PHYSICS NOTES

1. OPTICS

1.1. Let's observe a magnifying glass

A magnifying glass is a convex lens that lets the observer see a larger image of the object being observed. The lens is usually mounted in a frame with a handle (Figure 1).

Figure 1: Magnifying glass

Observation procedure:

- Magnification: Place the lens very close to the eye and move both the eye and the lens together to obtain the best focus. The magnification of a magnifying glass depends upon where it is placed between the user’s eye and the object being viewed and upon the total distance between eye and object.

The magnifying power is the ratio of the sizes of the images formed on the user's retina with and without the lens.

- Image location: Where does image seem to be located? somewhere before the object?
- Physical shape of the lens: Touch the lens to feel the thickness of the middle part and of the edges.

1.2. Virtual Image Formation by Converging Lens

Virtual Image Formation

Converging lenses form virtual images if the object distance is shorter than the focal length. Using the common form of the lens equation, i is negative. Such images are formed with the simple magnifier (Figure 1)

Figure 1: Magnifying glass (or simply magnifier)

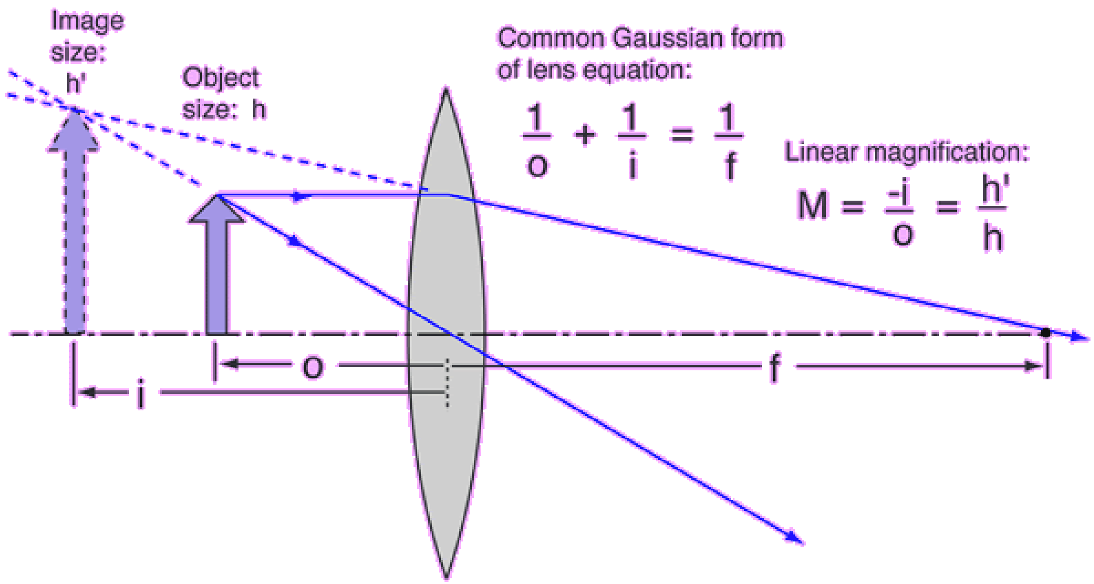


Figure 2: Virtual Image formation

Calculations

Find linear magnification M, given the details on Figure 3.

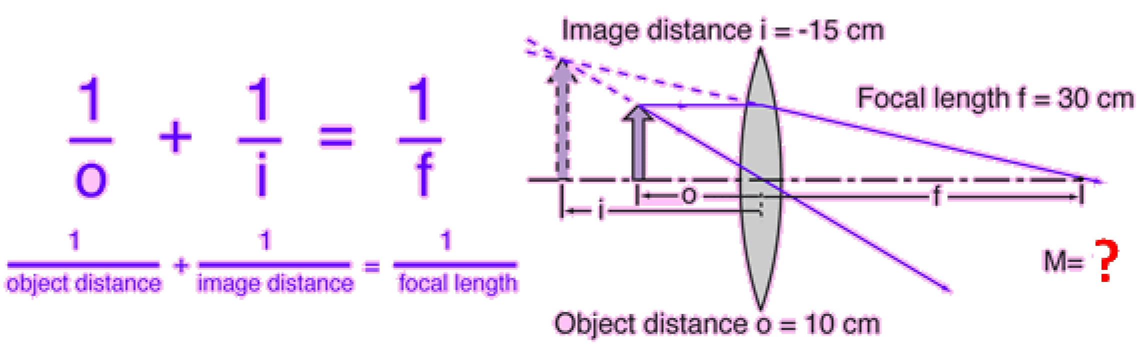


Figure 3: Calculation of linear magnification

1.3. Lens Simulation

The case discussed about in the section "Virtual Image Formation" is one of many a lens can take.

Let's explore different ways images can be formed using **Lens Simulator**

Below is example of how we can get a real image

f = 1.5; xo = -2.5; yo = -1 provide the image that is real and inverted.

1.4 Thin Lenses

1. What's a lens?

A lens is a transparent medium (usually glass) bounded by two curved surfaces either spherical, cylindrical, or plane surfaces.

As illustrated in Figure 1, the line which passes normally through both bounding surfaces of a lens is called the *optic (or optical) axis*. The point ***O*** on the optic (or optical) axis which lies midway between the two bounding surfaces is called the *optic (or optical) center*.

2. When do we say "This is a thin lens"?

If the **thickness of the lens is much smaller than its diameter**, we call that lens "thin".

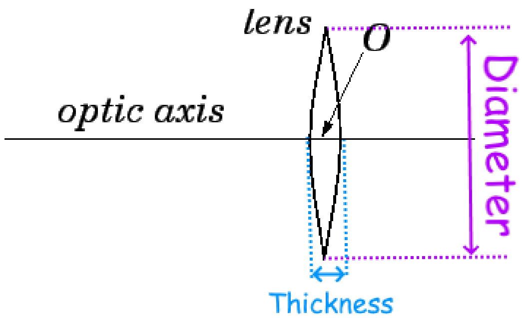


Figure 1 : The optic (or optical) axis of a lens

3. Terminology

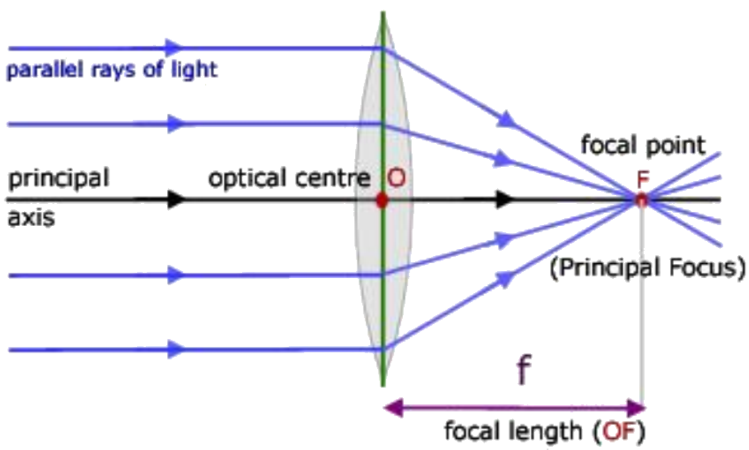


Figure 2 : Terms used for a converging lens

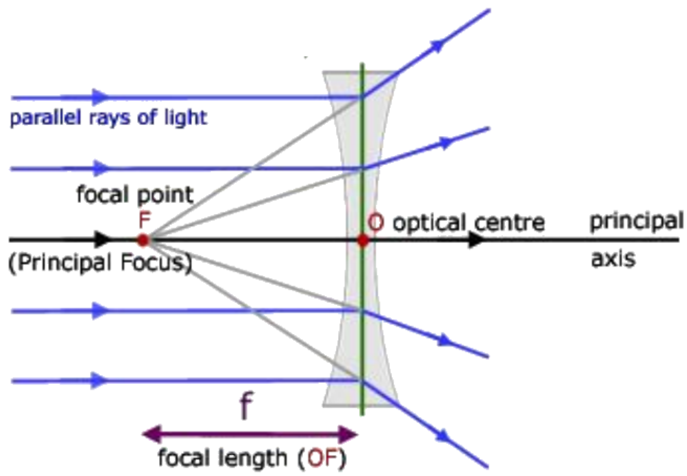


Figure 3 : Terms used for a diverging lens

3.1. Principal axis is a line which passes through the center of the lens, perpendicular to the lens surface.

3.2. Principal focus is a point on the principal axis where rays of light parallel to the principal axis converge.

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

3.4. Optical center is an imaginary point inside a lens through which a light ray is able to travel without being deviated.

3.5. Centre of curvature is the center of the sphere of which the lens surface is part.

4. Properties of images formed by lenses

There are two types of image formed by lens: real and virtual

Real images are produced from actual rays of light coming to a focus (e.g.: a film projected onto a screen)

Virtual images are produced from where rays of light appear to be coming from (e.g.: a magnifying glass image)

5. Rules for a ray diagram

a) The ray parallel to the principal axis is refracted through the focus point, F.

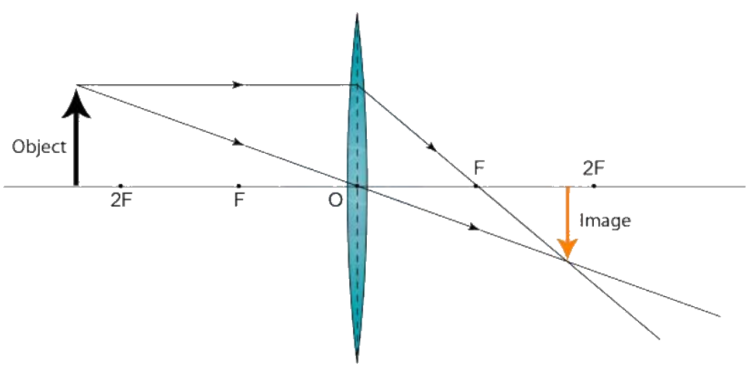
b) A ray passing through the focus point is refracted parallel to the principal axis.

c) A ray passing through the optical center travels straight without bending

6. Graphical construction of images by lenses

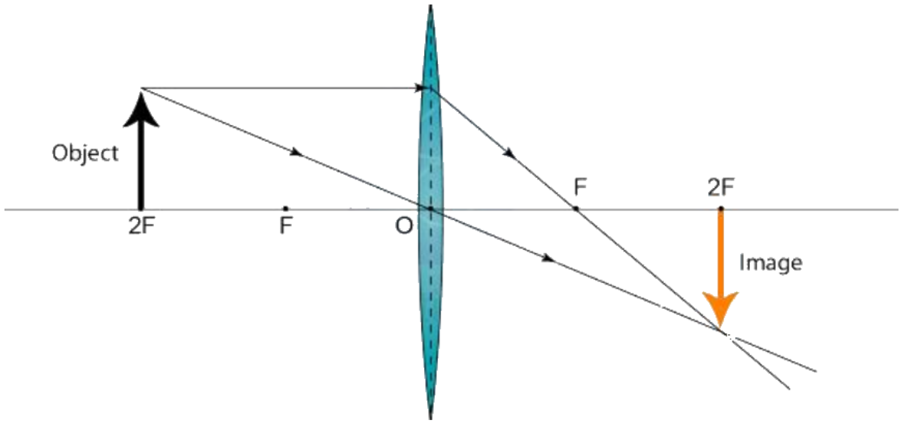
6.1. Images formed by converging lenses

a) Object beyond 2F



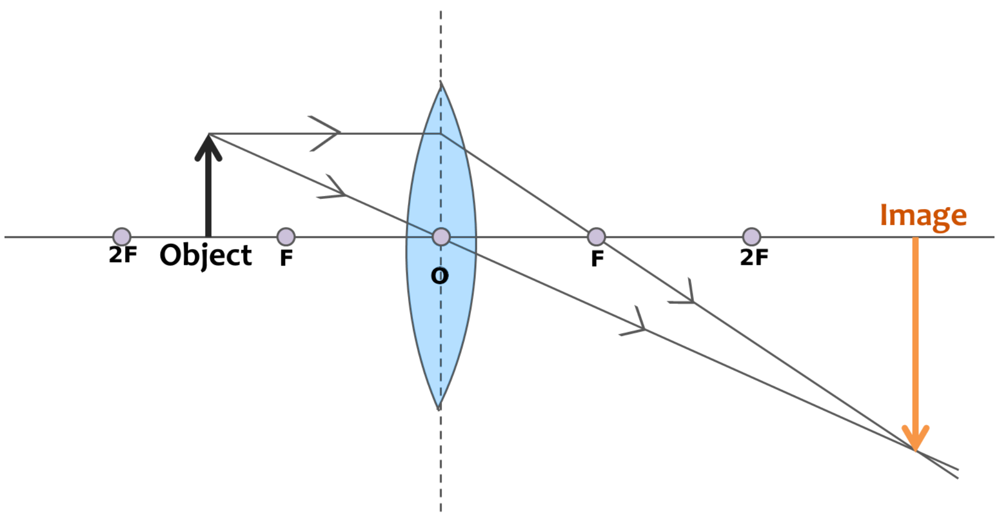
Characteristics of the Image: Real, inverted, and diminished

b) Object at 2F



Characteristics of the Image: Real, inverted, and of the same height as object

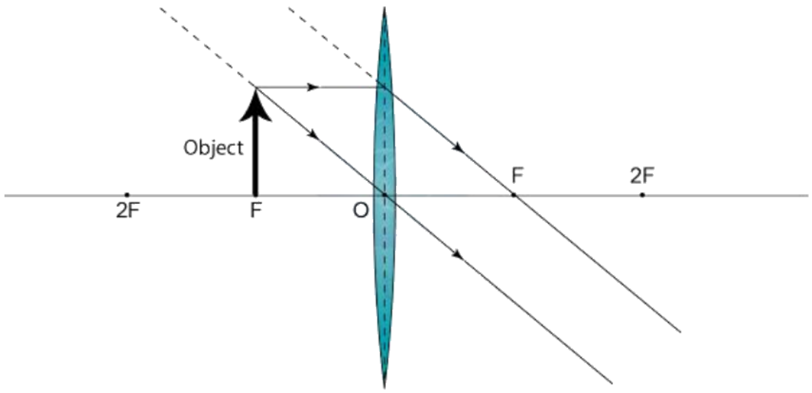
c) Object between



2F and F

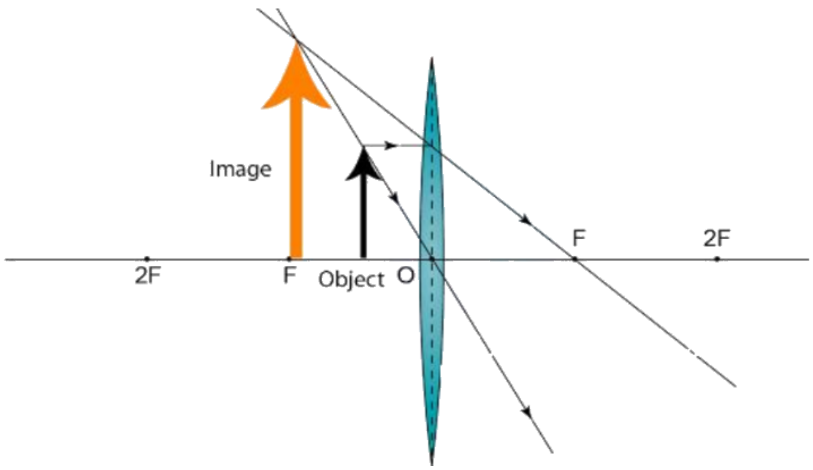
Characteristics of the Image: Real, inverted, and magnified

d) Object at F



Characteristics of the Image: Infinity

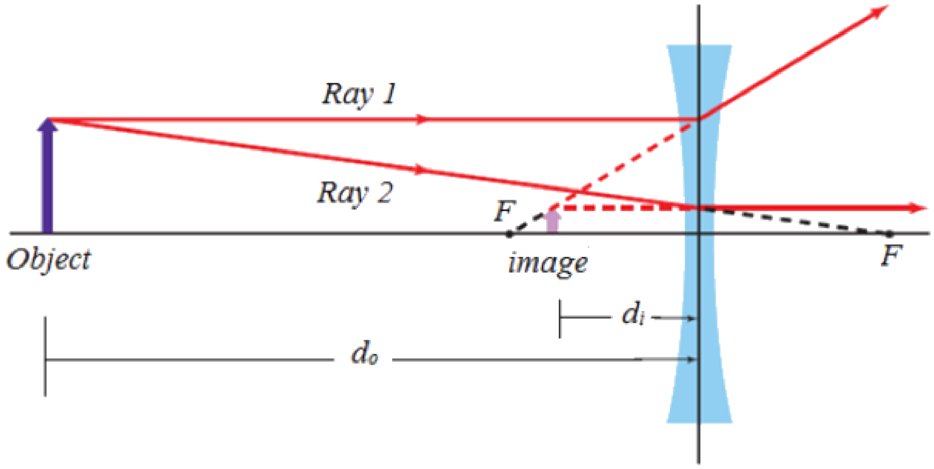
f) Object between F and optical center (Case for magnifying glass)



Characteristics of the Image: Virtual, upright (erect), and magnified

6.2. Images formed by diverging (concave) lenses

Concave lenses produce only virtual images that are upright and smaller compared to their objects.



