Optical Instruments

Objectives

After going through this lesson, the learners will be able to:

- Understand the working of the human eye as an unique and brilliant optical instrument
- Appreciate the need for optical instruments
- Use lenses to make a simple and compound microscope
- Combine lenses and mirrors to make astronomical telescopes reflecting and refracting
- Explain the meaning of magnification for microscopes and telescopes
- Learn the methods to make a telescope / microscope

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Human eye
- Microscope
- Compound microscope
- Telescope
- Making your own telescope
- Summary

Unit Syllabus

UNIT 6: Optics

Chapter–9: Ray Optics and Optical Instruments

Ray optics Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical; fibres; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification, power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue colour of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Wave optics: wavefront and Huygens principle; reflection and refraction of plane waves at a plane surface using wave fronts, proof of laws of reflection and refraction of light using Huygens principle. Interference; Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to single slit; width of central maxima; resolving power of microscope and astronomical telescope, polarization; plane polarized light; Brewster's law; uses of plane polarized light and polaroids.

Module Wise Distribution Of Unit Syllabus-15 Modules

Module 1	● Introduction ● How we will study optics-plan ● Light facts ● Ray optics, beams ● Light falling on surfaces of any shape texture ● Peculiar observations
Module 2	● Reflection of light ● Laws of reflection ● Reflection of light by plane and spherical surfaces ● Spherical Mirrors aperture, radius of curvature, pole principal axis ● Focus, Focal length, focal plane ● Image – real and virtual ● Sign convention ● The mirror equation, magnification ● To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror ● Application of mirror formula
Module 3	● Refraction of light ● Optical density and mass density

	● Incident ray, refracted ray emergent ray ● Angle of incidence, angle of refraction angle of emergence To study the effect on intensity of light emerging through different coloured transparent sheets using an LDR ● Refractive index ● Oblique incidence of light, Snell's law ● Refraction through a parallel sided slab, Lateral displacement, factors affecting lateral displacement ● To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab ● Formation of image in a glass slab
Module 4	● Special effects due to refraction ● Real and apparent depth ● To determine the refractive index of a liquid using travelling microscope ● Total internal reflection ● Optical fibres and other applications
Module 5	● Refraction through a prism ● Deviation of light -angle of deviation ● Angle of minimum deviation ● Expression relating refractive index for material of the prism and angle of minimum deviation ● To determine the angle of minimum deviation for a given prism by plotting a graph between angle of incidence and angle of deviation ● Dispersion, spectrum
Module 6	● Refraction at spherical surfaces ● Radius of curvature ● Refraction by a lens ● Foci, focal plane, focal length, optical centre, principal axis ● Formation of images real and virtual ● Lens maker's formula ● Lens formula and magnification

	• Sign convention • Application of lens formula • Power of lens • Combination of thin lenses in contact

Module 7A and 7B	• To study the nature and size of image formed by a
	  ○ convex lens
	  ○ concave mirror using a candle and a screen
	• To determine the focal length of convex lens by plotting graphs between u and v , between 1/u and 1/v
	• To determine the focal length of a convex mirror using a convex lens
	• To find the focal length of a concave lens using a convex lens
	• To find the refractive index of a liquid by using a convex lens and a plane mirror

Module 8	• Scattering of light – • Blue colour of sky • Reddish appearance of the sun at sunrise and sunset • Dust haze • Colour of clouds
Module 9	• Optical instruments • Human eye • Microscope • Astronomical telescopes reflecting and refracting • Magnification • Making your own telescope
Module 10	• Wave optics • Wave front • Huygen’s principle shapes of wave front • Plane wave front • Refraction and reflection of plane wave front using Huygen’s principle • Verification of Laws of refraction and reflection of light using Huygens principle

Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light • Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or coloured fringes
Module 13	• Diffraction • Diffraction at a single slit • Width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroids • Plane polarised light • Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

Module 9

Words You Must Know

Let us remember the words and the concepts we have been using in the study of this module:

- **Light:** Light is a form of energy which gives the sensation of vision when it falls on the retina of the eye.

- **Ray of light:** The straight line path along which light ordinally propagates is called a ray of light. Light rays start from each point of a source and travel along a straight line path until they strike an object or a surface separating two media.
- **Beam of light:** A group of rays of light is called a beam of light.
- **Parallel beam of light:** If all the rays of light in the group are parallel to one another then the beam is said to be a parallel beam of light.
- **Converging beam of light:** If the rays of light in the group come closer to each other i.e. converge to a point, then the beam is said to be a converging beam of light.
- **Diverging beam of light:** If the rays of light in the group move away from each other i.e. diverge, then the beam is said to be a diverging beam of light.
- **Transparent medium:** A medium through which light can pass freely over a large distance is called a transparent medium. Glass and still water are well known examples of transparent medium
- **Opaque medium:** A medium through which light cannot pass is called an opaque medium. Wood and metals are familiar examples of opaque objects.
- **Real image:** If the rays of light after reflection or refraction meet at a point. Image is said to be a real image.
- **Virtual image:** If the rays of light after reflection or refraction appear to come from a point, this point is the virtual image.
- **Absolute Refractive index:** The ratio of speed of light in vacuum to that in a medium. its value can never be less than 1 , it has no unit
- **Refractive index:** The ratio of speeds of light in a pair of medium (light travelling from medium 1 to medium 2) usually refractive index of medium 2 with respect to medium 1
- **Focal length:** A beam of light incident parallel to the principal axis passes through or seems to diverge from a point on it after reflection from a spherical mirror or after refraction through a spherical lens. This point is called a focus. The distance between the pole /optical center and the focus is called focal length.
- **Combination of lenses:** Lenses can be used such that light emerging from one is incident on another. the combination of lenses in contact with each other has a new focal length, f, is given by

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \dots$$

- **Power of a lens :** the ability of a lens ,to converge or diverge a beam of light is called its power the reciprocal of focal length, in meters is taken as the measure of its power

$$P = \frac{1}{focal\ length\ in\ meters}$$

Unit of power is diopter = m^{-1}

Combined power for lenses in contact is given by

$$P = P_1 + P_2 + ..$$

- **Magnification:** Ratio of size of image to the size of object
- **Rules for drawing ray diagrams:**

  It is convenient to choose any two of the following rays:

  - The ray from the point which is parallel to the principal axis. The reflected ray goes through the focus of the mirror.
  - The ray passing through the centre of curvature of a concave mirror or appearing to pass through it for a convex mirror. The reflected ray simply retraces the path.
  - The ray passing through (or directed towards) the focus of the concave mirror or appearing to pass through (or directed towards) the focus of a convex mirror. The reflected ray is parallel to the principal axis.
  - The ray incident at any angle at the pole. The reflected ray follows laws of reflection
- **Mirror equation:**

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

- **Sign convention:** The Cartesian sign convention

  According to this, all distances are measured from the pole of the mirror or the optical centre of the lens. The distances measured in the same direction as the incident light is taken as positive and those measured in the direction opposite to the direction of incident light are taken as negative

  The heights measured upwards (+ y direction) with respect to x -axis and normal to the principal axis (x-axis) of the mirror/lens are taken as positive. The heights measured (- y direction) downwards are taken as negative
- **Lens formula:**

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

Introduction

Optical instruments are instruments which help us see and appreciate the world around us.

Our eye is, of course, one of the most important optical devices nature has endowed us with.

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A number of optical devices and instruments have been designed by utilising reflecting and refracting properties of mirrors, lenses and prisms.Periscope, kaleidoscope, binoculars, telescopes, microscopes are some examples of optical devices and instruments that are in common use.

Using periscope- an instrument to see objects at different levels

https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcTHVnubnTzXA82gy6YAMdP2aq0kvqQZ3zqDgU0cV8TjFmfSVJi6

Using telescope – an instrument to see far off objects

https://www.flickr.com/photos/futurilla/11369052214

Using microscope-an instrument to see very small objects

https://www.flickr.com/photos/zeissmicro/7039028961

Starting with the eye, we will then go on to describe the principles of working of the microscope and the telescope.

The Human Eye

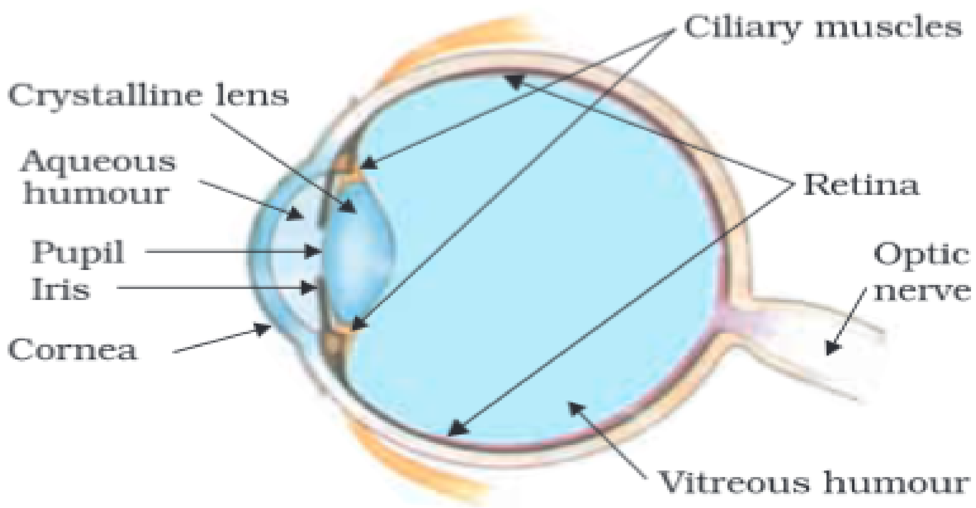
The human eye behaves as a complex optical structure sensitive to wavelengths between 380 nm to 760nm (Nanometer).Light enters the eye through a curved front surface the cornea. It passes through the pupil which is the central hole in the iris.The size of the pupil can change by control of ciliary muscles .Light entering the eye is refracted as it passes from air through the tear film-cornea interface.

It then propagates through the aqueous humor and the pupil (a diaphragm controlled by the iris) and is further refracted by the crystalline lens before passing through the vitreous humor and impinging on the retina.

