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Al-Mustansiriyah Univ.
College of Science
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الجامعة المستنصرية
كلية العلوم
قسم الفيزياء

Tutorial: Modern Optics

Report: Optical instruments

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Lenses :

Lenses:

What are lenses ? and from what it made up?

A Lens is a transmissive optical device that focuses or disperses a light beam by means of refraction. A lens is made up of a transparent refracting medium, generally of some type of glass, quartz, saltpeter, and plastic with spherically shaped surfaces on the front and back. A ray incident on the lens refracts at the front surface (according to Snell's law) propagates through the lens, and refracts again at the rear surface. Figure (1) shows a rather thick lens refracting rays from an object OP to form an image O′P′.

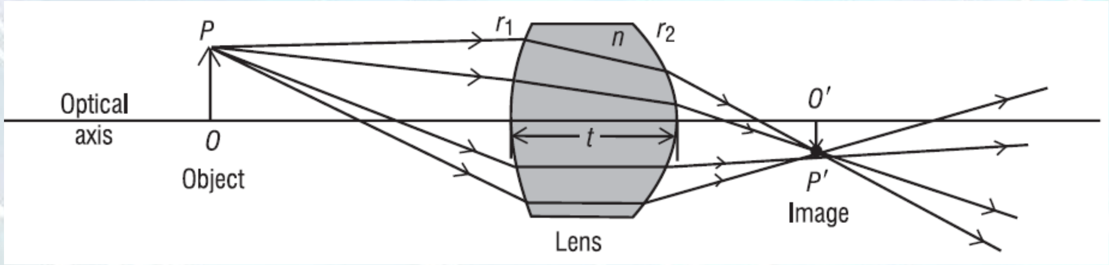


Figure (1)

What are the types of lenses?

Lenses divided according to its thickness to ***Thin*** that If the axial thickness of a lens is small compared with the radii of curvature of its surfaces **,**and ***Thick*** If the thickness of a lens is not negligible compared with the radii of curvature of its faces And on other hand there are two types of lenses **:** ***converging*** and ***diverging.***

Converging or positive lenses:

In figure (2)first three lenses

1..Its has positive focal lengths.

2.. The focal points of lenses are defined in terms of their effect on parallel light rays and plane wave fronts. For the positive lens, refraction of the light brings it to focal point *F* (real image) to the right of the lens.

3.. The plane wave fronts are changed to converging spherical wave fronts by the positive lens, this occurs because light travels more slowly in the lens medium than in the surrounding air, so the thicker parts of the lens retard the light more than do the thinner parts, see figure (3)

Lenses :

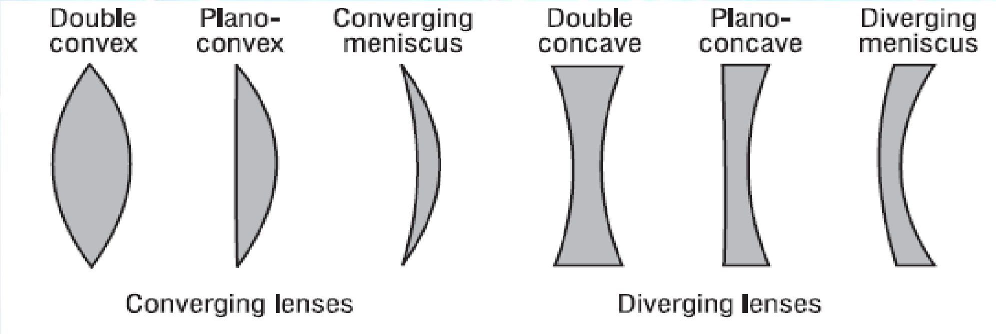


Figure (2) types of lenses

Diverging lenses or negative lenses:

The last three lenses in figure :

1.. These lenses give rise to negative focal lengths.

2.. The focal points of lenses are defined in terms of their effect on parallel light rays and plane wave fronts. For the negative lens, refraction of the light causes it to diverge as if it is coming from focal point F (virtual image) located to the left of the lens.

3.. The plane wave fronts are changed to converging spherical wave fronts by the positive lens, this occurs because light travels more slowly in the lens medium than in the surrounding air, so the thicker parts of the lens retard the light more than do the thinner parts, see figure

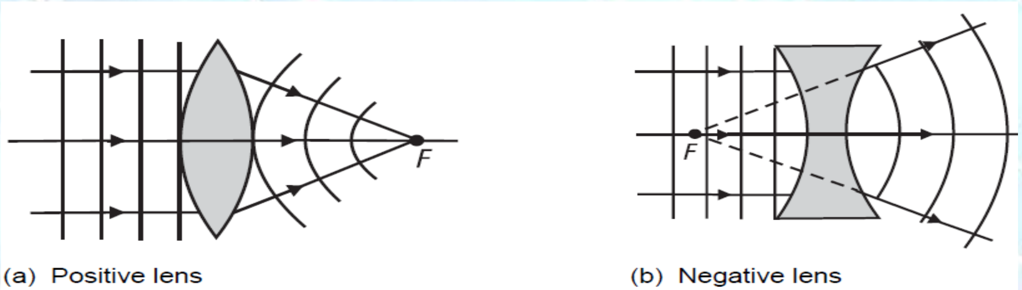


Figure (3) Focal points for positive and negative lenses

for mirrors, there is but a *single* focal point for each mirror surface since light remains always on the same side of the mirror. For thin lenses, there are *two* focal points, symmetrically located on each side of the lens, since light can approach from either side of the lens. The sketches in Figure (down) indicate the role that the two focal points play, for positive lenses (a) and negative lenses (b). Study these figures carefully.

