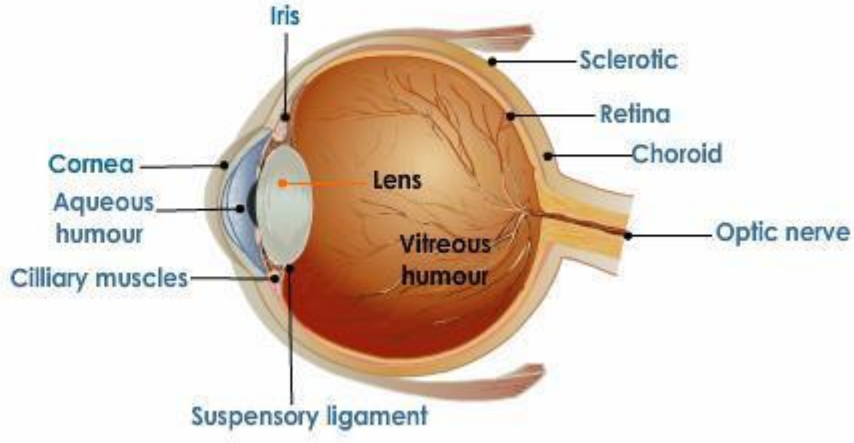
Optical Instruments

Contents

2. OPTICAL INSTRUMENTS

2.1 HUMAN EYE

The human eye uses light and enables us to see objects around us. Our eye is the most important natural optical instrument. The eye is nearly spherical in shape with a slight bulge in the front part.



Structure of the Human Eye

2.1.1 The Important Parts of the Eye and their Functions

Cornea: The front part of the eye is covered by a transparent spherical membrane called the cornea. Light enters the eye through cornea. The space behind the cornea is filled with a liquid called aqueous humour.

Iris: Just behind the cornea is a dark coloured muscular diaphragm which has a small circular opening in the middle.

Pupil: Pupil is the small circular opening of iris. The pupil appears black because no light is reflected from it.
The iris regulates the amount of light entering the eye. It regulates the light by adjusting the size of the pupil.

Eye Lens: The eye lens is a convex lens made of a transparent jelly - like proteinaceous material. The eye lens is hard at the middle and gradually becomes soft towards the outer edges. The eye lens is held in position by ciliary muscles. The ciliary muscles help in changing the curvature and focal length of the eye lens.

Retina: The inner back surface of the eye ball is called retina. It is a semi-transparent membrane which is light sensitive and is equivalent to the screen of a camera. The light sensitive receptors of the retina are called rods and cones. When light falls on these receptors they send electrical signals to the brain through the optic nerve. The space between the retina and eye lens is filled with another fluid called vitreous humour.

Blind Spot: It is a spot at which the optic nerve enters the eye and is insensitive to light and hence the name.

Let us see how iris regulates the amount of light entering the eye.

- When the intensity of light is more or if it is a bright source of light then the iris makes the pupil to contract and as a result the amount of light entering the eye decreases.
- When the intensity of light is less or if the light is dim then the iris dilates the pupil so that more light can enter the eye.

Working of an eye

The light coming from an object enters the eye through cornea and pupil. The eye lens converges these light rays to form a real, inverted and diminished image on the retina. The light sensitive cells of the retina get activated with the incidence of light and generate electric signals. These electric signals are sent to the brain by the optic nerves and the brain interprets the electrical signals in such a way that we see an image which is erect and of the same size as the object.

2.1.2 Accommodation of the Eye

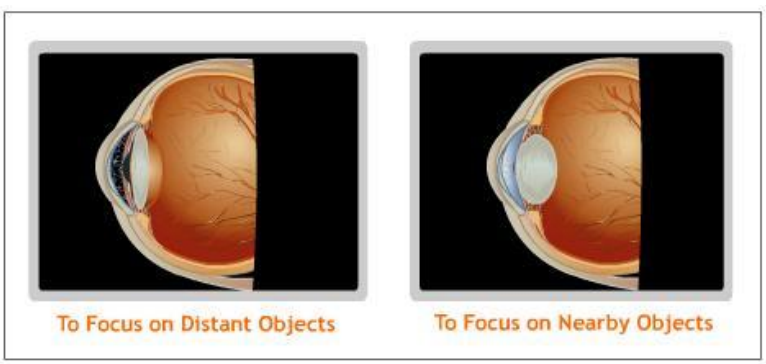
The process by which the ciliary muscles change the focal length of an eye lens to focus distant or near objects clearly on the retina is called the accommodation of the eye.

