



# Chapter 27 Optical Instruments

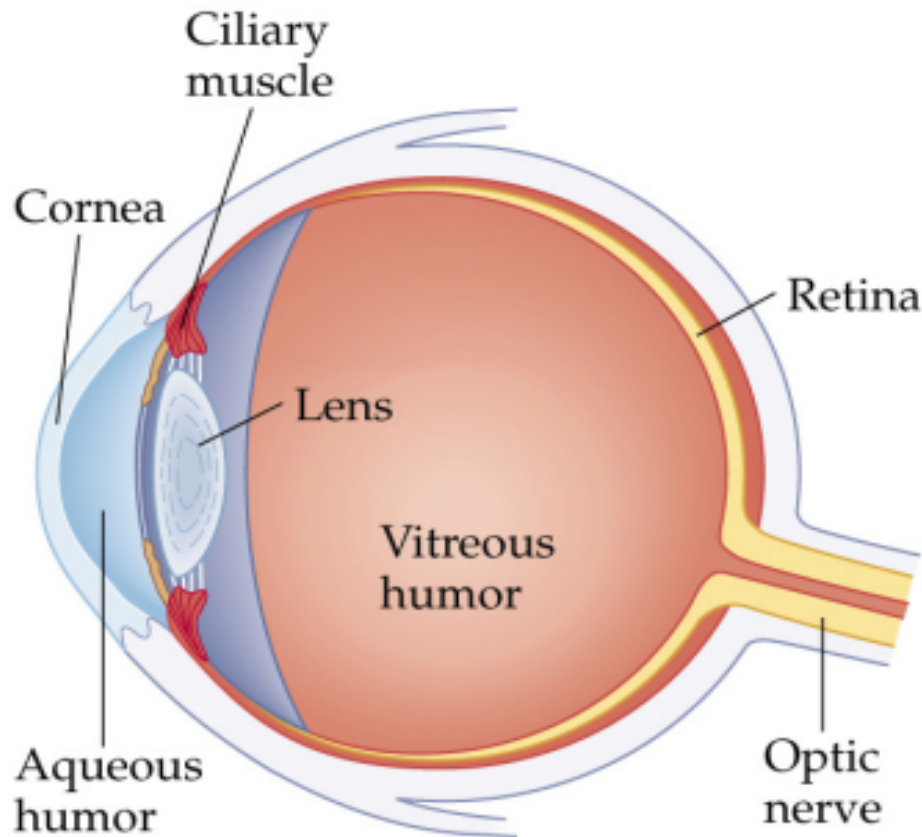
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27.1 The Human Eye and the Camera

27.2 Lenses in Combination and Corrective Optics

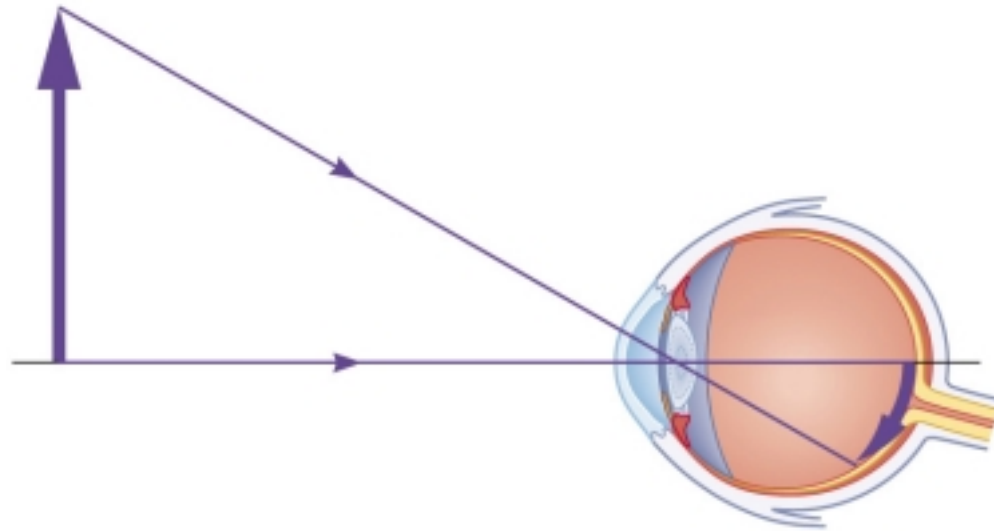
27.3 The Magnifying Glass

# Figure 27–1 Basic elements of the human eye



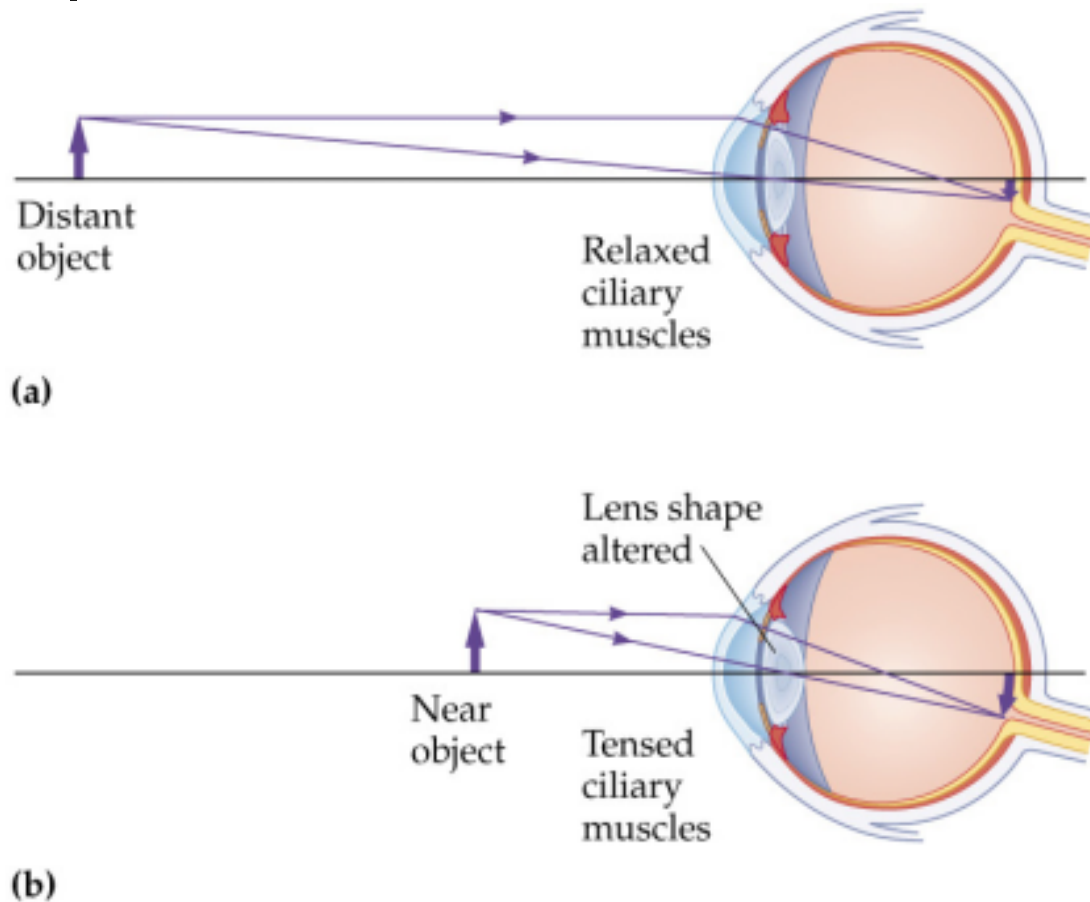
- Light enters the eye through the cornea and the lens. It is focused onto the retina by the ciliary muscles, which change the shape of the lens.

