Geometric Optics

[اكتب العنوان الفرعي للمستند]

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Optics IV

Optical instruments

First: **The human eye**
Second: **Camera**
Third: **Telescope**

First: **The human eye**

The human eye is an optical instrument that enables us to view all the objects around us is a very complex organ. The simplest model of the human eye is a single lens with an adjustable focal length that forms an image on **the retina**.

The circular part is **the iris**. The color of the eye is determined by the color of the iris. The center transparent area of the iris is **the pupil**. The iris works like the shutter of the camera. It absorbs most of the light falling on it and allows it to pass through the pupil.

The amount of light that enters the inner part of the eye depends on the size of the pupil. In bright light, the iris contracts the pupil to restrict the light, whereas in low light it widens the pupil to emit more light into the eye. **The eyeball** is spherical in shape. The retina of the eye is able to detect the light and its color because of the presence of senses known as **rods** and **cones**.

Rods are responsible for vision at low light levels (scotopic vision). They do not mediate color vision, and have a low spatial acuity.

Cones are active at higher light levels (photopic vision), are capable of color vision and are responsible for high spatial acuity.

There are **three types** of cones which we will refer to as the short-wavelength sensitive cones, the middle-wavelength sensitive cones and the long-wavelength sensitive cones or S-cone, M-cones, and L-cones for short.

The eye is either relaxed (in its normal state in which rays from infinity are focused on the retina), or it is accommodating (adjusting the focal length by flexing the eye muscles to image closer objects).

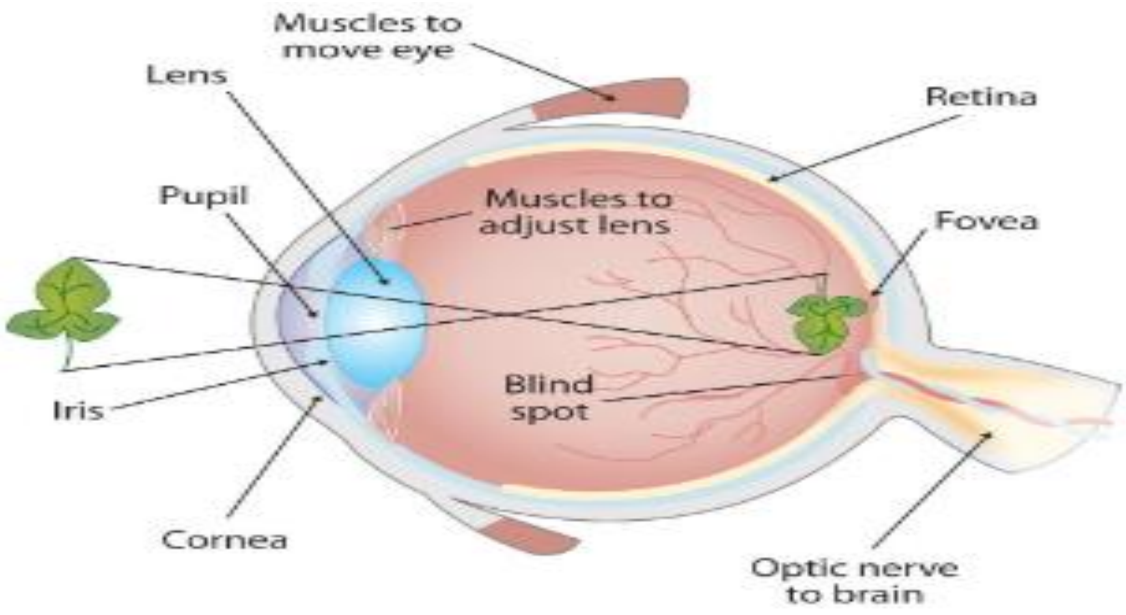


Fig. (41): The human eye.

<u>The near point of a human eye</u> defined to be (u= 25 cm) is the shortest object distance that a typical or "normal" eye is able to accommodate, or to image onto the retina.