7. Magnification

The Cartesian magnification of lens is

$$m = \frac{h_i}{h_o} = \frac{OB'}{BO}$$

, where hi is the image height, ho object height, OB', the image distance, and BO the object distance.

8. Power of Lenses

Whenever a ray of light passes through a lens it bends except when it passes through the optical center. The degree of convergence or divergence of a lens is expressed as power. A lens of short focal length deviates the rays more while a lens of large focal length deviates the rays less. Thus the power of a lens is defined as the reciprocal of its focal length.

Power of lens P = 1/f

The unit of power is dioptre (D)

$1D = m^{-1}$

In case the lenses are combined

$P = P_1 + P_2 + ... + P_{n-1} + P_n$

$1/F = 1/f_1 + 1/f_2 + ... + 1/f_{n-1} + 1/f_n$

9. Combination of lens

Consider two convex lenses in contact. Let a point object O be placed at a distance u_1 from the lenses A whose real image I_1 is formed at a distance v_1.

1.5. Types of Lenses and their Characteristics

1. Types of lenses

There are two types of lenses; a convex lens also called a converging lens and a concave lens also known as a diverging lens.

2. Characteristics of Lenses

2.1. Characteristics of Converging Lenses

•Thicker at the center

As a general rule, converging lenses are characterized by being thicker at the center than at the edges.

•Focal Point (focus) behind the lens

A converging lens brings all incident light-rays parallel to its optical axis together at a point ***F***, behind the lens, called the ***focal point F*** (or ***focus)*** of the lens.

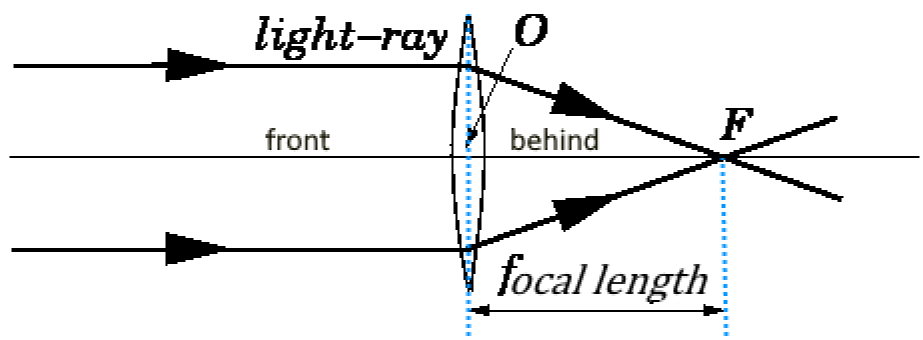


Figure 1: *The focus of converging lens*

As a general rule, diverging lenses are are characterized by being thicker at the edges than at the center.

2.1.1. Bi-convex, or double-convex lens

This is the most commonly occurring type of converging lens.

In this type of lens, both bounding surfaces have a focusing effect on light-rays passing through the lens.

2.1.2. Plano-convex lens

This is a fairly common type of converging lens.

In this type of lens, only the curved bounding surface has a focusing effect on light-rays. The plane surface has no focusing or defocusing effect.

2.1.3. Convex-meniscus lens

This is a less common type of converging lens.

In this type of lens, the front bounding surface has a focusing effect on light-rays, whereas the back bounding surface has a defocusing effect, but the focusing effect of the front surface wins out.

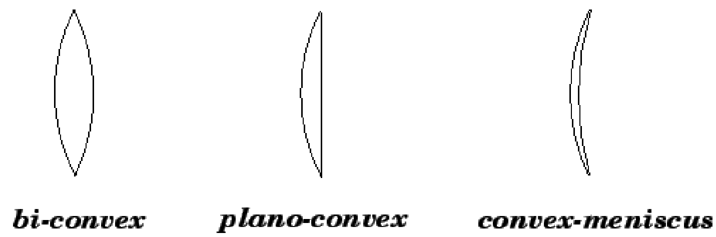


Figure 2: *Converging lenses*

2.2. Characteristics of Diverging Lenses

•Thicker at the edges

As a general rule, converging lenses are characterized by being thicker at the edges than at the center.

•Focal Point (focus) in front of the lens

A diverging lens spreads out all incident light-rays parallel to its optic axis so that they appear to diverge from a *virtual focal point* ***F*** in front of the lens.

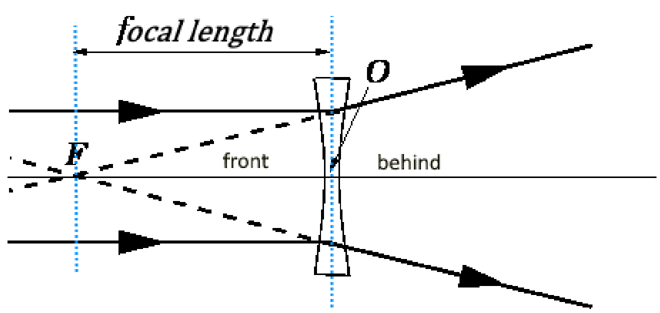


Figure 3: *The focus of diverging lens*

2.2.1. Bi-concave, or double-concave lens

This is the most commonly occurring type of diverging lens is a *bi-concave*, or *double-concave*, lens.

In this type of lens, both bounding surfaces have a defocusing effect on light-rays passing through the lens.

2.2.2. Plano-concave lens

This is a fairly common type of diverging lens is a *plano-concave* lens. In this type of lens, only the curved bounding surface has a defocusing effect on light-rays. The plane surface has no focusing or defocusing effect.

2.2.3. Concave-meniscus lens

This is a less common type of diverging lens is a *concave-meniscus* lens.

In this type of lens, the front bounding surface has a defocusing effect on light-rays, whereas the back bounding surface has a focusing effect, but the defocusing effect of the front surface wins out.

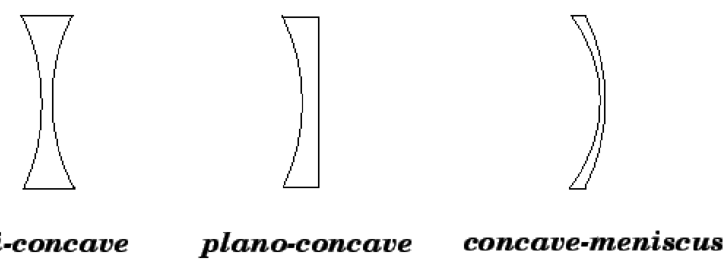


Figure 4: Di*verging lenses*

<u>1.6. Cartesian Sign Convention</u>

1. Old Form of Cartesian Sign Convention

1. All figures are drawn with light traveling from left to right.

2. Distances to the left of the reference surface (such as a refracting surface) are negative.

3. The focal length of a surface that makes light rays more convergent is positive.

4. The distance of a real object (located on the left side of the lens) is negative

5. The distance of a real image is positive.

6. Heights above the optic axis are positive.

7. Angles measured clockwise from the optic axis are negative.

2. New Form of Cartesian Sign Convention

1. Distances measured in the same direction as that of incident light are taken as positive. It is deduced from this rule that "object distance is **always positive"**, "real image distance is **always positive"**, and "the focal length of a converging lens is positive".

2. Distances measured against the direction of incident light are taken as negative. It is deduced from this rule that "virtual image distance is **always negative"** and "the focal length of a diverging lens is negative".

3. Distances measured upward and perpendicular to the principal axis are taken as positive.

4. Distance measured downward and perpendicular to the principal axis are taken as negative.

3. Why do we study both new and old forms of Cartesian Sign Convention?

The reason is simple. Some sources we read use old form of Cartesian Sign Convention while others use the new form. It is important to know that both forms exist and that they are in use in the scientific world.

1.7. Lens Formula

1. What is Lens Formula?

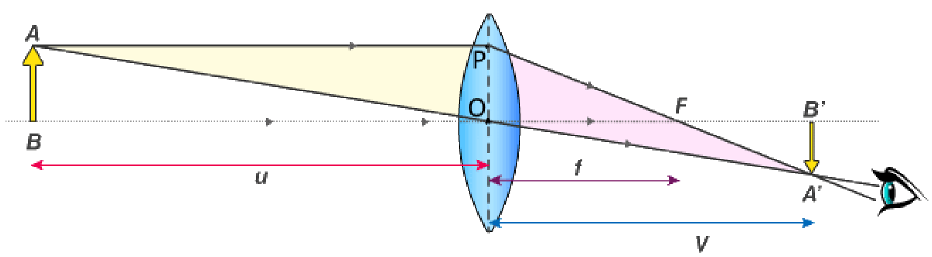
In optics, the relationship between the distance of an image (v), the distance of an object (u) and the focal length (f) of the lens is given by the formula known as Lens formula.

Lens formula is applicable for convex as well as concave lenses. These lenses have negligible thickness. The lens formula has two variants:

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \text{and} \quad \frac{1}{f} = \frac{1}{v} + \frac{1}{u}$$

2. Derivation of Lens Formula

Consider a **convex lens** with object AB kept on the principal (optical axis) axis. Two rays are considered such that one ray is parallel to the principal axis and after refraction at the point P, it passes through the focus. The second ray is towards the optical center O such that it passes undeviated.



A′ is the point where the two rays intersect and also the image formed by point A.

Point B' (the image formed by point B) is obtained on the principal axis as the point B is on the principal axis.

As the object is perpendicular to the principal axis, even the image is perpendicular to the principal axis.

To get B', the image formed by point B, we need to draw a perpendicular from point A′ to the principal axis.

Following are the things obtained after drawing the figure:

$\frac{AB}{A'B'} = \frac{BO}{OB'}$ (from similar ΔABO and ΔA'B'O) (equ. 1)

$\frac{PO}{OF} = \frac{A'B'}{FB'}$ (from similar ΔPOF and ΔFB'A')

$\therefore \frac{AB}{OF} = \frac{A'B'}{FB'}$ (from figure PO = AB)

$\frac{AB}{A'B'} = \frac{OF}{FB'}$ (equ. 2)

$\frac{BO}{OB'} = \frac{OF}{FB'}$ (from equ. 1 and equ. 2)

on the figure OF+FB' = OB'

$\therefore \frac{BO}{OB'} = \frac{OF}{OB' - OF}$

2.1. Variant 1 of Les Formula: Based on Old Cartesian Sign Convention which states that "the distance of a real object is negative" we take BO as a negative distance, hence $-u$

$\frac{-u}{+v} = \frac{+f}{v-f}$ (substituting optical distance values)

$\therefore \frac{-uv}{uvf} + \frac{uf}{uvf} = \frac{fv}{uvf}$ (dividing by uvf on both the sides)

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

$-\frac{1}{f} = -\frac{1}{v} + \frac{1}{u}$ (equ. 3)

$\boxed{\frac{1}{f} = \frac{1}{v} - \frac{1}{u}}$ (Having multiplied by -1 on both sides of equ. 3)

2.2. Variant 2 of Les Formula: Based on New Cartesian Sign Convention which states that "Distances measured in the same direction as that of incident light are taken as positive" we take BO as a positive distance, hence $+u$

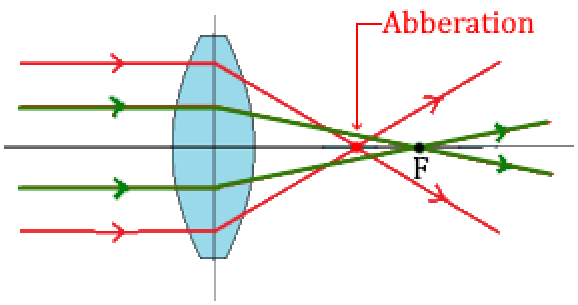
1.7. Aberrations of Lenses

There are several different types of aberration which can cause the image to be an imperfect replica of the object(Spherical aberration, chromatic aberration, coma, field curvature, barrel, pincushion distortion, astigmatism, etc)

1. Spherical aberration

Spherical aberration comes into play when light rays parallel to the principal axis are unable to focus at the same point on the principal axis resulting in a blurring of the image.

That occurs when those rays are a relatively long way from the axis, so that they fail to be brought to a focus.



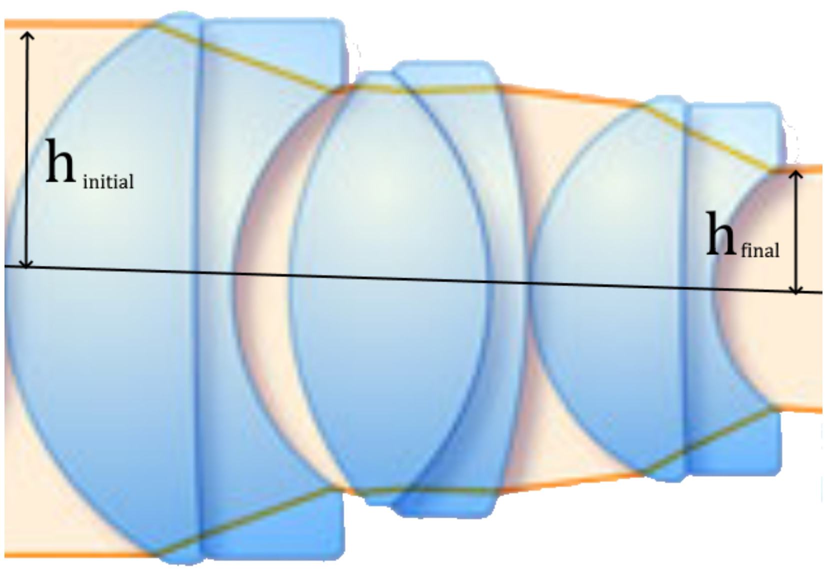
Correction of spherical aberration

Correction 1: Using lenses whose bounding surfaces are *non-spherical*

Spherical aberration in lenses can be completely cured by using lenses whose bounding surfaces are *non-spherical*. But because such lenses are more difficult to manufacture, and, hence, more expensive, than conventional lenses whose bounding surfaces are spherical; lenses whose bounding surfaces are *non-spherical are* only employed in situations where the spherical aberration of a conventional lens would be a serious problem.