2.1.3 Power of Accommodation

The ability of the eye to focus objects lying at different distances is called the power of accommodation of the eye.

Question: How Does an Eye Focus Objects at Varying Distances?

Answer: To focus on distant objects the ciliary muscles relax making the eye lens thin. As a result the focal length of the eye lens increases and we see the distant objects. But to focus on nearby objects the ciliary muscles contract making the eye lens thick. As a result the focal length of the eye lens decreases and we see the nearby objects. In short it is the adjustment of the focal length of the eye lens which enables us to focus on objects situated at different distances.



2.1.4 Near point or Least Distance of Distinct Vision

Near point or least distance of distinct vision is the point nearest to the eye at which an object is visible distinctly.

For a normal eye the least distance of distinct vision is about 25 centimetres. However, it varies with age of the person. For example, for infants it is only 5 to 8 cm.

2.1.5 Far Point

Far point of the eye is the maximum distance up to which the normal eye can see things clearly. It is infinity for a normal eye.

2.1.6 Range of Vision

The distance between the near point and the far point is called the range of vision.

2.1.7 Defects of Vision and their Correction

There are four types of defect of the Eye:
1) Myopia
2) Hypermetropia
3) Presbyopia
4) Astigmatism.

1) Myopia: Nearsightedness, also called myopia is common name for impaired vision in which a person sees near objects clearly while distant objects appear blurred. In such a defective eye, the image of a distant object is formed in front of the retina and not at the retina itself. Consequently, a nearsighted person cannot focus clearly on an object farther away than the far point for the defective eye.

Causes: This defect arises because the power of the eye is too great due to the decrease in focal length of the crystalline lens. This may arise due to either excessive curvature of the cornea, or elongation of the eyeball.

Correction: This *defect* can be *corrected* by using a *concave (diverging*) lens. A concave lens of appropriate power or focal length is able to bring the image of the object back on the retina itself.

2) Hypermetropia: Farsightedness, also called hypermetropia, common name for a defect in vision in which a person sees near objects with blurred vision, while distant objects appear in sharp focus. In this case, the image is formed behind the retina.

Causes: This defect arises because either the focal length of the eye lens is too great, or the eyeball becomes too short, so that light rays from the nearby object, cannot be brought to focus on the retina to give a distinct image.

Correction: This defect can be corrected by using a *convex* (*converging*) l*ens* of appropriate focal length. Eyeglasses with converging lenses supply the additional focussing power required for forming the image on the retina.

3) Presbyopia: **Presbyopia,** progressive form of farsightedness that affects most people by their early 60s. The power of accommodation of the eye decreases with ageing. Most people find that the near point gradually recedes.

Cause and cure: It arises due to the gradual weakening of the ciliary muscles and diminishing flexibility of the crystalline lens. Simple reading eyeglasses with convex lenses correct most cases of presbyopia. Sometimes, a person may suffer from both *myopia* and *hypermetropia*. Such people often require *bi-focal lenses*. In the bi-focal lens, the upper portion of the bi-focal lens is a concave lens, used for distant vision. The lower part of the bi-focal lens is a convex lens, used for reading purposes.

4) Astigmatism: **Astigmatism,** a defect in the outer curvature on the surface of the eye that causes distorted vision. In *astigmatism*, a person cannot simultaneously focus on both horizontal and vertical lines.