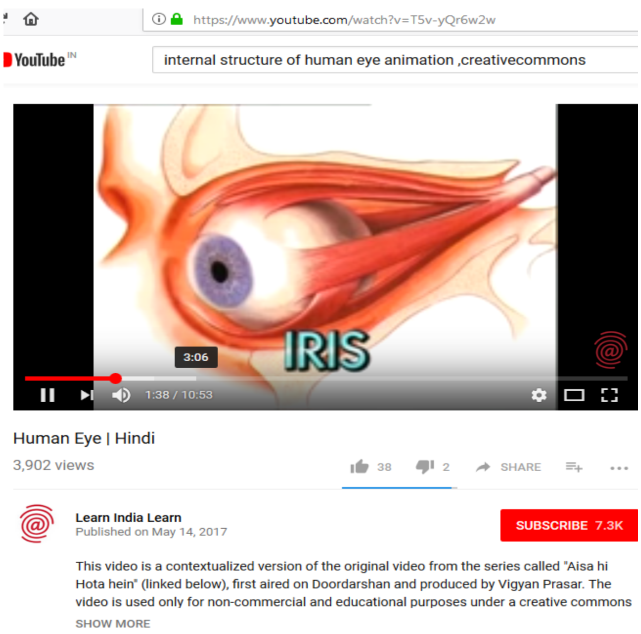
The ‘tear’ film-cornea interface and the crystalline lens are the major refractive components in the eye and act together as a (compound) lens to project an inverted image of different objects on the retina (the screen) of the eye

From the retina, the electrical signals get transmitted to the visual cortex, via the optic nerve

You may see the internal parts of the eye in the figure



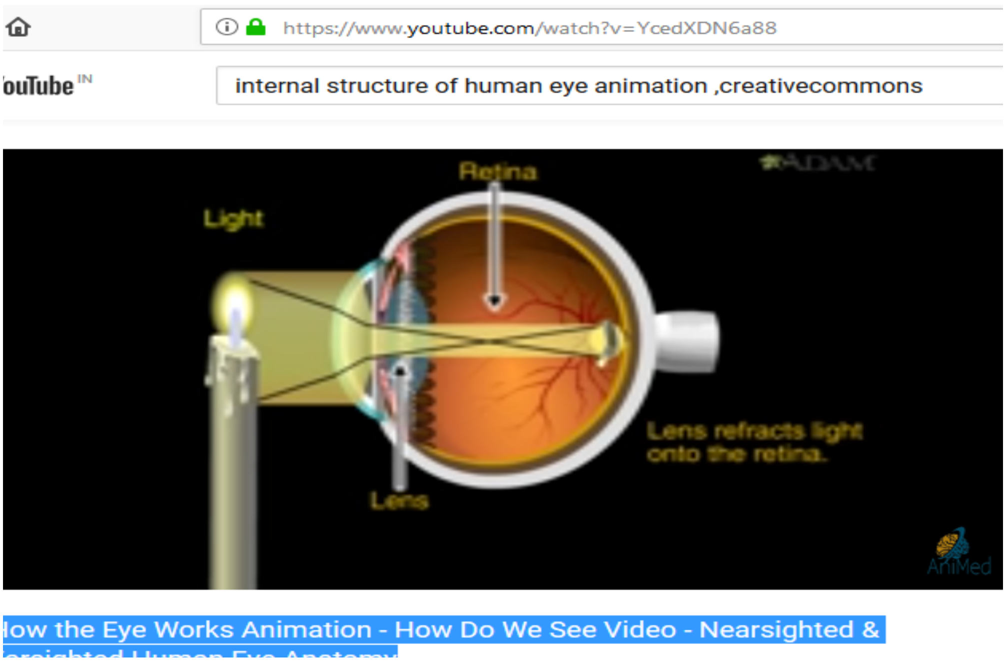
Watch : https://www.youtube.com/watch?v=T5v-yQr6w2w



Must watch for how we see things around us

https://www.youtube.com/watch?v=yzyphSTkW2U

How the Eye Works - Animation - How Do We See Video - Near-sighted & Farsighted, Human Eye Anatomy



https://www.youtube.com/watch?v=YcedXDN6a88

THINK ABOUT THESE

- There are many objects around us Some objects are self-luminous, and others are illuminated by any light source.They have different sizes, surface textures and colours. We see clearly only those objects on which we focus our eyes .Objects may be opaque, transparent or translucent.We do not see anything if we shut our eyes.At night, some light source is necessary to see objects.We cannot see objects behind our head without any other aid Objects, with polished surfaces reflect light more than unpolished objects surfaces.Our eyes can see different objects in the same line of sight but at different distances from us

Parts of The Eye

Name of the Part	Description	Function
Eye lid	Thick flexible outer cover of the eye blinks approximately 20 times a minute. The action is due to involuntary muscles. Also contains the tear glands.	Shuts and opens the eye as desired. Lubricate the eye surface, Dirt and unwanted particles are kept away by it
Eye lashes	The hair on the edge of the eyelid	Protects the eye from dust and other small particles
Iris	Thin circular structure in the eye Colour of the eye is due to this	Controls the amount of light entering the eye through the pupil
Pupil	Central dark opening in the iris	Control the light entering the eye from objects
Eyeball	A near spherical system about 2.5 cm placed in the eye sockets	Holds the eyes in a safe way
Cornea	The cornea is a transparent tissue, the cornea in the adult typically measures 10.5 mm vertically and 11.5 mm horizontally and its thickness increases from the center (about 530 µm) to the periphery (about 650 µm).	The tear film-cornea interface and the crystalline lens are the major refractive components in the eye and act together as a (compound) lens to project an inverted

		image of the object on the retina (screen) of the eye.
Aqueous humor	Behind the cornea, the aqueous humor has the same refractive index as the vitreous humor (1.336), whereas the refractive index of the cornea is 1.376.	Because the change in refractive index between cornea and aqueous humor is relatively small compared to the change at the air–cornea interface, it has a negligible refractive effect
Eye lens	It has an ellipsoidal, biconvex shape with the posterior surface being more curved than the anterio.r The crystalline lens is typically 10 mm in diameter and has a thickness of approximately 4mm, although its size and shape changes during accommodation, and it continues to grow throughout a person's lifetime. The crystalline lens achieves **transparency** due to its composition, as 90% of it is formed by tightly packed **proteins** and there is an absence of organelles such as a nucleus, endoplasmic reticulum and mitochondria within the mature lens fibers.	The eye lens is remarkable as it changes its focal length according to what we want to see.
Ciliary muscles	Cluster of fine muscles holding the eye lens.	Change the focal length of the eye lens depending upon what the eye needs to see

Vitreous humor	A jelly like material filling up the space between the eye lens and the retina.	Fills the eyeball, Keeps the retina safe.
Retina	A thin parchment made up of rods and cones.	Image is formed on the retina.
Blind spot	Point on the retina.	An image formed at the blind spot cannot be seen.
Optic nerve	Nerves linking the eye to the brain.	Helps the brain recognise the image of the object on which the eye focuses on. It is like a decoder of information from the retina to the brain.

Detailed Description of Some Parts of The Eye

Cornea

The tear filmcornea interface is the most anterior refractive surface of the eye as well as the most powerful due to the difference between its refractive index and that of air.

The anterior radius of the tear film-cornea interface is approximately 7.80 mm and the refractive index of the tear film is 1.336, which gives a dioptric power of approximately 43.00 diopters.

Therefore, small variations in its curvature can cause significant changes in the power of the eye.The cornea is more curved than the eyeball and hence protrudes anteriorly.

www.intechopen.com/books/topics-in-adaptive-optics/the-need-for-adaptive-optics-in-the-human-eye

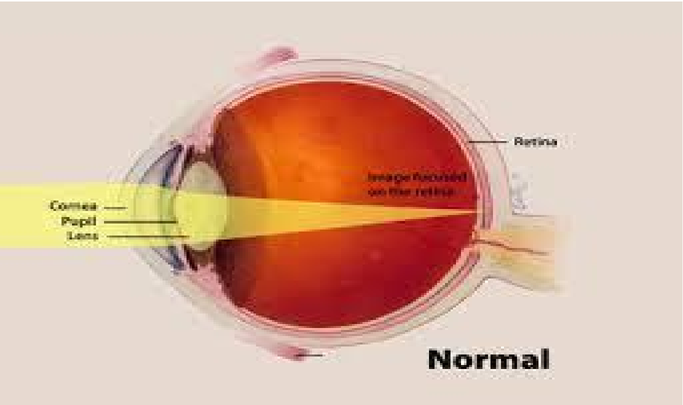
Iris- Pupil

The intensity of the light reaching the retina is regulated by the diaphragm formed by the iris: the pupil. The pupil is important in regulating the aberrations of the eye, the magnitude of the aberrations increase with larger pupil diameters. Depending upon the intensity of light the pupil aperture automatically adjusts its size. This is the reason why we suddenly experience darkness when we come in doors from a bright well lit outside during the day. Our pupil does not adjust immediately to allow more light to enter our eyes for a few seconds.

Think why we use dark glasses or sunglasses when going out on a sunny day!

Crystalline Eye Lens

It has an ellipsoidal, biconvex shape with the posterior surface being more curved than the anterior.



https://www.flickr.com/photos/nationaleyeinstitute/7543920666

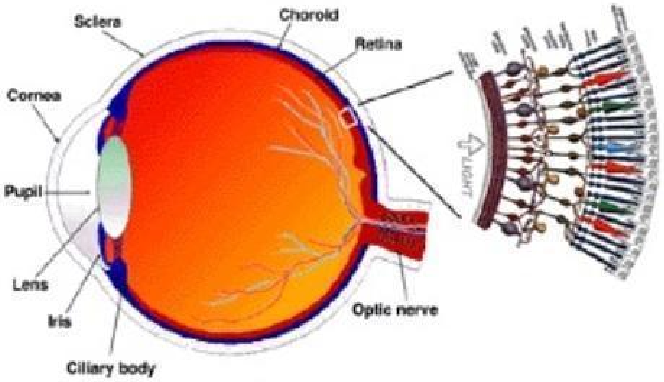
The shape (curvature) and therefore the ciliary muscles can modify the focal length of the lens. For example, when the muscle is relaxed, the focal length is about 2.5 cm and objects at infinity are in sharp focus on the retina.