Correction 2: Combining conventional lenses

Apart from using lenses whose bounding surfaces are *non-spherical,* spherical aberration can be cured using the method of *combining* conventional lenses (*i.e.*, compound lenses).



$h_{final} < h_{initial}$

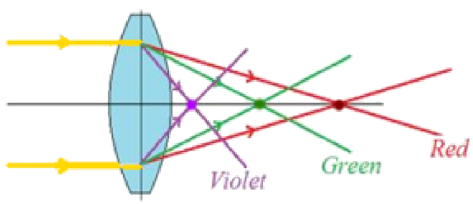
Light ray has been brought close to the principal axis

Chromatic aberration

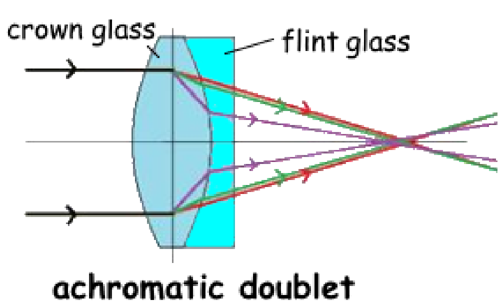
Chromatic aberration is caused by the dispersion of the lens material.

Since, from the lens formulas, f is dependent upon n, it follows that different colors of light will be focused to different positions. Chromatic aberration can be minimized by using an achromatic doublet (or achromatic) in which two materials with differing dispersion are bonded together to form a single lens.

::Aberration



::Correction



Note: Along this course, we shall make use of the *paraxial approximation*, in which spherical aberration is completely **ignored**, and all light-rays parallel to the optic axis are assumed to be brought to a focus, or a virtual focus, at the same point F.

*Paraxial approximation is **valid** as long as the **radius of the lens is small compared to the object distance and the image distance.***

1.8. Refraction and Total Internal Reflection (TIR)

1. Refraction

Refraction of light is a phenomena where the direction of light is changed when it crosses the boundary between two materials of different optical densities. It due to the change in the velocity of light as it passes from one medium into another.

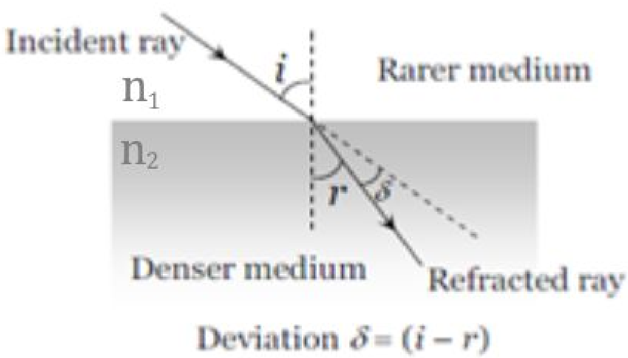
An example of refraction is if you take a pencil and dip it in water, the pencil appears to be bent. It does not appear straight. Why is the pencil appearing bent even though it is a straight nice pencil? This is because of a phenomenon of refraction. The medium involved here is air and water. As soon as the light waves enter the water, the light rays bend and because of this bending of light waves, we see the pencil as broken.

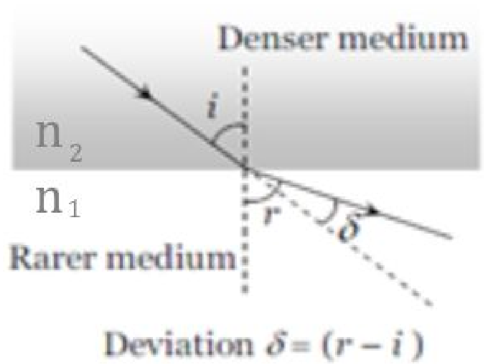
Important: If the light passes through less dense to more dense medium it bends towards normal. If the light passes through high dense to less dense medium it bends away the normal.

The Laws of Refraction

The incident ray, the refracted ray and the normal at the point of entry are all in the same plane.

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a particular wavelength (Snell's Law).





Snell's law (also known as Snell-Descartes law and the law of refraction) is a formula used to describe the relationship between the angle of incidence and the angle of refraction, when referring to light or other waves passing through a boundary between two different isotropic media (not possessing any special direction in their structure), such as water, glass, or air.

Snell's law states that The ratio of sine of the angle of incidence (i) to the angle of refraction (r) is a constant called refractive index.

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$ (equation 1)

For two media, Snell's law can be written as

$$\frac{\sin i}{\sin r} = n = \frac{n_2}{n_1}$$

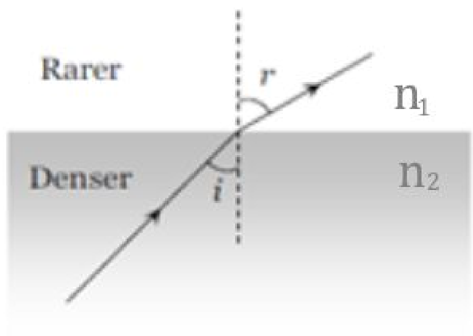
2. Total Internal reflection

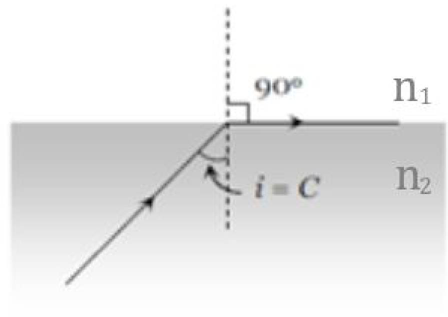
When a ray of light goes from denser to rarer medium it bends away from the normal.

Also, as the angle of incidence in denser medium increases, the angle of refraction in rarer medium also increases.

When the angle of incidence in denser medium increases until the point where the angle of refraction in rarer medium becomes 900, this angle of incidence is called critical angle (C).

When angle of incidence exceeds the critical angle, the light ray comes back in to the same medium after reflection from interface. This phenomenon is called **Total internal reflection.**





n2*sin i = n1*sin 900

For the critical angle

n2*sin C = n1*1

From Snell's Law, the refractive index *n*

$$n = \frac{n_2}{n_1} \qquad n = \frac{n_2}{n_1} = \frac{1}{\sin C}$$

sin C = n1/n2

C = arcsin (n1/n2)

Example:

Consider a ray of light moving from water to air.

The refractive indices of water and air are approximately 1.333 and 1, respectively.

Find the critical angle for which the light ray will emerge lying flat on the water.

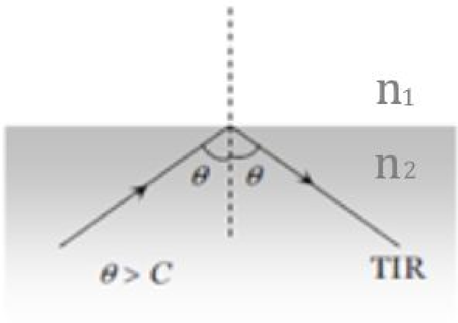
Answer:

C = arcsin(1/1.333)

C = arcsin(0.750)

Click here for ArcSin Calculator

C = 48.60

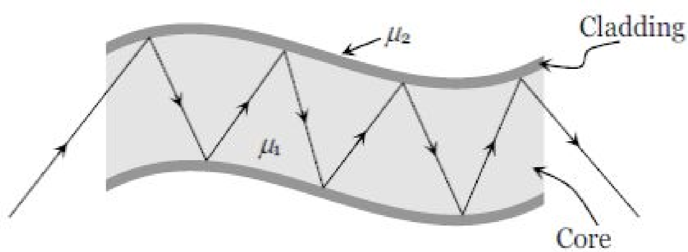


Examples of total internal reflection (TIR)

Optical fibre

Optical fibres consist of many long high quality composite glass/quartz fibres. Each fibre consists of a core and cladding. The refractive index of the material of the core n_1 is higher than that of the cladding (n_2).

When the light is incident on one end of the fibre at a small angle, the light passes inside, undergoes repeated total internal reflections along the fibre and finally comes out.



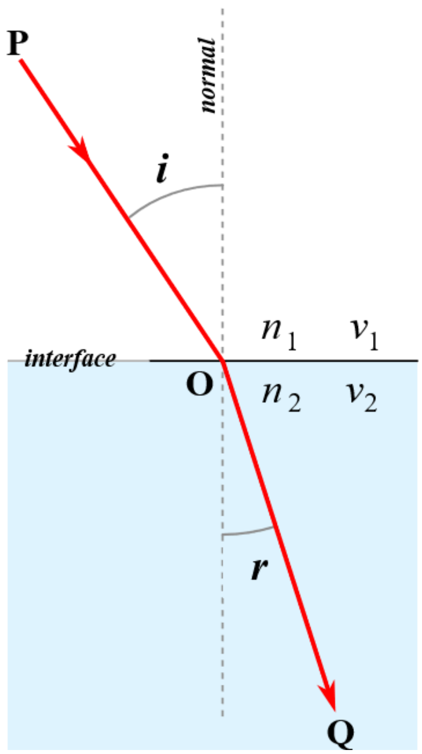
Taking the Light Velocity (Speed) into Consideration

When the velocity of a ray traveling from one medium to another is taken into consideration we get the Snell's Law is expressed as:

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$ (equation 2)

Combining equation 1 and equation 2, it ensures that

$$\frac{n_1}{n_2} = \frac{v_1}{v_2}$$



Test yourself

Attempt exercises no 1, 3, 7, 8, 9, and 27 on the section Exercises

1.8. Refraction Through Glass Prism

Terms associated with refraction of light passing through a prism

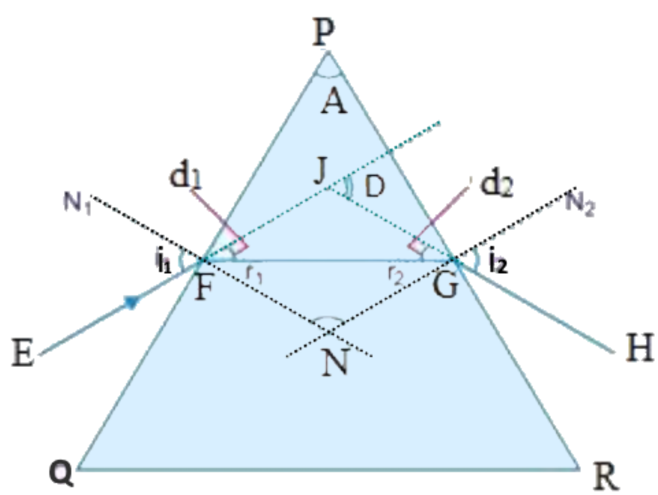
In optics, a prism is a transparent medium bounded by the three plane faces. Out of the three faces, one is grounded and the other two are polished. The polished faces are called refracting faces. The angle between surfaces is known as "**refracting angle"** or "angle of prism".

Deviation of light by prism

A prism deviates light on both faces. These deviations do not cancel. Thus the total deviation of a ray due to refraction at both faces of the prism is the sum of deviation of a ray due to refraction at the first surface and its deviation at the second face.

Let d1 and d2 be the angles of deviation at the first and the second faces of the prism respectively.

Total deviation D = d1 + d2 ;



Angle JFG named d1 = i1 - r1 and

angle JGF named d2 = i2 - r2

Given that the sum of interior angles of any triangle is 1800, angle FJG = 180-(d1 + d2)

= 180-(d1 + d2)

= 180-((i1 - r1)+(i2 - r2))

= 180-i1 + r1 - i2 + r2

Given that the angle of a straight line is 1800 ,

the angle of deviation D + FJG = 1800

D = 1800 - FJG

D = 180 - (180 - i1 + r1 - i2 + r2)

= 180-180+i1-r1+i2- r2

= i1 - r1 + i2 - r2

= i1 + i2 - r1- r2

=(i1 + i2) - (r1 + r2) (equ.1)

Again, given that the sum of angles of any triangle is 1800,

angle FNG = 180-(r1 + r2)

In figure PFNGP,

Given that the normal lines N1 and N2 fall perpendicularly (at 900) to the concerned sides of the prism, and that the sum of interior angles of any quadrilateral is 3600,

we have the following equation:

A+90+FNG+90 = 360

A+90+180-(r1 + r2)+90 = 360

A+360-360=r1+r2

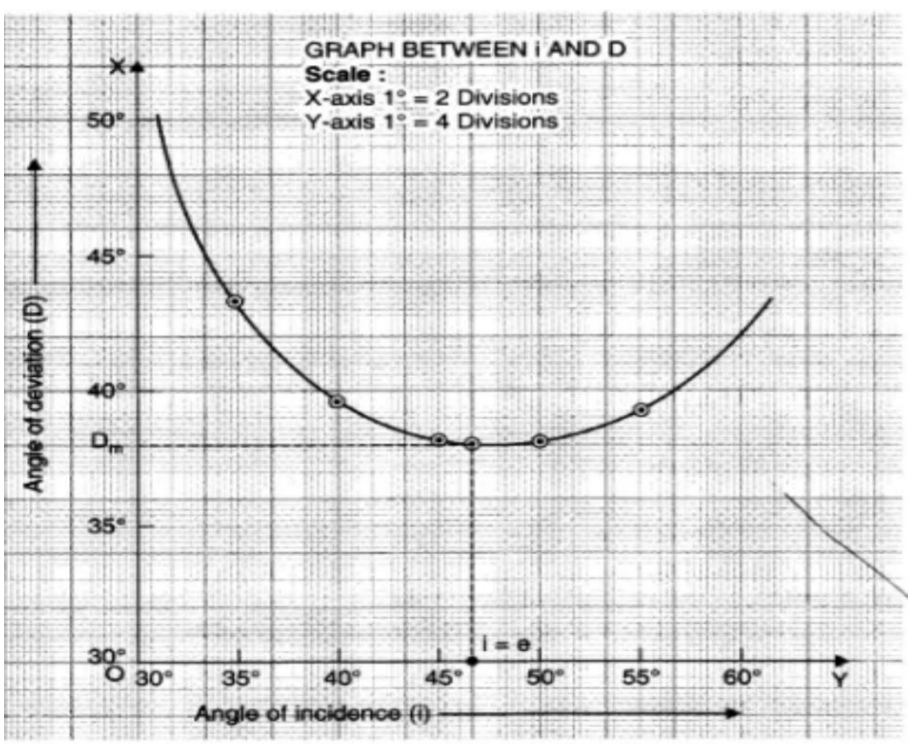
A=r1+r2 (equ. 2)

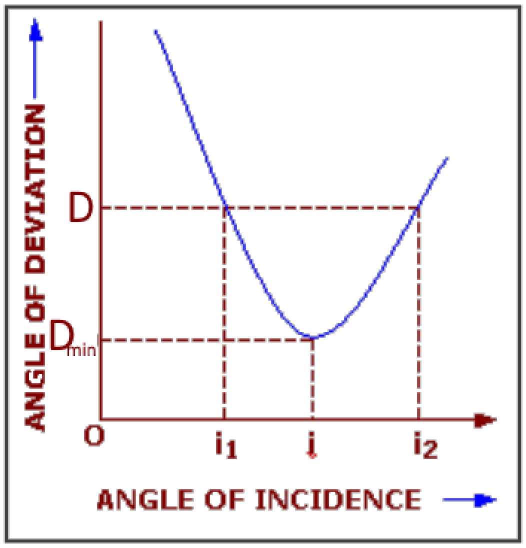
Merging equ. 1 and equ. 2,

D=(i1 + i2) - A   (equ. 3)

Equation 3 means that the angle of deviation D of a ray of light passing through a prism doesn't only depend upon its material (medium) but also upon the angle of incidence.