<u>The far point of a human eye</u> is the farthest object distance that a typical eye is able to image onto the retina. It is at infinity for the "normal" eye.

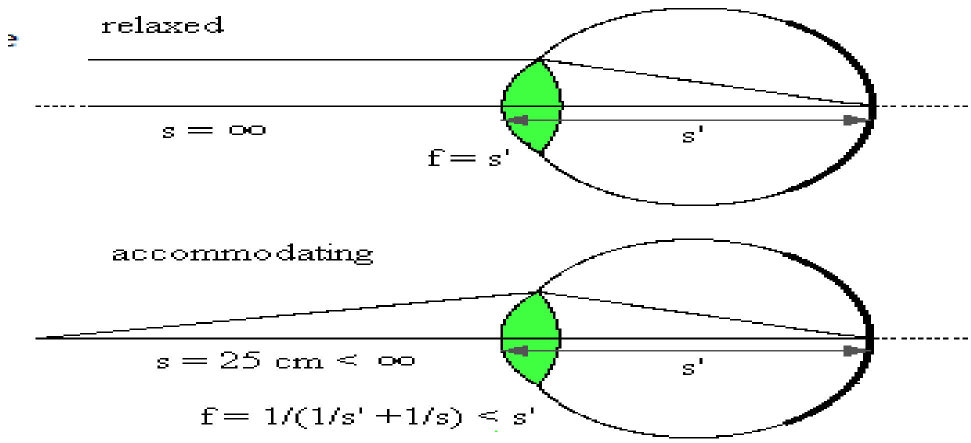


Fig. (42): the near and the far points of the human eye.

For the near point (relaxed)

u= infinity, v= 25 cm, the focal length is:

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f_1} \qquad \Longrightarrow \qquad \frac{1}{\infty}+\frac{1}{25\ \text{cm}}=\frac{1}{f_1} \qquad \Longrightarrow \qquad f = 25\ \text{cm}$$

For the far point (accommodating)

u= finite, v= 25 cm, the focal length is:

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f_1} \quad \Rightarrow \quad \frac{1}{u}+\frac{1}{25}=\frac{1}{f} \quad \Rightarrow \quad \mathbf{f < 25\ cm}$$

Second: Camera

Cameras use convex lens to take real inverted images. This is because light rays always travels in a straight line, until a light ray hits a medium. The medium in this case is glass. The glass causes the light rays to refract (or bend) this causes them to form inverted on the opposite side of the medium.

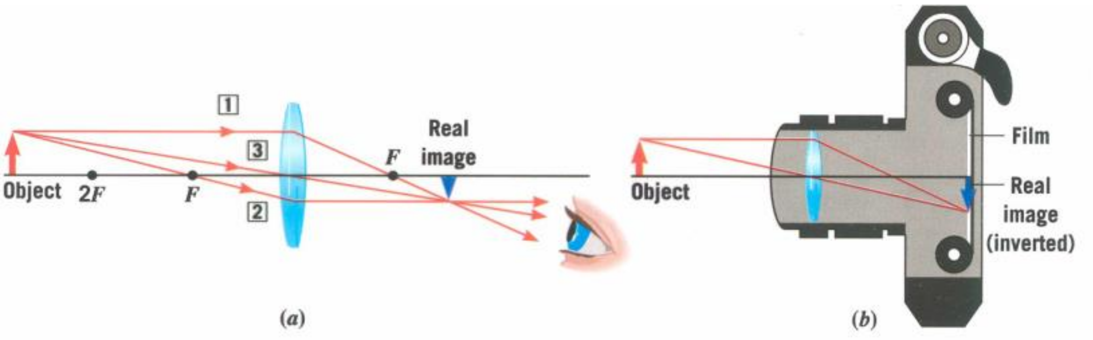


Fig. (43): The parts of camera.

Camera has basic three parts are:

Aperture: A hole which size can be changed to allow light passes out of the lens, and into the camera. This is important for clear images without distortion around the edges.

