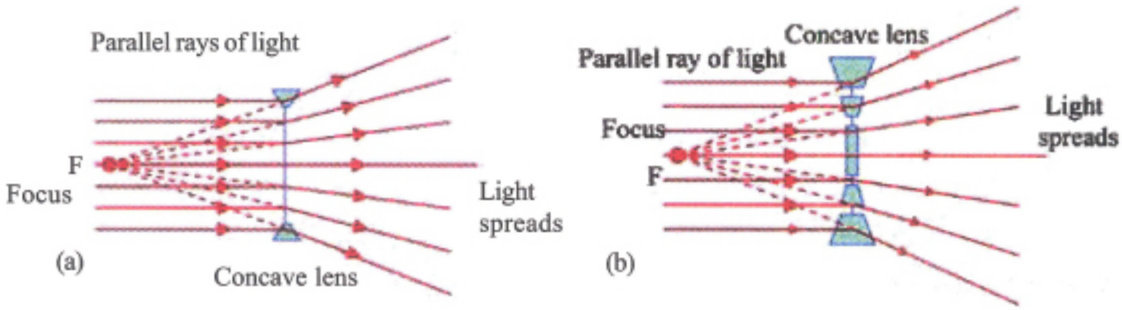


Figure 14.4: Action of concave lens on parallel rays of light

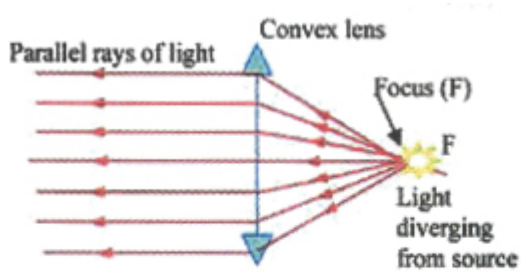


Figure 14.5a: Reversibility of light

(c) Reversibility of light

The path of light is reversible. If the direction of light is reversed, it will still move along the old path but in the opposite direction. This is called **reversibility of light**. Parallel rays of light are brought to the focus after refraction through the lens. When a source of light is placed at the focus, the lens produces parallel rays after refraction according to the principle of reversibility of light.

Terms and definitions used in describing lenses

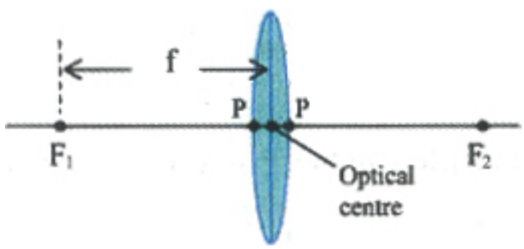


Figure 14.5b: Lenses are bifocal

1. **The pole** (P): the pole of a lens is the centre of the curved surface.
2. **The optical centre** (C): optical centre of a lens is the centre of the lens.
3. **The principal axis** is the imaginary line passing through the optical centre and perpendicular to it.
4. **The secondary axes** are the lines parallel and close to the principal axis.
5. **The principal focus** (F) of a convex lens is the point on the principal axis where parallel rays close to the principal axis converge. *The focus of a convex or converging lens is real because light rays truly pass through the point.*

6. **The principal focus** (F) of a concave lens is the point on the principal axis where parallel rays close to the principal axis seem to diverge. *Concave or diverging lens has virtual focus since no light rays pass through it.*
7. **The focal length** (f) is the distance between the principal focus (F) and the optical centre (C) of the lens.
8. **The power of a lens** is the reciprocal of the focal length of the lens in metres. *Lenses with shorter focal lengths, have greater power. Lenses with long focal lengths have low power.* The unit of power of a lens is dioptres (D).

$$\text{Power of lens} = \frac{1}{\text{focal length}} \quad \text{or} \quad P = \frac{1}{f}$$

Worked example

Calculate the power of the following lenses:

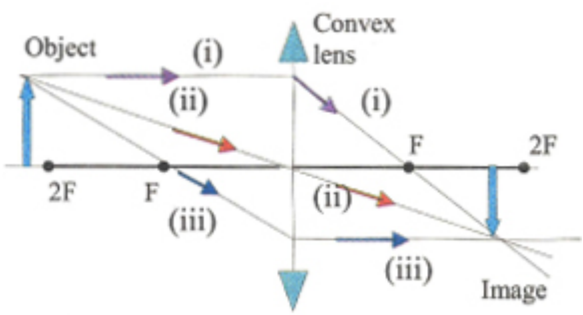
(a) a convex lens of focal length 20 cm;

(b) a concave lens of focal length 10 cm.

Solution

$$\text{(a) Power of lens} = \frac{1}{\text{focal length}} = \frac{1}{0.2} = +5\text{D} \qquad \text{(b) Power of lens} = \frac{1}{\text{focal length}} = -10\text{D}$$

Construction of ray diagrams



Lenses form images by refraction of light. The position of the image is located by using at least two of the ray constructions.

(i) A ray of light parallel to the principal axis is refracted through the principal focus.

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

(iii) A ray passing through the optical centre is not deviated, it just passes through the lens.

The constructions (i) and (iii) applies to only thin converging lenses. The point of intersection of any two of the rays locates the position of the image. The image formed is drawn perpendicular to the principal axis.

Location and characteristics of image formed by convex lenses

At least two out of the three ray constructions discussed above can be used to locate the position of the image formed by convex lenses. The characteristics of the image formed depends on the position of the object. We will consider six different cases.

(a) Object at infinity:

- â€¢ **Size of image:** the image formed is diminished (smaller than the object).
- â€¢ **Position of image:** the image is formed at the focus.
- â€¢ **Nature of image:** the image is real and inverted.

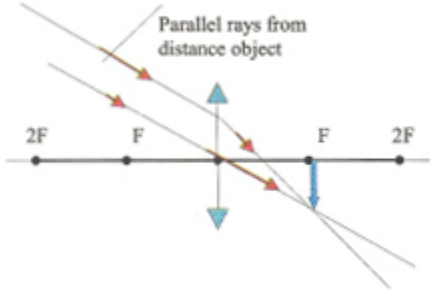


Figure 14.6a: Object at infinity produces a real inverted and diminished image at the focus

(b) Object placed beyond 2F:

- â€¢ **Size of image:** the image formed is diminished (smaller than the object).
- â€¢ **Position of image:** the image formed is between the focus F and 2F.
- â€¢ **Nature of image:** the image is real and inverted.

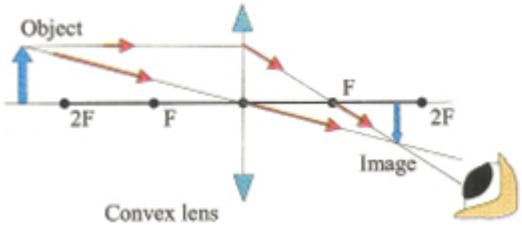


Figure 14.6b: Object at 2F produces a real, inverted and diminished image between F and 2F

(c) Object placed at 2F:

- â€¢ **Size of image:** The image formed is the same size as object.
- â€¢ **Position of image:** The image formed is at 2F.
- â€¢ **Nature of image:** The image is real and inverted.

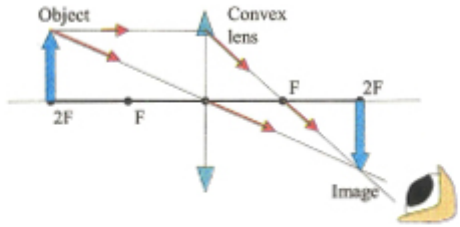


Figure 14.6c: Object beyond 2F produces a real, inverted image at 2F

(d) Object placed between F and 2F:

- â€¢ **Size of image:** The image formed is magnified (bigger than the object)
- â€¢ **Position of image:** The image formed is beyond 2F.
- â€¢ **Nature of image:** The image is real and inverted.

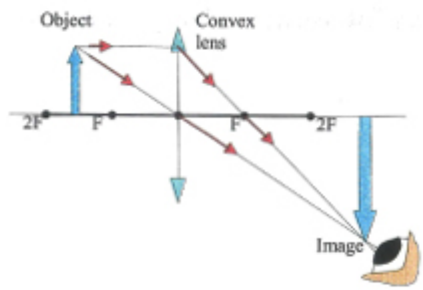


Figure 14.6d: Object between F and 2F produces a real, inverted and magnified image beyond 2F

(e) Object placed at the focus (F)

We cannot state exactly what the image looks like since the eye cannot see it but we can say that the image is formed at infinity. See Figure 14.6e.

(f) Object placed between the focus (F) and optical centre (C)

- â€¢ **Size of image:** The image formed is magnified (bigger than the object)
- â€¢ **Position of image:** The image formed is behind the object.
- â€¢ **Nature of image:** The image is virtual and erect.