Angle of minimum deviation and determination of refractive index of the prism





The above figure shows the nature of variation of the angle of deviation with the angle of incidence. It is clear that an angle of deviation has the minimum value Dmin for only one value of the angle of incidence.

The minimum value of the angle of deviation when a ray of light passes through a prism is called the angle of minimum deviation.

Notes: Minimum deviation occurs when the angle of emergence of the ray from the second face equals to the angle of incidence of the ray on the first face. At the minimum deviation, $i1 = i2 = i$ and $r1 = r2 = r$

Therefore, reconsidering equation 3

$Dmin=2i - A$

$2i = Dmin +A$

$$i = \frac{D_{min} + A}{2}$$

And reconsidering equation 2,

A=2r

hence

$$r = \frac{A}{2}$$

Given that the refractive index of the material of the prism, n, is given by:

$$n = \frac{\sin i}{\sin r}$$ *(From Snell's Law)*

and replacing i and r by the above equivalences, it turns out that

$$n = \frac{\sin\left(\frac{D_{\min} + A}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

And a minimum deviation Dmin can be extracted from the above formula as follows:

$$n*\sin(\frac{A}{2}) = \sin(\frac{D_{min}+A}{2})$$

$$\frac{D_{min}+A}{2} = \arcsin(n*\sin(\frac{A}{2}))$$

$$D_{min} = 2\arcsin(n*\sin(\frac{A}{2})) - A$$

Test yourself

Attempt exercises no 10, 11, 12, 13, 14, and 35 on the section [Exercises on Lens]

1.9. Lens-Maker's Formula

The *focal length* of a lens, which is usually denoted f, is defined as the distance between the optic center O and the focal point F, as shown in Figure 2.

However, by convention, *converging* lenses have *positive* focal lengths, and *diverging* lenses have *negative* focal lengths.

In other words, if the focal point lies behind the lens then the focal length is positive (converging lens), and if the focal point lies in front of the lens then the focal length is negative (diverging lens).

Consider a conventional lens whose bounding surfaces are *spherical*.

Let

C_f be the center of curvature of the front surface, and

C_b the center of curvature of the back surface.

R_f the radius of curvature of the front surface is the distance between the optic center O and the point C_f.

R_b the radius of curvature of the front surface is the distance between the optic center O and the point C_b.

Because *by convention*, the radius of curvature of a bounding surface is *positive* if its center of curvature lies *behind* the lens, and *negative* if its center of curvature lies *in front* of the lens, in Figure 3, R_f is positive and R_b is negative.

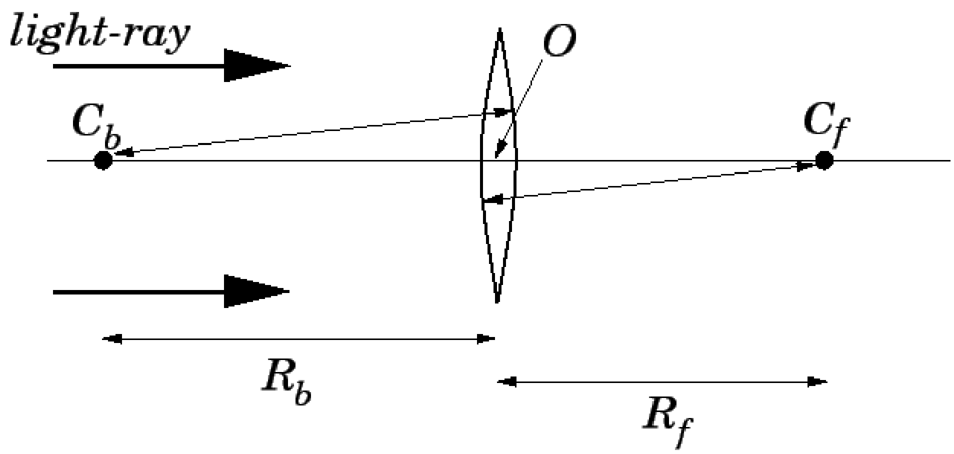


Figure 78: *A thin lens.*

In the paraxial approximation, it is possible to find a simple formula relating the *focal length* f of a lens to the radii of curvature, R_f and R_b, of its front and back bounding surfaces. This formula is written

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_f} - \frac{1}{R_b}\right),$$ where n is the refractive index of the lens.

Equation 1: L*ens-maker's formula*

The above formula is usually called the *lens-maker's formula*, and was discovered by Descartes.

Note that the lens-maker's formula is only valid for a *thin lens* whose thickness is small compared to its focal length.

What Equation 1 is basically telling us is that light-rays which pass from air to glass through a *convex* surface are *focused*, whereas light-rays which pass from air to glass through a *concave* surface are *defocused*.

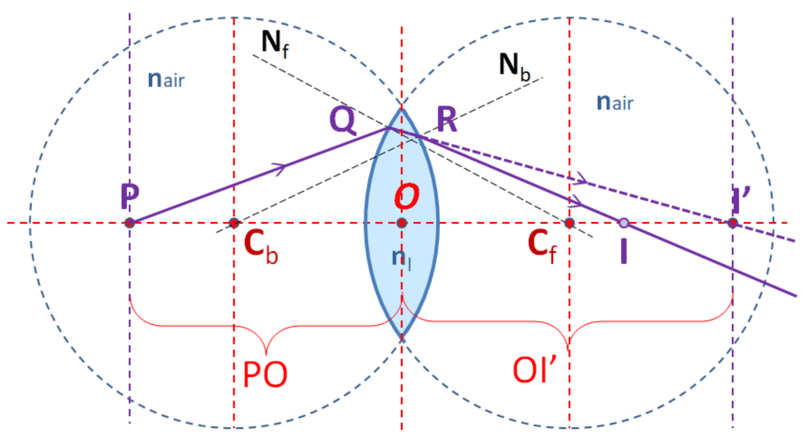
Furthermore, since light-rays are *reversible*, it follows that rays which pass from glass to air through a *convex* surface are *defocused*, whereas rays which pass from air to glass through a *concave* surface are *focused*. Note that the net focusing or defocusing action of a lens is due to the *difference* in the radii [ˈreɪdɪʌɪ] of curvature of its two bounding surfaces.

Suppose that a certain lens has a focal length f. What happens to the focal length if we turn the lens around, so that its front bounding surface becomes its back bounding surface, and *vice versa*?

It is easily seen that when the lens is turned around $R_f \to -R_b$ and $R_b \to -R_f$. However, the focal length f of the lens is invariant under this transformation, according to Equation 1.

Thus, the focal length of a lens is the same for light incident from either side. In particular, a converging lens remains a converging lens when it is turned around, and likewise for a diverging lens.

1.10. Derivation of Lens-Maker's Formula



For refraction at front surface

Relation for "a ray moving from a rarer medium to a denser medium"

$$\frac{nl}{OI'} - \frac{nair}{-PO} = \frac{nl-nair}{OCf}$$

$$\frac{nl}{OI'} + \frac{nair}{PO} = \frac{nl-nair}{OCf} \qquad (1)$$

Relation for "a ray moving from a denser medium to a rarer medium"

For this

step the object has been placed at point I' and its image is at point I

$$\frac{nair}{OI} - \frac{nl}{OI'} = \frac{nair-nl}{-OCb}$$

$$\frac{nair}{OI} - \frac{nl}{OI'} = \frac{nl-nair}{OCb} \qquad (2)$$

Adding (1) and (2)

$$\frac{nl}{OI'} + \frac{nair}{PO} + \frac{nair}{OI} - \frac{nl}{OI'} = \frac{nl-nair}{OCf} + \frac{nl-nair}{OCb}$$

$$nair\left(\frac{1}{PO} + \frac{1}{OI}\right) = (nl - nair)\left(\frac{1}{OCf} + \frac{1}{OCb}\right)$$

$$\frac{1}{PO} + \frac{1}{OI} = \left(\frac{nl}{nair} - 1\right)\left(\frac{1}{OCf} + \frac{1}{OCb}\right)$$

$$\frac{1}{PO} + \frac{1}{OI} = \frac{1}{f}$$ where f is the focal length

$$\frac{1}{f} = (\frac{nl}{nair} - 1)(\frac{1}{Rf} + \frac{1}{-Rb})$$

$$\frac{1}{f} = (\frac{nl}{nair} - 1)(\frac{1}{Rf} - \frac{1}{Rb})$$

In the air nair = 1. Therefore,

$$\boxed{\mathbf{\frac{1}{f} = (nl - 1)(\frac{1}{Rf} - \frac{1}{Rb})}}$$

1.11. Human Eye

1. Definition: The eye is a biological instrument used to see objects at different distances. It uses a convex lens system to form a small inverted, real image of an object in front of it.

2. Structure of the eye

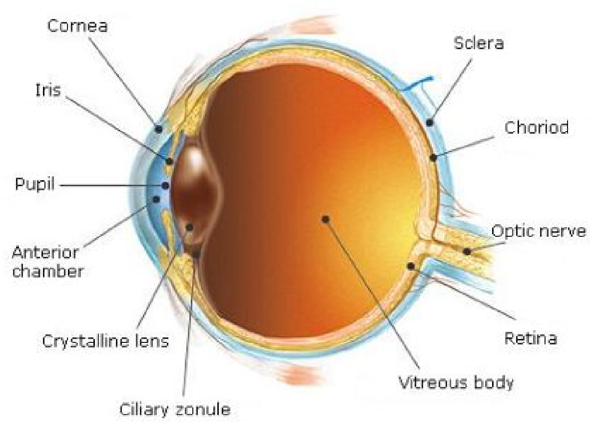
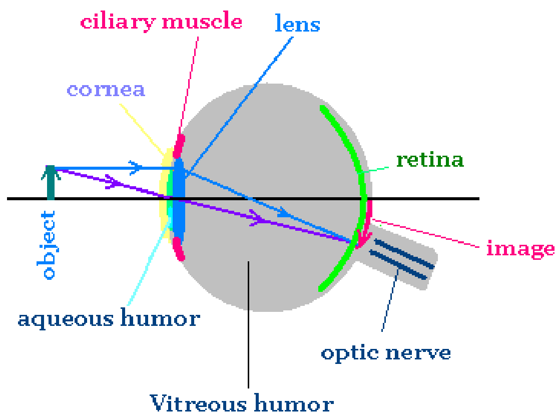


Figure 1: Parts of the eye



2.1. The cornea: it is made out of a fairly dense, jelly like material which provides protection for the eye, and seals in the aqueous humour.

2.2. The aqueous humour: this is a watery liquid that help to keep the cornea in a rounded shaped, similar to that of a lens.

2.3. The iris: The iris is the colored part of the eye that controls the amount of the light entering the eye.

2.4. The lens: this is used to focus an image on retina.

2.5. The ciliary muscles: these control the thickness of the lens during focusing.

2.6. The retina: The retina may be described as the "screen" on which an image is formed by light that has passed into the eye via the cornea, aqueous humour, pupil, lens, then the hyaloids and finally the vitreous humour before reaching the retina. The retina contains photosensitive elements (called rods and cones) that convert the light they detect into nerve impulses that are then sent onto the brain along the optic nerve.

2.6. The vitreous humour: this is a jelly-like substance that helps the eye to keep its round shape. It is very close in optical density to the lens material.

2.7. The optical nerve: this is the nerve that transmits images received by the retina to the brain for interpretation.

3. Accommodation of the eye

Accommodation of the eye is the ability of the eye to see near and distant objects. The eye is capable of focusing objects at different distances by automatic adjustment of the thickness of the eye lens which is done by the ciliary muscles.

3.1. Near point of the eye

The near point of the eye is the nearest point that can be focused by the unaided eye. It is a closest distance that a normal human eye can observe clearly without any strain to the eye. It is called the least distance of distinct vision. The near point of a normal eye is 25cm.

3.2. Far point of the eye

The far point is the farthest point that can be focused by the eye. The far point of the eye is infinity.

4. Defects of Vision and their Correction

There are four types of defect of the Eye: Myopia, Hypermetropia, Presbyopia and Astigmatism. Below are given the nature of the defect, its causes and corrective measures.

4.1. 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.

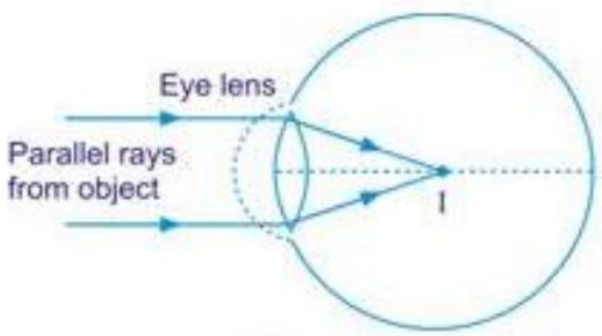


Figure 2: Image formation by myopic eye

4.1.1. 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

i. excessive curvature of the cornea, or

ii. Elongation of the eyeball.

4.1.2. Correction

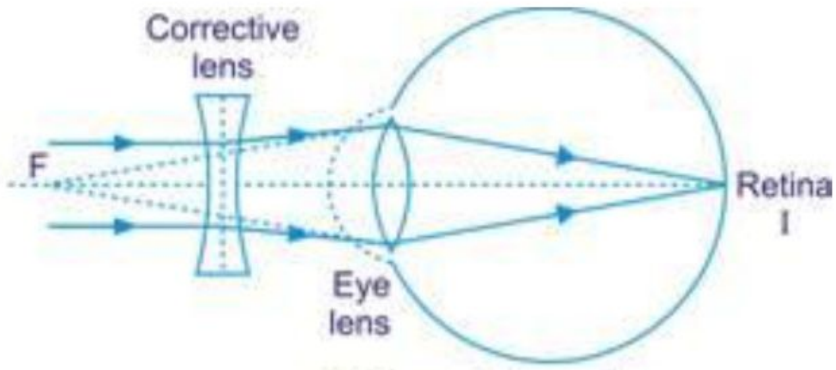


Figure 3: Corrected myopia

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.

4.2. 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.