When the object is brought closer to the eye, in order to maintain the same image-lens distance (≅ 2.5 cm), the focal length of the eye lens becomes shorter by the action of the ciliary muscles.This property of the eye is called **accommodation.**

The crystalline lens is flexible and may change its shape using the mechanism of accommodation, by adjusting the ciliary muscles so that the images may be more accurately focused on the retina.

Retina

The retina is a film of nerve fibres covering the curved back surface of the eye.



https://commons.wikimedia.org/wiki/File:Retinal_anatomy.jpg

The retina contains rods and cones which sense light intensity and colour respectively, and transmit electrical signals via the **optic nerve** to the brain which finally processes this information.

How The Eye Works

- Light enters the eye through a curved front surface, the cornea.
- It passes through the pupil which is the central hole in the iris.
- The size of the pupil can change under control of muscles.
- The light is further focused by the eye lens on the retina.
- The retina is a film of nerve fibers covering the curved back surface of the eye.
- The retina contains rods and cones which sense light intensity and colour, respectively, and transmit electrical signals via the optic nerve to the brain which finally processes this information.

When the object is too close to the eye, the lens cannot curve enough to focus the image on to the retina, and the image is blurred. The closest distance for which the lens can focus light on the retina is called the least distance of distinct vision, or the near point.The standard value of least distance of distinct vision for a normal eye is about 25 cm.

This distance increases with age, because of the decreasing effectiveness of the ciliary muscle and the loss of flexibility of the lens. The near point may be as close as about 7 to 8 cm in a child ten year of age, and may increase to as much as 200 cm at 60 years of age.

Thus, if an elderly person tries to read a book at about 25 cm or less from the eye, the image appears blurred. This condition (defect of the eye) is called **presbyopia**.

It is corrected by using a converging lens for reading.

Thus, our eyes are marvelous organs that have the capability to interpret incoming visible electromagnetic waves as images through a complex process.

These are our greatest assets and we must take proper care to protect them.

Imagine the world without a pair of functional eyes. Yet many amongst us bravely face this challenge by effectively overcoming their limitations to lead a normal life. They deserve our appreciation for their courage.

Defects of Vision

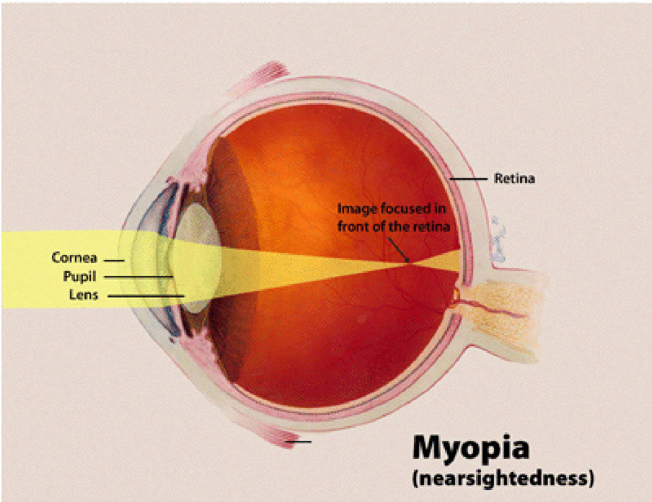
In spite of all precautions and proactive action, our eyes may develop some defects due to various reasons. We shall restrict our discussion to some common optical defects of the eye.

Near sightedness or Myopia

The light from a distant object arriving at the eye-lens may converge at a point in front of the retina.

This type of defect is called near sightedness or myopia.

This means that the eye is producing **too much convergence** in the incident beam.

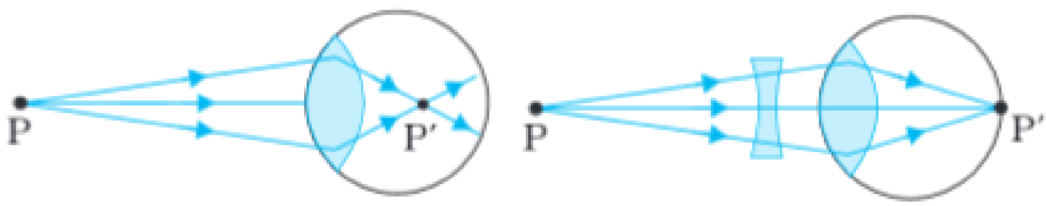


https://commons.wikimedia.org/wiki/File:Myopia.gif

There are two main reasons for this defect

- The eyeball becomes elongated.
- The eye lens converges the rays too much.

To compensate this, we interpose a concave lens between the eye and the object, with the diverging effect desired to get the image focused on the retina.



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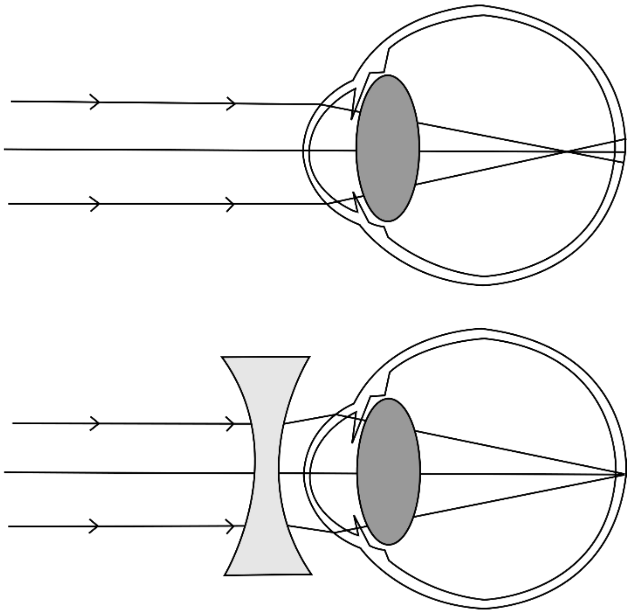


https://commons.wikimedia.org/wiki/File:Myopia-2-3.svg

Persons, with a negative power, say – 3 mean they are using a concave lens for correcting their vision, the focal length of the correction lens in this case would be

$$-\ 3\,D\ =\frac{100}{f}$$

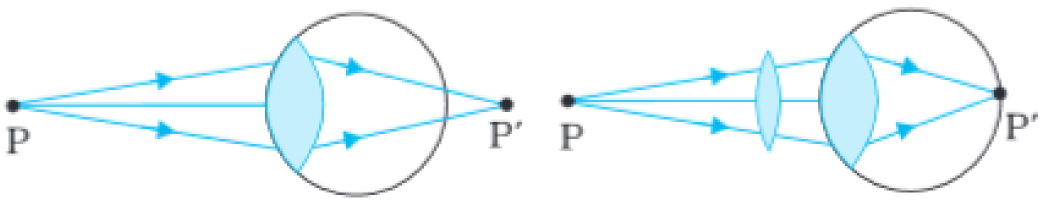
Or $f\ =-\ 33.3\ cm$

Far Sightedness or Hypermetropia

If the eye-lens focuses the incoming light at a point behind the retina, a converging lens is needed to compensate for the defect in vision.This defect is called farsightedness or hypermetropia.

This may be due to two reasons

- The eyeball has become smaller.
- The eye lens loses its ability to converge the rays.



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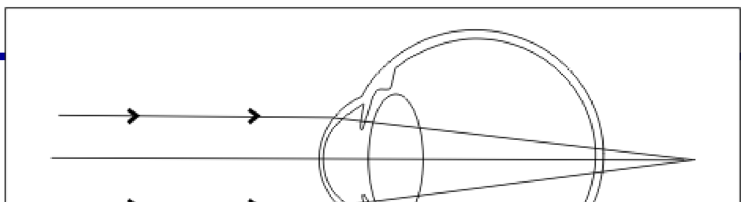


https://commons.wikimedia.org/wiki/File:Hypermetropia.png

Example

Calculate the focal length of reading lenses for a person for whom the least distance of distinct vision is 50 cm?

Solution

The distance of normal vision is 25 cm.

So if a book is at u = – 25 cm, its image should be formed at v = – 50 cm.

Therefore, the desired focal length is given by

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

Or

$$\frac{1}{f} = \frac{1}{-50} - \frac{1}{-25} = \frac{1}{50}$$

f= + 50 cm or it is a convex lens of 50 cm focal length.

Example

The far point of a myopic person is 80 cm in front of the eye.

- What is the power of the lens required to enable him to see very distant objects clearly?
- In what way does the corrective lens help the above person? Does the lens magnify very distant objects? Explain carefully.
- The above person prefers to remove his spectacles while reading a book. Explain why?

Solution

- Solving as in the previous example, we find that the person should use a concave lens of focal length = – 80 cm, i.e., of power = – 1.25 diopter.
- No. The concave lens, in fact, reduces the size of the object, but the angle subtended by the distant object at the eye is the same as the angle subtended by the image (at

the far point) at the eye. The eye is able to see distant objects not because the corrective lens magnifies the object, but because it brings the object (i.e., it produces a virtual image of the object) at the far point of the eye which then can be focused by the eye-lens on the retina.

- The myopic person may have a normal near point, i.e., about 25 cm (or even less). In order to read a book with the spectacles, such a person must keep the book at a distance greater than 25 cm so that the image of the book by the concave lens is produced no closer than 25 cm.

  The angular size of the book (or its image) at the greater distance is evidently less than the angular size when the book is placed at 25 cm and no spectacles are needed.

  Hence, the person prefers to remove the spectacles while reading.

Example

- The near point of a hypermetropic person is 75 cm from the eye. What is the power of the lens required to enable the person to read clearly a book held at 25 cm from the eye?
- In what way does the corrective lens help the above person? Does the lens magnify objects held near the eye?
- The person above prefers to remove the spectacles while looking at the sky. Explain why?