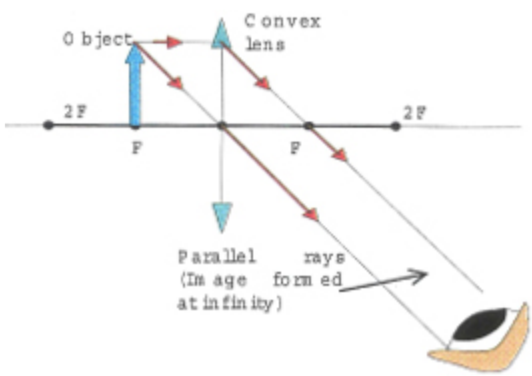


Figure 14.6e: Object at the focus produces image at infinity

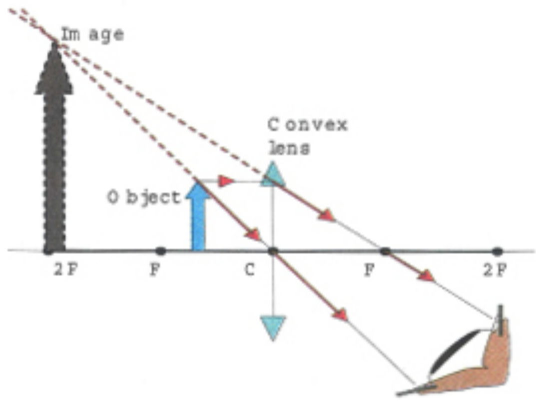


Figure 14.6f: Formation of magnified erect image by convex lens

A close study of the ray construction Figure 14.6a to Figure 14.6f reveal that the image moves away from the lens as the object moves closer to the lens.

Location and characteristics of image formed by concave lens

â€¢ **Size of image:** The image formed is diminished (smaller than the object).

â€¢ **Position of image:** The image formed is between the focus (F) and the optical centre (C).

â€¢ **Nature of image:** The image is virtual and erect.

The image formed by concave lenses is always **virtual, erect** and **diminished.**

Lens formula and sign convention

Figure 14.8 is used to derive the lens formula. Using the similar triangles LOC and AIC the ratios of the sides are equal and are given by:

$$\frac{AI}{LO}=\frac{CI}{OC}=\frac{v}{u}\text{.............}(i)$$

Triangles AIF and NCF are similar, therefore

$$\frac{AI}{NC}=\frac{IF}{FC}\text{.............}(ii)$$

But LO = NC

$$\therefore \frac{AI}{LO}=\frac{IF}{FC}=\frac{CI}{OC}$$

$$\frac{v}{u}=\frac{IF}{FC}=\frac{v-f}{f}$$

$$\frac{v}{u}=\frac{v}{f}-1\text{................}(iii)$$

Dividing equation three by v

$\frac{1}{u}=\frac{1}{f}-\frac{1}{v}$ and rearranging this equation

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

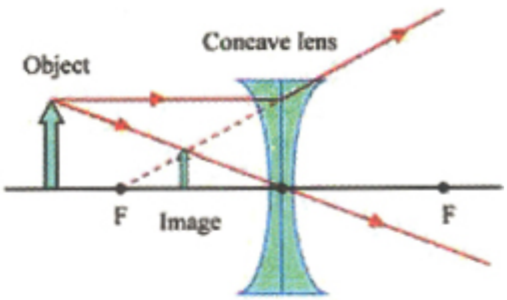


Figure 14.7: Image formation by concave lens

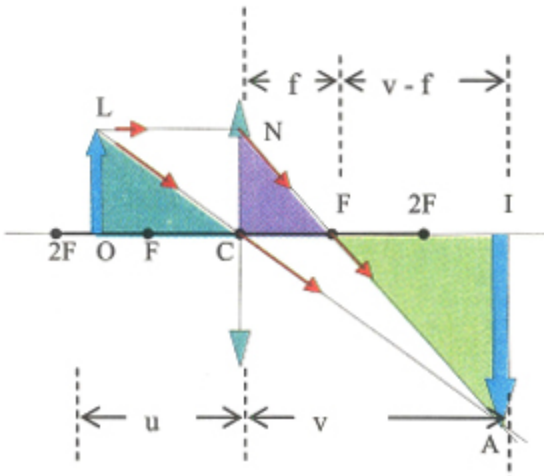


Figure 14.8: Object between 2F and F produces a real, inverted and magnified object beyond 2F

Magnification

The magnification (m) produced by both convex and concave lenses is given by:

$$\text{Linear magnification} = \frac{\text{Image height}}{\text{Object height}} \text{ or } \text{Linear magnification} = \frac{\text{Image distance}}{\text{Object distance}}$$

$$\therefore m = \frac{h_i}{h_o} = \frac{v}{u}, \text{ from equation (iii) } \frac{v}{u} = \frac{v}{f} - 1 \text{ and } m = \frac{v}{u} \qquad \therefore m = \frac{v}{f} - 1$$

Sign convention

The sign conventions applied to converging or convex lenses are the same as those used for converging or concave mirrors. The diverging or concave lenses share the same sign conventions as diverging or convex mirror.

Worked examples

1. A convex lens offocal length 15 cm forms a real image 45 cm from the lens. Calculate:
   (i) the magnification of the image;
   (ii) the size of image if the height of the object is 3cm.

Solution

(i) $$m = \frac{v}{f} - 1 = \frac{45}{15} - 1 = 3 - 1 = 2$$

(ii) $$\text{Linear magnification} = \frac{\text{Image distance}}{\text{Object distance}}$$

$$2 = \frac{h_i}{3} \Rightarrow h_i = 2 \times 3 = 6cm$$

Method 2

$$m = \frac{v}{u} \Rightarrow 3 = \frac{v}{u} \quad \therefore v = 3u$$

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \Rightarrow \frac{1}{u} + \frac{1}{3u} = \frac{1}{12}$$

$$\therefore \frac{4}{3u} = \frac{1}{12}$$

3u =48 cm

$\therefore$ v = 3u = 48 cm

$\therefore$ u = 16 cm

v+u = 48+16 = 64cm

2. The image formed by a converging lens is 3 times taller than the object. If the focal length of the lens is 12 cm, calculate the distance of the image from the object.

Solution

Method 1

$m = \frac{v}{f} - 1$ Where m = magnification,

f = focal length and v = image distance.

$3 = \frac{v}{12} - 1 \Rightarrow 4 = \frac{v}{12} \quad \therefore v = 48 \text{ cm}$

$m = \frac{v}{u} \Rightarrow 3 = \frac{48}{u} \therefore u = 16 \text{ cm}$

u+v = 48+16 = 64 cm.

3. A pin 6 cm high is placed in front of a diverging lens offocal length 15 cm. Calculate the position ofand the height ofimage formed.

Solution

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f} \quad \Rightarrow \quad \frac{1}{30} + \frac{1}{v} = \frac{1}{-15}$

$\frac{1}{v} = -\frac{1}{15} - \frac{1}{30} = -\frac{3}{30}$

v = – 10 cm

Methods of finding the focal length of convex lenses

1. Quick and approximate method:

A metre rule, a lens and a screen are arranged in straight line as shown in figure 14.9. The screen is adjusted until a sharp image of a distant object is formed on the screen. The screen in this position is the focus of the converging lens. The distance between the screen and the lens is measured and recorded as the focal length of the lens.

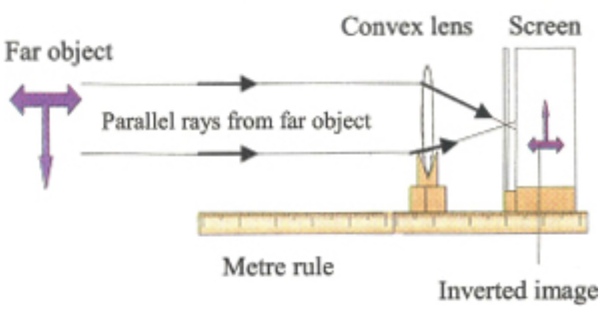


Figure 14.9: Quick and approximate method of finding focal length of a convex lens

2. Ray box and plane mirror method

The ray box, the lens and the plane mirror are arranged in a straight line as shown in figure 14.10. The position of the ray box is adjusted until a sharp image of the crosswire representing the object is formed close to it. The distance between the lens and the ray box is measured as the focal length of the lens.

3. Measurements of object and image distances

The ray box, the lens and the screen are arranged in a straight line as shown in figure 14.11. The lens is placed at a distance **u** greater than the focal length **f** of the lens from the ray box. The position of the screen is adjusted until a sharp image is formed on it. The distance **v** between the image and the screen is measured. The experiment is repeated five more times using different object distances and the corresponding image distances measured and recorded as shown in the table below.

u cm^{-1}	v cm^{-1}	$\frac{1}{u}$ $(cm^{-1})^{-1}$	$\frac{1}{v}$ $(cm^{-1})^{-1}$
?	?	?	?