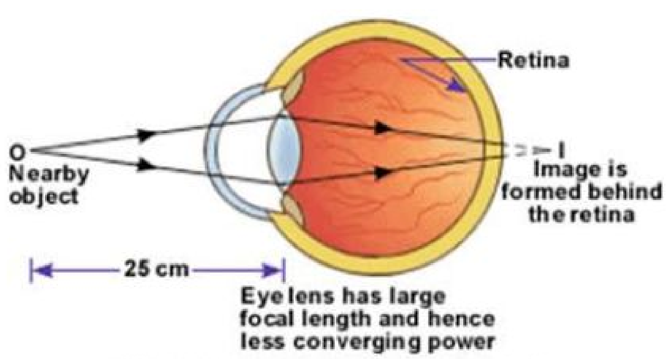


Figure 4: Any eye suffering from hypermetropia

4.2.1. Causes

This defect arises because either

i. the focal length of the eye-lens is too great, or

ii. The eyeball becomes too short, so that light rays from the nearby object, say at point **N**, cannot be brought to focus on the retina to give a distinct image.

4.2.2. Correction

This defect can be corrected by using a convex (converging) lens of appropriate focal length.

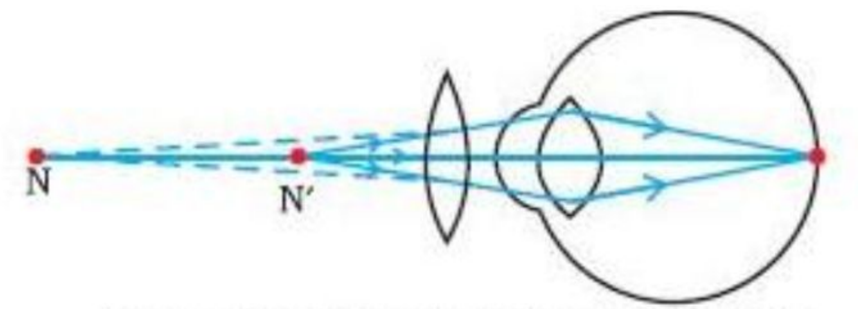


Figure 5: Correction for hypermetropic eye

When the object is at N', the eye exerts its maximum power of accommodation. Eyeglasses with converging lenses supply the additional focusing power required for forming the image on the retina.

4.3. Presbyopia

This defect of vision usually happens in old age when ciliary muscles become weak and can no longer adjust the eye-lens.The muscles become inflexible in this condition and cannot see nearby object clearly.

The near-point of an old person having presbyopia is much more than 25cm. Presbyopia corrects by wearing spectacles having convex lens.

N.B: 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 bifocal 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.

4.4. 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.

4.4.1. 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.

4.4.2. Correction

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

5. Eye Simulation: Geogebra/Optics-of-the-Human-Eye

6. Typical Exercises on Human Eye

To correct the vision impairment, we do nothing on the eye. We just use an appropriate lens to take the image where the eye can see it clearly.

6.1 Correction of Nearsightedness

What power of spectacle lens is needed to correct the vision of a nearsighted person whose far point is 30 cm, assuming the spectacle lens is held 1.5 cm in front of the eye by spectacle frames.

Reasoning

The person in this question used to have his far point at ∞ like most of us.

But since her/his vision got impaired s/he cannot see clearly objects located beyond 30 cm.

To help her/him we must find a way to place image at 30 cm from the eye an object located at the infinity.

But because the correcting lens is held by the frame 1.5 cm from the eye, counted from the correcting lens, the desired image distance is 28.5 cm i.e. 30cm - 1.5 cm.

Solution

The power of the spectacle is reciprocal to its focal length. That is expressed as $P = 1/f$

Using an old form of Cartesian Sign Convention whereby every distance on the side of object is negative,

$1/f = (1/v)-(1/u)$ or

$P= (1/v) - (1/u)$

$P = (1/(-28.5cm)) - (1/(-\infty))$

or $P = (1/(-28.5cm))$ given that $(1/(-\infty)) = 0$

Let's convert the image distance from centimeters to meters. In fact, for the power to be expressed in diopters distances should be measured in meters.

$P = P = (1/(-0.285m))$

$P = - 3.51$ D

D means diopters.

P having a negative sign means we need to use a concave lens.

6.2 Correction of Farsightedness

What power of spectacle lens is needed to allow a farsighted person whose near point is 1 m, to see clearly an object located at 25 cm away; assuming the spectacle lens is held 1.5 cm in front of the eye by spectacle frames.

Reasoning

A person with normal vision has a near point at 25 cm. Unfortunately the defect of the eye of the person in question has shifted the near point to 1 m (or 100 cm). To fix that we must find a way to place back to 1 m (or 100 cm) the image of the object placed at 25 cm from the eye. Taking into account that the spectacle lens is held 1.5 cm from the eye, the image is placed to 98.5 cm from the spectacle lens, while the object is located at 23.5 cm from the spectacle lens.

Solution

Let's use the old form of Cartesian Sign Convention whereby the lens formula is $1/f = 1/v - 1/u$ or $P = 1/f$ or $P = (1/v) - (1/u)$

From the above reasoning the object distance $u = -23.5$ cm or $u = -0.235$ m and because the image is going to be on the same side as the object $v = -0.985$ m.

$P = (1/-0.985) - (1/-0.235)$

$P = -1.015 - (-4.255)$

$P = 3.24$ D

D means diopters.

P being positive means we need to use a convex lens.

Test yourself

Attempt exercises no 40, 41, 42, 43, 44, and 45 on the section Exercises on Lens

1.12. Lens Camera

1. Lens Camera Simulation: **Geogebra/Focussing-a-camera**

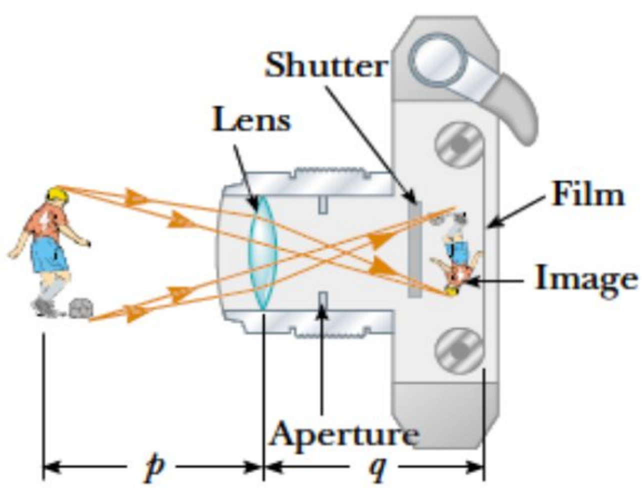
2. How the Lens Camera works

A photographic camera consists of:

- A converging lens

- A light sensitive film at the other end (Learn more how a film works: YouTube/How-Film-Works, Why Are Film Negatives Backward? HowStuffWorks/HowPhotographicFilmWorks)

- A focusing device for adjusting the distance of the lens from the film in order to provide the correct exposure



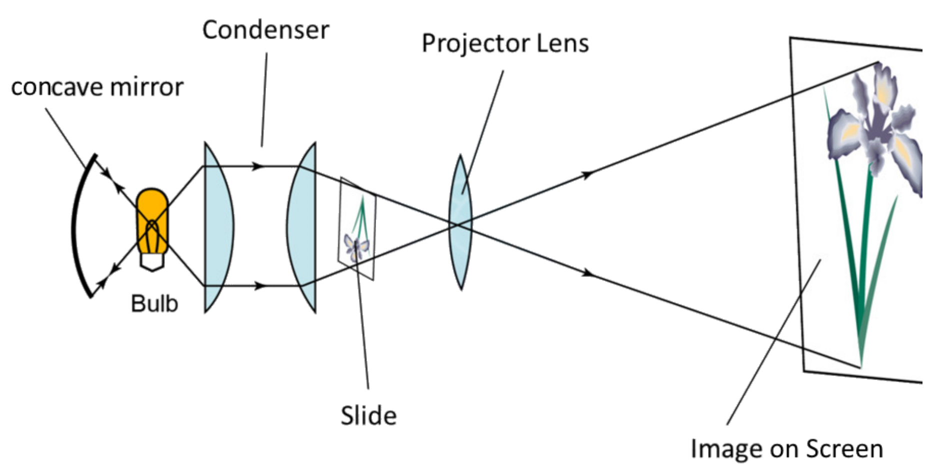
The shutter opens and closes quickly, thereby exposing the film to light for a short time for the light to enter the camera.

The object is placed in such a way that a real inverted image of the object is formed on the film.

1.13. Slide Projector

A slide projector is a device used to throw on a screen a magnified image of a film or a transparent slide. It produces a magnified real image of an object.

Videos:YouTube/SlideProjector,YouTube/HowToMakeASlideProjector



It consists of an illumination system and a projection lens.

The illumination system consists of a lamp, concave reflector and the condenser.

A lamp made in carbon electric arc or in quartz gives a small but very high intensity of light in order to make the image brighter.

This lamp located at the center of curvature of a spherical mirror reflects back the light along their original path.

The condenser made by two plano-convex lenses collects light that is spread out towards the film (slide).

The light is then scattered through the film and focused by a convex projection lens on to the screen.The projection lens is mounted in the *sliding tube* so that it is moved to and fro to focus a sharp image on the screen.

The linear magnification(or linear scale factor) of the projector is given by the square root of area scale factor (or area magnification of image).

$$m = \sqrt{M_i}$$

Where *m* is a linear scale factor or linear magnification

Mi is the area scale factor or area magnification of image.

$$M_i = \frac{Area \quad image}{Area \quad of \quad object}$$

$$M_i = \frac{A_i}{A_o}$$

Test yourself

Attempt exercises no 47 on the section Exercises on Lens

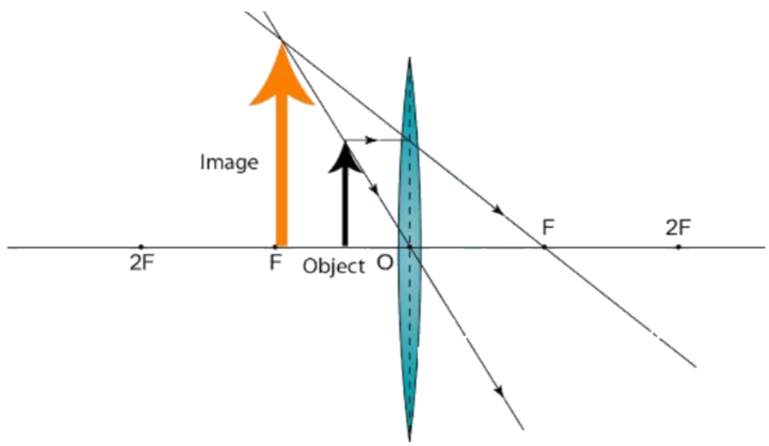
1.14. Microscopes

1. Simple Microscope

A magnifying glass consists of a thin converging lens and it is used to view a very small objects or a part of an organism which cannot be easily seen by a naked eye.

1.1. Formation of image by a magnifying glass

A magnifying glass forms a virtual, upright and magnified image of an object placed between the lens and the focus.



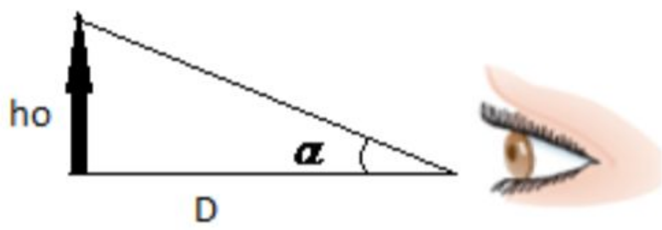
1.2. Magnifying power (angular magnification) of a simple microscope

The magnifying power is defined as the as the ratio of the angle β subtended at the eye by the image (when using an instrument) to the angle a subtended at the eye by the object at the near point (with naked eye).

Mathematically, angular magnification M = β/a

Magnifying power (angular magnification) of a simple microscope in normal adjustment

A simple microscope is said to be in normal adjustment when the final image is formed at near point.



Consider an object of height ho placed at a distance D

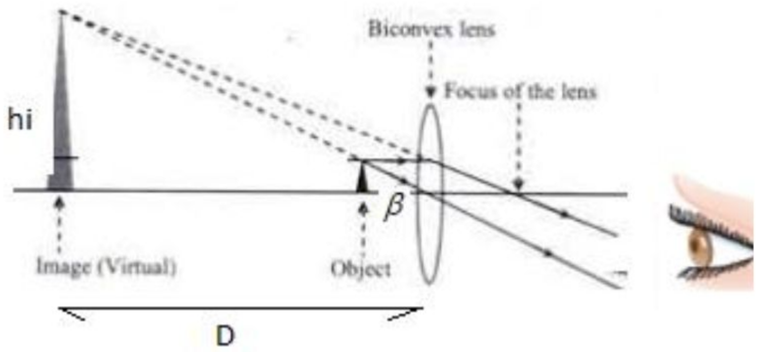
$$\tan \alpha = \frac{h_o}{D} \qquad \text{(Equ. 1)}$$

For a small angle $\tan \alpha = \alpha$ (refer to Wikipedia/SmallAngleApproximation)

example: tan 0.5 = 0.546; tan 0.25 = 0.255 (angle in radians)

Then the equation (1) becomes $\alpha = \frac{h_o}{D}$

Consider also, a simple microscope in normal adjustment



$$\tan\ \beta = \frac{h_i}{D} \qquad \text{(Equ. 2)}$$

For a small angle $\tan\ \beta \approx \beta$

Then equation 2 becomes $\beta = \frac{h_i}{D}$

From the definition of magnifying power

$$M = \frac{\beta}{\alpha} \qquad \text{(Equ. 3)}$$

Replacing into *Equation 3* the values of a and β in *equation 1* and *equation 2* respectively,

$$M = \frac{hi/D}{ho/D}$$

$$M = \frac{hi}{D} \times \frac{D}{ho}$$

But $\frac{hi}{ho}$ is linear magnification,m, ;

$$m = \frac{hi}{u} = \frac{v}{u} = \frac{D}{U}$$

From the lens formula

$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ or $v = -D$ (for virtual image),

we obtain

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

Multiply D both sides, leads to,

$$\frac{D}{u} + \frac{D}{v} = \frac{D}{f} \text{ or } \frac{1}{f} = \frac{D}{u} - 1 \leftrightarrow \frac{D}{f} = \frac{D}{u} - 1$$

$$\frac{D}{u} = \frac{D}{f} + 1, \text{ or } M = \frac{D}{u}$$

Therefore, angular magnification

$$\boldsymbol{M = \frac{D}{f}} + 1$$

$M_D = \left(1 + \frac{D}{f}\right)_{max}$ Where $D = +25cm$

2. Compound Microscope

The compound microscope consists of two optical components (thus the term compound): the objective lens system, which has a very short focal distance and is placed very close to the object; and the eyepiece system, which has a longer focal length, lower magnification;

The objective lens forms a real, inverted image and this image acts as an object for eyepieces lens

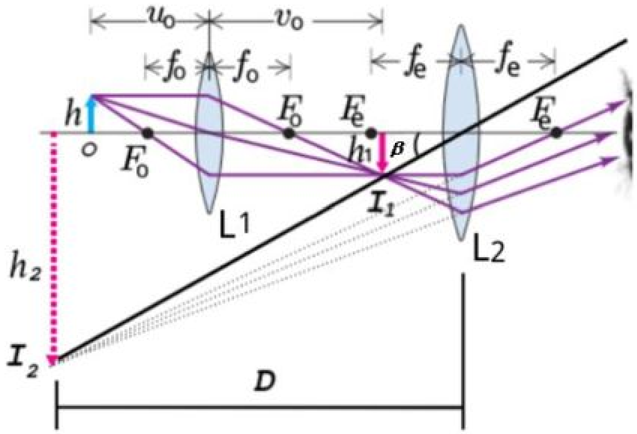
The eyepiece lens forms a virtual and magnified image

Magnifying microscope power of compound

Magnifying power of the microscope is defined as the ratio of the angle subtended by the image at the eye as seen through the microscope to the angle subtended by object at the unaided eye when both are placed at the least distance of distinct vision.

a) Compound microscope in normal adjustment

A compound microscope is said to be in normal adjustment when the final image is formed at infinity



The angular magnification, M, of the microscope is given by

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

β = The angle subtended at the eye by the image

α = The angle subtended at the unaided eye by the object

From the figure

$$\tan \beta = \frac{h_i}{D}$$

For a small angle $\tan \beta \approx \beta$

$$\beta = \frac{h_i}{D}$$

If the object were at the near point, it would subtended the small angle

$$\alpha = \frac{h_o}{D}$$

From the definition of angular magnification

$$M = \frac{hi/D}{h_0/D}$$

$$M = \frac{hi}{h_o}$$

Multiply and dividing both side by $\frac{h}{h}$, we get

$$M = \frac{h}{h_o} \times \frac{h_i}{h}$$

Where $m_1 = \frac{h}{h_0}$: Linear magnification produced by objective lens,

and $m_2 = \frac{h_i}{h}$: Linear magnification produced by eyepiece lens.