# Figure 27–2 Image production in the eye

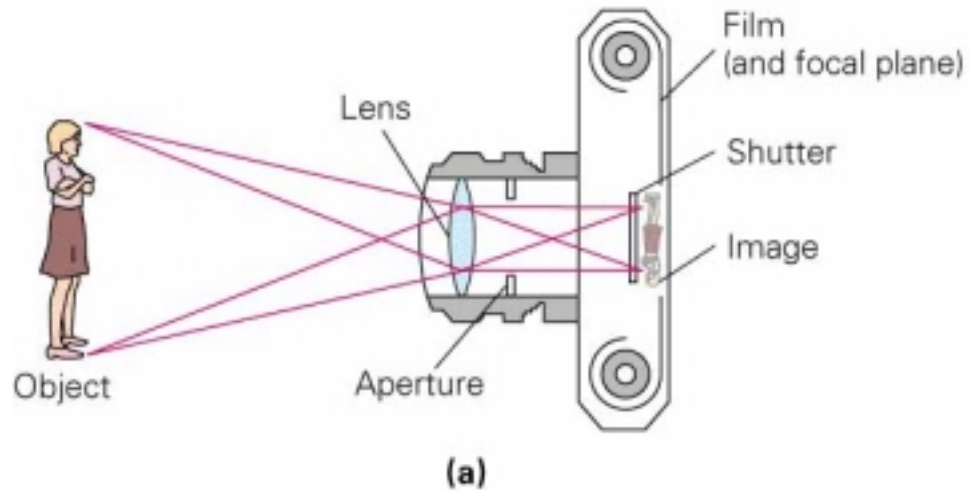


- The eye produces a real, inverted image on the retina.

# Figure 27–3 Accommodation in the human eye



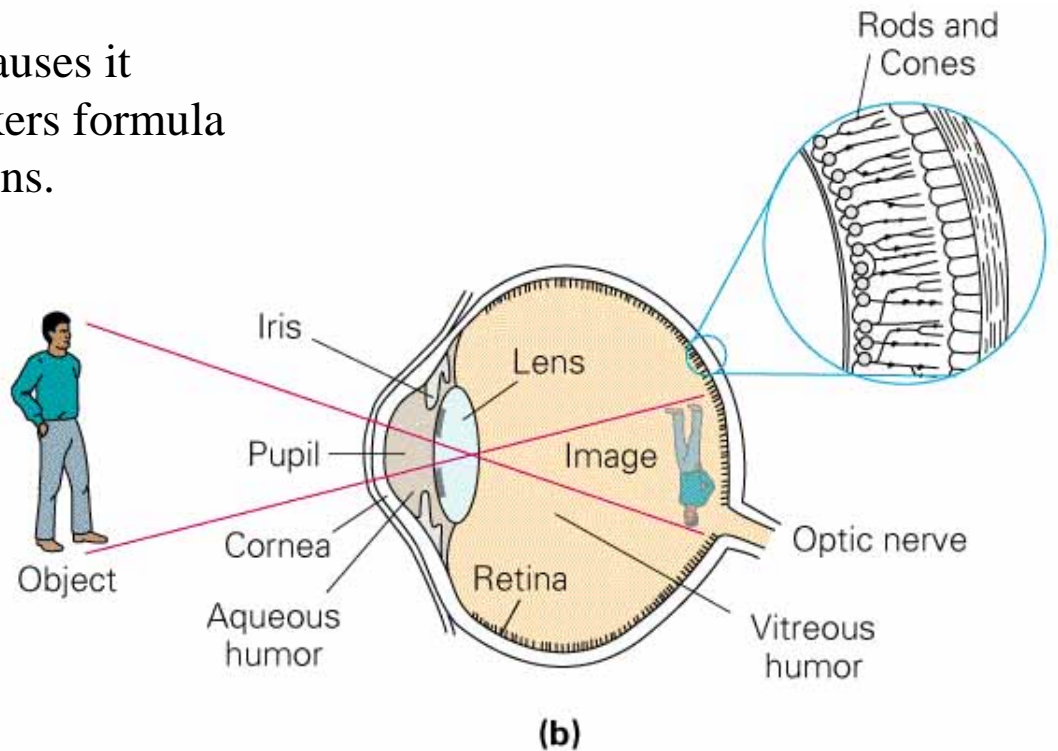
- (a) When the eye is viewing a distant object the ciliary muscles are relaxed and the focal length of the lens is at its greatest. (b) When the eye is focusing on a near object the ciliary muscles are tensed, changing the shape and reducing the focal length of the lens.



Ciliary muscles pull on lens. This causes it to change shape. From the lens-makers formula this changes the focal length of the lens.

We see objects at different distance by changing the shape of our eye lens.

## ACCOMMODATION



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### Images in the human eye

In the human eye, a real, inverted image is formed on a light-sensitive surface, called the **retina**.

**Accommodation** is the process by which the focal length of the eye is automatically adjusted, so that objects at different distance produce focused images on the retina.

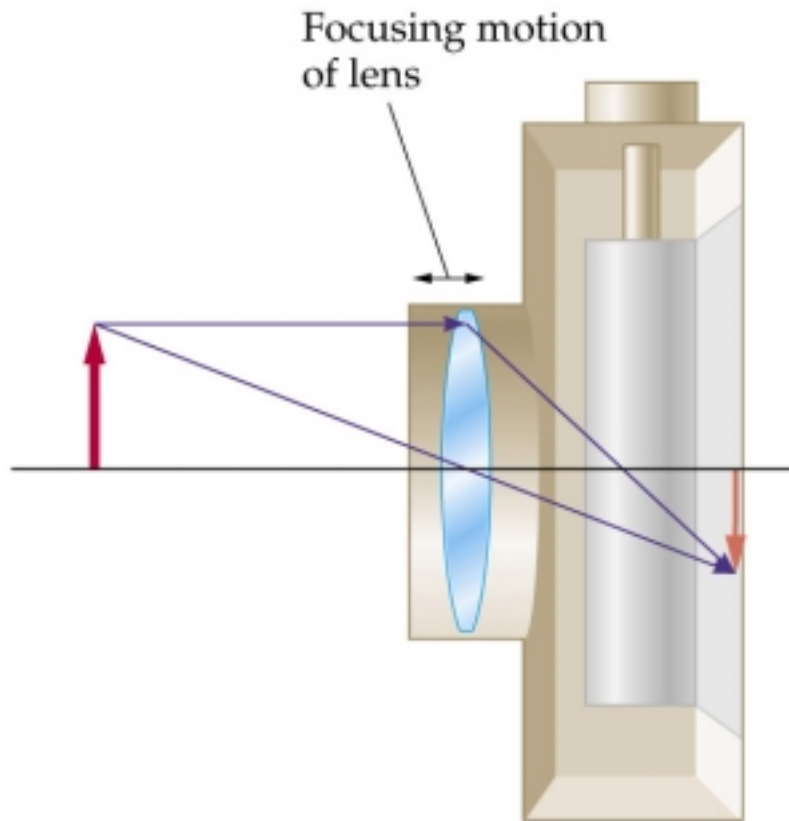
### Near point

The *near point* of the eye is the point nearest the eye at which an object can be placed and still have a sharp image produced on the retina. For a normal eye, the near point is located 25cm from the eye.