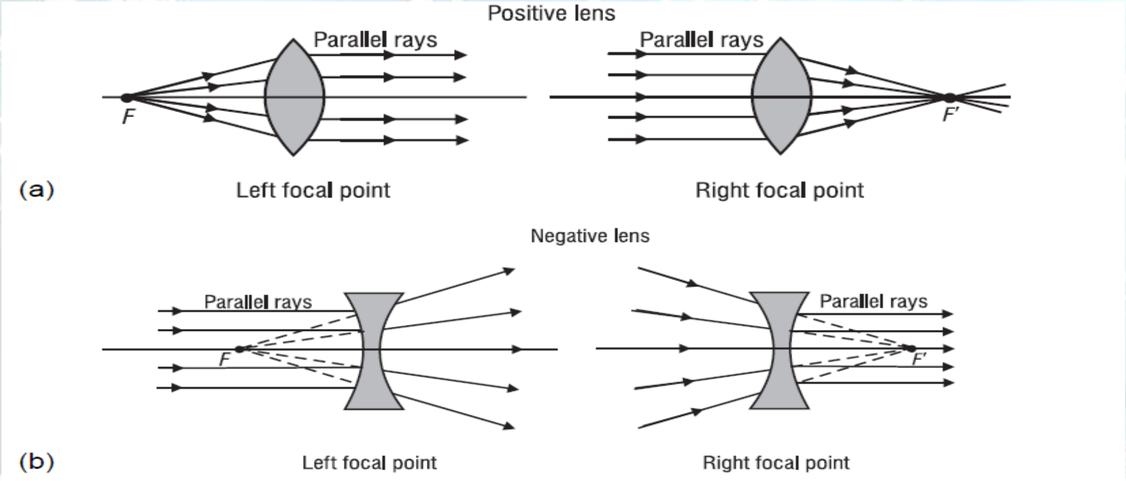


Figure (4) Relationship of light rays to right and left focal points in thin lenses

Lenses :

Equations for thin lens:
The thin lens equation

$$\frac{1}{p}+\frac{1}{q}=\frac{1}{f}$$ ………(1)

Where p is the object distance (from object to lens vertex V)
q is the image distance (from image to lens vertex V)
and f is the focal length (from either focal point F or F′ to the lens vertex V)

Lens maker's formula:

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{r_1}-\frac{1}{r_2}\right)$$ ……….(2)

Where μ is the index of refraction of the lens materials
r_1 , r_2 are the radius of curvature of the front face and of the rear face of the lens

The magnification m produced by a thin lens is given

$$m=\frac{h_i}{h_o}=-\frac{q}{p}$$ ………..(3)

where m is the magnification (ratio of image size to object size)
hi is the transverse size of the image
ho is the transverse size of the object
p and q are object and image distance respectively

Lenses :

Application of lenses:

The human eye:

The human eye is in many respects similar to camera .the cornea and lens combine to focus the image on a thin, curved layer of light sensitive cells the retina. These cells respond to the various intensities and colours of the light that falls upon them, and they send electric signals along the optic nerve to the brain straightens this out and you "see" the image the right way up. The image is focused on the retina by the lens.

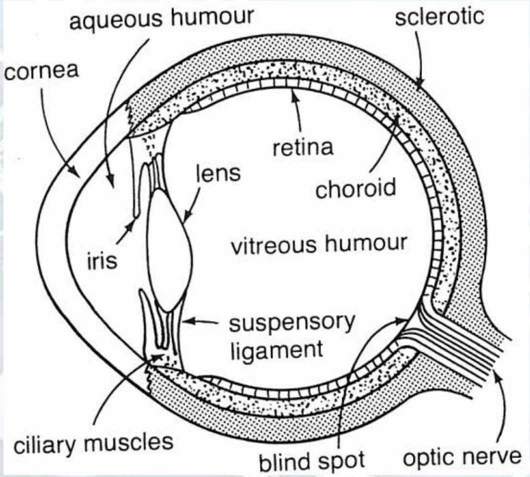


Figure (5) Main feature of the human eye

Mirror:

Mirror

A mirror is an object that reflects light in such a way that, for incident light in some range of wavelengths, the reflected light preserves many or most of the detailed physical characteristics of the original light.

Mirrors are manufactured by applying a reflective coating to a suitable substrate. The most common substrate is glass, due to its transparency, ease of fabrication, rigidity, hardness, and ability to take a smooth finish.

Plane and spherical mirrors are used to form three dimensional images of three-dimensional objects.

A. Images formed with plane mirrors:

Images with mirrors are formed when many nonparallel rays from a given point on a source are reflected from the mirror surface, converge, and form a corresponding image point. When this happens, point by point for an extended object, an image of the object, point by point, is formed.

In figure (6) Image formed by flat (plane) mirror the object distance denoted by p the image distance denoted by q.

Mirror :

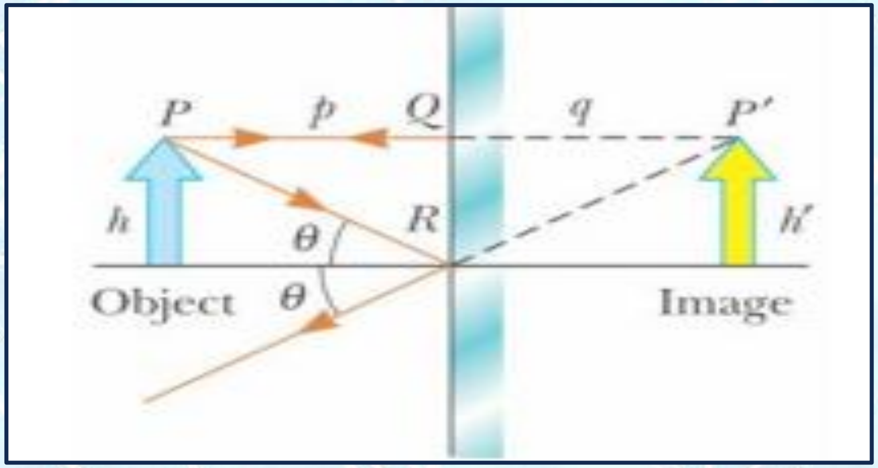


Figure (6) Image formation in a plane mirror.