(a) The graph of plotted against is a straight line with double intercepts as illustrated in figure 14.12. The intercept on the vertical axis = I_1 and the intercept on the horizontal axis = I_2. The average of the two intercepts is given by:

$$I = \frac{I_1 + I_2}{2}$$

The focal length of the lens is the reciprocal of the average intercept I.

$$f = \frac{1}{I} = \frac{2}{I_1 + I_2}$$

(b) Another way of finding the focal length of the lens is shown in the table below.

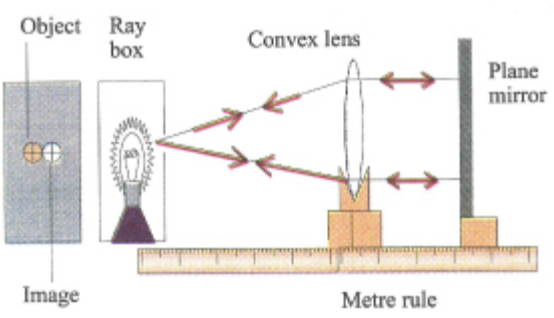


Figure 14.10: Ray box and plane mirror method of finding focal length of a convex lens

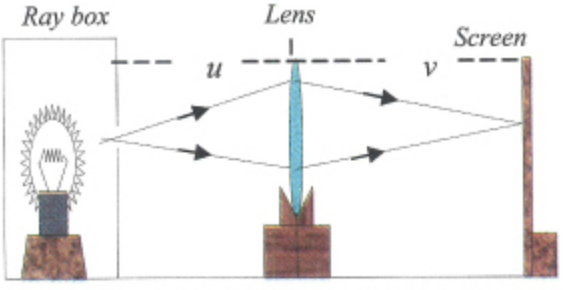


Figure 14.11: Measuring image distance and distance using the ray box

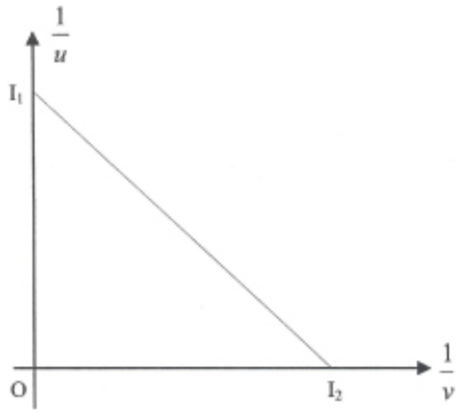


Figure 14.12 Graph of 1/u against 1/v

u cm^{-1}	v cm^{-1}	uv cm^{-2}	(u+v) cm^{-1}
?	?	?	?

When the graph of **uv** is plotted against **u+v**, a straight line passing through the origin is obtained as shown in figure 14.13.

The slope (s) of the graph represents the focal length of the lens.

$$Slope(s) = focal\ length(f) = \frac{uv}{u+v}$$

(c) The third method of finding the focal length of the lens is shown in the table below.

u cm^{-1}	v cm^{-1}	m = v/u

The graph of magnification (*m*) plotted against the image distance (*v*) is straight line cutting through the *m* axis at – 1 as shown in figure 14.14

The intercept on the v – axis is the focal length of the lens. The focal length of the lens is also the reciprocal of the slope of the graph.

The magnification equation is given by:

$$\frac{v}{f} = m+1 \quad \text{or} \quad m = \frac{v}{f} - 1$$

$$\text{Slope (s)} = \frac{1}{f} \quad \therefore f = \frac{1}{slope(s)}$$

The intercept on the **v** – axis is I. The value of **m** is zero at **I**, therefore

$$m = \frac{v}{f} - 1 = 0 \quad \therefore \frac{v}{f} = 1 \Rightarrow f = v$$

(v = image distance when m =0)

Precautions:

(i) I ensured that the illuminated object, the screen and the lens are in a straight line.

(ii) I avoided parallax error on the metre rule.

(iii) Image distances are measured when sharp images are formed on the screen.

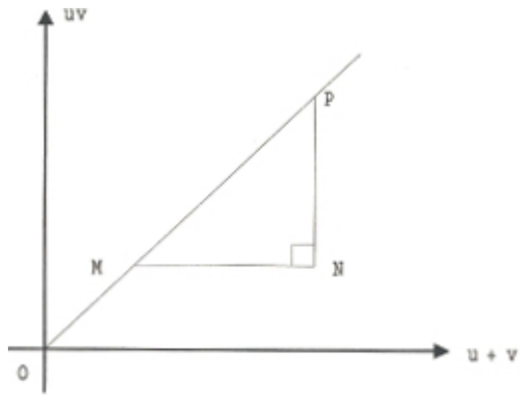


Figure 14.13: uv plotted against u + v

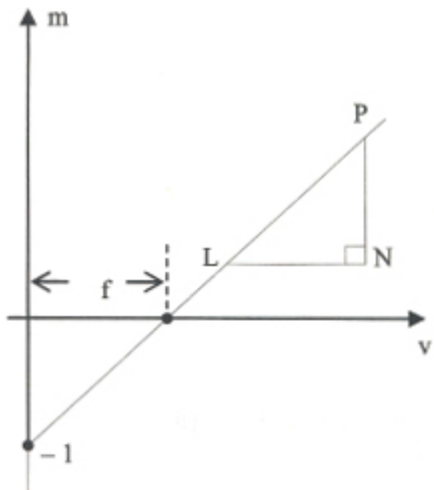


Figure 14.14: Graph of m against v

Summary

â€¢ Lenses are made of a transparent material (glass or plastic) with at least one curved surface.

â€¢ A **convex lens** is thicker at the centre than at the edges. *It converges parallel rays of light to a focus after refraction and are called* **converging lens**.

â€¢ **Concave lenses** are thicker at the edges than at the centre. *They diverge (spread) parallel rays of light as if they are coming from the focus, therefore they are called* **diverging lens**.

â€¢ **The principal focus** of a lens (F) is the point on the principal axis where parallel rays close to the principal axis converge or seem to diverge after refraction through the lens.

â€¢ The focus of a convex or converging lens is real because light rays truly pass through the point.

- â€¢ Concave or diverging lens has virtual focus since no light rays passes through it.
- â€¢ **The focal length** (f) is the distance between the principal focus (F) and the optical centre (C) of the lens.
- â€¢ The **image** formed by **concave lenses** is always **virtual, erect** and **diminished**.
- â€¢ **Virtual image** is formed by apparent intersection of light. No light actually passes through that point therefore the image cannot be formed on the screen placed at that point.
- â€¢ The **image** formed by **convex lenses** when the object is placed beyond 2F is always **real** and **inverted**.
- â€¢ **Real image** is formed by real intersection of light rays. Light truly passes through the point, therefore the image can be formed on a screen positioned at that point.
- â€¢ Convex lens forms a virtual image when the object is placed at a distance less than its focal length.
- â€¢ The lens formula is given by $\frac{1}{u}+\frac{1}{v}=\frac{1}{f}$ where v = image distance, u = object distance and f = focal length of the lens.

Practice questions 14a

1. (a) What is meant by the *focal length of a converging lens* is 20 cm?
   (b) An object of height 10 cm is positioned 15 cm in front of a convex lens of focal length 20 cm, calculate the position and height of image formed.
   (c) Using a scale of 5: sketch a diagram of how the image is formed.
2. (a) Explain what is meant by *real image.*
   (b) Use a ray construction to show how a converging lens can be used to form a magnified real image.
   (c) A converging lens forms a real image four times the size of the object and 60 cm from the optical centre of the lens.
      (i) Find focal length of the lens;
      (ii) What is the distance between the object and its image when they have the same size?
3. (a) Describe an experiment to determine the focal length of a thin converging lens. Explain how you will find the focal length of the lens by plotting a graph of uv against $u+v$.
   (b) State **two** precautions to observe to ensure accurate results.
   (c) The distance between an object and its real image is 40 cm, if

the magnification is 3, calculate the object and image distance if the focal length of the lens is 15 cm.

4. (a) Define the following terms applied to a converging lens: *optical centre, principal focus* and *focal length.*

   (b) Make a sketched diagram to illustrate how a converging lens can be used to:

   (i) produce a magnified and erect image of an object placed at right angle to its principal axis.

   (ii) ignite a stick of match.

   (c) Explain what is meant by the power of a lens? A converging lens of focal length 20 cm forms a real image twice the size of the object. Calculate:

   (i) the power of the lens;

   (ii) the position of the image.

5. (a) Define the principal focus of a concave lens.

   (b) Sketch a diagram to show how a concave lens forms an image of an object placed in front of it.

   (c) State the characteristics of the image formed by the lens.

Optical instruments

There are many uses of light waves. In this section, we will use light waves to explain the working of some optical instruments. *Optical instruments, which form real image of objects in front of them*, will be studied first. These instruments include the **eye, camera**, the **film** and the **slide projector**. *Optical instruments, which form virtual images of object in front of them like microscopes, telescopes and prism binocular*, will be considered later.