### Far point

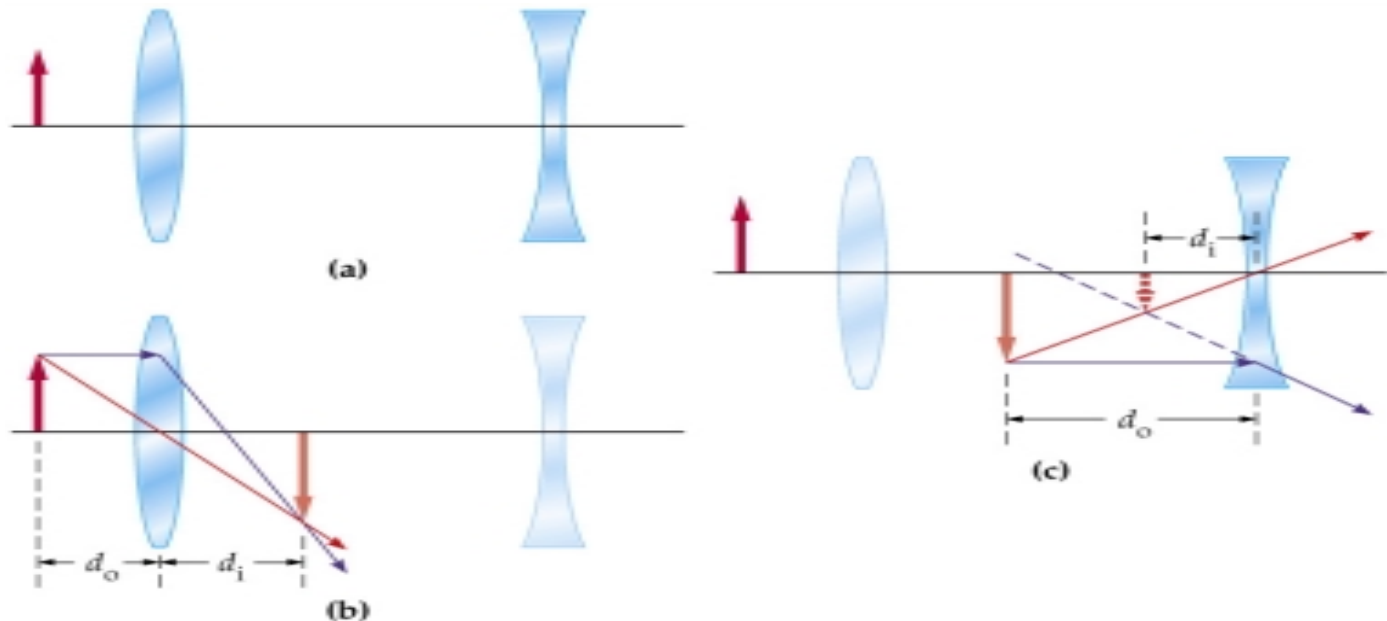
The *far point* of the eye is the location of the farthest object on which the fully relaxed eye can focus. For a normal eye, the far point is located at infinity.

# Figure 27–4 Basic elements of a camera



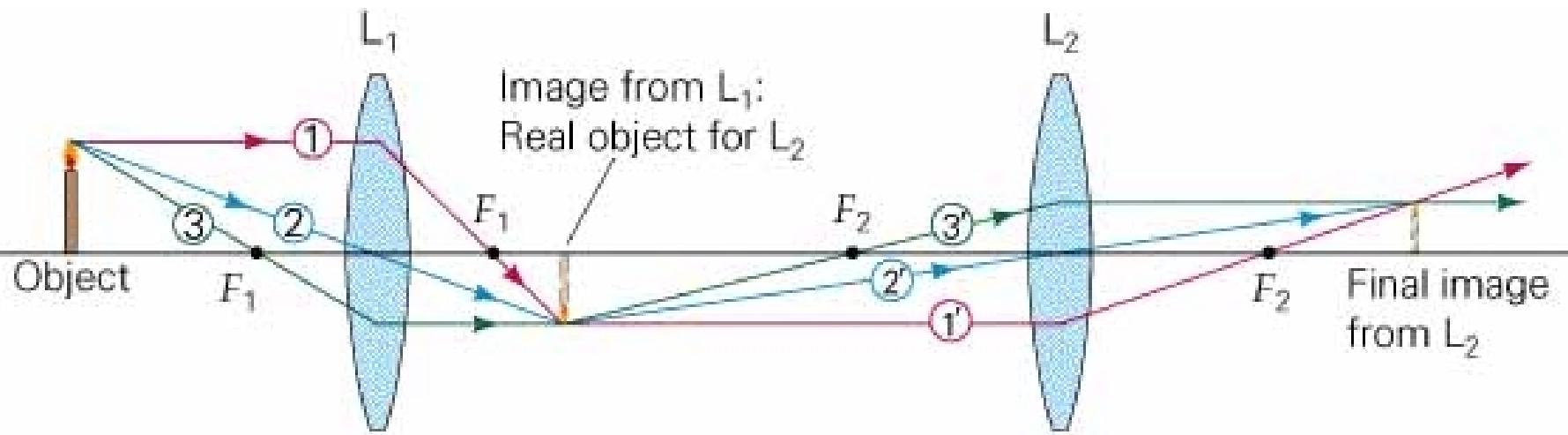
- A camera forms a real, inverted image on photographic film. The camera focuses by moving the lens back and forth relative to the film. Unlike the adjustable shape of the eye, the shape of the camera lens remains fixed.