Solution

- u = - 25 cm v = - 75 cm

  Using the lens formula

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

$$\frac{1}{f} = \frac{1}{-75} - \frac{1}{-25}$$

  f = 37.5 cm

  The corrective lens needs to have a converging power of +2.67 diopters.

- The corrective lens produces a virtual image (at 75 cm) of an object at 25 cm. The angular size of this image is the same as that of the object. In this sense the lens does not magnify the object but merely brings the object to the near point of the hypermetric eye, which then gets focused on the retina. However, the angular size is greater than that of the same object at the near point (75 cm) viewed without the spectacles

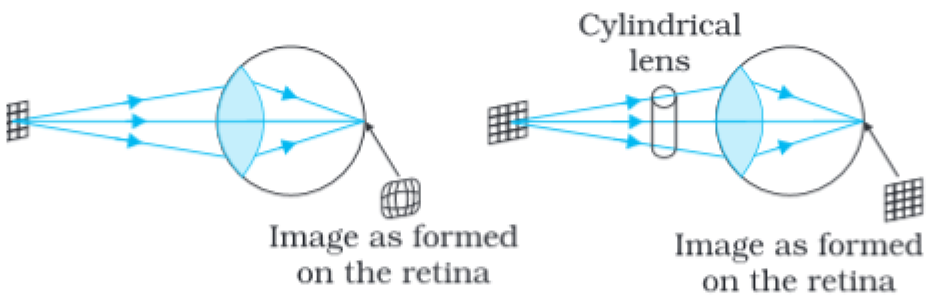
- A hypermetropic eye may have a normal far point i.e., it may have enough converging power to focus parallel rays from infinity on the retina of the shortened eyeball. Wearing spectacles of converging lenses (used for near vision) will amount to more converging power than needed for parallel rays.

  Hence the person prefers not to use the spectacles for far objects.

Astigmatism

Another common defect of vision is called astigmatism.

This occurs when the cornea is not spherical in shape. For example, the cornea could have a larger curvature in the vertical plane than in the horizontal plane or vice-versa. If a person with such a defect in eye-lens looks at a wire mesh or a grid of lines, focussing in either the vertical or the horizontal plane may not be as sharp as in the other plane. Astigmatism results in lines in one direction being well focussed while those in a perpendicular direction may appear distorted.



Astigmatism can be corrected by using a cylindrical lens of desired radius of curvature with an appropriately directed axis.This defect can occur along with myopia or hypermetropia.

Example

For a normal eye, the far point is at infinity and the near point of distinct vision is about 25cm in front of the eye. The cornea of the eye provides a converging power of about 40 dioptres, and the least converging power of the eye-lens behind the cornea is about 20 dioptres. From this rough data estimate the range of accommodation (i.e., the range of converging power of the eye-lens) of a normal eye.

Solution

To see objects at infinity, the eye uses its least converging power = (40 +20) diopters = 60 dioptres.

This gives a rough idea of the distance between the retina and cornea-eye lens: (5/3) cm.

To focus an object at the near point (u = –25 cm), on the retina (v = 5/3 cm), the focal length should be:

$$\left(\frac{1}{25}+\frac{3}{5}\right)^{-1}=\frac{25}{16}$$

= 1.562 cm

Corresponding to a converging power of 64 dioptres, the power of the eye lens then is (64 – 40) dioptre = 24 dioptre.

The range of accommodation of the eye-lens is roughly 20 to 24 diopters.

Example

Does short-sightedness (myopia) or long-sightedness (hypermetropia) imply necessarily that the eye has partially lost its ability of accommodation? If not, what might cause these defects of vision?

Solution

No, a person may have normal ability of accommodation of the eye lens and yet may be myopic or hypermetropia. Myopia can arise when the eye-ball from front to back gets too elongated; hypermetropia can arise when it gets too shortened.

In practice, in addition, the eye lens may also lose some of its ability of accommodation.

When the eyeball has the normal length but the eye lens partially loses its ability of accommodation (as happens with increasing age for any normal eye), the 'defect' is called presbyopia and is corrected in the same manner as hypermetropia.

Example

A myopic person has been using spectacles of power –1.0 dioptre for distant vision.

During old age he also needs to use a separate reading glass of power + 2.0 dioptres.

Explain what may have happened.

Solution

The far point of the person is 100 cm, while his near point may have been normal (about 25 cm). Objects at infinity produce virtual images at 100 cm (using spectacles). To view closer objects i.e., those which are (or whose images using the spectacles are) between 100 cm and 25 cm, the person uses the ability of accommodation of his eye-lens. This ability usually gets partially lost in old age (presbyopia). The near point of the person recedes to 50 cm.

To view objects at 25 cm clearly, the person needs a converging lens of power +2 dioptres.

Example

A person looking at a person wearing a shirt with a pattern comprising vertical and horizontal lines is able to see the vertical lines more distinctly than the horizontal ones. What is this defect due to? How is such a defect of vision corrected?

Solution

The defect (called astigmatism) arises because the curvature of the cornea plus eye-lens refracting system is not the same in different planes. [The eye-lens is usually spherical i.e., has the same curvature on different planes but the cornea is not spherical in case of an astigmatic eye.] In the present case, the curvature in the vertical plane is enough, so sharp images of vertical lines can be formed on the retina. But the curvature is insufficient in the horizontal plane, so horizontal lines appear blurred. The defect can be corrected by using a cylindrical lens with its axis along the vertical. Clearly, parallel rays in the vertical plane will suffer no extra refraction, but those in the horizontal plane can get the required extra convergence due to refraction by the curved surface of the cylindrical lens.

of course the curvature of the cylindrical surface has to be chosen appropriately.

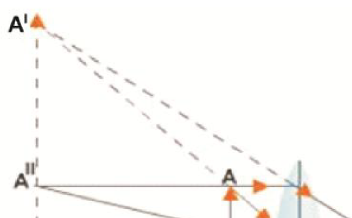
The Microscope

A simple magnifier or microscope is a converging lens of small focal length.

A biconvex lens used as a magnifier is the simple microscope

https://pixabay.com/en/magnifying-glass-daisy-field-green-479742/

Microscope uses the converging property of a lens of small focal length to give a magnified image. In microscopes a virtual, magnified and erect image is formed at the distance of distinct vision.



Magnifying Power Of A Simple Microscope

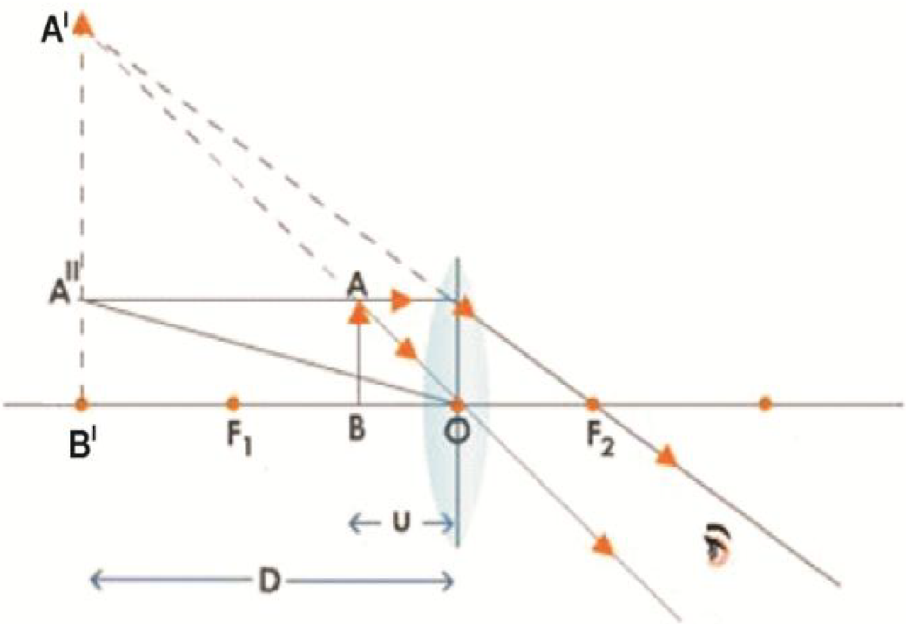
As we had considered in our earlier modules,

Linear magnification $= \frac{size\ of\ image}{size\ of\ object} = \frac{A'B'}{AB}$

The magnifying power can also be expressed by angular magnification of a microscope and may be defined as the ratio of the angle subtended by the image to the angle subtended by the object when both of them are at the distance of the distinct vision.

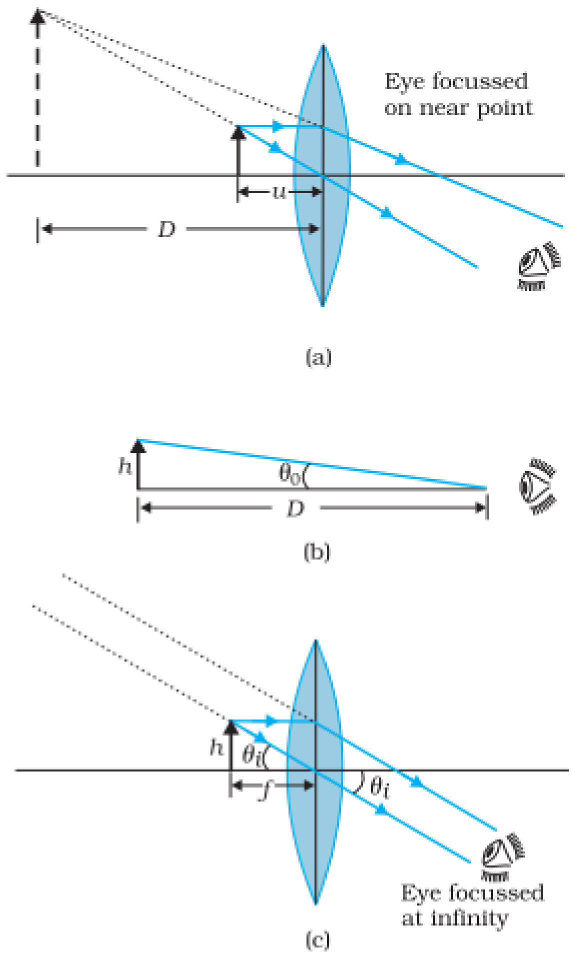
The ray diagram shows that the image of the object AB is formed at A'B'.