A. **Images formed with spherical mirrors:**

Spherical mirrors appear to be cut from a section of a sphere. They can be concave or convex. each kind of mirror makes a different kind of image.

The edges of *concave* mirrors always bend toward the oncoming light. Such mirrors have their center of curvature *C* and focal point *F* located to the *left* of the vertex as seen in Figure (7-a). The edges of *convex* mirrors always bend away from the oncoming light, and their center of curvature *C* and focal point *F* are located to the *right* of the vertex. See Figure (7-b).

Mirror:

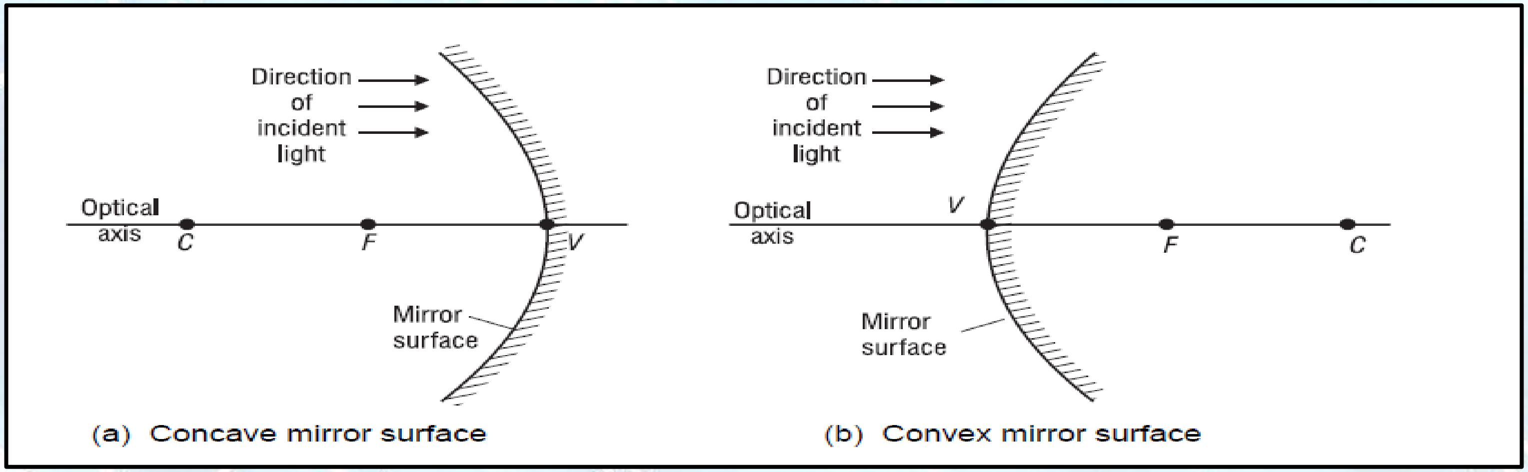


Figure (7) Defining points for concave and convex mirrors

R: Radius of curvature, C: Center of curvature, a line drawn from C to V is optical axis (principal axis of the mirror).

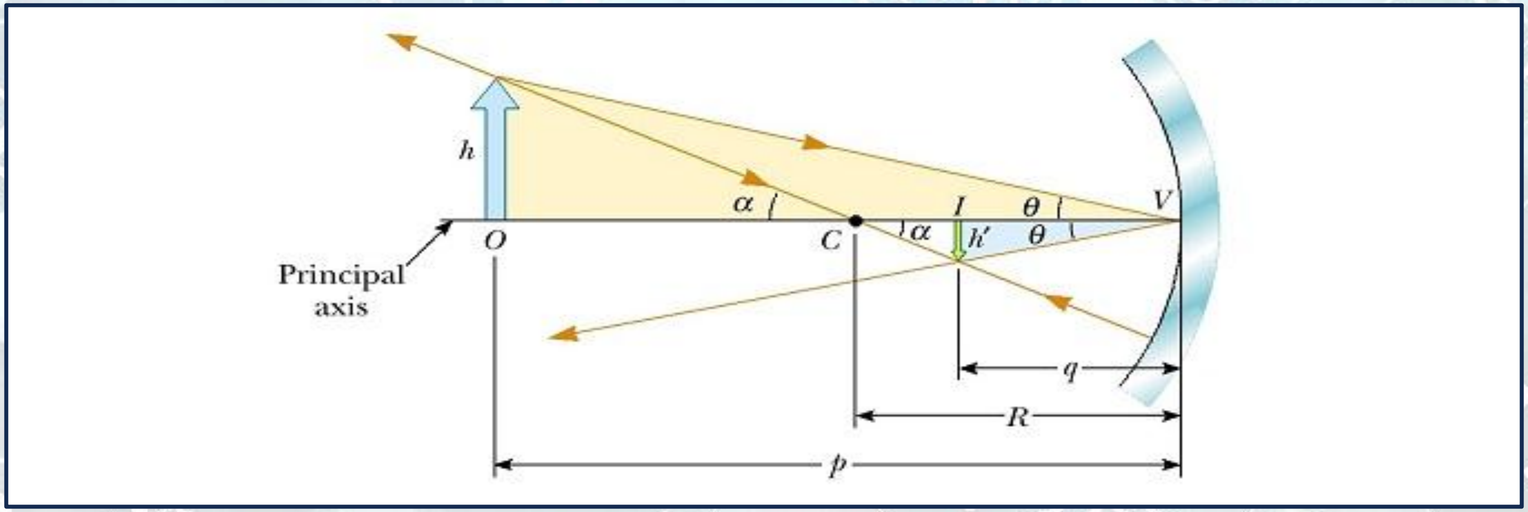


Figure (8) image formation in concave mirror.