# Figure 27-5 A two-lens system

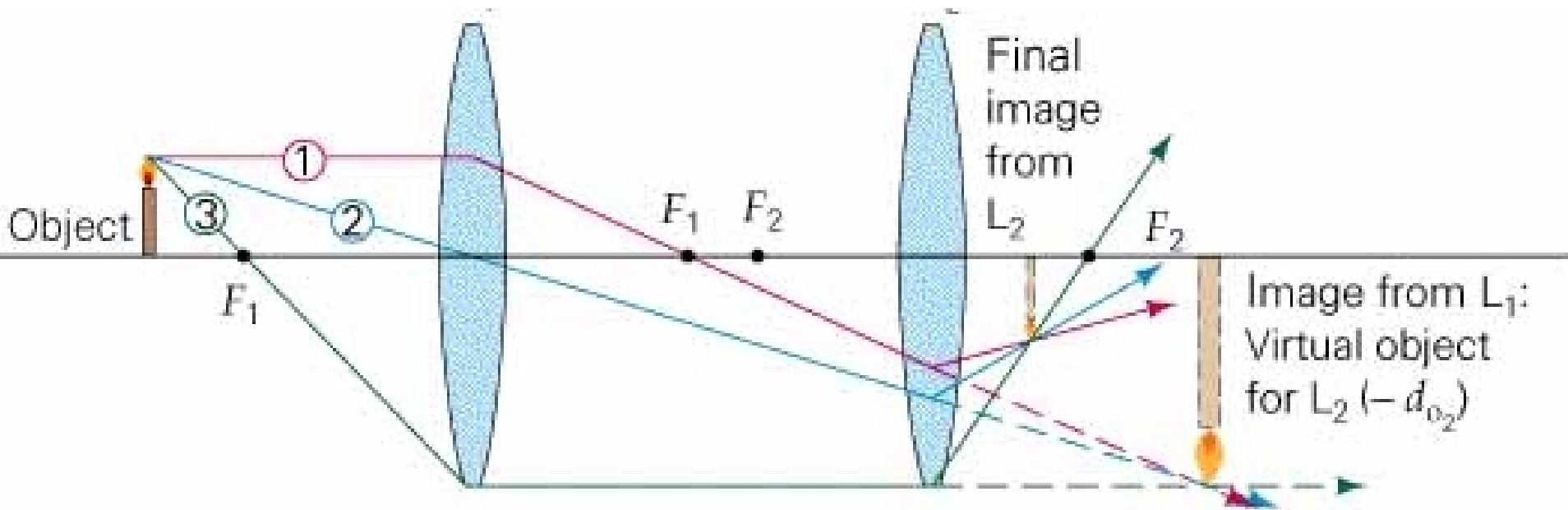


- In this system, a convex and a concave lens are separated by 50.0 cm. (a) An object is placed 20.0 cm to the left of the convex lens, whose focal length is 10.0 cm. (b) The image formed by the convex lens is 20.0 cm to its right. This image is the object for the concave lens. (c) The object for this lens is 30.0 cm to its left. Since the focal length of this lens is -12.5 cm, it forms an image 8.82 cm to its left. This is the final image of the system.





(a)



(b)

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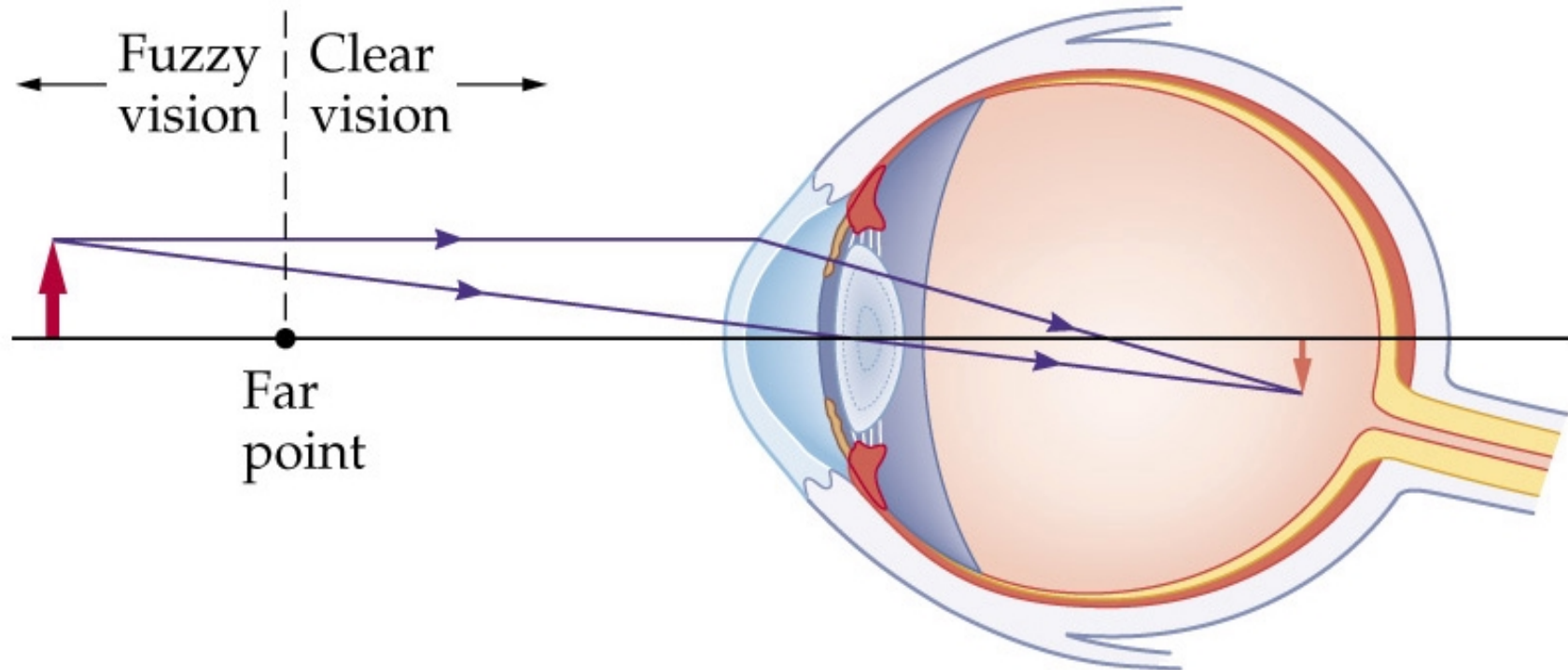
## **Nearsighted and farsighted**

A *nearsighted (myopic)* eye is one that can focus on nearby objects, but not on distant ones. This can be corrected by wearing eyeglasses or contact lenses made from diverging lenses. A *farsighted (hyperopic)* eye can see distant objects clearly, but not those close up. Farsightedness can be corrected by using converging lenses.

## **Refractive power**

The *refractive power* of a lens is measured in diopters and is given by  $1/f$ , where  $f$  is the focal length of the lens in meters. A converging lens has a positive refractive power, while a diverging lens has a negative refractive power.

# Figure 27–6 Eye shape and nearsightedness



- An eye that is elongated can cause nearsightedness. In this case, an object at infinity comes to a focus in front of the retina.

When an object is infinitely far ( $>20$  m) from our eyes. The eye is fully relaxed, meaning that the lens has least curvature and longest focal length.

Many people cannot see distant objects clearly.

They can see perfectly well objects that are not distant.

The point beyond which distant objects appear blurred is called the FAR POINT

The reason for this is that their eye lens cannot fully relax.