OBJECTIVES

At the end of this topic, students should be able to:

- describe the structure of the eye and explain the role played by some parts of the eye in the formation of image on the retina;
- state the defects of the eye and their causes;
- identify the types of lenses for correcting various defects of the eye;
- construct a model of a box camera;
- explain the optical principle involved in a snapshot camera, enlarging camera and copying camera;
- compare and contrast the eye and the camera;
- set up a single lens projector and use it to project a film stripped on a screen;
- explain the formation of images by the camera and the projector by tracing rays of light through them;
- trace the paths of light rays through simple and compound microscopes and telescopes.

Optical instruments that can form real images on a screen are:

â€¢ The eye
â€¢ The camera
â€¢ The film or slide projector

The eye

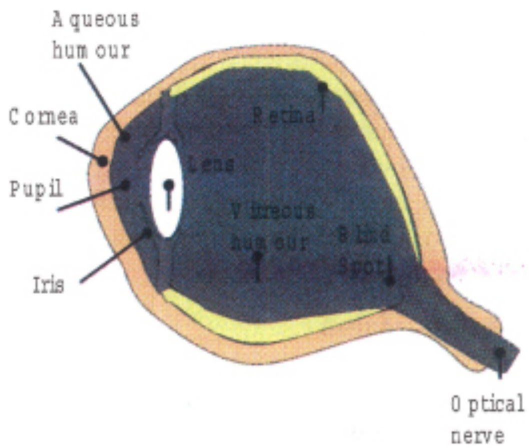


Figure 14.15: The eye

The eye is an optical instrument. The whole eye behaves like a thick lens refracting light waves and focusing it on the retina. The following parts of the eye are in involved in the refraction and focusing of light to the retina:

â€¢ **The cornea:** The cornea is the tough transparent layer of the eye through which light waves enter the eye. It protects the eye and begins the refraction of light.
â€¢ **The pupil:** The pupil is the circular opening (hole) in the eye, which permits light to enter the eye. In a dim light, the size of the hole (opening) is increased to allow more light to enter but the opening is decreased in a bright light to reduce the amount of light entering the eye.
â€¢ **The iris:** The iris controls or regulates the amount of light entering the eye. It increases or decreases the size of the pupil in order to control the amount of light entering the eye.
â€¢ **The eye lens:** The lens refracts light waves and focuses them on the retina.
â€¢ **The ciliary muscles:** The ciliaryâ€™s muscles use suspensory ligaments to support the lens. It squeezes or stretches the lens to vary its focal length so that the eye can focus objects at different distances on the retina.
â€¢ **The retina:** The retina is the light sensitive part of the eye where images are formed.
â€¢ **The optic nerves:** Optic nerves transmit light impulses from the retina to the brain for interpretation.
â€¢ **The aqueous and vitreous humours:** these are transparent

liquid, which fills the whole eye. The aqueous humour is before the lens and the vitreous is after the lens. They help in the refraction of light and maintaining the shape of the eye.

The working of the eye

Light waves from an illuminated object enter the eye and are focused on the retina after undergoing refractions at the cornea, the aqueous humour, the lens and the vitreous humour. The impulses are transmitted through the optic nerves to the brain for interpretation. The brain also inverts the image making it upright.

Accommodation

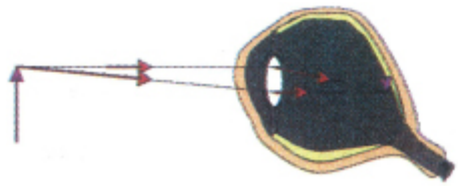


Figure 14.16: How the eye works

People with normal vision can focus clearly both far (distance) and near objects on the retina. This is because the ciliary muscles can vary the focal length of the eye lens in order to focus both parallel rays from far point and divergent rays from a near point on the retina.

Accommodation is the ability of the eye to focus clearly both objects at far and near points on the retina.

Persistence of vision

When an image is formed on the retina, the sensation of vision lasts for about 0.1 seconds after the image has disappeared. Within this very short time, we still appear to see the image. This is called **persistence of vision**. If different images, which vary slightly, are viewed one after the other in quick succession, persistence of vision makes the still pictures appear to be moving. This is how the television and the cinema movies work. In a television, about 25 pictures, which vary slightly, are sent to the screen per second; the viewer thinks that he is watching a moving movie. Light given out by an alternating current sources switch on and off 50 times per second, persistence of vision makes it appear continuous.

Binocular vision

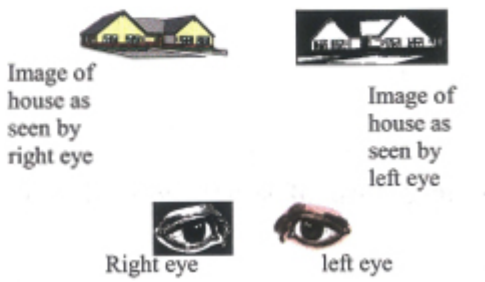


Figure 14.17: Binocular vision

We have two eyes. Each sees an object slightly different from different perspective. The left eye sees more of the left side of the object while the right eye sees more of the right side of the same object. The brain combines the two slightly different visions into a single 3-dimensional image of the object we see. Having two eyes is important because binocular vision assists us to judge distances accurately.

Near and far points

Near point

Near point is the closest point the eye can see an object clearly without strain. The near point for a normal adult is 25 cm from the eye. When looking at the object at the near point, the eye lens is squeezed fully (at its thickest) to form a clear image of the object on the retina. The distance between the eye and the near point is called the **least distance of distinct vision** (LDDV). If a book is placed at a distance less than 25 cm of the LDDV, blurred images of the letters are formed on the retina.

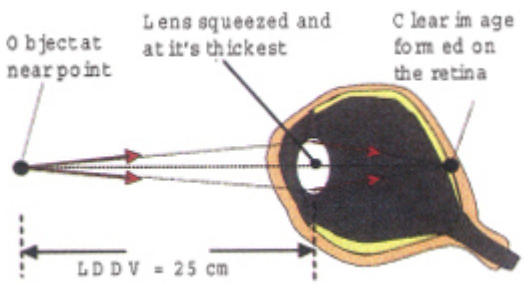


Figure 14.18: Near point of a normal eye

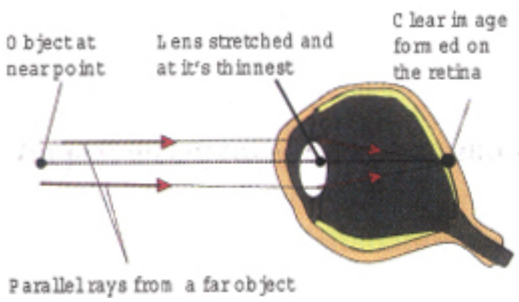


Figure 14.19: Far point of a normal eye

Far point

The far point is the most distant point the eye can see clearly. The far point for a normal adult eye is at infinity. At this point, the eye lens is stretched fully (at its thinnest) such that parallel rays from a distance object are focused on the retina.

Defects of the eye

An adult with a normal vision can see object clearly at both near and far points. Sight defect occurs if the eye is not able to form clear or sharp images on the retina. The **two** main types of eye or sight defects are the **short-sightedness** and the **long sightedness**.

Short sightedness (myopia)

Shortsighted people see near objects clearly but have difficulty seeing far or distant objects. Blurred images of far objects are formed on the retina.

Short-sightedness is the inability of the eye to focus clear or sharp images of far objects on the retina.

short-sightedness is caused by the eye lens being too strong (thick) or the eyeball being too long that sharp images of far objects are formed in front of the retina.

Correction of short-sightedness

A suitable concave lens in front of the eye corrects short-sightedness. The concave lens spread or diverge parallel rays of light so that the eye lens can focus them on the retina to form a clear or sharp image.

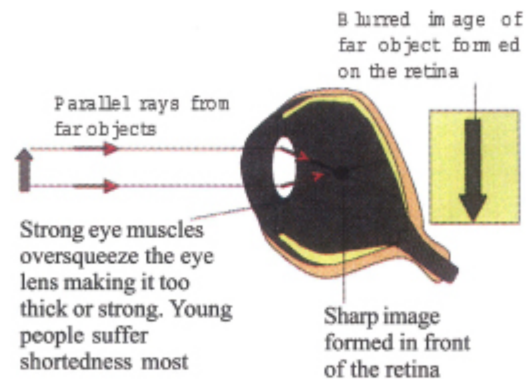


Figure 14.20: Short sightedness

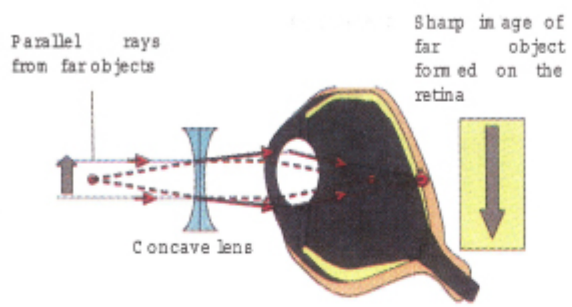


Figure 14.21: Correction of short-sightedness

Long-sightedness (hypermetropia)

People suffering from long-sightedness can see far objects clearly but cannot focus. Sharp images of near objects on the retina. The near point of a long-sighted person is more than 25 cm; therefore, blurred images of objects at the near point are formed on the retina. Sharp images of objects at near point are formed behind (outside) the retina.