Mirror

Mirrors equation :

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R} \quad (4)$$

Magnification is ratio of image height h_i to object height h_o

$$M = \frac{h_i}{h_o} = -\frac{q}{p} \quad (5)$$

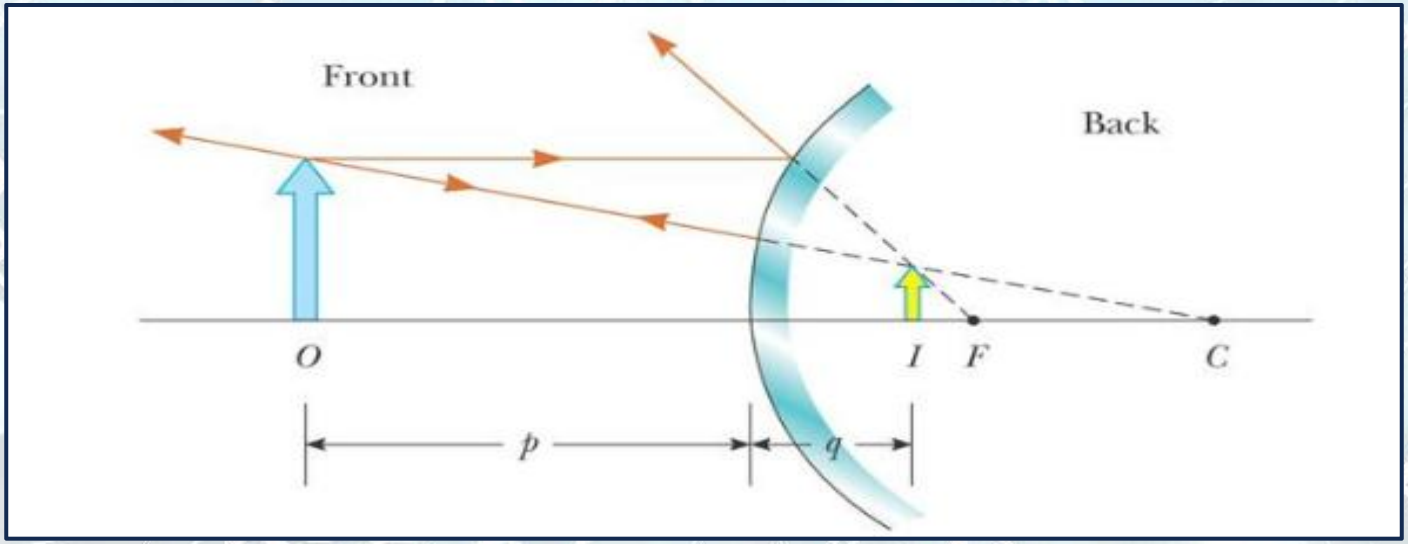


Figure (9) image formation in convex mirror.

Microscope:

Microscope:

A microscope is an instrument used to see objects that are too small for the naked eye. The science of investigating small objects using such an instrument is called microscopy. Microscopic means invisible to the eye unless aided by a microscope. There are many types of microscopes. The most common (and the first to be invented) is the optical microscope, which uses light to image the sample. Other major types of microscopes are the electron microscope (both the transmission electron microscope and the scanning electron microscope), and the various types of scanning probe microscope.

The optical microscope, often referred to as light microscope, is a type of microscope which uses visible light and a system of lenses to magnify images of small samples. Optical microscopes are the oldest design of microscope and were possibly invented in their present compound form in the 17th century. Basic optical microscopes can be very simple, although there are many complex designs which aim to improve resolution and sample contrast.

There are two basic configurations of the conventional optical microscope:

1. A simple microscope is a microscope that uses a lens or set of lenses to enlarge an object through angular magnification alone, giving the viewer an erect enlarged virtual image as in figure(10). Simple microscopes are not capable of high magnification.

Microscope:

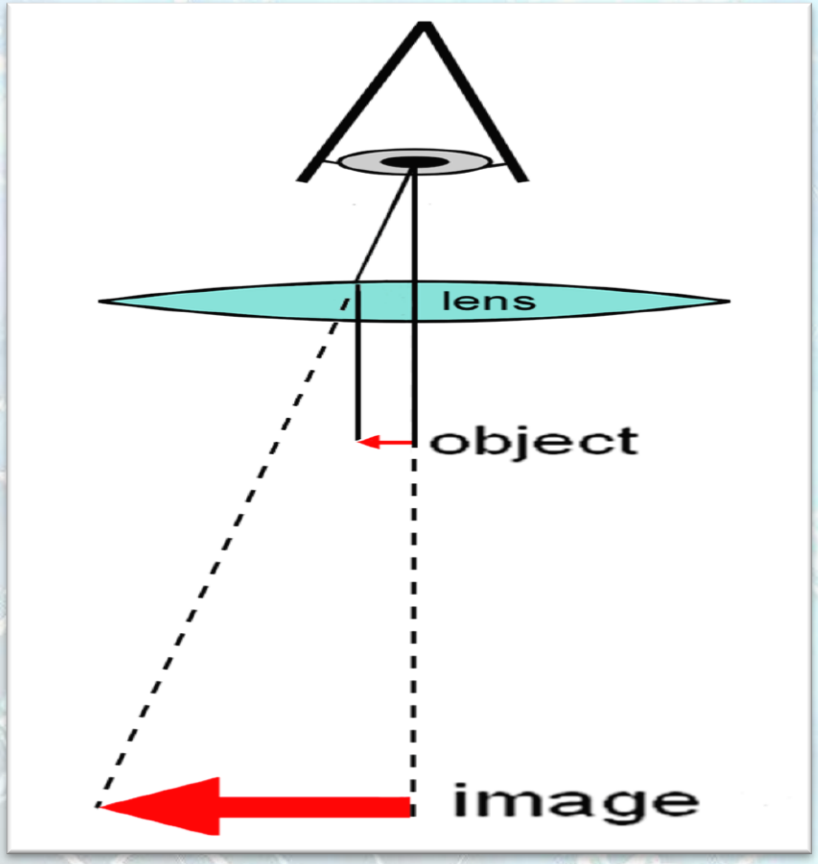


Figure (10)