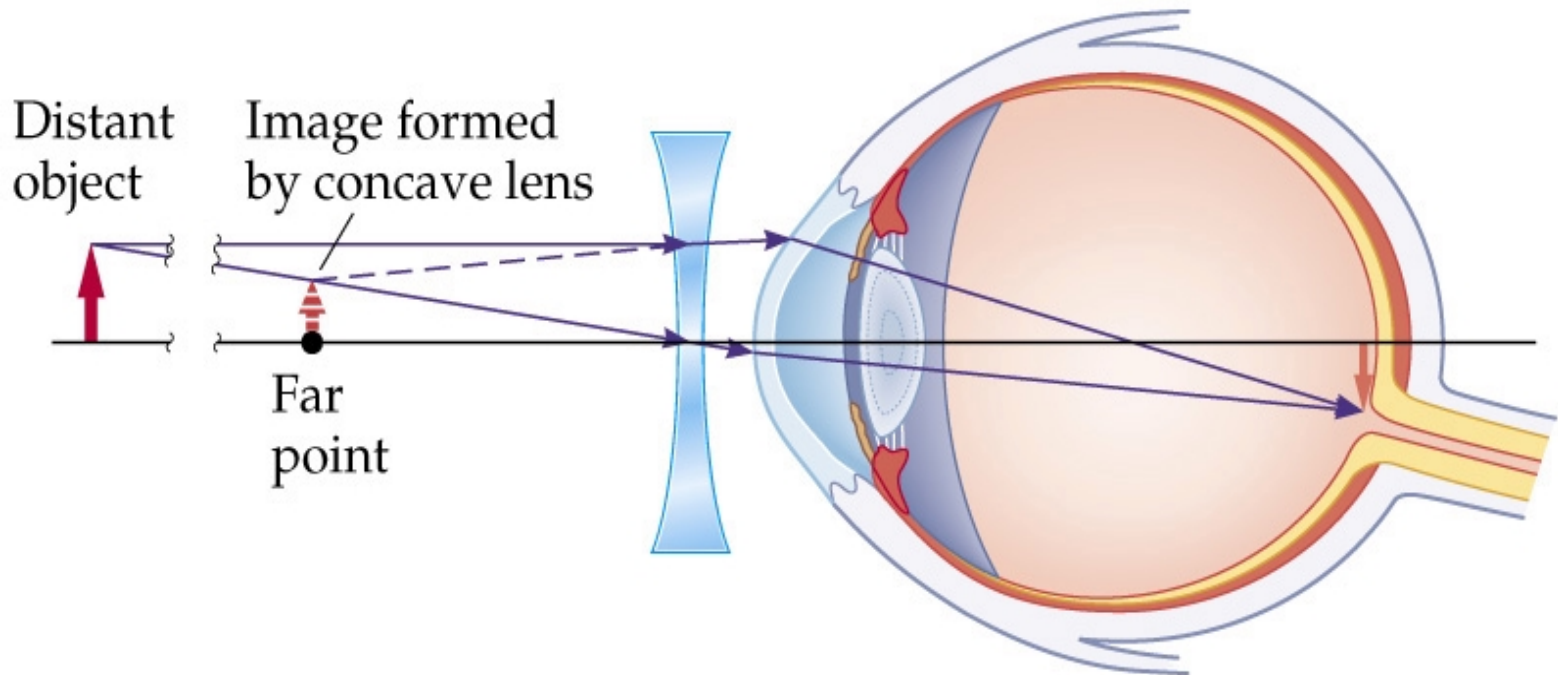
Due to problems with the muscles or the lens itself.

### **Far point**

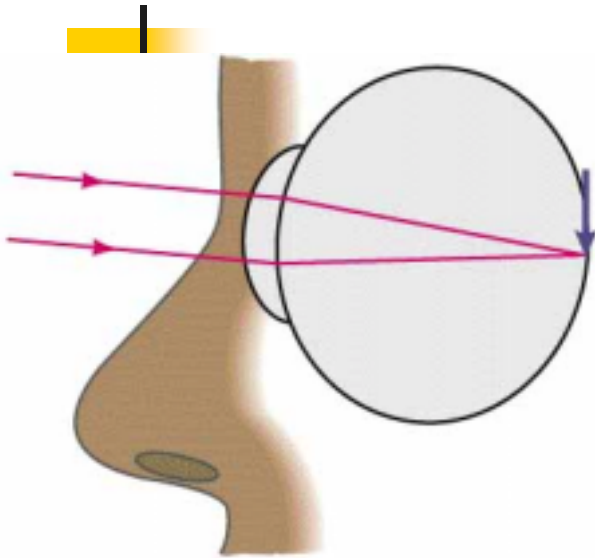
The *far point* of the eye is the location of the farthest object on which the fully relaxed eye can focus. For a normal eye, the far point is located at infinity.

Nearsightedness or myopic

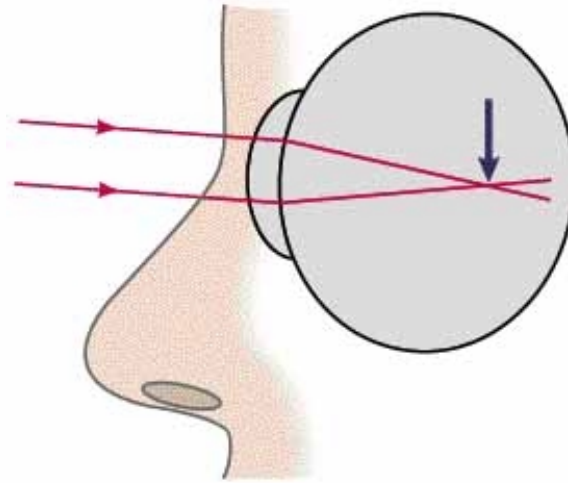
# Figure 27–7 Correcting nearsightededness



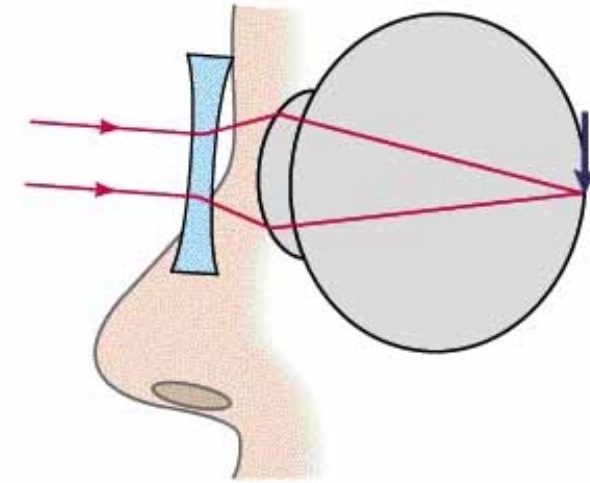
- A diverging lens in front of the eye can correct for nearsightedness. The concave lens focuses light from an object beyond the far point to produce an image that is at the far point. The eye can now focus on the image of the object.



**(a) Normal**



*Uncorrected*

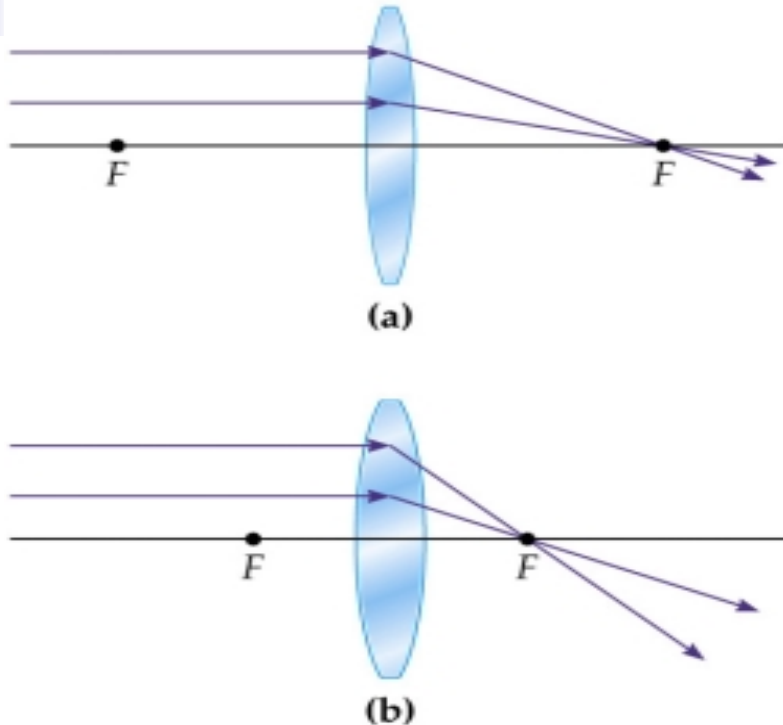


*Corrected*

**(b) Nearsightedness (myopia)**

Eye-lens can't get thin enough. Correct using a diverging lens

# Figure 27–8 Refractive power



- A lens with a shorter focal length, as in (b), has more refractive power than one with a longer focal length, as in (a), in the sense that it bends incoming rays of light more sharply.