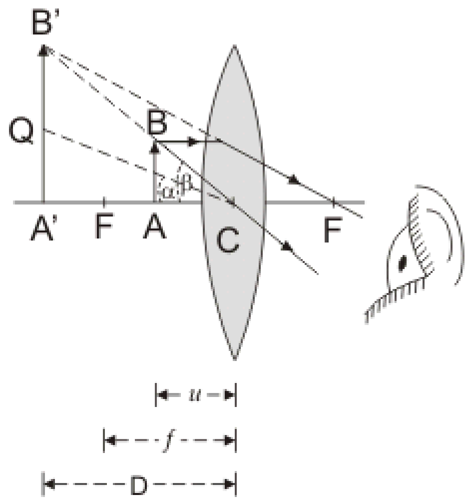
Causes: This defect is usually due to the cornea that is not perfectly spherical. Consequently, it has different curvatures in different directions in vertical and horizontal planes. This results in objects in one direction being well-focused, while those in a perpendicular direction not well focused.

Correction: This defect can be corrected by using eyeglasses with *cylindrical lenses* oriented to compensate for the irregularities in the cornea.

2.2 SIMPLE MICROSCOPE (MAGNIFYING GLASS)

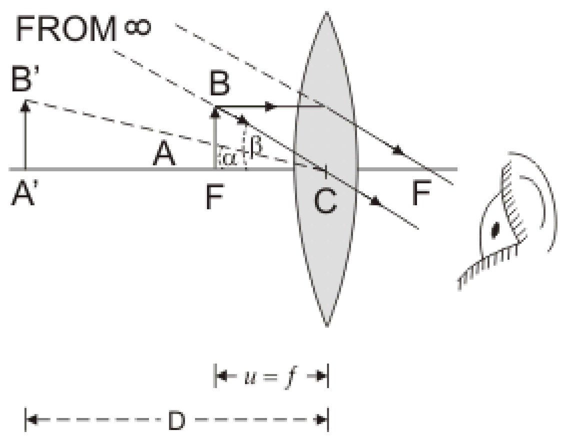
A convex lens of short focal length can be used to see magnified image of a small objects and is called a magnifying glass or a simple microscope.

Principle: When a small object is placed between the optical centre and the focus of a convex lens, its virtual, erect and magnified image is formed on the same side of the lens. The lens is held close to the eye and the distance of the objects is adjusted, till the image is formed at the least distance vision from the eye. For a normal eye, the least distance of distinct vision is 25 cm.



Working: Let AB be an object placed between the points F and C. Its virtual image A' B' will be formed on the same side of the object. If the distance of the object from the lens is changed, then the distance of the image also changes. The position of the object AB is so adjusted that the image A'B' is formed at the least distance of distinct vision (D) as shown in Fig.

Magnifying power (When image is formed at D): It is defined as the ratio of the angle subtended by the image at the eye to the angle subtended by the object seen directly when both lie at the least distance of distinct vision. It is also called the angular magnification produced the simple microscope. It is denoted by M.



By definition, the magnifying power of the simple microscope is given by

$$M = \beta / \alpha$$

$$M = 1 + \frac{D}{f} \quad \text{... (1)}$$

From the equation (1) it follows that the lesser is the focal length of the convex lens used as simple microscope, the greater is the value of the magnifying power obtained.

Further, the positive value of magnifying power of a simple microscope tells that image formed is erect and hence virtual.
Magnifying power (when image is formed at infinity)

$$M = \frac{D}{f}$$

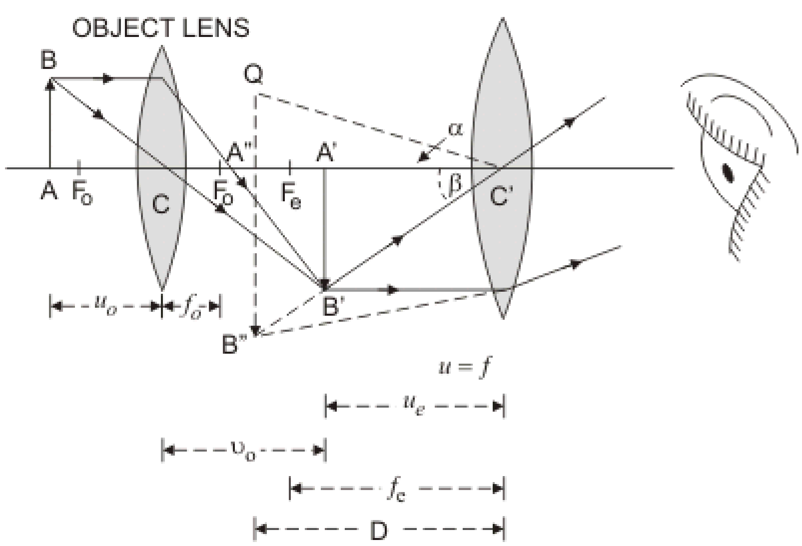
Uses:

1. Jewelers and watch makers make use of a convex lens of short focal length to obtain a magnified view of the fine jewellery work and the small components of the watches.
2. In Science laboratories, a magnifying glass is used to see slides and to read the vernier scales attached to the instruments.
3. The use of magnifying glass enables us to place the object close to the eye, making it appear bright and yet clearly visible. In the position AB, the object lies close to the eye. In the absence of lens, the object will not be clearly visible.

2.3 COMPOUND MICROSCOPE

A compound microscope is used to see the extremely small objects.
It consists of two lenses. A lens of short aperture and short focal length facing the object is called the object lens and another lens of short focal length but large aperture is called the eye lens. The two lenses are placed coaxially at the two ends of a tube. To focus over an object, the distance of the object lens from the object is adjusted with the help of rack and pinion arrangement.

Principle: When a small object is placed just outside the focus (F_0) of the object lens its real, inverted and magnified image is produced on the other side of the lens beyond $2F_0$. The image produced by the object lens acts as object for the eye lens. The distance of the object from the object lens is so adjusted that the final image is formed at the least distance of distinct vision from the eye.



Working: Let AB be an object placed just outside the focus F_0 of the object lens. Its real image A'B' is formed on the other side of the lens between the focus F_e and the optical centre C' of the eye lens and it acts as the object for the eye lens. Using the rack and pinion arrangement, the distance between the object lens and the object AB is adjusted, till its virtual and magnified image A''B'' is formed by the eye lens on the same side at the least distance of distinct vision.

Magnifying power (when image is formed at D): It is defined as the ratio of the angle subtended by the final image at the eye to the angle subtended by the object seen directly, when both are placed at the least distance of distinct vision.

By definition, the magnifying power of the compound microscope.

$$M = \frac{\beta}{\alpha}$$

$$M = m_0 \times m_e$$

$$m_0 = \frac{v_0}{u_0}$$

$$m_e = 1 + \frac{D}{f_e}$$

$$M = \frac{v_0}{u_0}$$

In practice, the focal length of the object lens is very short and the object AB is placed just outside the focus of the object lens.

$u_0 \approx f_0$ (In magnitude)

Since the focal length of the eye lens is also small, the distance of the image A'B' from the object lens is nearly equal to the length of microscope tube i.e.

$$v_0 \approx L$$

$$M = \frac{L}{f_0}\left(1 + \frac{D}{f_e}\right)$$

Magnifying power (When image is formed at infinity): The magnifying power of a compound microscope is given by

$$M = m_0 \times m_e$$

If u_0 is the distance of the object from the object lens and v_0, the distance of the image from it, then as obtained earlier,

$$m_0 = \frac{v_0}{u_0}$$

The eye lens produces the final image at infinity. Then, as discussed in the case of a simple microscope; it can be obtained that

$$m_e = \frac{D}{f_e}$$

Where f_e is the focal length of the eye lens.

Therefore, the magnifying power of a compound microscope is given by

$$M = \frac{v_0}{u_0} \times \frac{D}{f_e}$$

2.4 TELESCOPE

A telescope is an instrument for seeing the distant objects clearly and magnified (though apparently). It is of two types:

1. **Astronomical telescope**: A telescope used to see the heavenly bodies is called an astronomical telescope. It produces a real and inverted image. As the heavenly bodies are round, the inverted image does not affect the observation.