Long-sightedness is the inability of the eye to focus on the retina clear or sharp images of objects at the near point.

The eye lens being too weak (thin) or the eyeball being too short that sharp images of objects at near point are formed behind the retina causes long-sightedness.

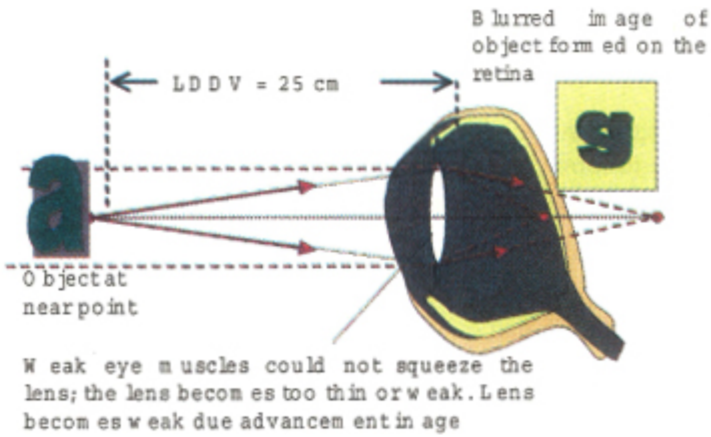


Figure 14.22: Long - sightedness

Correction of long-sightedness

Long-sightedness is corrected by placing the right **convex lens** in front of the eye. The convex lens converge light rays from the near point before the eye lens finally focuses them on the retina to form a sharp image of the object at the near point.

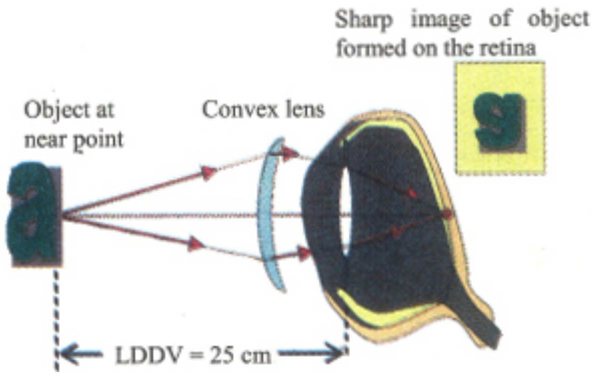


Figure 14.23: Correction of long-sightedness

The camera

A camera is a device that records both still images (photographs) and moving images (videos or movies). All cameras consist of a dark box, a single lens or systems of lenses. Traditional cameras capture light on the photographic film or photographic plate. Modern cameras have exposure control to regulate the amount of light entering the camera, range finder and focus to vary the position of the lens or system os lenses.

Exposure control

The exposure control regulates the amount light that reaches the film or the recording surface or how long the light hits recording surface. It consists of an aperture and a shutter. Cameras with large aperture allows more light to enter therefore the shutter must close fast to limit the amount of light hitting the film or recording surface. When aperture apeture is small,the shutter closes slowly to allow more light to strike the recording surface.

Rangefinder cameras

The rangefinder helps the user of a camera to estimate the distance of the objects therefore allows for the accurate focusing of the camera.

Focus

The focus helps to vary the positions of the lens so that a sharp image is always formed on the film at any object position. Modern cameras have auto-focus systems to focus the camera automatically by a variety of methods.

Camcoder

Front and back of a digital camera

Figure 14.24: Modern cameras

Digital cameras

A digital camera is a camera that can take video or still photographs, or both, digitally by recording images using an electronic image sensor. The captured images can be transferred or stored in a tape or computer memory inside the camera for later playback or processing. Many compact digital still cameras can record sound and moving video as well as still photographs. Digital cameras can do things film cameras cannot: displaying images on a screen immediately after they are recorded, storing thousands of images on a single small memory device, recording video with sound, and deleting images to free storage space.

Movie cameras

These are cameras that can capture many images in a sequence. They include modern digital cameras which has both still and motion recording modes. A video camera is a category of movie camera that captures images electronically; either using analogue or digital technology.

The single lens camera

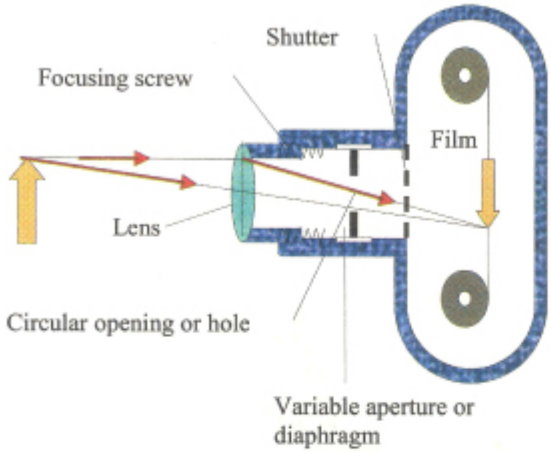


Figure 14.25: Single lens camera

The single lens camera uses a convex lens to form a real image of the object in its front on a light sensitive film. *A camera is light-tight box with a single convex lens or a system of lenses at one end and light sensitive film at the other end.*

A camera consists of the following important parts:

â€¢ **Single lens:** The lens focuses the light from the object on the film. To produce a sharp image of both far and near objects, the position of the lens is adjusted to vary its distance from the film. The process of changing the position of the lens to produce sharp images on the film is called **focusing**.

â€¢ **Shutters:** The shutters open for a short time to allow light to enter into the camera. **The shutter controls or regulates the amount of light entering the camera by controlling the time the film is exposed to light**. The time the film is exposed to light is called **exposure time**. Exposure time for fast moving bodies is very short (l/500th or 0.002 seconds). Still objects require longer exposure time (1/50th or 0.02 seconds).

â€¢ **Diaphragm or aperture stop:** The diaphragm has a hole or opening on it through which light enters the camera. The amount of light entering the camera depends on the size of the hole on the diaphragm. When the opening is small, less light enters the camera but both far and near objects can be focused at the same time to produce a sharp image on the film. Large opening lets in more light into the camera but far and near objects cannot be focused sharply on the film at the same time.

(i) Depth of focus *is the distance the film can move in order to form sharp images of near and far objects on the film at the same time*. The depth of focus is high for small opening on the diaphragm and low for large opening. The size of the hole or opening on the diaphragm is described by the **f -number**.

(ii) F-number *is the ratio of focal length of the lens and size of the hole on the diaphragm*. An f/4 on the diaphragm means that the size of the hole on the diaphragm is 1/4 th or 0.25 of the focal length of the lens. An f/12 has smaller opening and gives better depth of focus but lets in less light. The exposure time therefore should be longer. Snapping in a dim light requires low f-number and longer exposure time. The exposure time and f-number selected depends on the **brightness of the object** (i.e. if the object is in a bright or dim light), **sensitivity of the film** (i.e. if a fast or slow film is used) and the type of effect desired.

Differences and similarities between camera and eye

The similarities and differences between the eye and camera will be examined under the headings: **focusing** and **control of light intensity**.

I. Similarities

(i) The camera and the eye both converge light onto a light sensitive material.

(ii) The eye can change its focal length to form sharp images of far and near objects on the retina. The lens of a camera can be moved to form sharp images of far and near objects on a film.

(iii) The eye and the camera both form real, diminished and inverted image on a light sensitive material.

(iv) The camera and the eye both have holes, which regulate the amount of light entering them.

(v) The eye and the camera both shut out light entering them.

II. Differences:

(i) The focal length of the eye can be varied to form sharp images on the retina. The focal length of the lens of a camera is fixed.

(ii) The distance between the eye lens and the retina is fixed while the distance between the lens and the film in a camera can be varied.

(iii) The iris regulates the size of the pupil (hole) in the eye while the diaphragm controls the size of the hole in the camera.

(iv) The eyelids close to shut out light in the eye while the shutter closes to cut off light in the camera.