**Refractive Power.** Lens b has more refractive power. A shorter focal length and greater number of Diopters



Problem: A near sighted person has a far point located only 220 cm from her eyes. Determine the focal length of contact lenses that will enable this person to see distant objects clearly. What is the power of these lenses.

**Solution:**

Remember a diverging lens is required to correct near sightedness.

That is, the focal length of the lens is negative.

$$d_0 = \infty \Rightarrow \frac{1}{d_0} = 0$$

$$\frac{1}{f} = \frac{1}{d_0} + \frac{1}{d_i} = \frac{1}{d_i} \Rightarrow d_i = f = -220\text{cm} = -2.2\text{m}$$

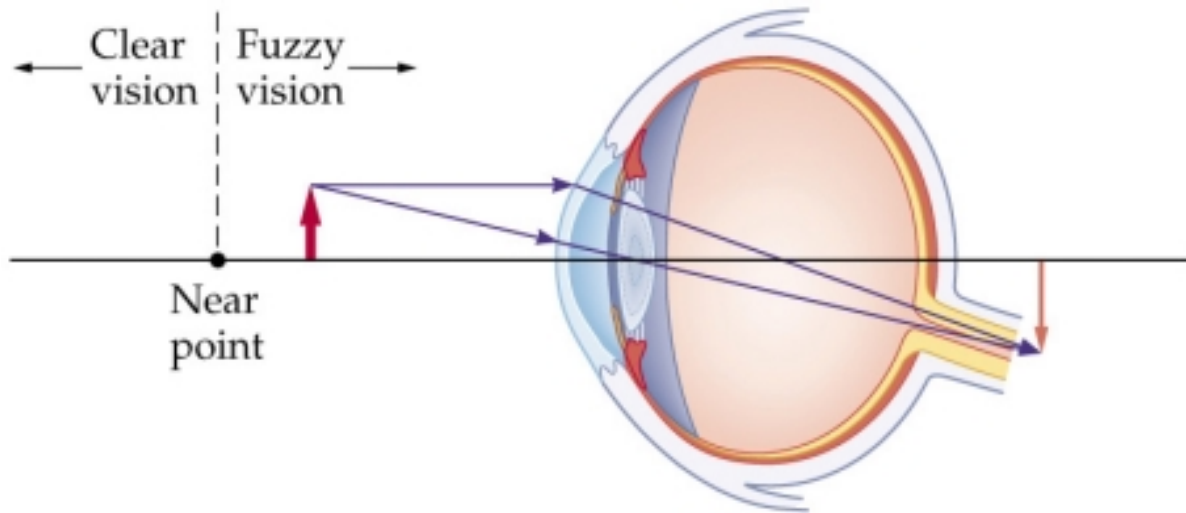
$d_i$  is negative so  $f$  is negative and the lens must be concave or diverging

$$P = \frac{1}{f(m)} = \frac{1}{-2.2} = -0.45\text{Diopter}$$

Glasses are generally worn 2 cm in front of the eye.  $f=218$  cm

See example 27.2

# Figure 27–10 Eye shape and farsightedness



- An eye that is shorter than normal can cause farsightedness. Note that an object inside the near point comes to a focus behind the retina.

When an object is nearby ( $>1-2$  m).

The eye is fully contracted, meaning that the lens has large curvature and shortest focal length.

Many people cannot see objects clearly that are close up.

They can see perfectly well objects that are distant.

The point beyond which close-up objects appear blurred is called the NEAR POINT

### **Near point**

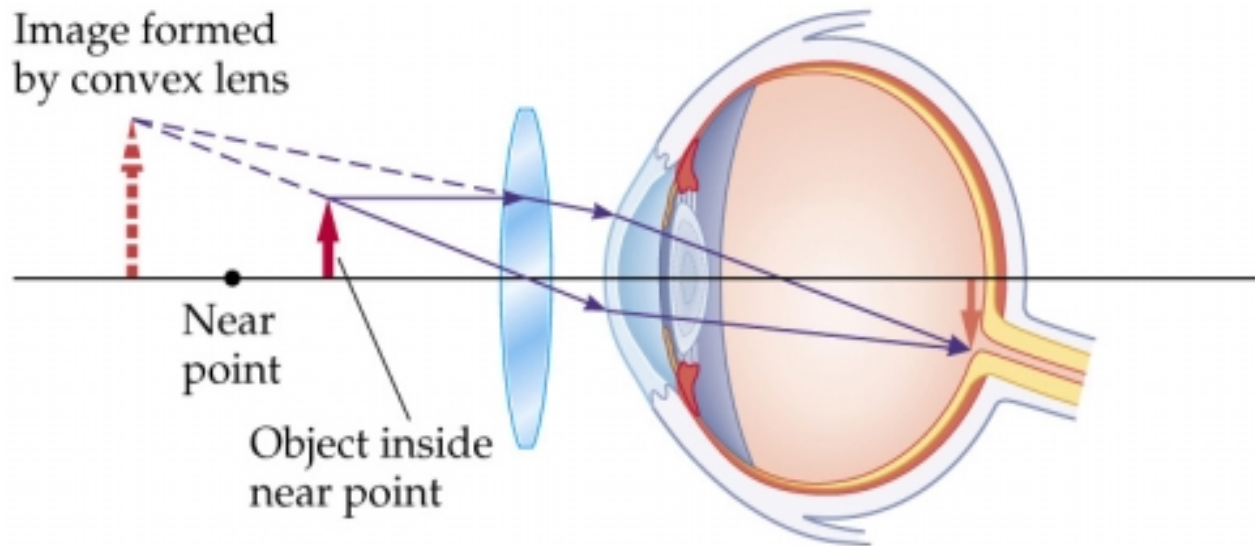
The *near point* of the eye is the point nearest the eye at which an object can be placed and still have a sharp image produced on the retina. For a normal eye, the near point is located 25cm from the eye.

The reason for this is that their eye lens cannot fully contract.