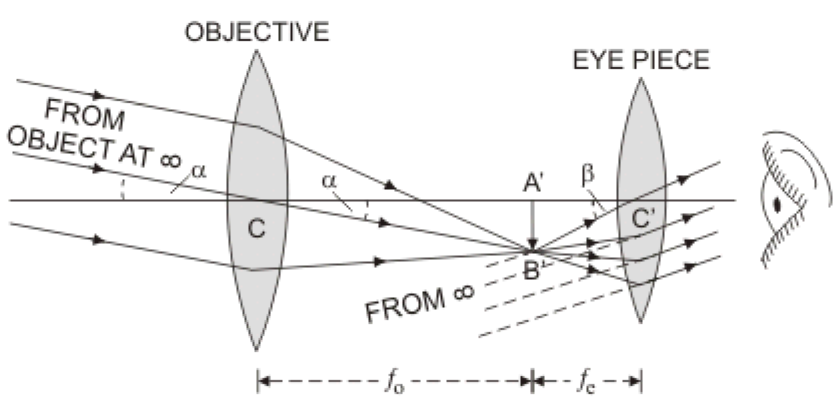
2. **Terrestrial telescope:** For observing objects on earth, it would be necessary to have an erect image. A telescope used for observing objects on the earth is called a terrestrial telescope.

2.4.1 Astronomical Telescope (Refracting Type)

An astronomical telescope is used to see the heavenly objects.
An astronomical telescope consists of two lens systems. The lens system facing the object is called objective. It has large aperture and is of large focal length (f_0). The other lens system is called eye-piece. It has small aperture and is of short focal length (f_e). The objective and the eye-piece are mounted coaxially in two metallic tubes. The tubes holding the eye-piece can be made to slide the tube holding the objective with the help of rack and pinion arrangement.

Principle: The objective forms the real and inverted image of the distant object at its focal plane. The distance of the eye-piece from the objective is adjusted, till the final image is formed at the least distance of distinct vision. In case, the position of the eye-piece is so adjusted that final image is formed at infinity, the telescope is said to be in normal adjustment.

(a) **When the final image is formed at infinity (Normal adjustment):** When a parallel beam of light rays from the distant object falls on the objective, its real and inverted image A’B’ is formed on the other side of the objective and at a distance equal to its focal length f_0. If the position of eye-piece is adjusted, so that the image A’B’ lies at its focus, then the final highly magnified image will be formed at infinity.

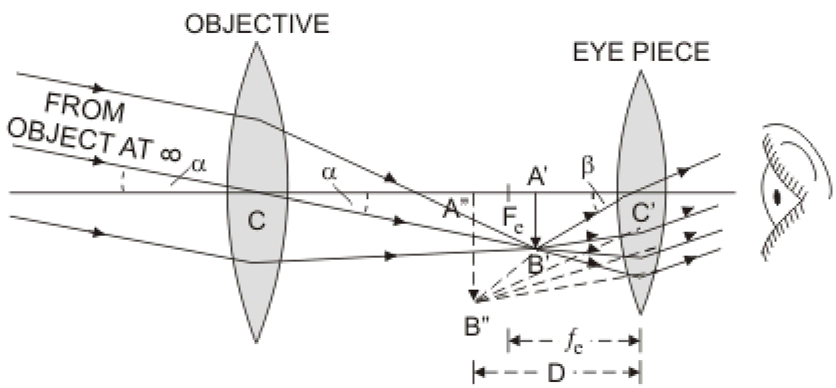


Magnifying power: Magnifying power of a telescope in normal adjustment is defined as the ratio of the angle subtended by the image at the eye as seen through the telescope to the angle subtended by the object seen directly, when both the object and the image lie at infinity. It is also called angular magnification of the telescope and is denoted by M.

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

It follows that the magnifying power of a telescope in normal adjustment will be large, if the focal length of the objective is large and that of the eye-piece is small. Further, the negative value of the magnifying power of the telescope tells that final image formed is inverted and real.

(b) **When the final image is formed at least distance of distinct vision:** When a parallel beam of light rays from the distant object falls on the objective, its real and inverted image A'B' is formed on the other side of the objective at a distance equal to its focal length f_0. The distance of the eye-piece formed at the least distance of distinct vision.