Film or slide projector

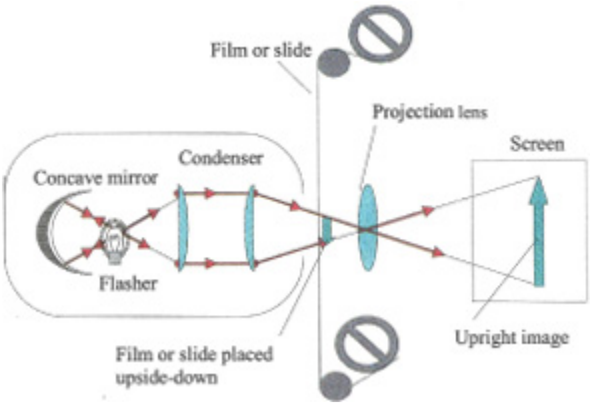


Figure 14.26: The film projector

The film or the slide projector is used to form a magnified real image of a slide or film on a screen. The section of the projector, which illuminates the slide or film, consists of; a concave mirror of short focal length, a flasher and a system of plano convex lens, called condenser, all work together to make the light reaching the slide or film uniform and brighter. This is achieved by placing the flasher at the centre of curvature of the concave mirror so that light rays incident on the mirror is reflected back along its own path. The condenser is placed in the path of the diverging light to converge it towards the film or slide, so that uniform and bright light illuminate it.

The projector lens spreads the light from the film on the screen. An erect, magnified and real image of the slide is formed on the screen if the slide or film is placed upside-down (inverted) between the focus and 2F of the projection lens.

Optical instruments that can produce virtual images are:

â€¢ **Microscopes**

â€¢ **Telescopes**

â€¢ **Prism binocular**

These serve as an extension of sight. Microscope is an *extension of eye to see tiny objects and microorganisms*. A telescope is an *extension of eye to view very far objects*. These objects cannot be seen with an unaided eye.

Microscopes

Microscopes magnify tiny objects many times to make them visible to the eye. We will consider two types: the **simple microscope** and the **compound microscope**.

Simple microscope or magnifying glass

The simple microscope is used to see in detail the features of a close object. It always produces a **magnified, erect** and **virtual image** of an object placed at a distance less than the focal length of the lens. The image is formed at the near point of the eye.

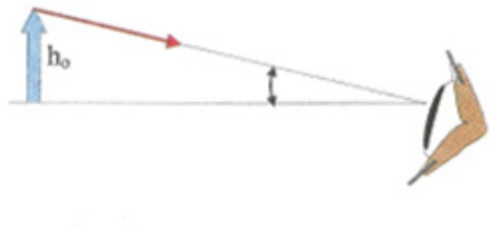


Figure 14.27a

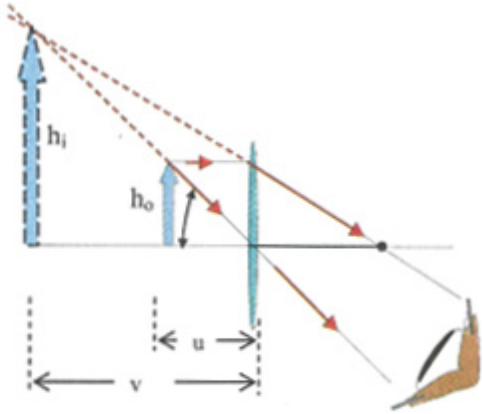


Figure 14.27b: The simple microscope

The angle Î² subtend by the image with the eye at the near point is more the angle Î± subtend by the object at the eye when viewed directly at the near point without the magnifying glass. The angular and linear magnifications are given by:

$$Angular\ magnification = \frac{\beta}{\alpha}$$

$$Linear\ magnification = \frac{v}{u} = \frac{h_i}{h_o}$$

The symbols h_i h_o, v, u have their usual meanings. The magnification equations of a simple microscope can be given by;

$$m = \frac{v}{f} - 1 = \frac{D}{f} - 1$$

D is the near point of the eye or the least distance of distinct vision (LDDV). This shows that the magnification of a simple microscope is higher for lenses with short focal lengths.

Compound microscope

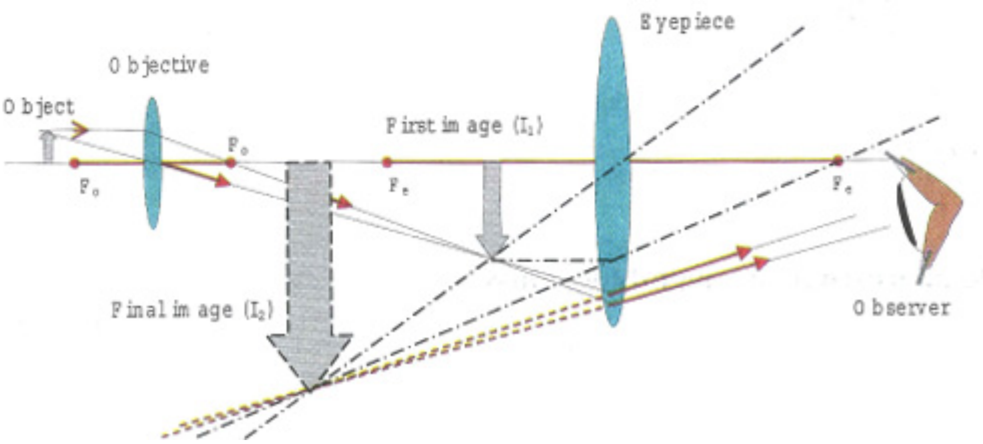


Figure 14.28: Compound microscope

Greater magnification is obtained when two convex lenses of short focal lengths are combined to make a compound microscope. The lens nearest to the object is called the **objective** and the one closest to the eye is called the **eyepiece**. The objective lens has a shorter focal length compared with the eyepiece lens. The objective lens is used to form a **magnified, real** and **inverted image** I_1 of the object placed just behind its focus. The image I_1 formed by the objective lens is the object for the eyepiece lens. The eyepiece acts as a magnifying glass to magnify the object, therefore, the image I_1 must be formed within the focal length of the eyepiece lens.

The final image I_2 produced by the eyepiece is virtual, inverted and magnified. Compound microscopes produce greater magnification, the magnifying power is the product of the magnifying powers of the objective and eyepiece.

$$m_o = \frac{v_o}{f_o} - 1 \quad and \quad m_e = \frac{D}{f_e} - 1$$

$$\therefore \ m = m_o \times m_e$$

$$m = \left(\frac{v_o}{f_o} - 1\right)\left(\frac{D}{f_e} - 1\right)$$

Basic parts of optical microscope

1. Ocular lens, or eyepiece 2. Objective turret 3. Objective lenses 4. Coarse adjustment knob 5. Fine adjustment knob 6. Object holder or stage 7. Mirror 8. Diaphragm and condenser

Figure 14.29: Modern optical microscope

Telescopes

A telescopeis an instrument designed to observe distant objects by the collection of electromagnetic radiation for viewing magnified image, taking photographs of distant objects and electronically storing data through image sensors.

Types of telescopes

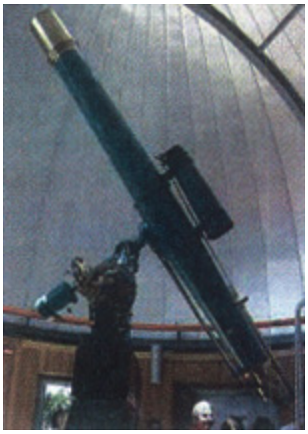
The types of telescopes include: the optical telescope, the radio telescope and X-ray and gamma telescopes.

The optical telescopes

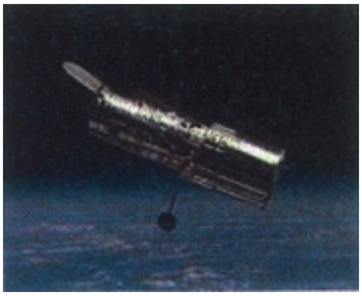
The three primary types of optical telescope are;

1. Refractors (Dioptrics) telescope which use lenses to collect visible light and focus them so that we view a magnified image, take photographs or collect data through electronic sensors.
2. Reflectors (Catoptrics) telescope which uses mirrors to do the same work as the refractors telescope.
3. Combined Lens-Mirror System (catadioptric) telescope which uses a combination of lenses and mirrors to capture magnified images for viewing.

Examples of optical telescopes:



Refracting telescope



The Hubble Space Telescope is in orbit beyond Earthâ€™s atmosphere to allow for observations not distorted by atmospheric seeing

Reflecting telescope

Radio telescopes

Radio telescopes are telescopes that can pick up radiations outside the visible light. It can collect microwave radiation, when any visible light is obstructed, such as from quasars. Some radio telescopes are used to search for extra-terrestial life.

The working of telescopes

An astronomical telescope is used to bring distant objects closer and to make them look bigger. It has two convex lenses. The **objective** has long focal length and the **eyepiece** with short focal length. Parallel light rays from distant objects like the planets are converged by the objective to the principal focus (F_0). A real, inverted and diminished image of the distant object is formed at the focus (F_0) of the objective. The image I_1 formed by the objective serves as an object to the eyepiece; the eyepiece acts as a magnifying glass magnifying it to produce a final image I_2 at the near point of the eye.