2. A compound microscope is a microscope which uses a lens close to the object being viewed to collect light (called the objective lens) which focuses a real image of the object inside the microscope (image 1). That image is then magnified by a second lens or group of lenses (called the eyepiece) that gives the viewer an enlarged inverted virtual image of the object (image 2) as in figure(11). The use of a compound objective/eyepiece combination allows for much higher magnification, reduced chromatic aberration and exchangeable objective lenses to adjust the magnification.

Microscope:

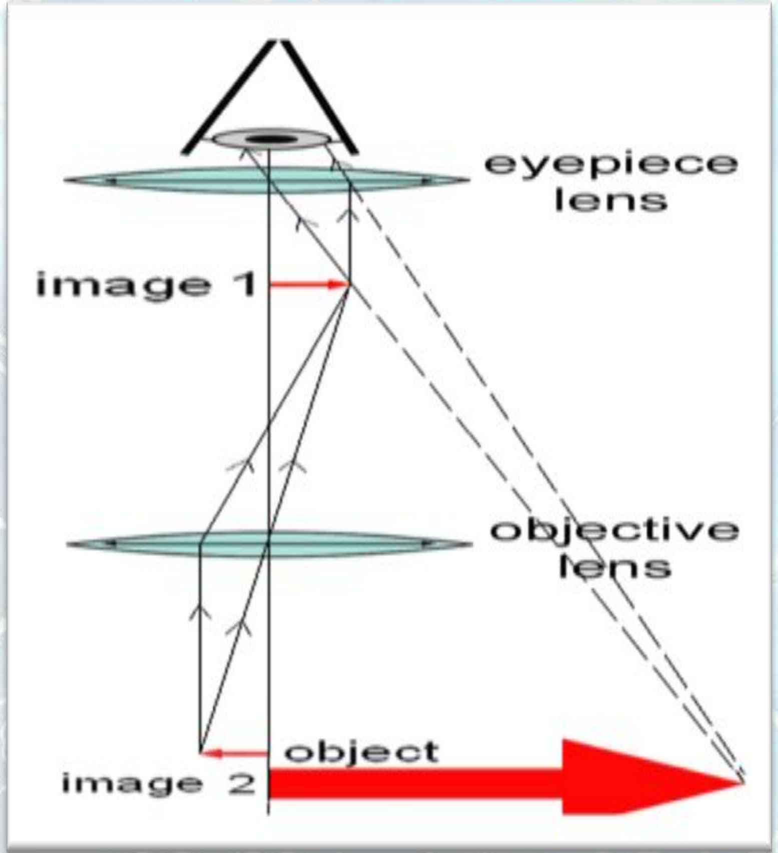


Figure (11)

All modern optical microscopes designed for viewing samples by transmitted light share the same basic components of the light path. In addition, the vast majority of microscopes have the same 'structural' components (numbered below according to the image in figure (12) :

Microscope:

- Eyepiece (ocular lens) (1)
- Revolving nose piece (to hold multiple objective lenses) (2)
- Objective lenses (3)
- Focus knobs (to move the stage)
- Coarse adjustment (4)
- Fine adjustment (5)
- Stage (to hold the specimen) (6)
- Light source (a light or a mirror) (7)
- Condenser (8)
- Mechanical stage (9)

Figure (12)

Telescope:

Telescope:

A telescope is an optical instrument that aids in the observation of remote objects by collecting electromagnetic radiation (such as visible light) by using glass lenses. They found use in both terrestrial applications and astronomy.

A telescope, in its original configuration (refractor), consists of two lenses. The first one, the objective lens, collects light and focuses it to a point. (Note that the objective mirror in a reflecting telescope does exactly the same thing). The second lens, the eyepiece, catches the light as it diverges away from the focal point and bends it back to parallel rays, so your eye can re-focus it to a point as in figure (13):