F_1 and F_2 are the two principal foci and O is the optical center of the convex lens used.



Angular magnification = $\frac{\angle A'OB'}{\angle A''OB'}$

Now, the two diagrams that follow show final image at least distance of distinct vision and at infinity



In order to use such a lens as a microscope, the lens is held near the object, one focal length away or less, and the eye is positioned close to the lens on the other side.

The idea is to get an erect, magnified and virtual image of the object at a distance so that it can be viewed comfortably, i.e., at 25 cm or more.

- If the object is at a distance f, the image is at infinity.

However,

- If the object is at a distance slightly less than the focal length of the lens, the image is virtual and closer than infinity.

Although the closest comfortable distance for viewing the image is when it is at the near point (distance D ≅ 25 cm), it causes some strain on the eye.

Therefore, the image formed at infinity is often considered most suitable for viewing by the relaxed eye.

This is what is shown in both cases, the first in Fig.(a), and the second in Fig. (b) and (c).

The linear magnification m, for the image formed at the near point D, by a simple microscope can be obtained by using the relation.

$$m = \frac{v}{u} = v\left(\frac{1}{u}\right)$$

But

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

so replacing 1/u

We get

$$m = v\left(\frac{1}{v} - \frac{1}{f}\right) = \left(1 - \frac{v}{f}\right)$$

Now according to our sign convention, v is negative, and is equal in magnitude to D. Thus, the magnification is

$$m = \left(1 + \frac{D}{f}\right)$$

Since D is about 25 cm, to have a magnification of six, one needs a convex lens of focal length, f = 5 cm.

Note that

$m = h'/h$

Where h is the size of the object

and,

h′ the size of the image.

This is also the ratio of the angle subtended by the image to that subtended by the object, if placed at the distance D for comfortable viewing.

(Note that this is not the angle actually subtended by the object at the eye, which is h/u.)

Important: What a single-lens simple magnifier achieves is that it allows the object to be brought closer to the eye than D.

We will now find the magnification when the image is at infinity.

In this case we will have to obtain the angular magnification.Suppose the object has a height h. The maximum angle it can subtend, and be clearly visible (without a lens), is when it is at the near point, i.e., a distance D. The angle subtended is then given by

$$tan\theta_0 = \left(\frac{h}{D}\right) \approx \theta_0$$

We now find the angle subtended at the eye by the image when the object is at u. From the relations

$$\frac{h'}{h} = m = \frac{v}{u}$$

we have the angle subtended by the image

$$\tan \theta_i = \left(\frac{h'}{-v}\right) = \frac{h}{-v} \cdot \frac{v}{u} = \frac{h}{-u} \approx \theta_i$$

The angle subtended by the object, when it is at u = –f.

$$\theta_i = \left(\frac{h}{f}\right)$$

as is clear from Fig.(c).

The angular magnification is, therefore

$$m = \left(\frac{\theta_i}{\theta_o}\right) = \frac{D}{f}$$

This is one less than the magnification when the image is at the near point, but the viewing is more comfortable and the difference in magnification is usually small.

In subsequent discussions of optical instruments (microscope and telescope) we shall assume the final image to be at infinity.

A simple microscope has a limited maximum magnification (≤ 9) for realistic focal lengths

Example

The image of a small electric bulb fixed on the wall of a room is to be obtained on the opposite wall 3m away by means of a large convex lens. What is the maximum possible focal length of the lens required for the purpose?

Solution

For fixed distance S between object and screen, the lens equation does not give a real solution for u or v if f is greater than S/4

Hence maximum focal length = 3m/4 = 0.75 m

Example

A card sheet divided into squares each of size 1 mm^2 is being viewed at a distance of 9 cm through a magnifying glass (a converging lens of focal length 10 cm) held close to the eye.

- What is the magnification produced by the lens? How much is the area of each square in the virtual image?

- What is the angular magnification (magnifying power) of the lens?
- Is the magnification in (a) equal to the magnifying power in (b)? Explain.

Solution

- $1/v + 1/9 = 1/10$

  i.e., $v = -90$ cm,

  Magnitude of magnification = $90/9 = 10$.

  Each square in the virtual image has an area $10 \times 10 \times 1 \text{ mm}^2 = 100 \text{ mm}^2 = 1 \text{ cm}^2$
- Magnifying power = $25/9 = 2.8$
- No, magnification of an image by a lens and angular magnification (or magnifying power) of an optical instrument are two separate things. The latter is the ratio of the angular size of the object (which is equal to the angular size of the image even if the image is magnified) to the angular size of the object if placed at the near point (25 cm). Thus, magnification magnitude is $|(v/u)|$ and magnifying power is $(25/ |u|)$. Only when the image is located at the near point $|v| = 25$ cm, are the two quantities equal.

Example

At what distance should the lens be held from the figure in the above example in order to view the squares distinctly with the maximum possible magnifying power? (b) What is the magnification in this case? (c) Is the magnification equal to the magnifying power in this case? Explain.

Solution

- Maximum magnifying power is obtained when the image is at the near point (25 cm)

  For this $u = -7.14$ cm.
- Magnitude of magnification = $(25 / |u|) = 3.5$.
- Magnifying power = 3.5

Yes, the magnifying power (when the image is produced at 25 cm) is equal to the magnitude of magnification.

Example

What should be the distance between the object in Exercise 9.30 and the magnifying glass if the virtual image of each square in the figure is to have an area of 6.25 mm^2. Would you be able to see the squares distinctly with your eyes very close to the magnifier?

Solution

Magnification = $\sqrt{(6.25/1)} = 2.5$

v = + 2.5 u

$\frac{1}{+2.5u} - \frac{1}{u} = \frac{1}{10}$

i.e., u = – 6 cm

|v| = 15 cm

The virtual image is closer than the normal near point (25 cm) and cannot be seen by the eye distinctly.

Example

Answer the following questions:

- The angle subtended at the eye by an object is equal to the angle subtended at the eye by the virtual image produced by a magnifying glass. In what sense then does a magnifying glass provide angular magnification?
- In viewing through a magnifying glass, one usually positions one's eyes very close to the lens. Does angular magnification change if the eye is moved back?
- Magnifying power of a simple microscope is inversely proportional to the focal length of the lens. What then stops us from using a convex lens of smaller and smaller focal length and achieving greater and greater magnifying power?

Solution

- Even though the absolute image size is bigger than the object size, the angular size of the image is equal to the angular size of the object. The magnifier helps in the following way: without it the object would have been placed no closer than 25 cm; with it the object can be placed much closer. The closer object has larger angular size than the same object at 25 cm. It is in this sense that angular magnification is achieved.
- Yes, it decreases a little because the angle subtended at the eye is then slightly less than the angle subtended at the lens. The effect is negligible if the image is at a very large distance away.
  [Note: When the eye is separated from the lens, the angles subtended at the eye by the first object and its image are not equal.]
- First, grinding lenses of very small focal length is not easy. More important, if you decrease focal length, aberrations (both spherical and chromatic) become more pronounced. So, in practice, you cannot get a magnifying power of more than 3 or so

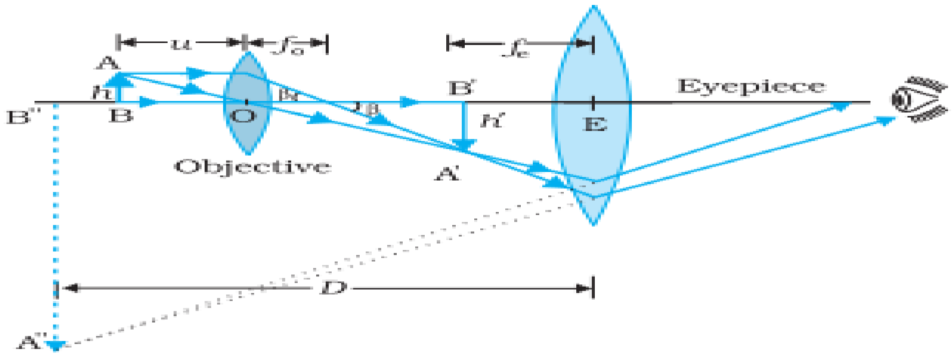
with a simple convex lens. However, using an aberration corrected lens system; one can increase this limit by a factor of 10 or so.

Compound Microscope

The most commonly used microscope for general purposes is the standard compound microscope. It magnifies the size of the object by an appropriate arrangement of a system of lenses.

For larger magnifications, one uses two lenses, one compounding the effect of the other. This is known as a compound microscope.

A schematic diagram of a compound microscope is shown in Fig.



Watch 'draw with me' to draw the ray diagram accurately

The lens near the object called the objective, forms a real, inverted, magnified image of the object.

The image of the object serves as the object for the second lens, the eyepiece, which functions essentially like a simple microscope or magnifier produces the final image, which is enlarged and virtual.

So

- The objective lens produces a magnified 'real image' first image) of the object.
- Microscope objectives are characterized by two parameters, magnification and aperture.
- Magnification typically ranges from 5 X to 100 X
- Focal lengths of about 40 to 2 mm, respectively.
- Aperture is important as the objective lens gathers the light coming from the object.
- Objective lenses with higher magnifications normally have a higher numerical aperture and a shorter depth of field in the resulting image.

This image is again magnified by the **second convex lens (eyepiece)** to obtain a magnified **'virtual image' (final image),** which can be seen by eye through the eyepiece.

As light passes directly from the source to the eye through the two lenses, the field of vision is brightly illuminated.

The first inverted image is thus near (at or within) the focal plane of the eyepiece at a distance appropriate for final image formation at infinity or a little closer for image formation at the near point.

Clearly, **the final image is inverted with respect to the original object.**

The distance between the two lenses can be adjusted by using rack and pinion arrangement.

This you may have experienced while focusing any object to be viewed by a microscope.

We now obtain the magnification due to a compound microscope.