Magnifying power: Magnifying power of a telescope is defined as the ratio of the angle subtended at the eye by the image formed at the least distance of distinct vision to the angle subtended at the eye by the object lying at infinity, when seen directly.

$$M = \frac{f_0}{f_e}\left(1 + \frac{D}{f_e}\right)$$

A refracting telescope will have large magnifying power, if the object lens is of large focal length and the eye lens is of short focal length. Further, the negative value of magnifying power of the telescope tells that the final image formed is inverted and real.

2.4.2 Reflecting Type Telescope (Cassegrain Telescope)

An astronomical telescope used to see the distant stars should possess large light gathering power (in order to obtain a bright image of even a faint star) and high resolving power (so as to observe its minute and finer details). Both the light gathering power and the resolving power for a telescope will be large, if the objective of the telescope is of large aperture. However, it cannot be achieved in a refracting type astronomical telescope. It is because; a convex lens of large aperture free from spherical and chromatic aberrations cannot be designed.

Reflecting type telescope was designed by Newton in order to overcome the drawbacks of refracting type telescope. In a reflecting type telescope, a concave mirror of large aperture is used as objective in place of a convex lens. It possesses a large light gathering power and a high resolving power. Due to this, it enables us to see even faint stars and observe their minute details.

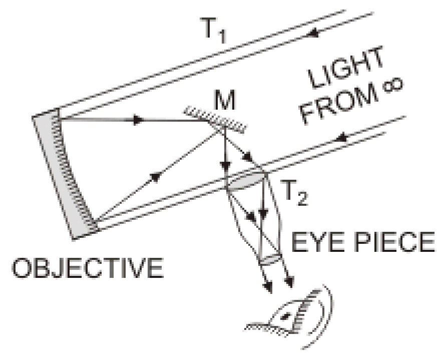


Figure shows the various parts of the reflecting type telescope and the course of rays showing the formation of the final image of the distant star. The concave mirror of large aperture and large focal length is fixed at one end of the tube T_1, Whose other end is kept open to allow the light from the distant star to fall on the spherical concave mirror. Before the reflected rays of light meet to form the real, inverted and diminished image of the star at the focal plane of the concave mirror, they are intercepted and reflected by a plane mirror (M) inclined at an angle of 45° to the axis of the tube T_1. The plane mirror deviates the rays and the real image is formed in front of the eye-piece fitted in a side metal tube T_2 with its axis at a right angle to the axis of the tube T_1. The eye-piece only acts as magnifier and produces the final virtual and magnified image of the star enabling eye to see it distinctly.

If f_0 is focal length of the concave spherical mirror used as objective and f_e, the focal length of the eye-piece, then magnifying power of the reflecting telescope is given by

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

Further, if D is diameter of the objective and d, the diameter of the pupil of the eye, then brightness ratio is given by

$$B = -\frac{D^2}{d^2}$$

A concave mirror of very large diameter can be easily manufactured and such a telescope may be used to observe even very faint stars.

Advantage of a reflecting type telescope:

A reflecting type telescope has following advantages over a refracting type telescope.

1. Since objective is not a lens, the image formed is free from chromatic aberration.
2. Spherical aberration can be minimized by making use of a parabolic mirror in place of concave spherical mirror as objective. It enables to produce a very sharp and distinct image.
3. A concave spherical mirror of large aperture can be easily manufactured and hence due to very large light gathering power, it enables to see even very faint stars.

4. Also, in a reflecting type telescope, the objective (a concave spherical mirror) of large aperture provides a very high resolving power so as to see even the minute and fine details of the distant stars.

2.4.3 Some Important Features of a Telescope

A telescope should have

1. High magnifying power.
2. High resolving power.
3. Large light gathering power.

2.5 SOLVED EXAMPLES

Question: The image formed by an objective of a compound microscope is:

(A) virtual and diminished
(B) real and diminished
(C) real and enlarged
(D) Virtual and enlarged.

Answer: (C)

Question: An astronomical telescope has a large aperture to:

(A) reduce spherical aberration
(B) have high resolution
(C) increase span of observation
(D) have low dispersion

Answer: The resolving power of the telescope is

$$R.P. = D/1.22\lambda$$

Therefore, resolving power of the telescope will be high, if its objective is of large aperture.