Shutter: The shutter is a doorway that will allow for light to pass through out of the aperture. The shutter speed will allow for long or short exposures thus allowing for pictures of fast moving object or low lighting photos to be taken.

Lens: A piece of curved glass that will focus light allowing for clear images to be transmitted onto the unexposed film.

Formula of the camera

We can model a combination lens as a single lens with an effective focal length (usually called simply "the focal length".

A zoom lens changes the effective focal length by varying the spacing between the converging lens and the diverging lens.

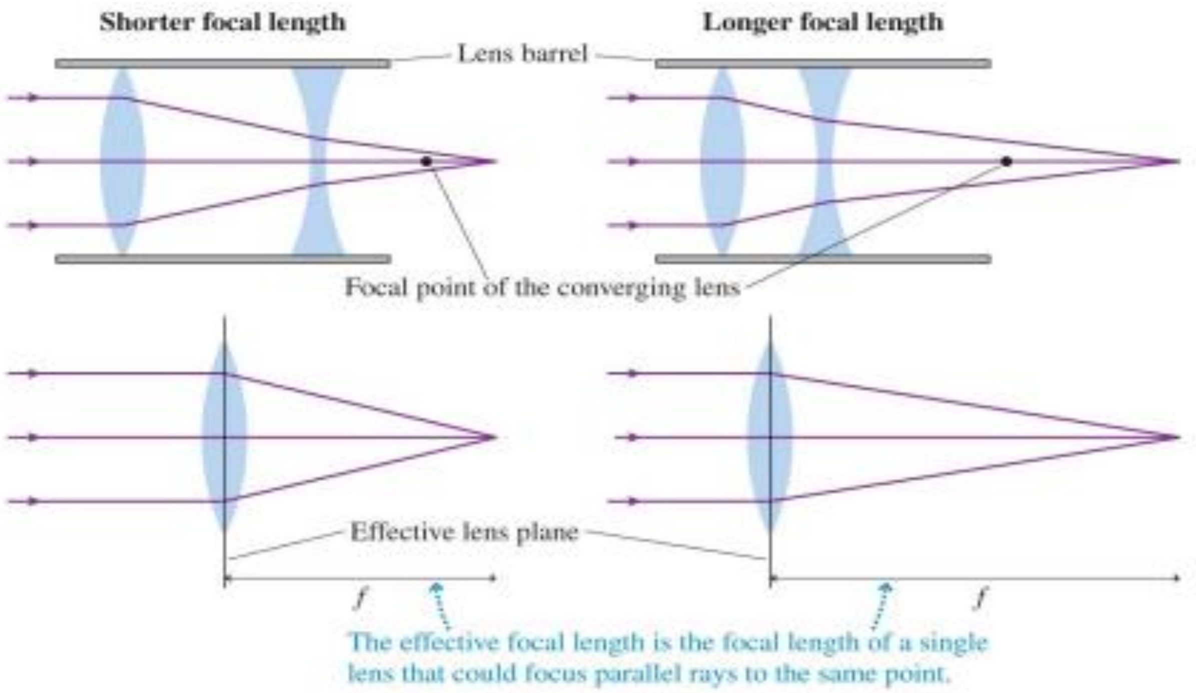


Fig. (44): A simple camera.

This formula used to able the lens to focus on an object. This equation is for ideal lenses, strictly speaking for lenses that have "zero thickness".

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

When cameras focus on objects that are more than (10) focal lengths away, the object is essentially "at infinity" and ($v \approx f$). The lateral magnification of the image is:

$$m = -\frac{v}{u} \approx -\frac{f}{u} \qquad (1-36)$$

The amount of light passing through the lens is controlled by an adjustable aperture, also called an iris because it functions much like the iris of your eye. The aperture sets the effective diameter (D) of the lens.

The light-gathering ability of a lens is specified by its f-number, defined as:

$$f-\text{number} = \frac{f}{D} \qquad (1-37)$$

The f- number is give a description of the lens (speed), i.e. a lens with a low f-number is a "fast" lens.