Magnifying Power of A Compound Microscope

The magnifying power of a compound microscope is defined as the ratio of the angle subtended by the final image to the angle subtended by the object, when both object and image are lying at the distance of distinct vision.

Magnifying power (m) = $\frac{angle\ subtended\ at\ the\ eye\ by\ the\ image}{angle\ subtended\ at\ the\ eye\ by\ the\ object}$

Let the focal length of eyepiece $=f_e$

And focal length of objective$=f_o$

For the objective lens

$$\frac{1}{f_o} = \frac{1}{v} - \frac{1}{u}$$

But as the distance of the object from the lens is –u we can write

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

Multiplying both sides by v

$$\frac{v}{f_o} = \frac{v}{v} + \frac{v}{u}$$

$$\frac{v}{f_o} = 1 + m_o$$

Or $m_o = \frac{v}{f_o} - 1$

For the eyepiece lens

We can use the same expression as that for a simple microscope.

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

For the combination

The magnifying power is the product of the magnification produced by objective and that produced by the eyepiece.

$$m = m_o \times m_e$$

Alternately in terms of angular magnification

When the final image is formed at infinity or the eye is relaxed when viewing the image

The ray diagram shows that the (linear) magnification due to the objective, namely h′/h, equals

$$m_o = \frac{h^{'}}{h} = \frac{L}{f_o}$$

$$tan\,\beta = \left(\frac{h}{f_0}\right) = \left(\frac{h^{'}}{L}\right)$$

Here h′ is the size of the first image, the object size is h and $_0$ is the focal length of the objective.

The first image is formed near the focal point of the eyepiece. The distance L, i.e., the distance between the second focal point of the objective and the first focal point of the eyepiece (focal length $_e$) is called the tube length of the compound microscope.

As the first inverted image is near the focal point of the eyepiece, we use the result from the discussion above for the simple microscope to obtain the (angular) magnification m_e due to it when the final image is formed at the near point, is

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

When the final image is formed at infinity, the angular magnification due to the eyepiece

$$m_e = \left(\frac{D}{f_e}\right)$$

Thus, the total magnification, when the image is formed at infinity, is

$$m = m_o \times m_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

Clearly, to achieve a large magnification of a small object (hence the name microscope), the objective and eyepiece should both have small focal lengths.

In practice, it is difficult to make the focal length much smaller than 1 cm.Also large lenses are required to make L large.

For example, with an objective with f_o = 1.0 cm, and an eyepiece with focal length f_e = 2.0 cm, and a tube length of 20 cm, the magnification is

$$m = m_o m_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

$$= \frac{20cm}{1cm} \times \frac{25cm}{2cm} = 250$$

The first image is formed near the focal point of the eyepiece.

Various other factors such as illumination of the object, contribute to the quality and visibility of the image.

In modern microscopes, multicomponent lenses are used for both the objective and the eyepiece to improve image quality by minimizing various optical aberrations (defects) in lenses.The distance L, i.e., the distance between the second focal point of the objective and the first focal point of the eyepiece (focal length fe) is called the tube length of the compound microscope.

As the first inverted image is near the focal point of the eyepiece, we use the result from the discussion above for the simple microscope to obtain the (angular) magnification due to it. When the final image is formed at the near point, is

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

Resolving Power of Objective

It is the ability of the objective to resolve each point (see distinctly) on the minute object into widely spaced points, so that the points in the image can be seen as distinct and separate from one another, and get a clear unblurred image.

It may appear that very high magnification can be obtained by using high power lenses. Though possible the highly magnified image obtained in this way is a blurred one.

That means each point in the object cannot be found as a widely spaced distinct and separate point on the image.

Mere increase in size (greater magnification) without the ability to distinguish structural details (greater resolution) is of little value. Therefore, the basic limitation in light microscopes is one not of magnification, but of resolving power the ability to distinguish two adjacent points as distinct and separate, i.e. to resolve small components in the object into finer details on the image.

Resolving power is a function of two factors given below:

- Numerical aperture (N.A.)
- Wavelength of the light (λ)

- **Numerical aperture** is a numerical value related to the diameter of the objective lens in relation to its focal length.

  In a microscope, light is focused on the object as a narrow beam of light, from where it enters into the object as a diverging beam.The numerical aperture of an objective is its light gathering capacity, which depends on the angular light cone and the refractive index of the medium existing between the object and the objective.

- **Wavelength of illuminating light** causes angular deviation.

  We will study the influence of wavelength on resolving power in later modules

Think About These

- Why must both the objective and the eyepiece of a compound microscope have short focal length?

  $F_{o,}$ and f_e of compound microscope must be small so that they have produce a large magnifying power

$$m_o = \left(\frac{L}{f_o}\right)\left(1 + \frac{D}{f_e}\right)$$

  Explain why viewing through a compound microscope why our eye should be at a short distance away from the eyepiece?

  When eyes are positioned a short distance away from the eyepiece then the image formed at infinity can be seen with a relaxed eye.

Example

A compound microscope consists of an objective lens of focal length 2.0 cm and an eyepiece of focal length 6.25 cm separated by a distance of 15 cm. How far from the objective should an object be placed in order to obtain the final image at?

- the least distance of distinct vision (25cm), and
- at infinity?

What is the magnifying power of the microscope in each case?

Solution

Focal length of objective lens f_1=2.0 cm

Focal length of eye lens f_2= 6.25 cm

Distance between objective and eye lens =L = 15 cm

- Least distance of distinct vision d = 25 cm

  Image distance for the eyepiece v_2 = - 25 cm

  Object distance for the eyepiece = u_2

  According to the lens formula, we have the relation:

$$\frac{1}{v_2} = \frac{1}{u_2} - \frac{1}{f_2}$$

$$\frac{1}{u_2} = \frac{1}{v_2} - \frac{1}{f_2}$$

$$\frac{1}{u_2} = \frac{1}{-25} - \frac{1}{6.25} = \frac{-1-4}{25} = \frac{-5}{25}$$

$$u_2 =- 5\ cm$$

Image distance for the objective lens, $v_1 = d + u_2 = 15 - 5 = 10$

Object distance for the objective lens is = u_1

$$\frac{1}{v_1} = \frac{1}{u_1} - \frac{1}{f_1}$$

$$\frac{1}{u_1} = \frac{1}{v_1} - \frac{1}{f_1}$$

$$= \frac{1}{10} - \frac{1}{2} = \frac{1-5}{10} = \frac{-4}{10}$$

$$u_1 = \ - 2.5\ cm$$

Magnitude of the object distance $\left|\mu_1\right| = 2.5$

The magnifying power of a compound microscope is given by the relation

$$m = \frac{v}{|\mu_1|}\left(1 + \frac{d}{f_2}\right)$$

$$m = \frac{10}{|2.5|}\left(1 + \frac{25}{6.25}\right) = 4(1 + 4) = 20$$

Hence, the magnifying power of the microscope is 20.

- The final image is formed at infinity

  Image distance of the eyepiece, $v_2 = \infty$

  Object distance of the eyepiece = u_2

  According to lens formula we have the relation:

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$

$$\frac{1}{\infty} - \frac{1}{u_2} = \frac{1}{6.25}$$

$$u_2 = \ - \ 6.25\ cm$$

Image distance for the objective lens $v_1 = d + u_2 = 15 - 6.25 = 8.75$

Object distance for the objective lens = u_1

According to the lens formula we have the relation:

$$\frac{1}{v_1} - \frac{1}{u_1} = \frac{1}{f_1}$$

$$\frac{1}{u_1} = \frac{1}{v_1} + \frac{1}{f_1}$$

$$= \frac{1}{8.75} - \frac{1}{2} = \frac{2-8.75}{17.5}$$

$$u_1 = \frac{17.5}{6.75} = \ - \ 2.59\ cm$$

Magnitude of the object distance $\left|\mu_1\right| = 2.59\ cm$

The magnifying power of a compound microscope is given by the relation:

$$m = \frac{v_2}{\left|\mu_1\right|}\left(\frac{d}{f_2}\right)$$

$$m = \frac{8.75}{2.59}\left(\frac{25}{6.25}\right) = 13.51$$

Hence, the magnifying power of the microscope is 13.51

Example

A person with a normal near point (25 cm) using a compound microscope with an objective of focal length 8.0 mm and an eyepiece of focal length 2.5cm can bring an object placed at 9.0mm from the objective in sharp focus. What is the separation between the two lenses? Calculate the magnifying power of the microscope.

Solution

Focal length of the objective lens, f_o = 8 mm = 0.8 cm

Focal length of the eyepiece, f_e = 2.5 cm

Object distance for the objective lens, u_o = - 9.0 mm = - 0.9 cm

Least distance of the distant vision, d = 25 cm

Image distance for the eyepiece, v_e = - d = -25

Object distance for the eyepiece = u_e

Using the lens formula, we can obtain the value of u_e as:

$$\frac{1}{u_e} = \frac{1}{v_e} - \frac{1}{f_e}$$

$$= \frac{1}{-25} - \frac{1}{2.5} = \frac{-1-10}{25} = \frac{-11}{25}$$

$$u_e =- \frac{25}{11} =- 2.27\ cm$$

We can also obtain the value of image distance for the objective lens (v) using the lens formula

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

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

$$\frac{1}{0.8} - \frac{1}{0.9} = \frac{0.9-0.8}{0.72} = \frac{0.1}{0.72}$$

$$v = 7.2\ cm$$

The distance between the objective lens and the eyepiece = $u_e + v_o$ = 2.27+7.2 = 9.4 cm

The magnifying power of the microscope is calculated as:

$$\frac{v_o}{|u_o|}\left(1 + \frac{d}{f_e}\right)$$

$$= \frac{7.2}{0.9}\left(1 + \frac{25}{2.5}\right) = 8(1 + 10) = 88$$

Hence the magnifying power of the microscope is 88.

Telescope

Telescopes are used to view distant objects.