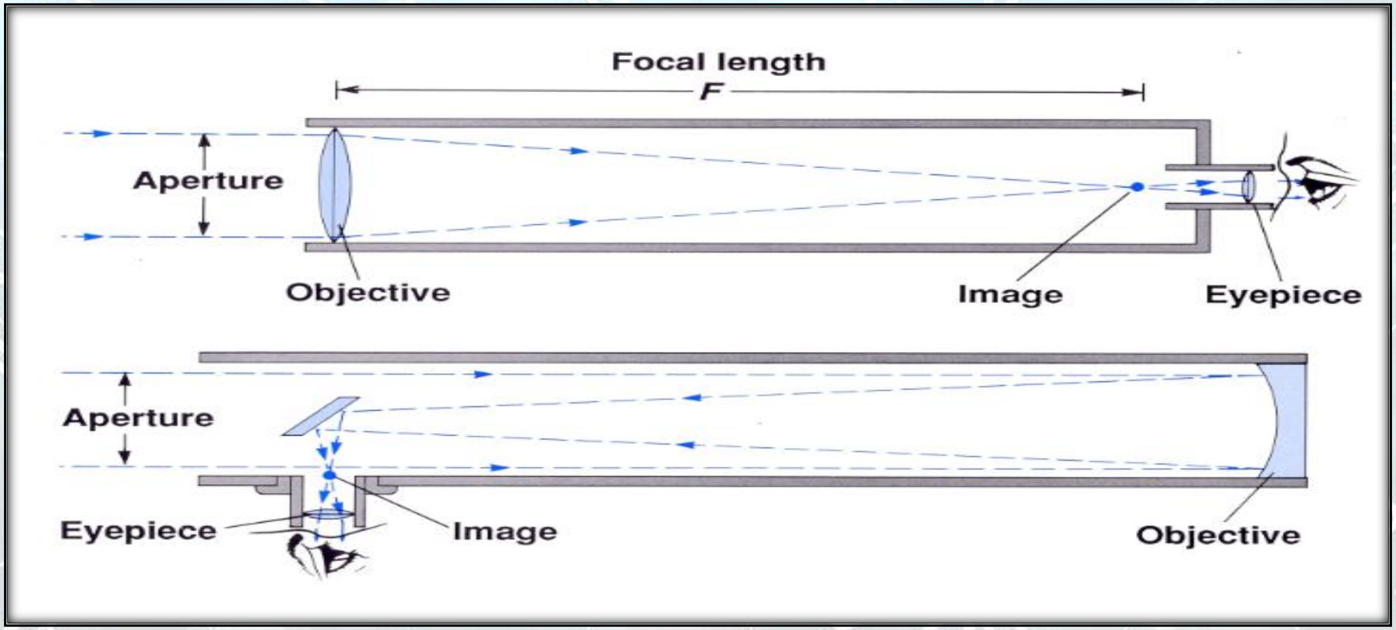


Figure (13)

Equation of microscope and telescope

microscope

$$\frac{1}{f_0} = \frac{1}{v_0} - \frac{1}{u_0}$$

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

$$m_0 = 1 + \frac{d}{f_0}$$

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

$$d = |u_e| + v_0$$

telescope

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

$$\frac{1}{f_0} = \frac{1}{u_0} + \frac{1}{v_0}$$

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

$$d = |u_e| + v_0$$

The magnification of the eyepiece = m_e

The magnification of the objective = m_0

Focal length of the objective lens, f_0

Focal length of the eyepiece,= f_e

Distance between the objective lens and the eyepiece = d

∴Image distance for the eyepiece, = v_e

Image distance for the Object = u_0

Problems :

Problem (1):

1. A thin, double-convex lens has a refractive index of 1.50. The radius of curvature of the front surface is 15 cm and that of the rear surface is 10 cm. See sketch.

(a)How far from the lens would an image of the sun be formed? (b) How far from the lens would an image of a toy figure 24 cm from the lens be formed? (c) How do the answers to (a) and (b) change if you flip the lens over?

Solution:

a) The ray comes from the sun is consider parallel and comes from infinity so its gather in focal point as illuminated point received

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{r_1} - \frac{1}{r_2}\right)$$

$$\frac{1}{f} = (1.5 - 1)\left(\frac{1}{15} - \frac{1}{10}\right)$$

$$\frac{1}{f} = -\frac{1}{60} \quad \rightarrow f = -60\ cm$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$-\frac{1}{60} = \frac{1}{24} + \frac{1}{q} \quad \rightarrow q = 39.57\ cm$$

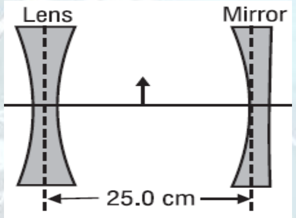
Problems :

b) The value of the answer of a and b do not change but the light be suffer less regressiveness than before

Problem (2)

The object shown in the accompanying sketch is midway between the lens and the mirror. The radius of curvature of the mirror is 20 cm. The concave lens has a focal length of 16.7 cm. (a) Where is the light that travels first to the mirror and then to the lens finally imaged? (b) Where is the light finally imaged that travels first to the lens? (Note: Be especially careful of applying the sign convention!)

Solution:



$$f = \frac{r}{2} \quad \rightarrow f = \frac{20}{2} \quad \rightarrow \quad f = 10\ cm$$

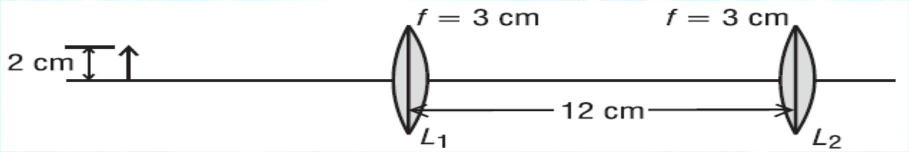
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad \rightarrow \quad q = -1.4287$$

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad \rightarrow -\frac{1}{16.7} = -\frac{1}{12.5} + \frac{1}{q} \quad \rightarrow q = 7.1489\ cm$$

$$m = -\frac{q}{p} \quad \rightarrow m = -\frac{7.1489}{12.5} \quad \rightarrow \quad m = 0.57$$

Problems :

Problem (3):
Two positive thin lenses, each of focal length *f* = 3 cm, are separated by a distance of 12 cm. An object 2 cm high is located 6 cm to the left of the first lens. See sketch.



On an 8½" × 11" sheet of paper, make a drawing of the two-lens system, *to scale*. (a) Use ray-tracing techniques to locate the final image and describe its size and nature. (b) Use the thin-lens equation to locate the position and size of the final image. How well do your results for (a) and (b) agree?