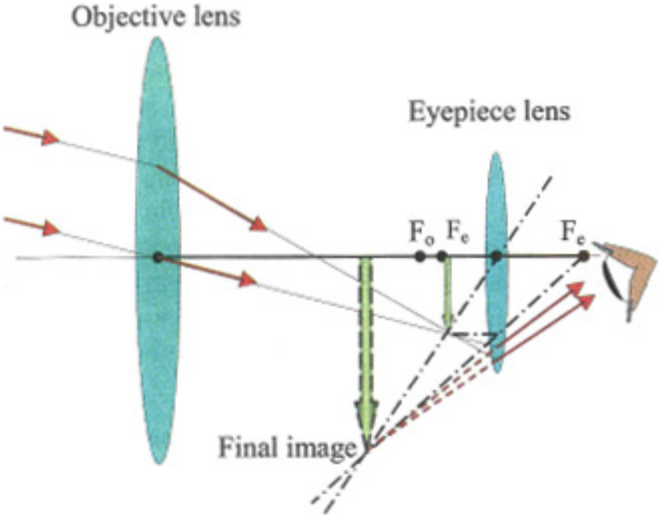


Figure 14.30: Telescope with image at near point of the eye

Normal adjustment of a telescope

The eyepiece of an astronomical telescope can be adjusted to form a final image at infinity. When this happens, the telescope is said to be under normal adjustment. ***Normal adjustment of telescope occurs when the focus of the objective F_o coincides with the focus F_e of the eyepiece***. The distance between the objective and the eyepiece is the sum of their focal lengths ($F_o + F_e$).

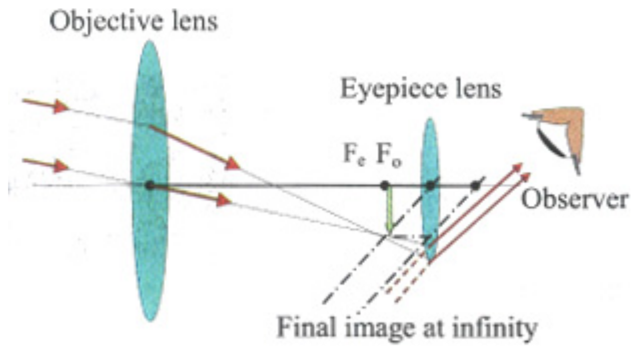


Figure 14.31: Telescope with image at infinity

Angular magnification

Angular magnification of a telescope is defined as the ratio of focal length of the objective lens to the focal length of the eyepiece lens.

$$m = \frac{f_0}{f_e}$$

m = angular magnification, f_o = focal length of the objective lens and f_e = focal length of the eyepiece lens.

Higher magnification is obtained by using objective lens of longer focal length and eyepiece of shorter focal length.

The reflecting telescopes

Reflecting telescope uses large concave mirror to collect and focus light from a distant object to a convex or plane mirror. The convex mirror intercepts the light before it reaches the focus of the converging mirror and reflects it to the eyepiece lens. The eyepiece lens acts as a magnifying glass to magnify the image of the object. The final image is formed at the near point of the eye is virtual and inverted.

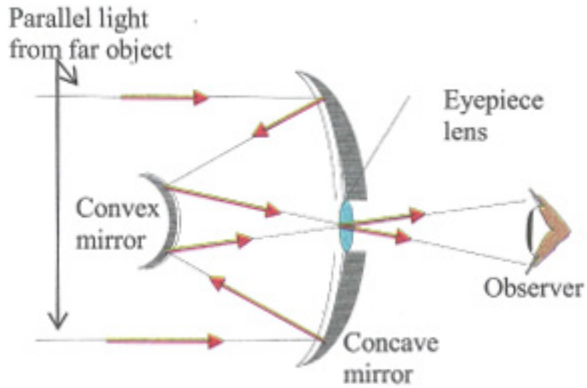


Figure 14.32: The reflecting telescope

Terrestrial telescope

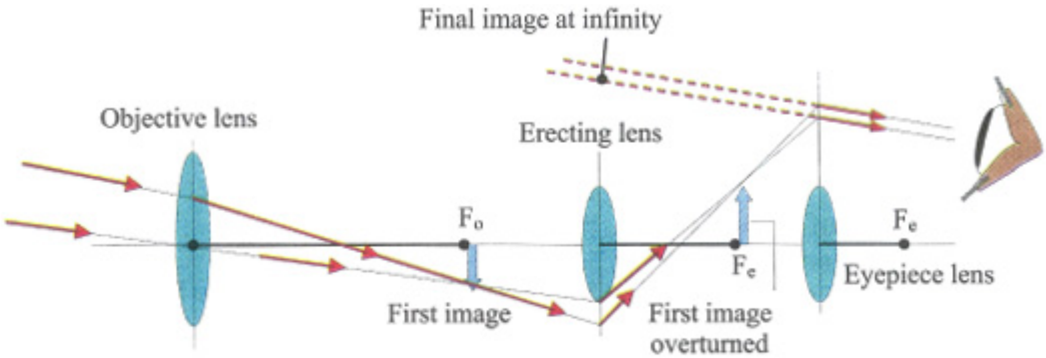


Figure 14.33: *Terrestrial telescope*

An terrestrial telescope is a modification of an astronomical telescope to produce a final erect or upright image. It is adapted to view distant object on the earthâ€™s surface. Terrestrial telescope (Figure 14.33) is made up of:

â€¢ **Objective lens** of long focal length to form the first image of the distant. This serves as an object to the eyepiece lens.

â€¢ **Erecting lens** to overturn the image to make the final image upright.

â€¢ **Eyepiece lens** to increase the magnifi-cation of the object.

The advantage of a terrestrial telescope is that it forms an erect image of the distant object. The disadvantages are:

(i) the erecting lens increases the length of the telescope by twice its focal length.

(ii) the final image is faint due to reflection at the surface of the erecting lens.

Galilean telescopes

Galileo was the first person to construct a telescope. His version of telescope known as Galilean telescope (Figure 14.34) is used to produce an erect image of a distant object. It has two lenses; **the objective** made of **convex lens** and the **eyepiece lens** made of **concave lens**. The objective lens has a long focal length while the eyepiece lens has a short focal length.

The objective lens collects parallel rays from the distant object and refracts it toward its focus F_0 . The refracted rays are diverged by the concave lens (eyepiece lens) before it gets to the focus of the objective lens F_o. A final erect image is formed at the near point of the eye or at infinity.

The telescope is normally adjusted when the final image is formed at infinity. Under normal adjustment, the distance between the objective lens and the eyepiece lens (D) is the difference of their focal lengths.

$$D = f_o - f_e$$

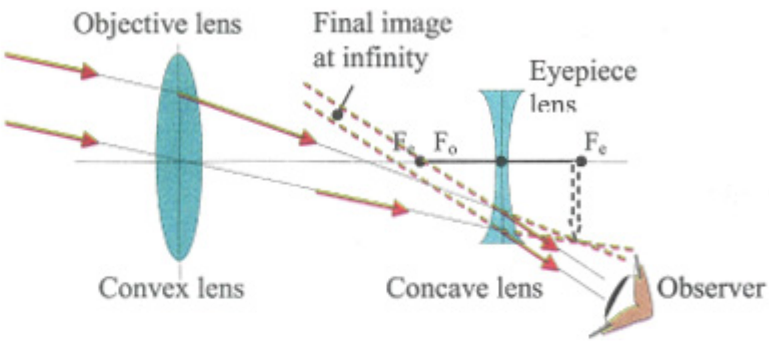


Figure 14.34: Galilean telescope

The angular magnification is the ratio of the focal length of the objective to the focal length of the eyepiece.

$$m = \frac{f_0}{f_e}$$

m = angular magnification, f_o = focal length of the objective lens and f_e = focal length of the eyepiece lens.

Magnification is increased using objective lens of longer focal length and eyepiece of shorter focal length. The disadvantages of a Galilean telescope is that it has a small field of view (covers smaller area) compared with the astronomical telescope. The concave lens diverge light rays so that it is not easy to position the eye to collect all the light rays refracted by the objective lens.

Prism binocular

An prism binocular is a condensed astronomical telescope. It has two astronomical telescopes in one giving an advantage of binocular vision. This arangement enables the user use both eyes to look at a distant object. The binocular vision helps the viewer to see a three-dimensional image of the object. The main features of prismatic binocular are:

â€¢ **Objective lens** which collects parallel rays of light from the object.

â€¢ **Erecting triangular prism** with 45Â° - 45Â° - 90Â° to turn the light rays through 180Â° in order to produce an erect image.

â€¢ **Eyepiece lens** which magnifies the first image to produce a final image.

Uses of binoculars

1. Binoculars are used in military to view enemyâ€™s target.
2. Binoculars like the Galilean telescope are used to watch actors on stage.
3. Binoculars are used outdoors by tourists view birds and animals.
4. Binoculars are widely used by amateur astronomers; their wide field of view makes them useful for comet and supernova seeking (giant binoculars) and general observation (portable binoculars).

Ceres, Neptune, Pallas, Titan, and the Galilean moons of Jupiter are invisible to the naked eye but can readily be seen with binoculars.