The telescope is used to provide angular magnification of distant objects

Telescope in Vellore Tamilnadu

- Telescopes used to view heavenly bodies like stars, planets and satellites are called astronomical telescopes.
- Telescopes used to view mountains, far off ships, birds etc. are called terrestrial telescopes

In this module we will consider only astronomical telescopes

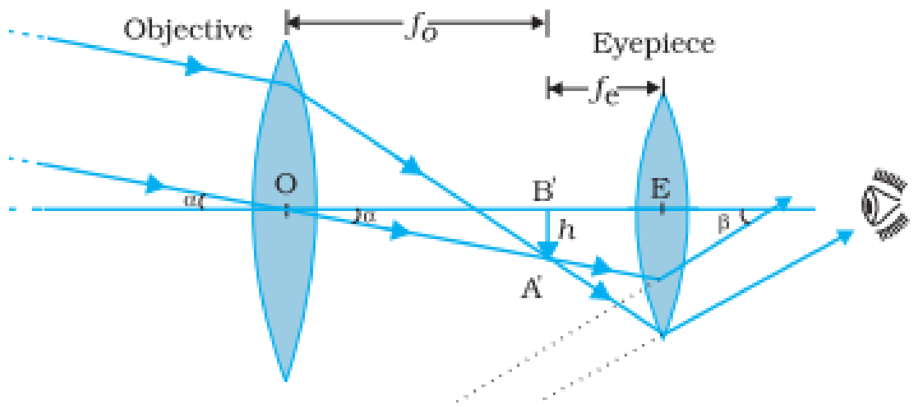
The simplest telescope consists of two convex lenses called objective and eyepiece.

Unlike the microscopes, the telescope objective lens has a large focal length and a much larger aperture than the eyepiece.Light from a distant object enters the objective and a real image is formed in the tube at its second focal point.

The eyepiece magnifies this image producing a final inverted image.The objective is of large focal length and large aperture, whereas the eyepiece is of short focal length and small aperture. The distance between the two lenses can be adjusted by using rack and pinion arrangement.

When the light rays from distant objects fall on the object, they converge at the focal plane. Image AB is formed as shown. The position of the eyepiece is so adjusted that the image AB should lie at the focus of the eyepiece so that the final image is formed at infinity.

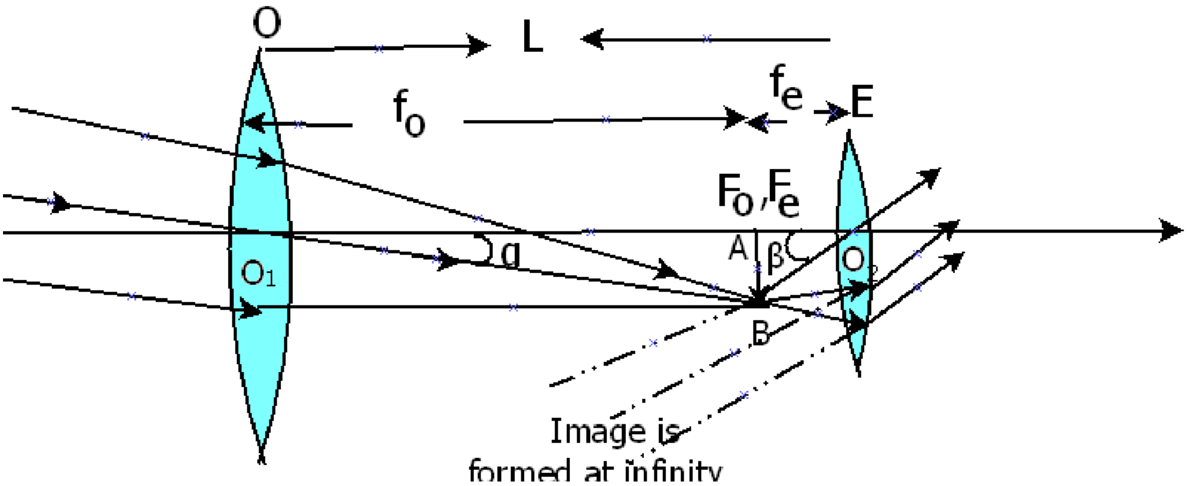
Since both object and image are formed at infinity it is called **Normal adjustment method.**



Schematic diagram of a refracting telescope

The Magnifying Power of A Telescope In Normal Adjustment

The magnifying power m is the ratio of the angle β subtended at the eye by the final image to the angle α which the object subtends at the lens or the eye. Hence,



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

In triangle O_1AB, tan α $= \frac{AB}{AO_1} = \alpha$

In triangle O_2AB tan β $= \frac{AB}{AO_2} = \beta$

Since α *and* β are small

$$m = \frac{AO_1}{AO_2} = \frac{f_o}{-f_e}$$

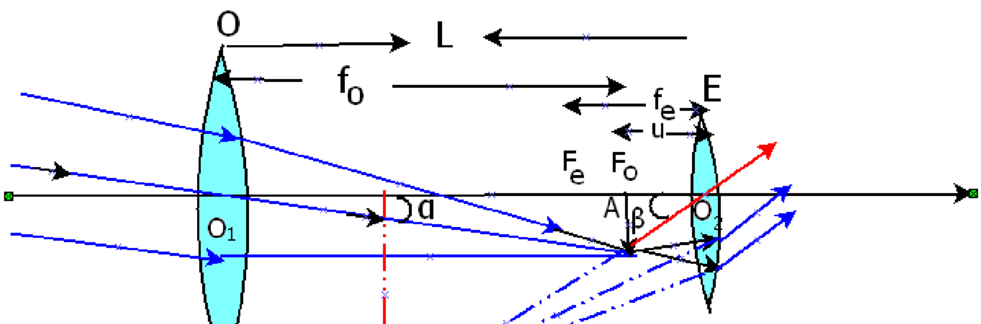
In this case, the length of the telescope tube is $f_o + f_e$.

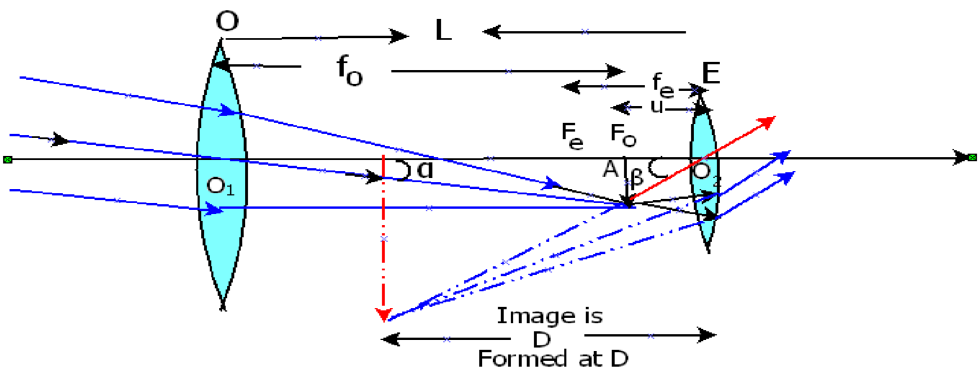
Magnifying power m of a telescope is the ratio of the angle β subtended at the eye by the image to the angle α subtended at the eye by the object.

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

where f_o and f e are the focal lengths of the objective and eyepiece, respectively.

In case the final image is formed at least distance of distinct vision





$$\frac{1}{v_e} - \frac{1}{u_e} = \frac{1}{f_e}$$

$$-\frac{1}{u_e} = -\frac{1}{v_e} + \frac{1}{f_e}$$

Substituting $v_e = -D$

$$-\frac{1}{u_e} = \frac{1}{D} + \frac{1}{f_e}$$

On multiplying both sides by f_0

$$m = \frac{f_o}{f_e} \times \left(1 + \frac{f_e}{D}\right)$$

Magnifying power of a telescope when the final image is formed at least distance of distinct vision is greater than when the final image is formed at infinity.

Terrestrial telescopes, in addition, have a pair of inverting lenses to make the final image erect.

Refracting telescopes can be used both for terrestrial and astronomical observations. For example, consider a telescope whose objective has a focal length of 100 cm and the eyepiece a focal length of 1 cm.

The angular magnifying power of this telescope is m = 100/1 = 100.

Resolving Power of A Telescope

Watch resolving power of optical instruments included later in the unit.

Let us consider a pair of stars of actual separation 1′ (one minute of arc). The stars appear as though they are separated by an angle of 100 × 1′ = 100′ =1.67°.

The main considerations with an astronomical telescope are its light gathering power and its resolution or resolving power.

The former clearly depends on the area of the objective. With larger diameters, fainter objects can be observed. The resolving power or the ability to observe two objects distinctly, which are in very nearly the same direction also depends on the diameter of the object.

So, the desirable aim in optical telescopes is to make them with an objective of large diameter. The largest lens objective in use has a diameter of about ~1.02 m. It is at the Yerkes Observatory in Wisconsin, USA. Such big lenses tend to be very heavy and therefore, difficult to make and support by their edges. Further, it is rather difficult and expensive to make such large sized lenses which form images that are free from any kind of chromatic aberration and distortions.

Spherical And Chromatic Aberration

Spherical aberration is an optical effect observed in an optical device (lens, mirror, etc.) that occurs due to the increased refraction of light rays when they strike a lens or a reflection of light rays when they strike a mirror near its edge, in comparison with those that strike nearer the centre.

It signifies a deviation of the device from the norm, i.e., it results in an imperfection of the produced image.

A typical value of refractive index for crown glass is 1.5, which indicates that only about 43% of the area (67% of diameter) of a spherical lens is useful.

It is often considered to be an imperfection of telescopes and other instruments which makes their focusing less than ideal due to the spherical shape of lenses and mirrors.

This is an important effect because spherical shapes are much easier to produce than aspherical ones. In many cases, it is cheaper to use multiple spherical elements to compensate for spherical aberration than it is to use a single aspheric lens.

Chromatic aberration, also known as “color fringing” or “purple fringing” is a common optical problem that occurs when a lens is either unable to bring all wavelengths of color to the same focal plane, and/or when wavelengths of different color are focused at different positions in the focal plane.

In optics, chromatic aberration, also called chromatic distortion, is an effect resulting from dispersion, in which there is a failure of a lens to focus all colours to the same convergence point.

It occurs because lenses have different refractive indices for different wavelengths of light. The refractive index of transparent materials decreases with increasing wavelength by amounts unique to each.