Solution:

The image by first lens

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{q} \quad \rightarrow \frac{1}{q}=\frac{1}{3}-\frac{1}{6} \quad \rightarrow q=6\ cm$$

Image by first lens is represented object to the second lens and it has distance (12-6=6 cm), so the final image is fare from the second lens by :

$$\frac{1}{f}=\frac{1}{p}+\frac{1}{q} \quad \rightarrow \frac{1}{q}=\frac{1}{3}-\frac{1}{6} \rightarrow q=6\ cm$$

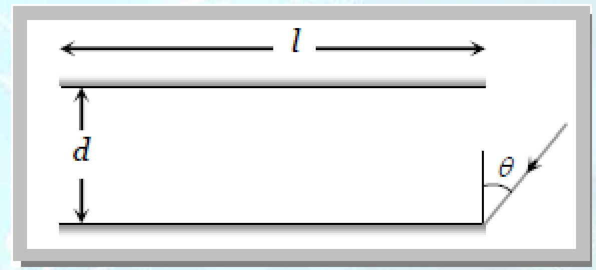
$$m=-\frac{q}{p} \quad \rightarrow m=-\frac{6}{6} \quad \rightarrow m=-1$$

The image is invert as size as the object

Problems

Problem (4):

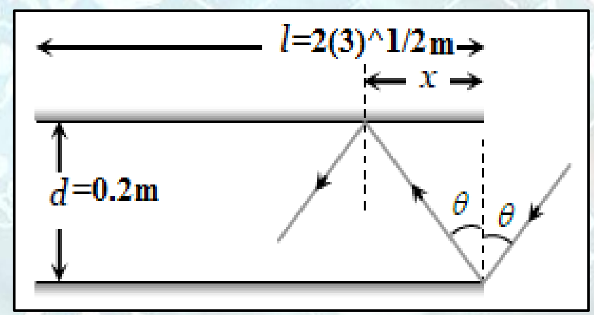
Two plane mirrors A and B are aligned parallel to each other, as shown in below figure . A light ray is incident at an angle of 30° at a point just inside one end of A. the plane of incidence coincides with the plane of figure. What is the maximum number of times the ray undergoes reflections (including the first one) before it emerges out is ?



Solution:

Suppose n = Total number of reflection light ray undergoes before exist out.

x = Horizontal distance travelled by light ray in one reflection.



$$nx = l$$

$$\tan\theta = \frac{x}{d}$$

$$x = d\tan\theta$$

$$= 0.2\tan 30 \quad = \frac{0.2}{\sqrt{2}}m$$

$$n = \frac{l}{x}$$

$$= \frac{2\sqrt{3}m}{0.2/\sqrt{3}m} = 30$$

Problems

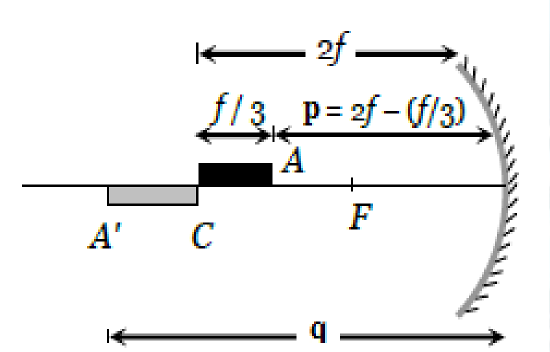
Problem (5):

A thin rod of length f/3 lies along the axis of a concave mirror of focal length f. One end of its magnified image touches an end of the rod. What the length of the image is?

Solution:

If end A of rod acts an object for mirror then it's image will be A' and if

$r = 2f \; we \; have \;\; p = 2f - \frac{f}{3} = \frac{5f}{3}$



So by using

$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$\frac{1}{-f} = \frac{1}{-\frac{5f}{3}} + \frac{1}{q}$$

$$q = -\frac{5}{2}f$$

$$length \; of \; image = \frac{5}{2}f - 2f$$

$$= \frac{f}{2}$$

Problems

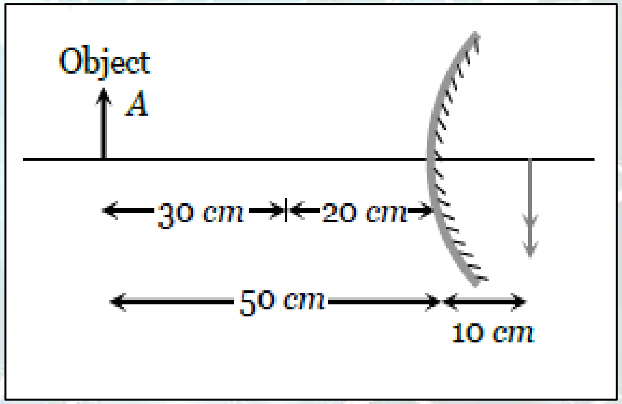
Problem (6) :

An object is placed in front of a convex mirror at a distance of 50cm. A plane mirror is introduced covering the lower half of the convex mirror. If the distance between the object and plane mirror is 30cm, it is found that there is no parallel between the images formed by two mirrors. What is radius of curvature of mirror ?

Solution:

Since there is no parallel, it means that both images (By plane mirror and convex mirror) coinciding each other. According to property of plane mirror it will form image at a distance of 30 *cm* behind it. Hence for convex mirror $p = -50\ cm$, $q = +10\ cm$

By using:



$$\frac{1}{p} + \frac{1}{q} = \frac{1}{f}$$

$$\frac{-1}{50} + \frac{1}{10} = \frac{4}{50}$$

$$f = \frac{25}{2} cm$$

$$r = 2f = 25cm$$

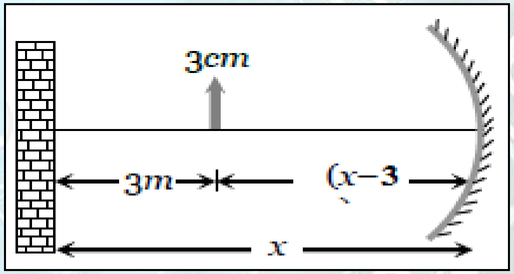
Problems

Problem (7):

A candle flame 3cm is placed at distance of 3m from a wall. How far from wall must a concave mirror be placed in order that it may form an image of flame 9cm high on the wall?