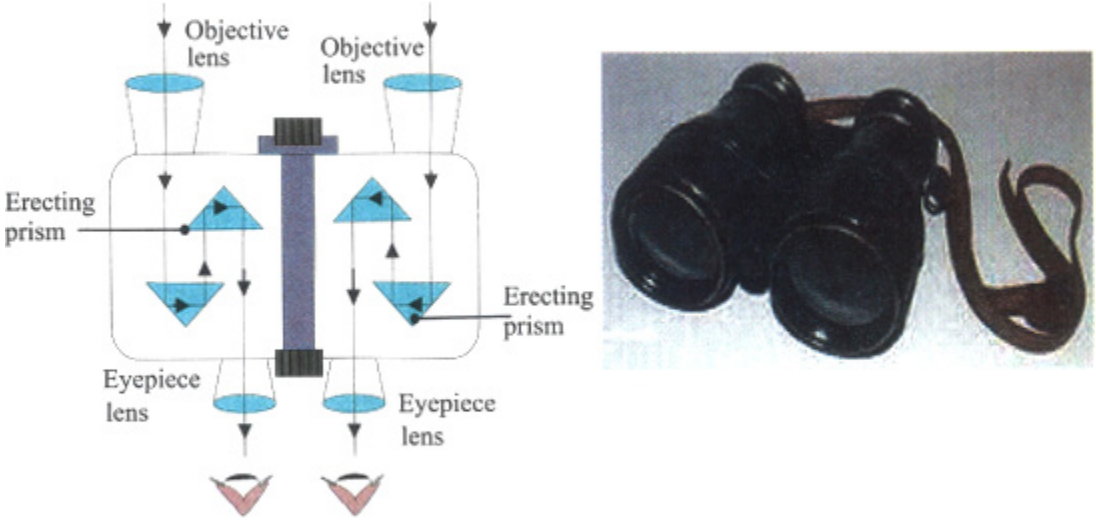


Figure 14.35: Prism binocular

Summary

â€¢ Optical instruments which form real image of objects in front of them, are the **eye, camera** and **film** or **slide projector**.

â€¢ **Optical instruments which form virtual images** of object in front of them are **microscopes, telescopes** and **prism binocular.**

â€¢ The eye behaves like a thick lens refracting light waves and focusing it on the retina.

â€¢ **Accommodation** is the ability of the eye to focus clearly both objects at far and near points on the retina.

â€¢ **Near point** is the closest point the eye can see an object clearly without strain. The near point for normal adult is 25 cm from the eye.

â€¢ **Far point** is the most distant point the eye can see clear clearly. The far point for a normal adult eye is at infinity.

â€¢ **Sight defect** occurs if the eye is not able to form clear or sharp images on the retina. The **two** main types of eye or sight defects are the **short sightedness** and the **long sightedness**.

â€¢ **Short-sightedness** is the inability of the eye to focus clear or sharp images of **far** objects on the retina.

â€¢ **Long-sightedness** is the inability of the eye to focus on the retina clear or sharp images of objects at the **near** point.

â€¢ **A camera** is light-tight box with a single convex lens or a system of lenses at one end and light sensitive film at the other end.

â€¢ **The film or the slide projector** is used to form a magnified real image of a slide or film on a screen. An erect magnified real image of the slide is formed on the screen if the slide or film is placed upside-down (inverted) between the focus and 2F of the projection lens.

â€¢ **Microscopes** magnify tiny objects many times to make them visible to the eye.

â€¢ The **simple microscope** is used to see in detail the features of a close object. It always produces a magnified, erect and virtual image of an object placed at a distance less than the focal length of the lens.

â€¢ **The compound microscope** uses two convex lenses of short focal lengths to obtain greater magnification.

â€¢ **An astronomical telescope** is used to bring distant objects closer and make them look bigger. It has two convex lenses. The objective has long focal length and the eyepiece with short focal length.

â€¢ An astronomical telescope is in **normal adjustment** if the eyepiece can be adjusted to form a final image at infinity.

Past questions

1. A person can focus an object only when it is within 200 cm from him. Which spectacles should be used to increase his maximum distance of distinct vision to infinity?

   A. Plane glasses

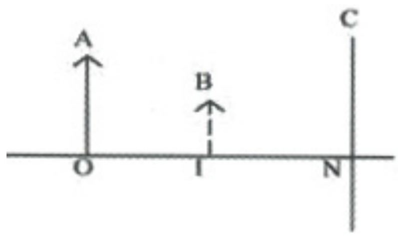
   B. Concave lens

   C. Convex lens

   D. Binoculars

JAMB

2. In the figure below, OA is an object whose virtual image is IB.



   Then CN is a

   A. concave mirror.

   B. converging lens.

   C. convex mirror.

   D. diverging lens.

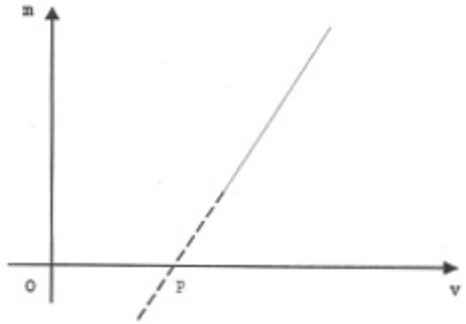
   E. plane mirror.

NECO

3. A magnified and virtual image of a near object is produced by
   A. prism binocular.
   B. astronomical telescope.
   C. periscope.
   D. simple microscope.

WASSCE

4. In an experiment using a converging lens to produce real images on a screen, the linear magnification, **m**, is plotted against the image distance, **v**, as illustrated in the diagram below. The distance O P represents the



   A. focal length of the lens.
   B. thickness of the lens.
   C. radius of curvature of the lens.
   D. diameter of the lens.

WASSCE

5. A converging lens produces an image four times as large as an object placed 25 cm from the lens. Calculate its focal length.
   A. 100 cm.
   B. 33 cm.
   C. 29 cm.
   D. 20 cm.

WASSCE

6. A converging lens has a focal length of 5 cm. Determine its power.
   A. +20.0 D.
   B. +0.2 D.
   C. –20.0 D.
   D. –0.2 D.

WASSCE

7. Which of the following correctly describes the image formed by a diverging lens?
   A. Diminished, erect and virtual.
   B. Diminished, inverted and real.
   C. Diminished, inverted and virtual.
   D. Magnified, erect and virtual.

E. Magnified, inverted and real.

NECO

8. The inability of the eye to focus near objects is known as
   A. astigmatism.
   B. eye ring.
   C. hypermetropia.
   D. myopia.
   E. presbyopia

NECO

9. A converging lens of focal length 15 cm forms a virtual image at a point 10 cm from the lens. Calculate the distance of the object from the lens.
   A. 10.00 cm.
   B. 6.00 cm.
   C. 5.00 cm.
   D. 1.50 cm.

WASSCE

10. In a compound microscope, the image formed by the objective lens is at a distance of 3.0 cm from the eye lens. If the final image is at 25.0 cm from the eye lens, calculate the focal length of the eye lens.
    A. 0.3 cm.
    B. 2.7 cm.
    C. 3.4 cm.
    D. 8.3 cm.

WASSCE

11. An object is placed 20 cm from a lens. If the image is formed on a screen 260 cm away from the lens, calculate the magnification of the image.
    A. 28.
    B. 26.
    C. 24.
    D. 13.

WASSCE

12. What part of the camera corresponds to the iris of the eye?
    A. diaphragm.
    B. film.
    C. focusing.
    D. lens.
    E. shutter.

NECO

13. In the normal use of a simple microscope, a person sees an
    A. erect, real and magnified image. B. erect, virtual and magnified

image.

C. inverted, virtual and magnified image.

D. inverted, real and magnified image.

E. Inverted and real image the same size as the object.

NECO

14. The image of an object formed on the retina of the human eye is

A. virtual and diminished.

B. erect and diminished.

C. inverted and real.

D. erect and real.

WASSCE

15. An object placed 15 cm from a converging lens forms a real image whose magnification is 2.0. What is the focal length of the lens?

A. 5.00 cm.

B. 10.00 cm.

C. 15.00 cm.

D. 18.00 cm.

E. 20.00 cm

NECO

16. What part of a camera functions in a similar way to the retina of the eye?

A. diaphragm.

B. film.

C. focusing.

D. lens.

E. shutter.

NECO

17. When an astronomical telescope is in normal adjustment, the focal length of the objective lens is 50 cm and that of the eye piece is 5.0 cm. what is the distance between the lenses?

A. 10.0 cm.

B. 30.0 cm.

C. 45.0 cm.

D. 55.0 cm.

E. 250 cm.

NECO

18. (a) When is an astronomical telescope said to be in normal adjustment?

(b) The objective and the eyepiece of an astronomical telescope have focal lengths of 50 cm and 5 cm respectively. What is the distance apart of the lenses if:

(i) object and final image are both at infinity,

(ii) the object is at infinity and the final image is formed 25 cm from the eye lens.

NECO