Chromatic aberration manifests itself as "fringes" of colour along boundaries that separate dark and bright parts of the image because each colour in the optical spectrum cannot be focused at a single common point. Since the focal length *f* of a lens is dependent on the refractive index *n*, different wavelengths of light will be focused on different positions.

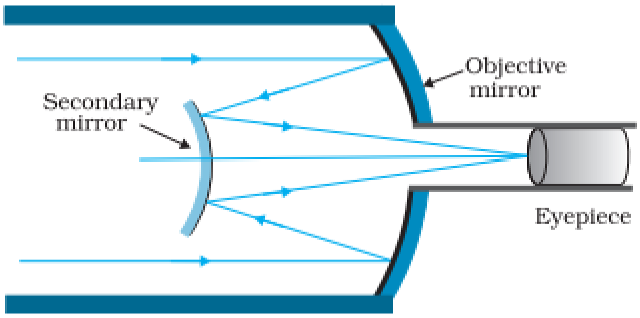
https://en.wikipedia.org/wiki/Chromatic_aberration

Reflecting Telescope

For these reasons, modern telescopes use concave mirrors rather than a lens for their objective. Telescopes with mirror objectives are called reflecting telescopes.

They have several advantages.

- First, there is no chromatic aberration in a mirror.
- Second, if a parabolic reflecting surface is chosen, spherical aberration is also removed.



Schematic diagram of a reflecting telescope (Cassegrain)

Mechanical support is much less of a problem since a mirror weighs much less than a lens of equivalent optical quality, also it can be supported over its entire back surface, not just over its rim.

One obvious problem with a reflecting telescope is that the objective mirror focuses light inside the telescope tube.

One must have an eyepiece and the observer right there, obstructing some light (depending on the size of the observer cage).

This is what is done in the very large 200 inch (~5.08 m) diameters, Mt. Palomar telescope, California.

The viewer sits near the focal point of the mirror, in a small cage.

Another solution to the problem is to deflect the light being focused by another mirror.

One such arrangement using a convex secondary mirror to focus the incident light, which now passes through a hole in the objective primary mirror, is shown in the figure.

This is known as a Cassegrain telescope, after its inventor.

It has the advantages of a large focal length in a short telescope.

In India

The Vainu Bappu Observatory, or VBO for short, is an astronomical observatory owned and operated by the Indian Institute of Astrophysics. It is located in the Javadi Hills Kavalur, near Vaniyambadi of Vellore district in the Indian state of Tamil Nadu, 175 km south-east of Bangalore.

View And Read More About Kavalur

https://www.youtube.com/watch?v=SbIhaCObnzE

https://en.wikipedia.org/wiki/Vainu_Bappu_Observatory

The largest telescope in India is in Kavalur, Tamil Nadu.

It is a 2.34 m diameter reflecting telescope (Cassegrain). It was ground, polished, set up, and is being used by the Indian Institute of Astrophysics, Bangalore.

The largest reflecting telescopes in the world are the pair of Keck telescopes in Hawaii, USA, with a reflector of 10 metre in diameter.

Think About These

- Can we use Compound Microscope as a telescope by using the objective of compound microscope as the eye piece in the telescope and vice versa? Give two reasons
- Under what conditions can the angular magnification and linear magnification be equal?
- The power and aperture of three lenses A, B and C are as under:

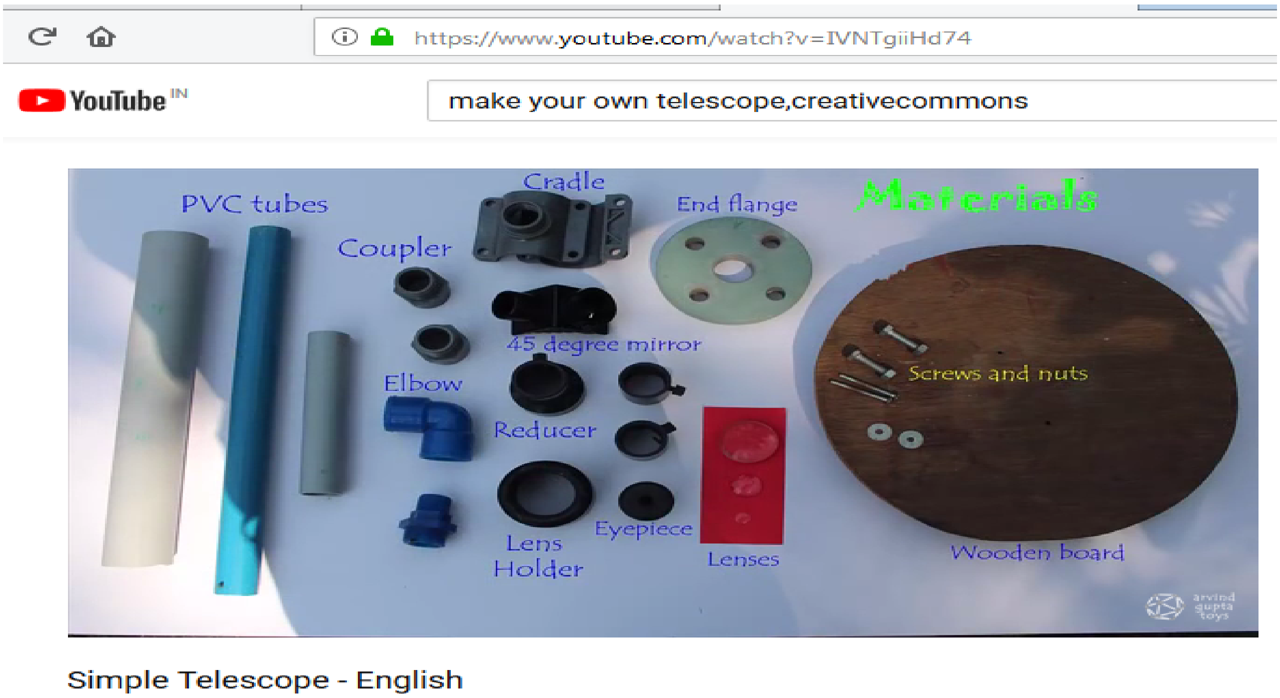
Lens	Power	Aperture
A	5D	50cm
B	20D	10cm
C	1D	100cm

  Which one is used as an objective and eyepiece in astronomical telescopes so that magnifying power is high? Calculate its magnifying power
- A convex lens of focal length 5cm is used as a magnifier. Calculate the maximum and minimum angular magnification.
- A compound microscope has an objective of focal length 0.3 cm and an eyepiece of focal length 2.5 cm. If an object is at 3.4 mm from the objective, what is the magnification?

Making Your Own Telescope

https://www.youtube.com/watch?v=KnGXZ20V0fE

Use and follow the Arvind Gupta video to make a telescope



This really Simple Telescope was designed by SASTA – the South African Agency for Science & Technology. The telescope's tube consists of 3 cardboard tubes, each 30-cm long. There are two lenses – the BIG OBJECTIVE is Convex-concave and the SMALL EYEPIECE is Concave-concave. The three tubes of slightly different diameters fit into each other and can easily slide. Thus the length of the tube can be increased and decreased. The sliding of the tubes helps in adjusting the focal length to view far and near objects clearly. These sliding tubes are called TELESCOPIC TUBES. This is the small eyepiece with a focal length 4-cm and diameter of 1.8-cm. The larger OBJECTIVE LENS has a focal length of 70-cm and a diameter of 6.7 cm. Hold both lenses in your hands and adjust the distance between them to see a far-away object clearly. This schematic diagram shows the RAY DIAGRAM of the telescope. First glue the outer rim of the EYEPIECE on the lens holder. Then glue the EYEPIECE to the small end of the tubes. The tubes can easily expand / contract and help you in getting a clear image of a far-away object. Finally glue the BIG OBJECTIVE on the big end of the tubes.

Now the telescope is ready. In the expanded position the telescope might be 85-cm long. In the contracted position it might be just 30-cm long. Now point the big lens towards what you wish to observe. Adjust the focal length by sliding the tubes. Soon you will see a clear image of your desired object. You can watch birds, wild life or gaze at the moon with this SIMPLEST TELESCOPE. This work is supported by IUCAA (www.iucaa.in) and TATA Trust (www.tata.com/aboutus/sub_index/Tata-trusts) Credits: Ashok Rupner, Manish Jain, Pradnya Pujari, Shivaji Mane, Jyoti Hiremath, Arvind Gupta, TATA Trust: Education is one of the key focus areas for Tata Trusts, aiming towards enabling access of quality education to the underprivileged population in India. To facilitate quality in teaching and learning of Science education through workshops, capacity building and resource creation, Tata Trusts have been supporting Muktangan Vigyan Shodhika (MVS), IUCAA's Children's Science Centre, since inception. To know more about other initiatives of Tata Trusts, please visit www.tatatrusts.org

Summary

- **The Eye:** The eye has a convex lens of focal length about 2.5 cm. This focal length can be varied somewhat so that the image is always formed on the retina. This ability of the eye is called accommodation. In a defective eye, if the image is focused before the retina (myopia), a diverging corrective lens is needed; if the image is focused beyond the retina (hypermetropia), a converging corrective lens is needed. Astigmatism is corrected by using cylindrical lenses.
- **Magnifying power m of a simple microscope** is given by m = 1 + (D/f), where D = 25 cm is the least distance of distinct vision and f is the focal length of the convex lens. If the image is at infinity, m = D/f. For a
- **Magnifying power m of a compound microscope**, the magnifying power is given by m = me × m_0 where me = 1 + (D/fe), is the magnification due to the eyepiece and mo is the magnification produced by the objective.

  Approximately, where f_0 and f_e are the focal lengths of the objective and eyepiece, respectively, and L is the distance between their focal points.

$$m = \frac{f_o}{f_e} \times \left(1 + \frac{f_e}{D}\right)$$

- **Magnifying power m of a telescope** is the ratio of the angle β subtended at the eye by the image to the angle α subtended at the eye by the object.

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

where f_o and f_e are the focal lengths of the objective and eyepiece, respectively.