Solution:

When an object is placed perpendicular to the principle axis, then linear magnification is called lateral or transverse magnification.



$$m = \frac{h_i}{h_\circ} = \frac{-q}{p}$$

$$\frac{-9}{3} = \frac{-(-x)}{-(x-3)}$$

$$3x = 9x - 27$$

$$6x = 27$$

$$x = 4.5m$$

$$= 450m$$

Problems :

Problem (8):

A tank is filled with water to a height of 12.5 cm. The apparent depth of a needle lying at the bottom of the tank is measured by a microscope to be 9.4 cm. What is the refractive index of water? If water is replaced by a liquid of refractive index 1.63 up to the same height, by what distance would the microscope have to be moved to focus on the needle again?

solution

Actual depth of the needle in water h1 = 12.5 cm

Apparent depth of the needle in water h2 = 9.4 cm

Refractive index of water = μ

The value of μ can be obtained as follows:

$$\mu = \frac{h_1}{h_2}$$

$$= \frac{12.5}{9.4} \approx 1.33$$

Hence, the refractive index of water is about 1.33.

Water is replaced by a liquid of refractive index,

The actual depth of the needle remains the same, but its apparent depth changes. Let y be the new apparent depth of the needle.

Hence, we can write the relation:

Problems :

$$\mu' = \frac{h_1}{y}$$

$$\therefore y = \frac{h_1}{\mu'}$$

$$= \frac{12.5}{1.63} = 7.67 \text{ cm}$$

Hence, the new apparent depth of the needle is 7.67 cm. It is less than h2. Therefore, to focus the needle again, the microscope should be moved up.

∴Distance by which the microscope should be moved up

$= 9.4 - 7.67 = 1.73$ cm

Problem (9):

A person with a Least distance of distant vision (25 cm) using a compound microscope with objective of focal length 8.0 mm and an eyepiece of focal length 2.5 cm can bring an object placed at 9.0 mm 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, fo = 8 mm = 0.8 cm

Focal length of the eyepiece, fe = 2.5 cm

Object distance for the objective lens, uo = −9.0 mm = −0.9 cm

Least distance of distant vision, d = 25 cm

Image distance for the eyepiece, ve = −d = −25 cm

Object distance for the eyepiece u_e = ?

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

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

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

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

Problems :

We can also obtain the value of the image distance for the objective lens using the lens formula.

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

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

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

$$\therefore v_o = 7.2 \text{ cm}$$

The distance between the objective lens and the eyepiece Name

$$= |u_e| + v_o$$

$$= 2.27 + 7.2$$

$$= 9.47 \text{ cm}$$

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.

Problems :

Problem (10):

A small telescope has an objective lens of focal length 144 cm and an eyepiece of focal length 6.0 cm. What is the magnifying power of the telescope? What is the separation between the objective and the eyepiece?

solution

Focal length of the objective lens, f_o= 144 cm

Focal length of the eyepiece, f_e= 6.0 cm

The magnifying power of the telescope is given as:

Title

$$m = \frac{f_0}{f_e} \Rightarrow m = \frac{144}{6} = 24$$

The separation between the objective lens and the eyepiece is calculated as:

$$f_0 + f_e = 144+6 = 150$$

Hence, the magnifying power of the telescope is 24 and the separation between the objective lens and the eyepiece is 150 cm.

Problem (11):

A giant refracting telescope at an observatory has an objective lens of focal length 15 m. If an eyepiece of focal length 1.0 cm is used, what is the angular magnification of the telescope?

If this telescope is used to view the moon, what is the diameter

formed by the objective lens? The diameter of the moon is

Problems :

3.48×10^6

lunar orbit is 3.8×10^8

solution

Focal length of the objective lens fo = 15 m = cm

Focal length of the eyepiece fe = 1.0 cm

The angular magnification of a telescope is given as

$$\alpha = \frac{f_0}{f_e} \Rightarrow \alpha = \frac{15 \times 10^2}{1.0} = 1500$$

Hence, the angular magnification of the given refracting telescope is 1500.

Diameter of the moon, $d = 3.48 \times 10^6 m$

Radius of the lunar orbit, $r_o = 3.8 \times 10^8 m$

Let be the diameter of the image of the moon formed by the objective lens.

The angle subtended by the diameter of the moon is equal to the angle subtended by the Image

$$\frac{d}{r_0} = \frac{d'}{f_o}$$

$$\frac{3.48 \times 10^6}{3.8 \times 10^8} = \frac{d'}{15}$$

$$\therefore d' = \frac{3.48}{3.8} \times 10^{-2} \times 15$$

$$= 13.74 \times 10^{-2} \text{ m} = 13.74 \text{ cm}$$

Hence, the diameter of the moon's image formed by the objective lens is 13.74 cm

Problems :

Problem (12):

A small telescope has an objective lens of focal length 140 cm and an eyepiece of focal length 5.0 cm. What is the magnifying power of the telescope for viewing distant objects when the telescope is in normal adjustment (i.e., when the final image is at infinity)? the final image is formed at the least distance of distinct vision (25 cm)?

Answer

Focal length of the objective lens, = 140 cm

Focal length of the eyepiece, fe = 5 cm

Least distance of distinct vision, d = 25 cm

When the telescope is in normal adjustment, its magnifying power is given as:

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

$$= \frac{140}{5} = 28$$

When the final image is formed at (d) image of the tower formed by the objective lens?

$$\frac{f_o}{f_e}\left[1 + \frac{f_e}{d}\right]$$

$$= \frac{140}{5}\left[1 + \frac{5}{25}\right]$$

$$= 28[1 + 0.2]$$

$$= 28 \times 1.2 = 33.6$$