Therefore M= m1 × m2

uo = Distance of object from objective (o),

vo = Distance of image A'B' formed by objective from objective,

ue = Distance of A' B' from eye lens,

ve=Distance of final image from eye lens,

fo= Focal length of objective,

fe= Focal length of eye lens.

•From the objective lens, a real image is formed.

$$\frac{1}{u_o} + \frac{1}{v_o} = \frac{1}{f_o}$$

Multiply both side by $\mathbf{v_o}$

$$\frac{u_0}{u_o} + \frac{v_0}{v_o} = \frac{v_o}{f_o} \rightarrow \frac{v_0}{u_o} = \frac{v_o}{f_o} - 1$$

Therefore

$$m_0 = \frac{v_o}{f_o} - 1$$

•From the eyepiece lens a virtual image is formed.

The eyepiece lens formula

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

$$\frac{D}{f_e} = \frac{D}{u_e} - \frac{D}{D} \quad \text{(Multiplying D on both sides)}$$

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

Therefore $\boldsymbol{m_2 = \frac{D}{u_e} = \frac{D}{f_e} + 1}$

Total Magnification M= m1 × m2

$$M = \left(\frac{v_o}{f_o} - 1\right)\left(1 + \frac{D}{f_e}\right) \text{ at near point.}$$

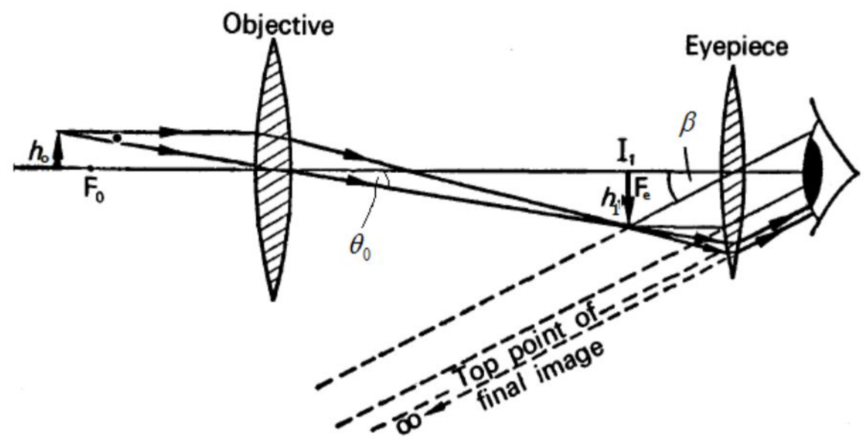
b) Angular magnification of microscope when the final image is at infinity

The intermediate image is formed at the focal point of the eyepiece.

The final image is at infinity,

$$m_e = \frac{h_1}{f_e}$$

since the eyepiece acts as a simple microscope which is not in normal use. The eye is at rest.



If the object were at the near point, it would subtended the small angle

$$\theta_0 = \frac{h_o}{D}$$

$$M_\infty = \frac{\beta}{\theta_0} = \frac{h_1}{f_e} \times \frac{D}{h_o} = \frac{h_1}{h_o} \times \frac{D}{f_e} = m_o \times \frac{D}{f_e}$$

is the magnification of the objective.

Then

$$M_\infty = \left(\frac{v_o}{u_o} - 1 \right) \frac{D}{f_e}$$

Test yourself

Attempt exercises no 46, 48, 49, 50, 51, 52, 53, 54, 61, 64, 66, 67, 70, 71, 72, and 75 on the section Exercises on Lens

1.15. Microscopes

1. Astronomical Telescope

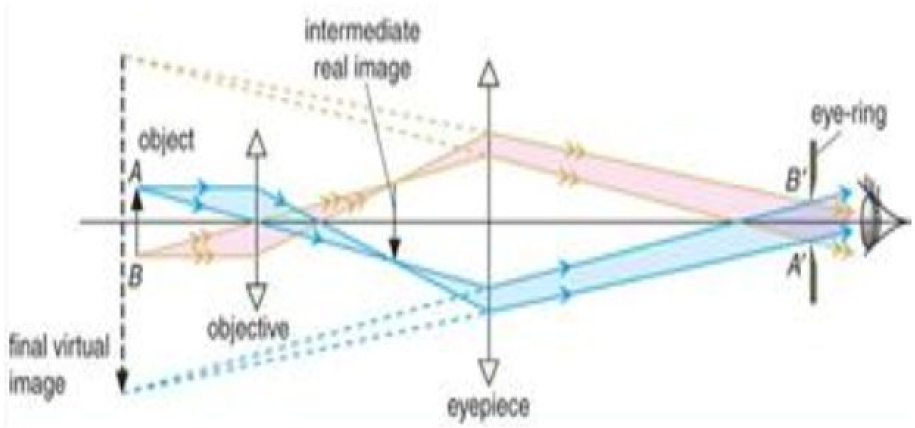
An astronomical telescope is an optical instrument which is used to see the magnified image of distant heavenly bodies like stars, planets, satellites and galaxies etc.

It consists of two convex lenses called objective and eyepiece.

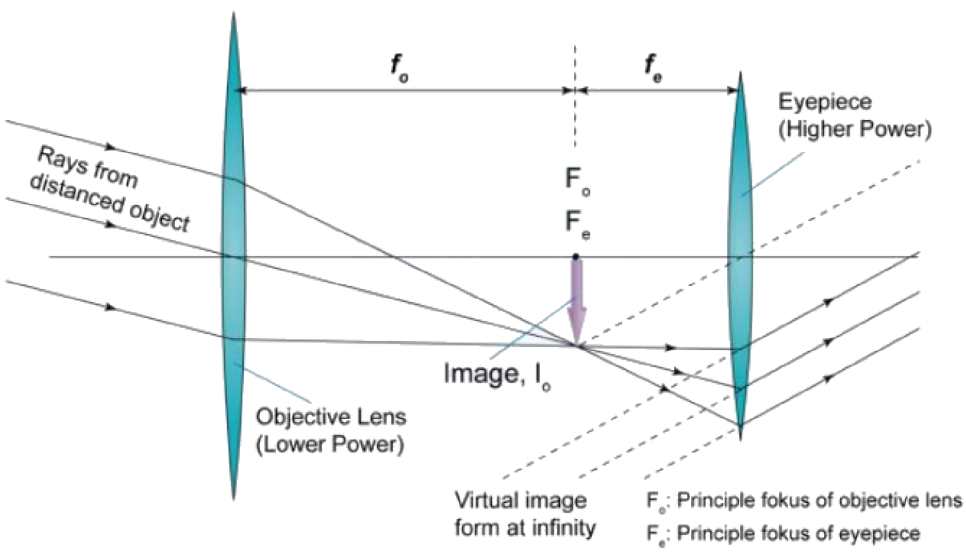
The objective is of large focal length whereas the eyepiece is of short focal length. The distance between the two lenses can be adjusted by adjusting the tube which holds the lens.

Eye ring

The eye ring is the best position to place the eye in order to be able to view as much of the final as possible. In case of telescope, all the light from a distant must pass though the eye ring after leaving the telescope. So by placing the eye at the eye ring, the viewer is able to see the final image as much possible.



Consider three rays from the "top" point of a very distant object. (The "bottom" point of the object is assumed to be on the principal axis.) See diagram below.

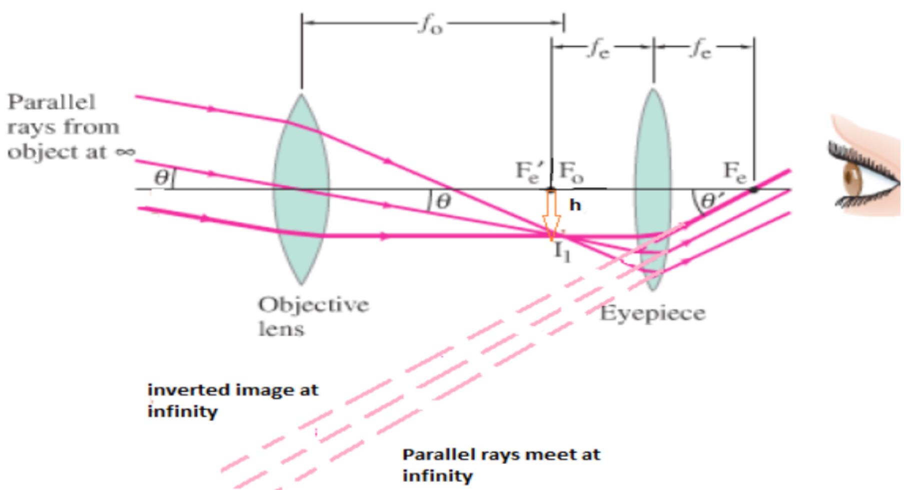


Magnifying power of an astronomical

Magnifying power of an astronomical telescope may be defined as the ratio of the angle subtended at the eye by the image to the angle subtended at the eye by the object

a) Magnifying power of refracting telescope when final image is at infinity (normal adjustment)

The object is at infinity, and therefore, the intermediate image is in the focal plane of the objective lens. The separation of the lenses is such that their focal planes coincide, and therefore, the eyepiece lens acting as magnifying glass, produces a final image which is at infinity. The eye is relaxed.



For good approximation $\tan\beta \approx \beta$, and $\tan\alpha = \alpha$

β = the angle subtended at the eye by the image

α = the angle subtended at the unaided eye by the object

Since both the object and the final image are at infinity, the angles they subtend at the unaided eye are the same as those they subtend at the objective and at the eyepiece respectively. It follows that β and α are shown in figure above, from which

$\alpha = \frac{h}{f_o}$ and $\beta = \frac{h}{f_e}$

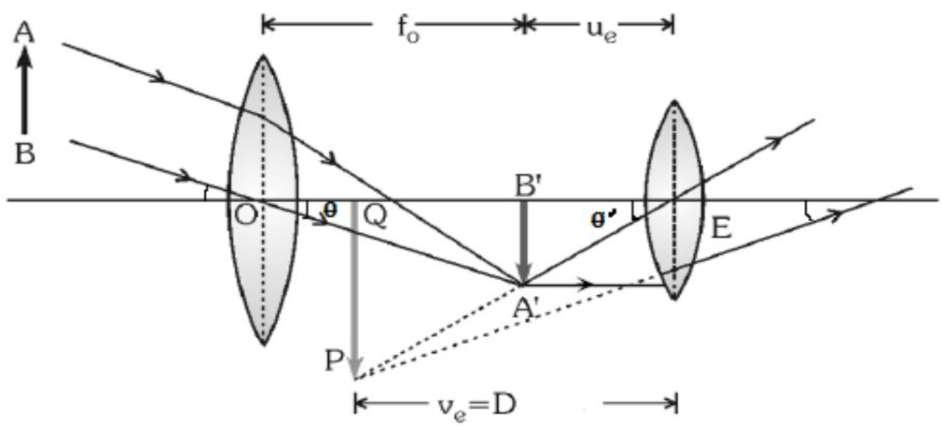
Therefore, since $M = \frac{\theta'}{\theta}$ and $M = \frac{h \div f_e}{h \div f_o}$

Or $\mathbf{M} = \frac{\mathbf{f_o}}{\mathbf{f_e}}$

Length between the two lenses $\boldsymbol{L = f_o + f_e}$

b) Magnifying power of refracting telescope when final image is at near point

The arrangement is shown in figure below.



The separation of the lenses is less than when the final image is formed at infinity. The intermediate image, though still in the focal plane of the objective, is now inside the focal point (Fe) of the eyepiece lens and in such a position that the final image is at the near point.

The angular magnification is defined as the ratio of the subtended at eye by the final image to the angle subtended at unaided eye by the object.

$M = \frac{\beta}{\alpha}$ where $\alpha = \frac{h}{f_o}$, and $\beta = \frac{h}{u_e}$

$\tan\ \beta \approx \beta$, and $\tan \alpha \approx \alpha$

Therefore, since $M = \frac{\beta}{\alpha}$

$= \frac{h \div u_e}{h \div f_o}$

$= M = \frac{f_o}{u_e}$

From the lens formula $\frac{1}{f_e} = \frac{1}{u_e} - \frac{1}{v_e}$

And also ve = D

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

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

$$u_e = \frac{f_e \times D}{f_e + D}$$

$$M = \frac{f_0}{\frac{f_e \times D}{f_e + D}}$$

$$= \frac{f_0 (f_e + D)}{f_e \times D}$$

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

$$M = \frac{f_o}{f_e}\left(\frac{f_e}{D} + \frac{f_e}{f_e}\right)$$ (Multiplying and dividing by fe)

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

The length of the tube is given by $L_D = f_o + u_e = f_o + \frac{f_e \times D}{f_e + D}$

Difference between compound microscope and telescope

Compound microscope	Astronomical telescope
Objective lens has smaller focal length, than the eyepiece	Objective lens has larger focal length than the eyepiece
Distance between the objective lens and the eyepiece is greater than fo+fe	Distance between the objective lens and the eyepiece is equal to fo+fe
It is used to see very small objects	It is used to see distant astronomical objects

2. Terrestrial telescope

- Used to see far off object on the earth.