The light intensity on the detector is related to the lens's f- number by:

$$I \propto \frac{D^2}{f^2} = \frac{1}{(f-\text{number})^2} \qquad (1-38)$$

Examples:

1) Your digital camera lens, with an effective focal length of (10 mm) is focused on a flower (20 cm) and its diameter is (14 mm). You then turn to take a picture of a distant landscape. How far and in which direction must the lens move to bring the landscape into focus? What is f- number and intensity of this camera?

Solution:

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

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10\text{ mm}} - \frac{1}{200\text{ mm}} \qquad \Rightarrow v = 10.5\text{ mm}$$

The distant landscape is effectively at object distance (v=∞), so its image distance is (v= f= 10 mm). To refocus as you shift scenes, the lens must move (0.5 mm) closer to detector.

$$f - \text{number} = \frac{f}{D} = \frac{10\text{ mm}}{14\text{ mm}} = 10{:}\,14$$

$$I = \frac{1}{(f-\text{number})^2} = \frac{1}{\left(\frac{14\text{ mm}}{10\text{ mm}}\right)^2} = 1.96\text{ mA}$$

2) Suppose the focal length of a person's eye is (3 cm) when fully relaxed (looking at a distant object). If the person's retina is (3.3 cm) behind the eye lens (a nearsighted eye compared to the normal distance of 3.0 cm), what must be the focal length of the corrective lenses so that this person can see objects at infinity?

Solution:

Using the thin lens equation with (u=∞, v=3.3 cm), we find an effective focal length of (3.3 cm) needed. Because the effective focal length of such a two-lens system (the lens of the eye and the corrective lenses) is:

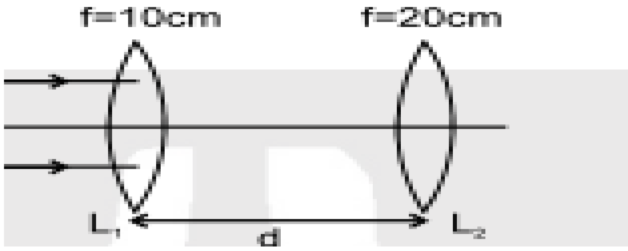
$$\frac{1}{f_{effective}} = \frac{1}{f_{lens}} + \frac{1}{f_{eye}}$$

$$\frac{1}{f_{lens}} = \frac{1}{f_{effective}} + \frac{1}{f_{eye}} \quad \Rightarrow f_{lens} = -33\ cm$$

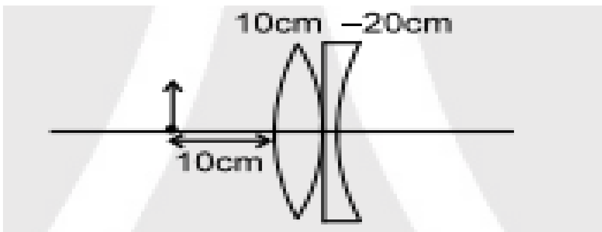
$$P = \frac{1}{f_{lens}(m)} = \frac{1}{-0.33(m)} = -3\ D$$

Homeworks:

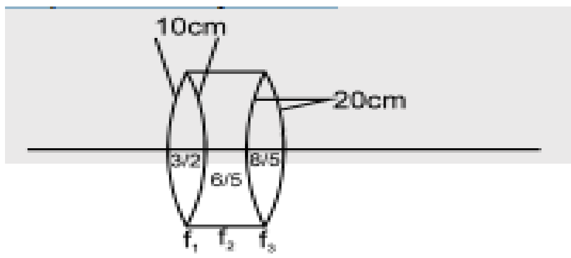
1) Figure shows two converging lenses. Incident rays are parallel to principal axis. What should be the value of d so that final rays are also parallel.



2) Find the lateral magnification produced by the combination of lenses shown in the figure.