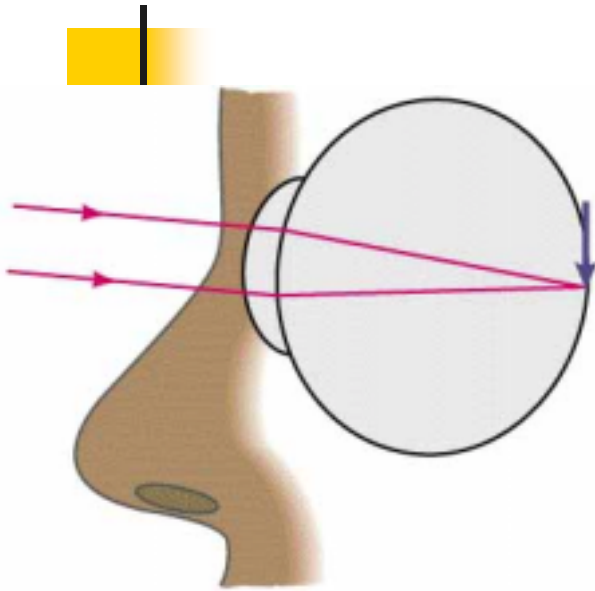
Due to problems with the muscles or the lens itself.

far-sightedness or hyperopic

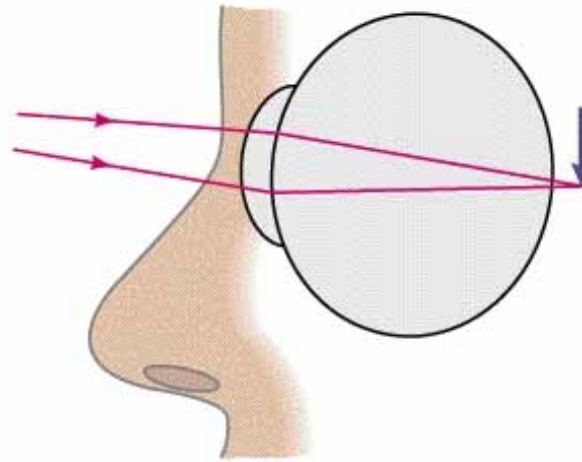
# Figure 27–11 Correcting farsightedness



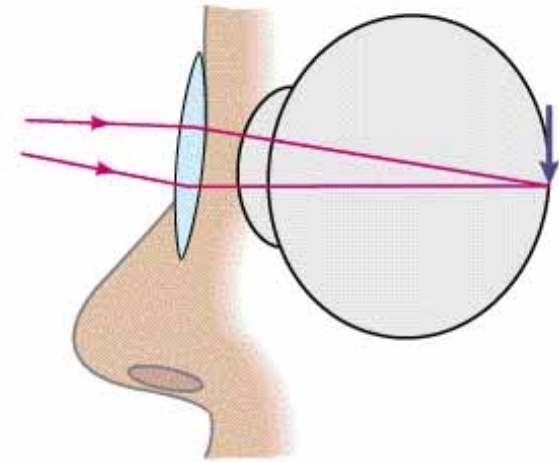
- A converging lens in front of the eye can correct for farsightedness. The convex lens focuses light from an object inside the near point to produce an image that is beyond the near point. The eye can now focus on the image of the object.



**(a) Normal**



*Uncorrected*



*Corrected*

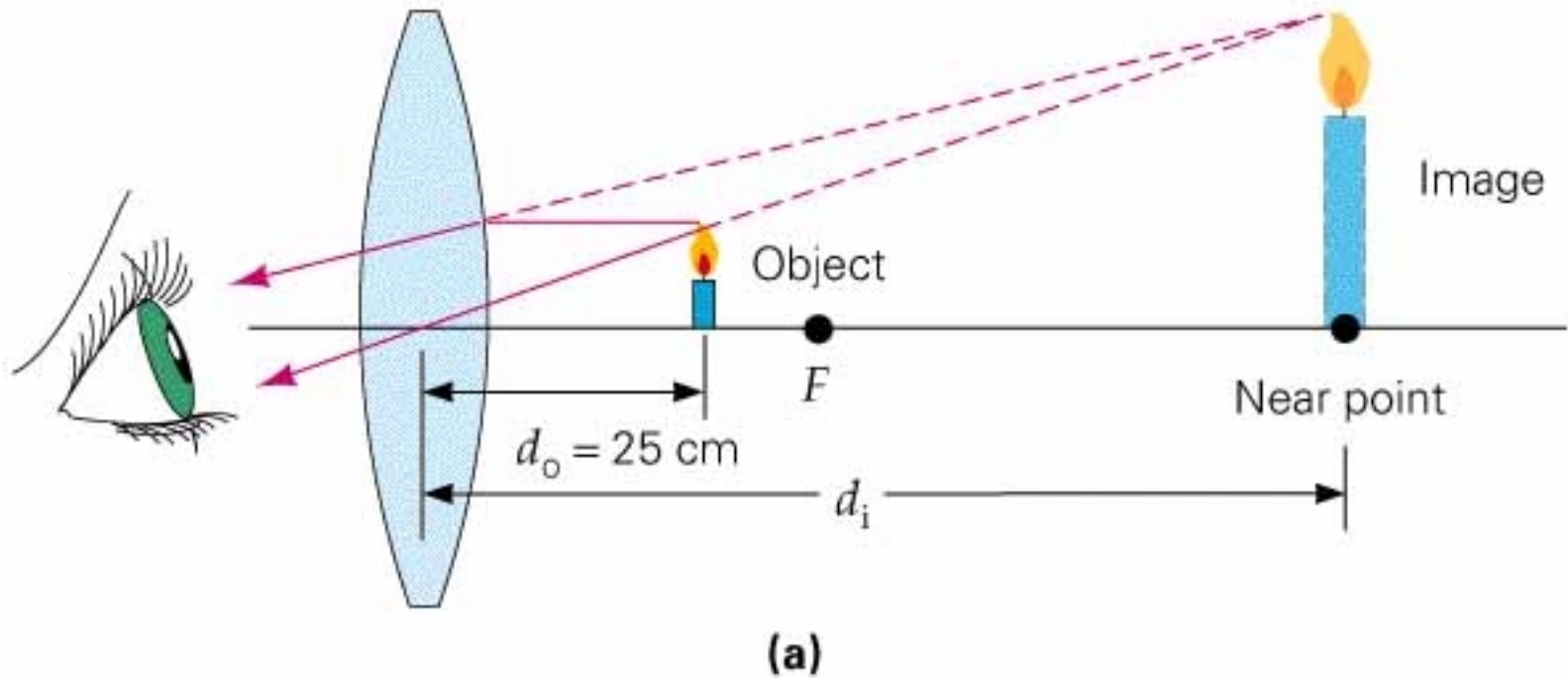
**(c) Farsightedness (hyperopia)**

Eye-lens can't get "fat" enough. Correct using a converging lens

Hyperopia-correct using a converging lens.

The lens images nearby objects further from the eye than the near point.

With the corrective aid, the **IMAGE** of the object can be seen clearly.



Problem: A far sighted person cannot see clearly objects that are closer to the eye than 73 cm. Determine the focal length of contact lenses that will enable this person to read a magazine at a distance of 25 cm.

**Solution:**

Remember a converging lens is required to correct far sightedness. That is, the focal length of the lens is positive.

Far sighted-objects close up are blurred.

Distant objects need to be imaged at most 73 cm from the eye.

$$d_o = 25\text{cm}, \quad d_i = -73\text{cm}$$

$$f = \frac{d_i d_o}{d_o + d_i} = \frac{(25)(-73)}{(25 - 73)} = +38\text{cm} \quad \text{focal length positive} \Rightarrow \text{converging lens}$$

$$P = \frac{1}{f(m)} = \frac{1}{0.38} = +2.6\text{Diopter}$$

Problem: A college professor can see objects clearly only if they are between 70 and 500 cm from his eyes. His optometrist prescribes bifocals that enable him to see distant objects clearly through the top half of the lenses and read students papers at a distance of 25 cm through the lower half. What are the powers of the top and bottom lenses.