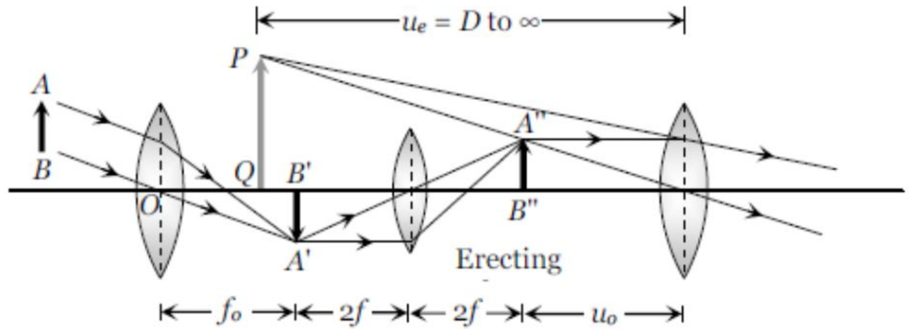
- It consists of three converging lens: objective, eye lens and erecting lens.

- It's final image is virtual erect and smaller

- Angular magnification $M = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)$ at near point

- Angular magnification of image at infinity

$$\boldsymbol{M = \frac{f_o}{f_e}}$$



- Length of the tube when the image is at near point:

$$L_D = f_o + 4f + u_e$$

$$= f_o + 4f + \frac{f_e \times D}{f_e + D}$$

And at infinity $L_\infty = f_o + 4f + f_e$

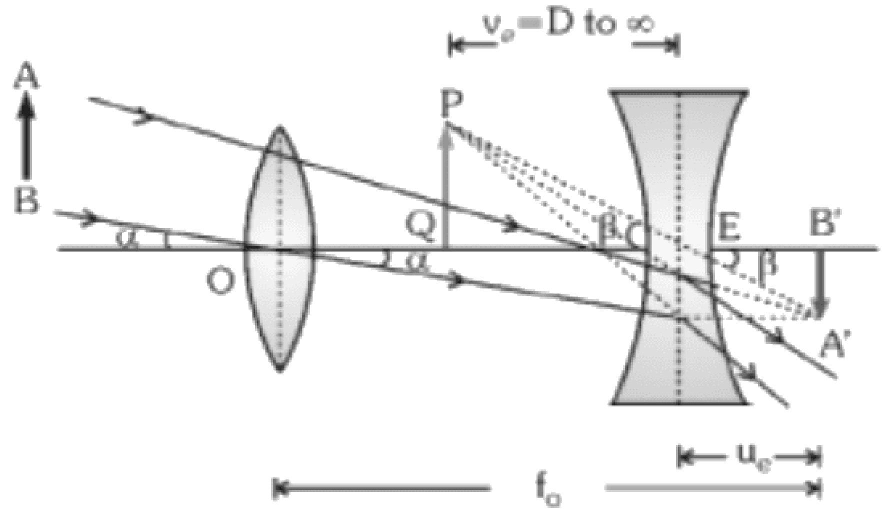
3. Galilean telescope

- It is also a terrestrial telescope but of much smaller field of view.

- Objective is a converging lens while eyepiece lens is diverging lens.

- Magnification of image at near point: $M_D = \frac{f_o}{f_e}\left(1 - \frac{f_e}{D}\right)$, and image at infinity $M_\infty = \frac{f_o}{f_e}$

- Length of the tube when image formed at near point: $L_D = f_o - u_e$, and when image is at infinity the length of the tube is: $L_\infty = f_o - f_e$



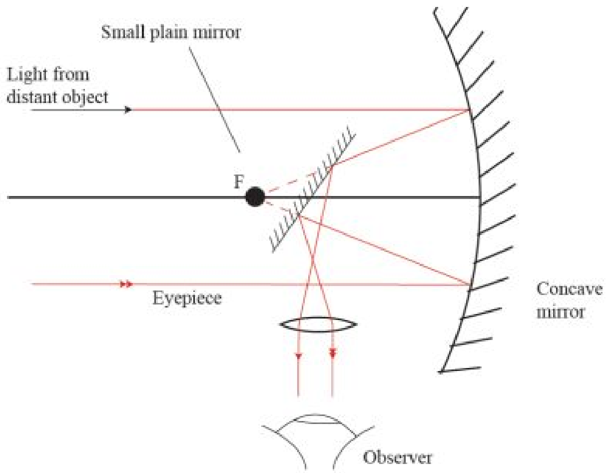
4. Reflecting telescopes

Reflecting telescopes consist of a large concave mirror of long focal length as their objective.

Note: The reflecting telescopes are free from chromatic aberration since no refraction occurs.

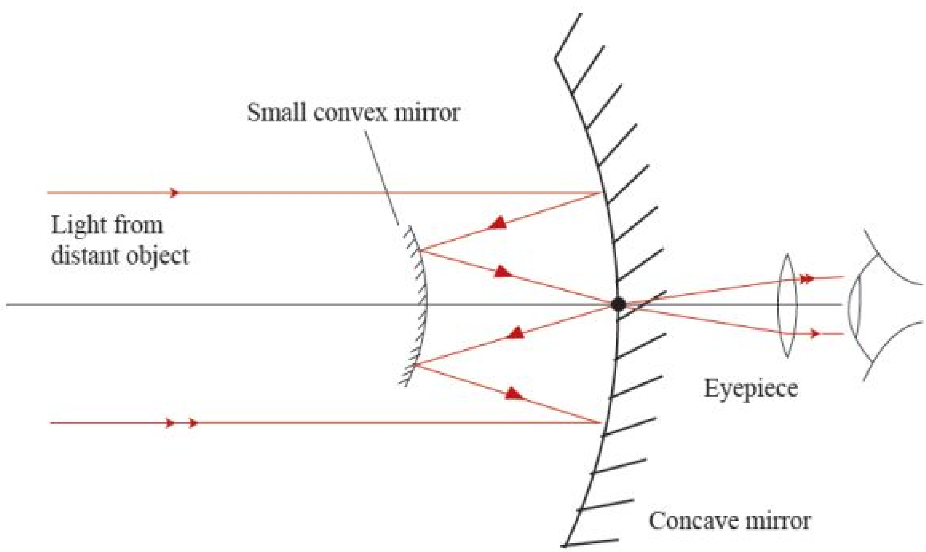
There are three kinds of reflector telescopes, all named after their inventors.

4.1) The Newtonian reflecting telescope



The Newtonian telescope is commonly used by amateur astronomers. A small plane mirror is used to direct the light from the concave mirror, which acts as an objective into an eye piece.

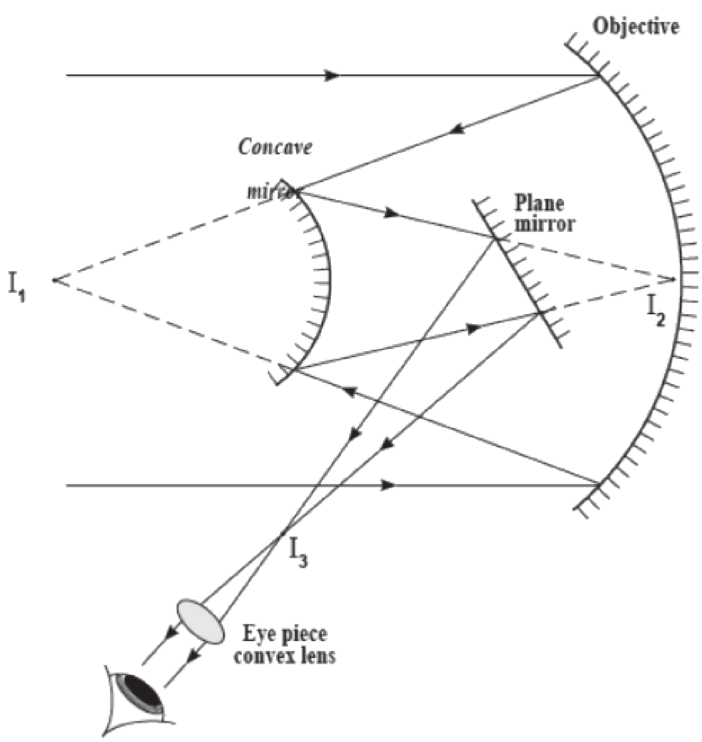
4.2) Cassegrain reflecting telescope



This is the type used in most observatories. It consists of a concave mirror which acts as an objective, a small convex mirror and the eye piece lens. Light from a distant object is reflected by the concave mirror to the convex mirror which reflects it back to the center of the concave mirror where there is a small hole to allow the light through. So the convex mirror forms the final image (real) at the pole of the objective.

4.3) Coude Reflector Telescope

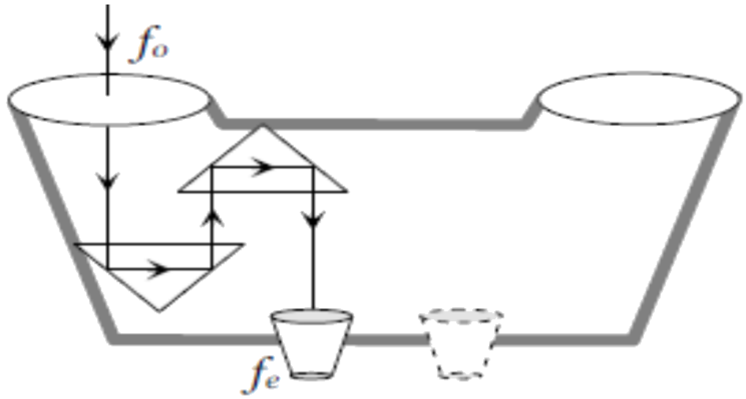
This is a combination of Newtonian and Cassegrain reflector telescopes.



The plane and convex mirrors used in reflecting telescopes are used to bring the light to a more convenient focus where the image can be photographed and magnified several times by the eye piece for observation.

5. Prism Binocular

If two telescopes are mounted parallel to each other so that an object can be seen by both the eyes simultaneously, the arrangement is called 'binocular'.

In a binocular, the length of each tube is reduced by using a set of totally reflecting prisms which provided intense, erect image free from lateral inversion. Through a binocular we get two images of the same object from different angles at same time.

Test yourself

Attempt exercises no 55, 60, 62, 63, 65, 69, 73, 74, and 76 on the section Exercises on Lens

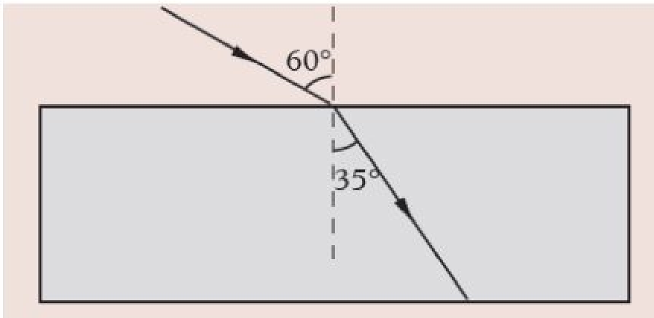
1.16. Exercises

1. (a) Define critical angle. (b) Write down the relationship between the critical angle and the refractive index of a medium.

2. State the two conditions under which total internal reflection occurs.

3. Calculate the value of critical angle for a liquid-air interface, if the refractive index of the liquid is 1.40.

4. Given the details on the below figure calculate the refractive index of glass.



5. The velocity of light in glass is 2.0 × 10^8 m/s. Calculate (a) the refractive index of glass and (b) the angle of refraction in the glass for a ray of light passing from air to glass at an angle of incidence of 40°.

6. The angle of incidence for a ray of light passing from air to water is 30° and the angle of refraction is 22°. Calculate the refractive index of water.

7. Calculate the critical angle for glass-air interface, if the refractive index of glass is 1.50.

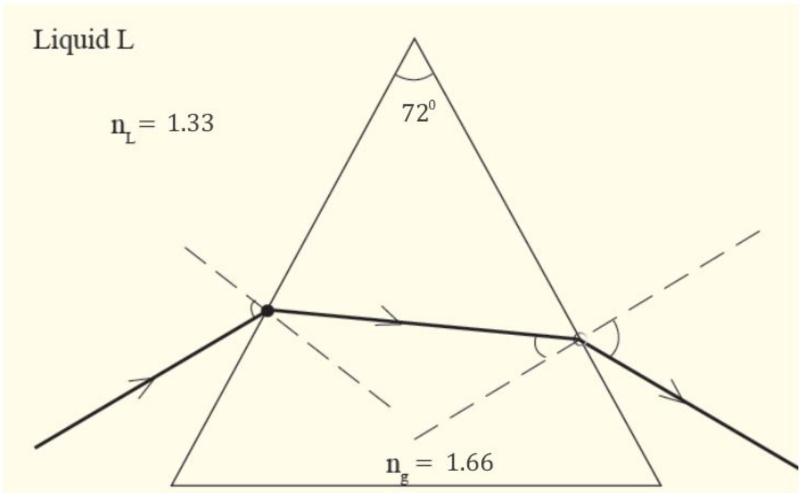
8. Calculate the critical angle at the water-air interface if the refractive index of water is 1.33

9. Calculate the refractive index of diamond, if the critical angle for the diamond is 24°.

10. A glass prism of refracting angle 60o has a refractive index of 1.5. Calculate the angle of minimum deviation for a parallel beam of light passing through it.

11. A glass prism of refracting angle 720 and index of refraction 1.66 is immersed in a liquid of refractive

index 1.33. What is the angle of minimum deviation for a parallel beam of light passing through the prism?



12. A glass prism of refracting angle 600 has a refractive index of 1.5. Calculate the angle of minimum deviation for a parallel beam of light passing through it.

13. A monochromatic light is incident on one refracting surface of a prism of refracting angle 60o, made of glass of refractive index 1.50. Calculate the least angle of incidence for the ray to emerge through the second refracting surface.

14. A ray of light incident from air to a prism of refracting angle 600 grazes the boundary on the second face of the prism. Find the angle of incidence of the ray on the first face. (Take ng = 1.52).

15. A 50 mm tall object is placed 12 cm from a converging lens of focal length 20 cm. What are the nature, size, and location of the image?

16. An object 10 cm high is held 8 cm from a diverging meniscus lens of focal length 12 cm. What are the nature and location of the image?

17. What is the magnification of a lens if the focal length is 40 cm and the object distance is 65 cm?

a) the lens is converging

b) the lens is diverging

18. An object 3.00 cm high is placed 20.0 cm in front of a diverging lens of 15.0 cm focal length.

(a)Draw a ray diagram.

(b) Find the image distance xi.

(c) Find the magnification M.

(d) Find the height of the image hi.

(e) Is the image real or virtual?

(f) Is the image erect or inverted?

19. Where should an object be placed in front of a 20.0-cm lens in order for the image to be the same size as the object?

20. An object 7.00 cm high is placed 5.00 cm in front of a convex lens of 10.0 cm focal length.

(a) Draw a ray diagram.

(b) Find the image distance.

(c) Find the magnification.

(d) Find the height of the image.

21. How far in front of a 20.0-cm converging lens should an object be placed in order to produce an image 25.0 cm from the lens on the same side of the lens as the object?

22. An object is placed 15.0 cm in front of a diverging lens of 5.00 cm focal length. Where is the

image located and what is its magnification?