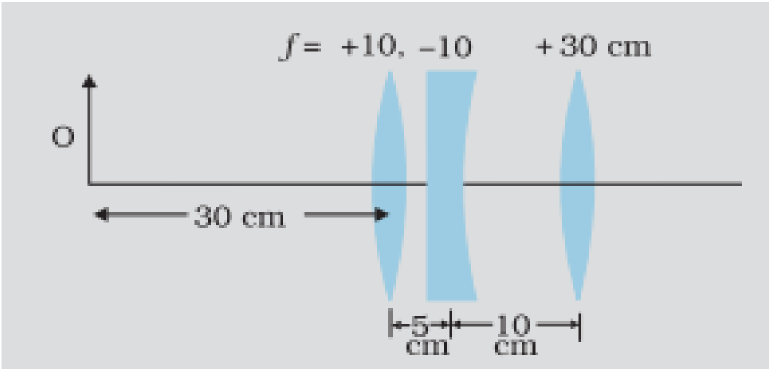


3) Find the focal length of equivalent system.



4) Find the position of final image formed. (The gap shown in figure is of negligible width)

5) Find the position of the image formed by the lens combination given in the Figure



Third: Telescope

A telescope is a device used to observe distant things. You can gaze at the planets using a telescope if you want to. The higher the power on the telescope, the clearer the image.

The telescope is of two types. One is the reflecting type and another one is the refracting type.

Fig. (45): Refracting and reflection telescope.

The most common two-lens telescope uses two convex lenses and is shown in figure (46- a). The object is so far away from the telescope that it is essentially at infinity compared with the focal lengths of the lenses ($u \approx \infty$). The first image is thus produced at ($v = f_o$), as shown in the figure (39- b). To prove this, note that:

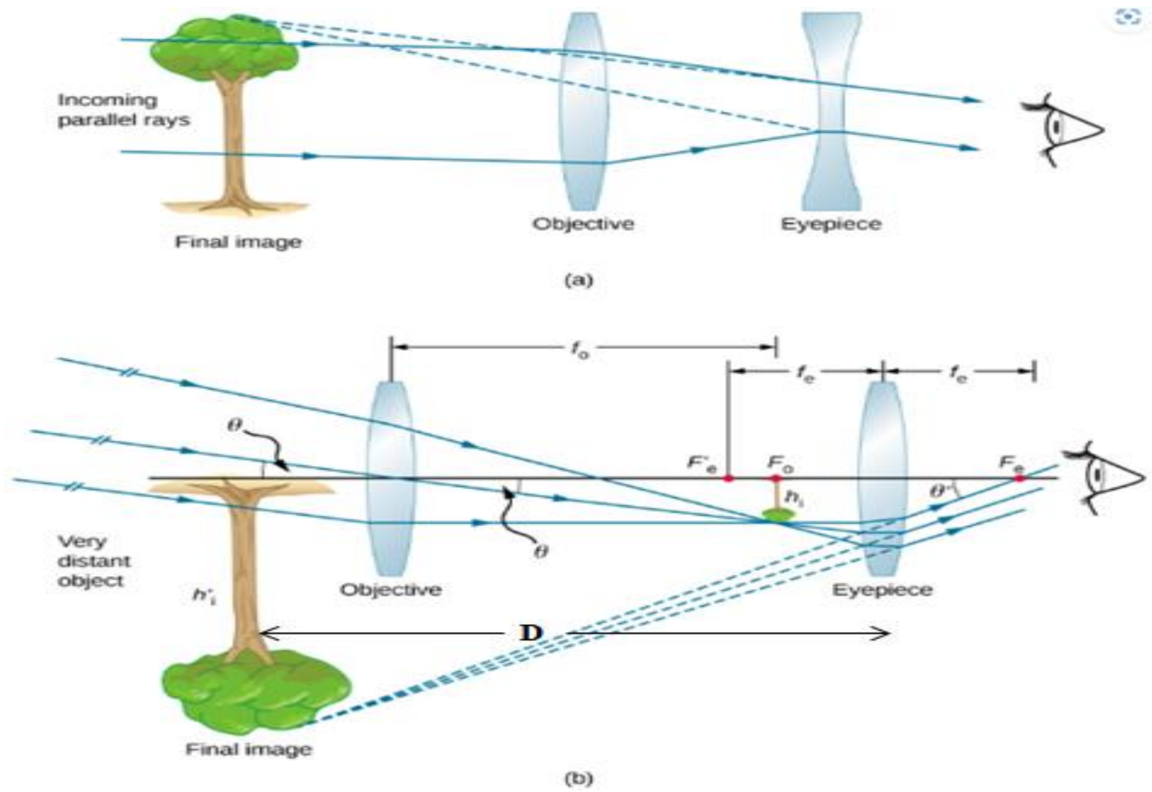


Fig.(46): Telescope uses two convex lenses.

$$\frac{1}{u}+\frac{1}{v}=\frac{1}{f_0} \quad \Rightarrow \quad \frac{1}{v}=\frac{1}{f_0}-\frac{1}{\infty} \quad \Rightarrow$$

$$f_0 = v \qquad (1-39)$$

It is true that for any distant object and any lens or mirror, the image is at the focal length.

If the angle subtended by an object as viewed by the unaided eye is (θ), and the angle subtended by the telescope image is (θ′), then the angular magnification (m) is defined to be their ratio. That is:

$$m = \frac{\theta'}{\theta} \qquad (1-40)$$

The angular magnification of a telescope is related to the focal lengths of the objective and eyepiece; and is given by:

$$m = \frac{\theta'}{\theta} = -\frac{f_0}{f_e} \qquad (1-41)$$

Magnifying power: It is defined as the ratio of the angle subtended at the eye by the image formed at (D) to the angle subtended by the object lying at infinity:

$$m = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right) \qquad (1-41)$$

where (D) is the distance between formation image by telescope and the eyepiece.

Examples:

1) What is the area of a (1 m) diameter telescope? A (4 m) diameter one?

Solution:

Using the equation for the area of a circle:

$$A = \frac{\pi d^2}{4}$$

the area of (1 m) telescope is:

$$A = \frac{\pi d^2}{4} = \frac{\pi (1\ m)^2}{4} = 0.79\ m^2$$

the area of (4 m) telescope is:

$$A = \frac{\pi d^2}{4} = \frac{\pi (4\ m)^2}{4} = 12.6\ m^2$$

2) The focal length of the objective of an astronomical telescope is (75 cm) and that of the eyepiece is (5 cm). If the final image is formed at the least distance of distinct vision from the eye, calculate the magnifying power of the telescope.

Solution:

$f_0 = 75$ cm, $f_e = 5$ cm, $D = 25$ cm

$$m = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right) = -\frac{75}{5}\left(1 + \frac{5}{25}\right) = -18$$

3) An astronomical telescope has an objective of focal length (40 cm) and an eyepiece of focal length (4 cm). To view an object which is at (200 cm) away from the objective, the length of telescope must be?

Solution:

$f_0 = 40$ cm, $f_e = 4$ cm, $u = -200$ cm

Using lens formula for objective lens:

$$\frac{1}{u_0} + \frac{1}{v_0} = \frac{1}{f_0} \quad \Longrightarrow \quad \frac{1}{v_0} = \frac{1}{40} - \frac{1}{200} \quad \Longrightarrow \quad v_0 = 50 \text{ cm}$$

So length of telescope (L):

$$L = v_0 + f_e$$

$$L = 50 + 4 = 54 \text{ cm}$$

4) A simple telescope has two convex lenses, the objective and the eyepiece, which have a common focal point. The focal length of the objective is (1 m). If the angular magnification of the telescope is (10), find the optical path length between objective and eyepiece?

Solution:

$f_o = 1$ m, $m = 10$,

$$m = \frac{f_0}{f_e} \quad \Longrightarrow \quad f_e = \frac{f_0}{m} = \frac{1\text{m}}{10} = 0.1 \text{ m}$$

The optical path length between objective and eyepiece means length of tube and is given by:

$$L = |f_0| + |f_e| = 1 + 0.1 = 1.1 \text{ m}$$