Top:  $d_o = \infty$ ,  $d_i = -500 \text{ cm} = -5.0 \text{ m}$  (image on object side).

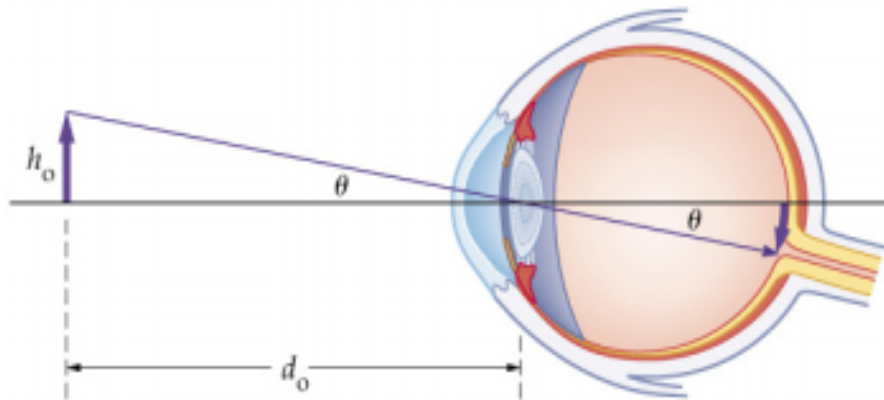
$$P = \frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i} = \frac{1}{\infty} + \frac{1}{-5.0 \text{ m}} = \boxed{-0.20 \text{ D}}.$$

Bottom:  $d_o = 25 \text{ cm} = 0.25 \text{ m}$ ,  $d_i = -70 \text{ cm} = -0.70 \text{ m}$  (image on object side).

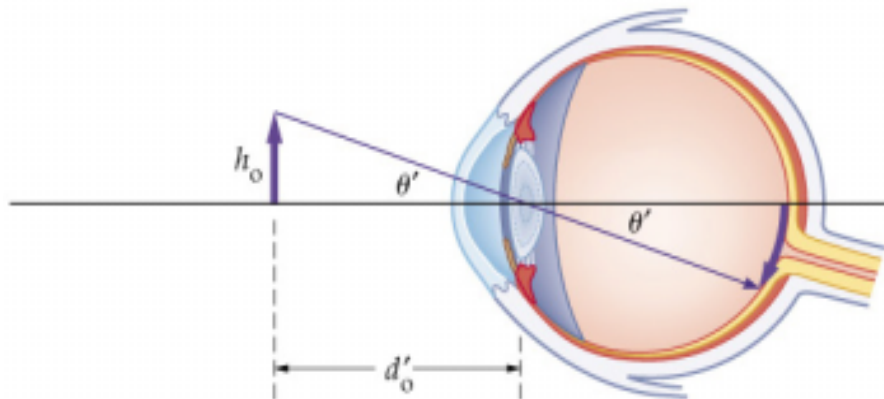
$$P = \frac{1}{0.25 \text{ m}} + \frac{1}{-0.70 \text{ m}} = \boxed{+2.6 \text{ D}}.$$



# Figure 27–12 Angular size and distance



(a)



(b)

- The angular size of an object depends on its distance from the eye, even though its height,  $h_o$ , remains the same.

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### **Angular size**

The *angular size* of an object is the angle that it subtends at the eye of the viewer. For small angles, the angular size in radians is  $h_o / d_o$ , where  $h_o$  is the height of the object and  $d_o$  is the object distance.

### **Angular magnification**

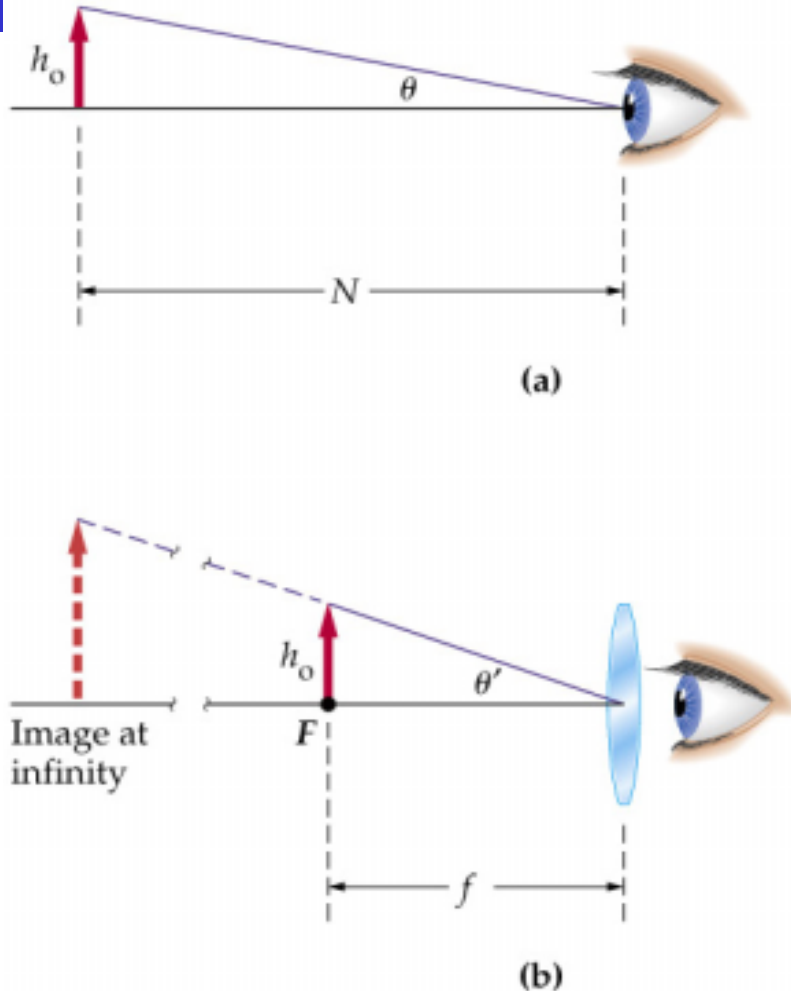
The *angular magnification*  $M$  of an optical instrument is the angular size ( $\theta'$ ) of the final image produced by the instrument divided by the reference angular size ( $\theta$ ) of the object, which is seen without the instrument:

$$M = \theta' / \theta$$

### **Magnifying glass**

A *magnifying glass* is usually a single converging lens that forms an enlarged, upright, and virtual image of an object placed at or inside the focal point of the lens. For a magnifying glass held close to the eye, the angular magnification is approximately  $(1/f - 1/d_i)N$ , where  $f$  is the focal length of the lens,  $d_i$  is the image distance, and  $N$  is the distance of the viewer's near point from the eye.

# Figure 27–13 How a simple magnifier works



(a) An object viewed with the unaided eye at the near point of the eye subtends an angle  $\eta \approx h_o/N$ . (b) With a magnifier, the object can be viewed from the distance  $f$ , which is less than  $N$ . As a result, the angular size of the object is  $\eta' \approx h_o/f$ , which is greater than  $\eta$ .