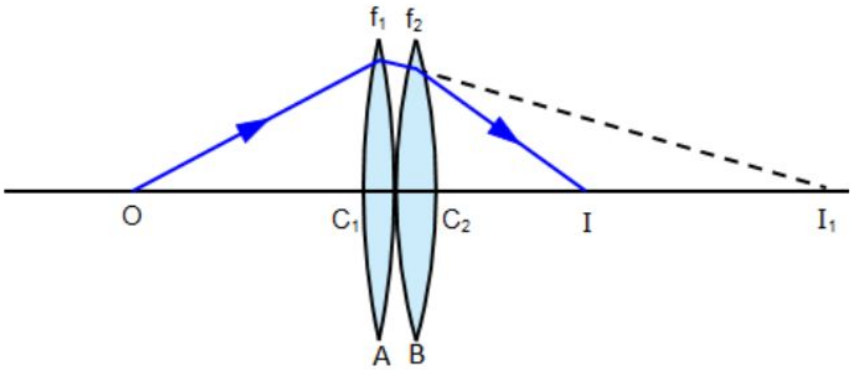
23. Where should an object be placed in front of a diverging lens of 10.0 cm focal length in order to give an image a magnification of 0.500?

24. An object 5.00 cm high is placed 20.0 cm in front of a converging lens. The image is measured to be 7.00 cm high. Where is the image located?

25. An object 5.00 cm high is placed 30.0 cm in front of a converging lens of 7.50 cm focal length.

What is the size of the image?

26. Two converging lenses, with the focal length f1 = 10 cm and f2 = 15 cm are placed 40 cm apart. An object is placed 60 cm in front of the first lens as show on the below figure.



a) Find the position of the final image formed by the combination of the two lenses?

b) Find magnification of the final image formed by the combination of the two lenses?

27. What is the critical angle between water and air? The index of refraction for water is 1.33.

28. White light makes an angle of incidence of 300 as it strikes a piece of glass. Find the angle of refraction for (a) red light if n = 1.55 for red light and (b) for violet light if n = 1.53

29. A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of material of prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.

30. If an object is 8 cm away from a convex lens of focal length 2 cm where will the image be? (Draw a ray diagram of how this image is formed to see if your answer is plausible.)

31. What image is produced by placing an object 4 cm away from a convex lens of focal length 8 cm?

32. If an object is 6 cm from a concave lens with focal length f = 3 cm, what is its position and nature?

33. An object AB of 1cm is placed at 8cm from a converging lens of focal length 12cm. Find its image (Position, nature and the size).

34. A thin glass lens n = 1.5 has a focal length +10cm in air. Compute its focal length in water n = 1.33.

35. A prism which has a refracting angle equals 60o and refractive index 1.5 receives a ray at an angle of incidence 45o; calculate the angle of emergence and the deviation of the ray.

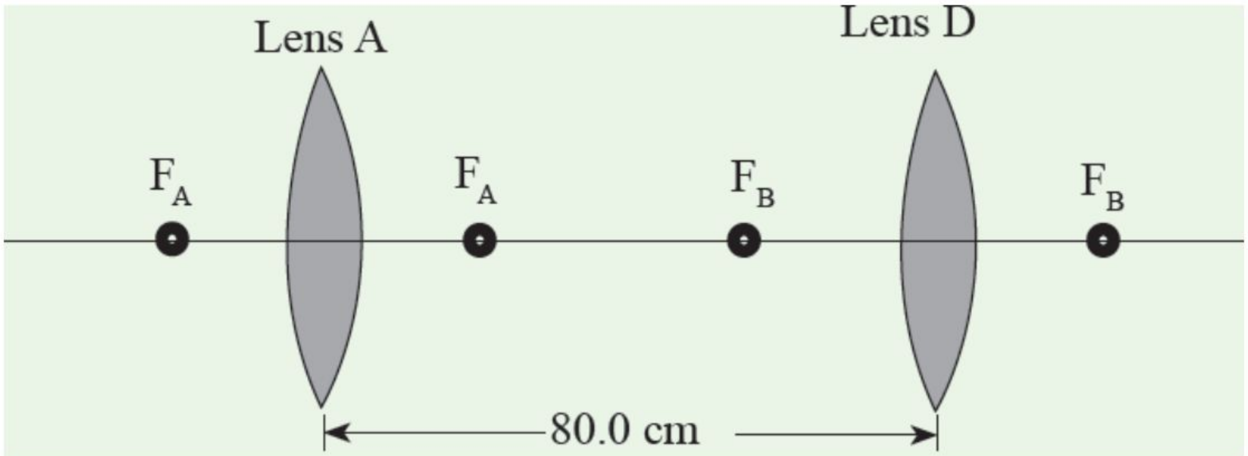
36. An object of 2cm is placed at 50cm from a diverging lens of focal length 10cm. Determine its image.

37. An object located 32.0 cm in front of a lens forms an image on a screen 8.00 cm behind the lens.

(a) Find the focal length of the lens.

(b) Determine the magnification. (c) Is the lens converging or diverging?

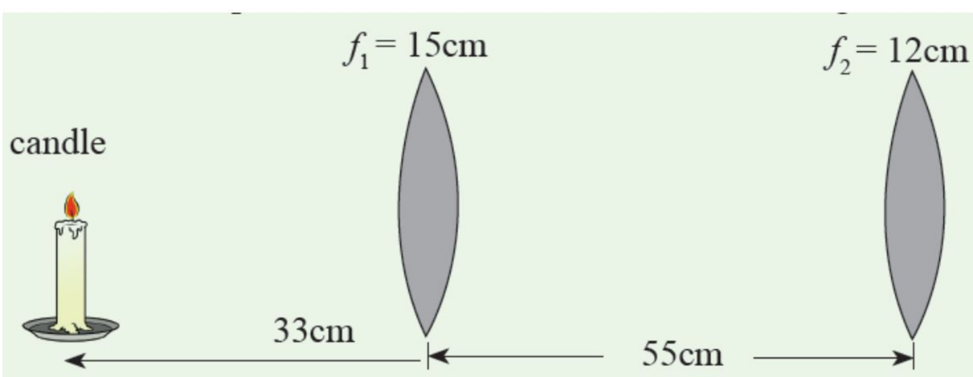
38. Two converging lenses A and B, with focal lengths fA=20cm and fB = 25cm, are placed 80cm apart, as shown in the figure below.



An object is placed 60cm in front of Lens A.

Determine (a) the position, and (b) the magnification, of the final image formed by the combination of the two lenses.

39. A lighted candle is placed 33cm in front of a converging lens of focal length f1=15cm, which in turn is 55cm in front of another converging lens of focal length f2=12cm as shown on the below figure.



a) Draw a ray diagram and estimate the location and the relative size of the final image.

b) Calculate the position and relative size of the final image.

40. A nearsighted person has a far point that is 323 cm from her eye. If the lens in a pair of glasses is 2.00 cm in front of this person's eye, what focal length must it have to allow her to focus on distant objects?

41. A farsighted person wears glasses to enable him to read a book held at a distance of 25.0 cm from his eyes, even though his near-point distance is 57.0 cm. If his glasses are at a distance of 2.00 cm from his eyes, find the focal length of his lenses (glasses) to place the image of the book at the near point.

42. Find the focal length of a pair of contact lenses that will allow a person with a near point distance of 145 cm to read a newspaper held at 25.1 cm from his eyes.

43. A nearsighted person cannot see objects clearly beyond 25.0 cm (her far point). If she has no astigmatism and contact lenses are prescribed for her, what (a) power and (b) type of lens are required to correct her vision?

44. The near point of a person's eye is 60.0 cm. To see objects clearly at a distance of 25.0 cm, what should be the (a) focal length and (b) power of the appropriate corrective lens? (Neglect the distance from the lens to the eye.)

45. A patient has a near point of 45.0 cm and far point of 85.0 cm.

a) Can a single pair of glasses correct the patient's vision? Explain the patient's options.

(b) Calculate the power lens needed to correct the near point so that the patient can see objects 25.0 cm away. Neglect the eye (lens distance). (c)

Calculate the power lens needed to correct the patient's far point, again neglecting the eye (lens distance).

46. A simple microscope is made of a combination of two lenses in contact of powers +15D and +5D. Calculate the magnifying power of the microscope, if the image is formed at 0.25m, the least distance of distinct vision.

47. A slide projector has a converging lens of focal length 20cm and is used to magnify the area of a slide, 5cm2 to an area of 0.8m2 on a screen. Calculate the distance of the slide from the projector lens.

48. A compound microscope consists of an objective lens of focal length 2.0cm and an eye-piece of focal length 6.25cm 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 (25 cm) . What is the magnifying power?

49. A compound microscope has an eye piece of focal length 2.5cm and an objective of focal length 1.6cm. If the distance between the objective and eyepiece is 22.1cm, calculate the magnifying power produced when the final image is at infinity.

50. A microscope has its objective and eyepiece 18 cm apart. If fobj = 0.40 cm and feye = 5.0 cm, where must a specimen be located to produce a final virtual image at infinity? What is the total magnification of this microscope?

51. A compound microscope has an objective with a power of 45 D and an eyepiece with a power of 80 D. The lenses are separated by 28 cm. Assuming that the final image is formed 25 cm from the eye, what is the magnifying power?

52. A microscope has a magnifying power of 600, and an eyepiece of angular magnification of 15. The objective lens is 22 cm from the eyepiece. Without making any approximations, calculate (a) the focal length of the eyepiece, (b) the location of the object such that it is in focus for a normal relaxed eye, and (c) the focal length of the objective lens.

53. A microscope has an objective lens of focal length 5.00 mm. The objective forms an image 16.5 cm from the lens. The focal length of the eyepiece is 2.80 cm. Objective image is formed at the focal point of the eyepiece. What is the total angular magnification? The near point is 25.0 cm.

54. A microscope has a 13.0 x eyepiece and a 57.0 x objective lens 20.0 cm apart. Calculate the focal length of each lens. Where the object must be for a normal relaxed eye to see it in focus?

55. Magnification produced by astronomical telescope for normal adjustment is 20 and length of telescope is 1.05m. The magnification when image is formed at least distance of distinct vision (taking D=25cm) is (a)6 (b)10 (c)14 (d)24

56. An object is placed at a distance of 40cm from an optical center of a *converging* lens whose focal length is 20cm.

(a) how long is the distance of the image from the optical center?

(b) is the image is real or virtual?

(c) is the image is upright or inverted?

(d) what is the image size?

(e) Calculate the magnification of that lens.

57. An object is placed at a distance of 40cm from an optical center of a *diverging* lens whose focal length is 20cm.

(a) how long is the distance of the image from the optical center?

(b) is the image is real or virtual?

(c) is the image is upright or inverted?

(d) what is the image size?

(e) Calculate the magnification of that lens.

58. A certain eye can focus only on objects closer than 50.0 cm. What word characterizes this type of vision problem? What sort of contact lens (described both in focal length and power) will correct this problem?

59. A patient's eye can focus only on objects beyond 100 cm. What word characterizes this type of vision problem? What are the focal length and power of the contact lens needed to correct this problem?

60. A distant object is viewed with a relaxed eye with the help of a small Galilean telescope having an objective of focal length 15 cm and an eye piece of focal length 3 cm(A) The distance between the objective and the eyepiece lens is 12cm.(B) The angular magnification of object is 5(C) Image of the object is erect(D) The distance between objective and eye piece lens is 18 cm

61. A microscope consists of an objective with a focal length 2 mm and an eye piece with a focal length 40 mm. The distance between the foci (which are between the lenses) of objective and eyepiece is 18 cm.The total

magnification of the microscope is (Consider normal adjustment and take D = 25 cm)(A) 562.5 (B) 625 (C) 265 (D) 62.5

62. An astronomical telescope has its two lenses spaced 75.2 cm apart. If the objective lens has a focal length of 74.5 cm, what is the magnification of this telescope? Assume a relaxed eye

63. An astronomical telescope has an angular magnification of magnitude 5 for distant objects. The separation between the objective and the eyepiece is 36 cm. The Final image is formed at infinity. The focal length *fo* of the objective and *fe* of the eyepiece are(A) 45 cm and – 9 cm respectively(B) 50 cm and 10 cm respectively(C) 7.2 cm and 5 cm respectively (D)30 cm and 6 cm respectively

64. A single converging lens used as a simple microscope. In the position of maximum angular magnification,(A) the object is placed at the focus of the lens(B) the object is placed between the lens and its focus(C) the image is formed at infinity(D) the object and the image subtend the same angle at the eye.

65. In a reflecting astronomical telescope, if the objective (a spherical mirror) is replaced by a parabolic mirror of the same focal length and aperture, then(A) The final image will be erect(B) The larger image will be obtained(C) The telescope will gather more light(D) Spherical aberration will be absent

66. The focal lengths of the objective and the eyepiece of a compound microscope are 2.0 cm and 3.0 cm respectively. The distance between the objective and the eyepiece is 15.0cm. The final image formed by the eye piece is at infinity. Find the distance of object and image produced by the objective, from the objective lens.

67. A compound microscope consists of a 10X eyepiece and 50X objective 17cm apart. Determine (a) the overall magnification, (b) the focal length of each lens, and (c) the position of the object when the final image is in focus with eye relaxed.Assume a normal eye, so N = 25cm.

68. An 8cm focal-length converging lens is used as a "jeweler's loupe", which is a magnifying glass. Estimate (a) the magnification when the eye is relaxed, and (b) the magnification if the eye is focused at its near point N=25cm.

69. An astronomical telescope has an objective of focal length 200 cm and an eyepiece of focal length 4.0 cm,the telescope is focused to see an object 10 km from the objective. The final image is formed at infinity.Find the length of the tube and the angular magnification produced by the telescope.

70. A microscope has a magnifying power of 600, and an eyepiece of angular magnification of 15. The objective lens is 22 cm from the eye piece. Without making any approximations, calculate (a) the focal length of the eyepiece, (b) the location of the object such that it is in focus for a normal relaxed eye,and (c) the focal length of the objective lens.

71. A microscope has an objective lens of focal length 5.00 mm. The objective forms an image 16.5 cm from the lens. The focal length of the eye piece is 2.80 cm. Objective image is formed at the focal point of the eye piece. What is the total angular magnification? The near point is 25.0cm.

72. A microscope has a 13.0x eye piece and a 57.0 x objective lens 20.0 cm apart. Calculate the focal length of each lens. Where the object must be for a normal relaxed eye to see it in focus?

73. A telescope is constructed from two lenses with focal lengths of 95.0 cm and 15.0 cm, the 95.0 cm lens being used as the objective. Both the object being viewed and the final image are at infinity.a) Determine the angular

magnification of the telescope.b) Determine the height of the image formed by the objective of a 60.0 m tall building located 3.00 km away.c) What is the angular size of the final image as viewed by an eye very close to the eyepiece?

74. A lady cannot see objects closer than 40 cm from the left eye and closer than 100 cm from the right eye.While on a mountaineering trip, she is lost from her team. She tries to make an astronomical telescope from her reading glasses to look for her teammates.(a) Which glass should she use as the eyepiece?(b) What magnification can she get with relaxed eye?

75. A compound microscope has a magnifying power of 100 when the image is formed at infinity. The objective has a focal length of 0.5 cm and the tube length is 6.5 cm. Find the focal length of the eyepiece.

76. The eyepiece of an astronomical telescope has a focal length of 10cm. The telescope is focused for normal vision of distant objects when the tube length is 1.0 m. Find the focal length of the objective and the magnifying power of the telescope.

2. MECHANICS