Chapter 26   Geometrical Optics

Outline

26-1 The Reflection of Light

26-2 Forming Images with a Plane Mirror

26-3 Spherical Mirror

26-4 Ray Tracing and the Mirror Equation

26-5 The Refraction of Light

26-6 Ray Tracing for Lens

26-7 Thin Lens Equation

26-5 The Refraction of Light

Refraction:

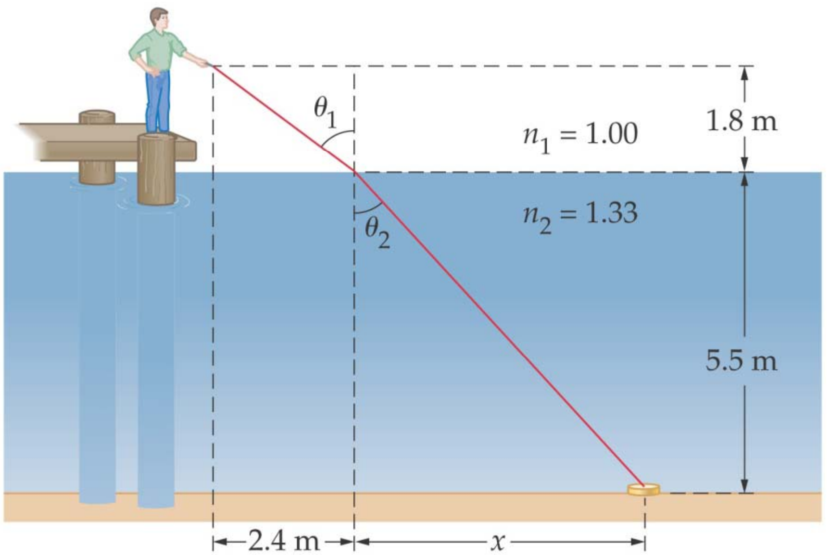
Light will change the motion direction when it travels from one medium to the other. This phenomenon is called **refraction**.

Definition of the index of refraction in a medium, n >=1

$$n = \frac{c}{v} \qquad (26-10)$$

Where, v is the speed in the medium. C is the speed in vacuum.

Refraction is caused by the difference of speeds in two mediums !



Derive the Snell's law (refraction law):

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

For the green and grey triangles, for the same wave-front we have

$$\sin\theta_1 = \frac{v_1 \Delta t}{AB}, \qquad \sin\theta_2 = \frac{v_2 \Delta t}{AB},$$

$$\text{Combining these two eqs, we have } \frac{\sin\theta_1}{v_1} = \frac{\sin\theta_2}{v_2}$$

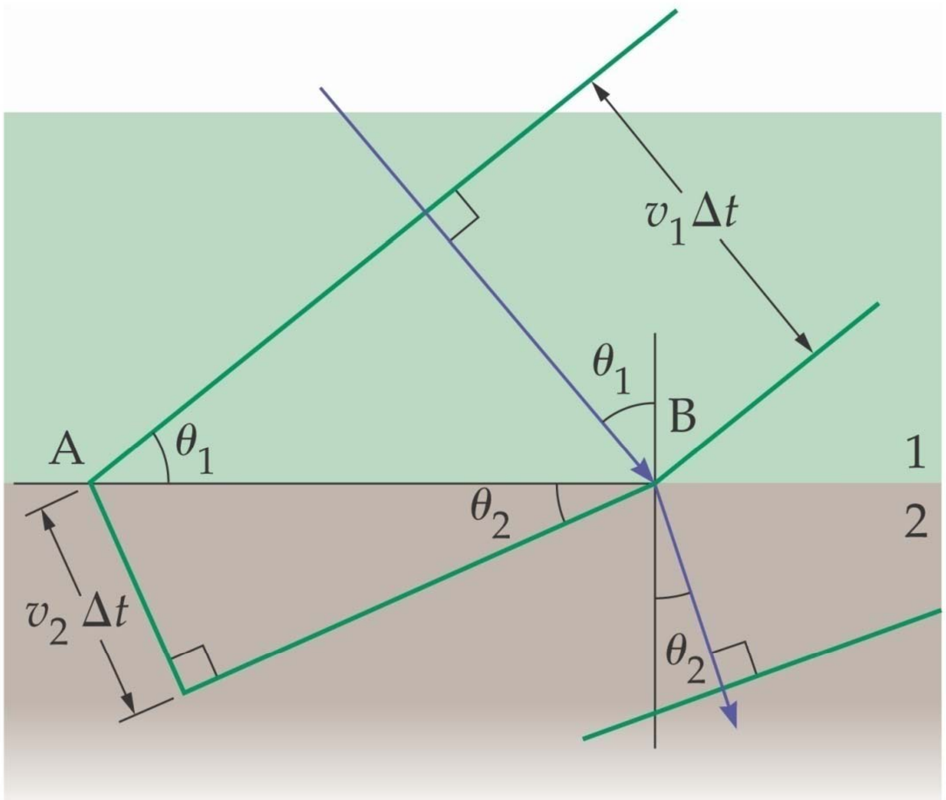


Figure 26-21
The Basic Mechanism of Refraction

That is, $$\frac{\sin\theta_1}{(c/n_1)} = \frac{\sin\theta_2}{(c/n_2)}$$

Snell's Law (Refraction Law)

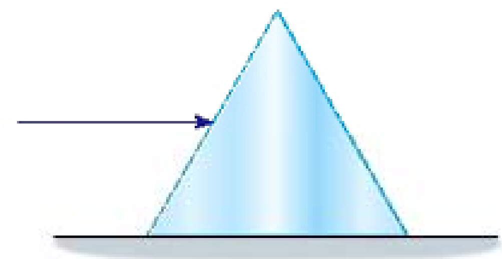
$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (26-11)$$

Exercise 26-4

A beam of light in air enter (a) water (n= 1.33) or (b) glass (n= 1.50) at an angle of 60º relative to the normal. Find the angles of refraction for each case.

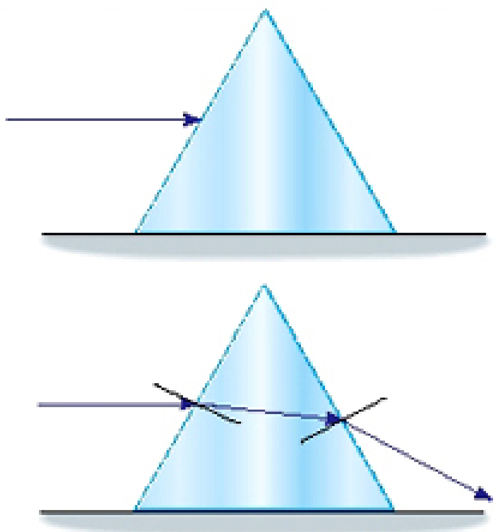
CONCEPTUAL CHECKPOINT 26–4

A horizontal ray of light encounters a prism, as shown in the first diagram. After passing through the prism, is the ray **(a)** deflected upward, **(b)** still horizontal, or **(c)** deflected downward?



CONCEPTUAL CHECKPOINT 26–4

A horizontal ray of light encounters a prism, as shown in the first diagram. After passing through the prism, is the ray **(a)** deflected upward, **(b)** still horizontal, or **(c)** deflected downward?



Reasoning and Discussion

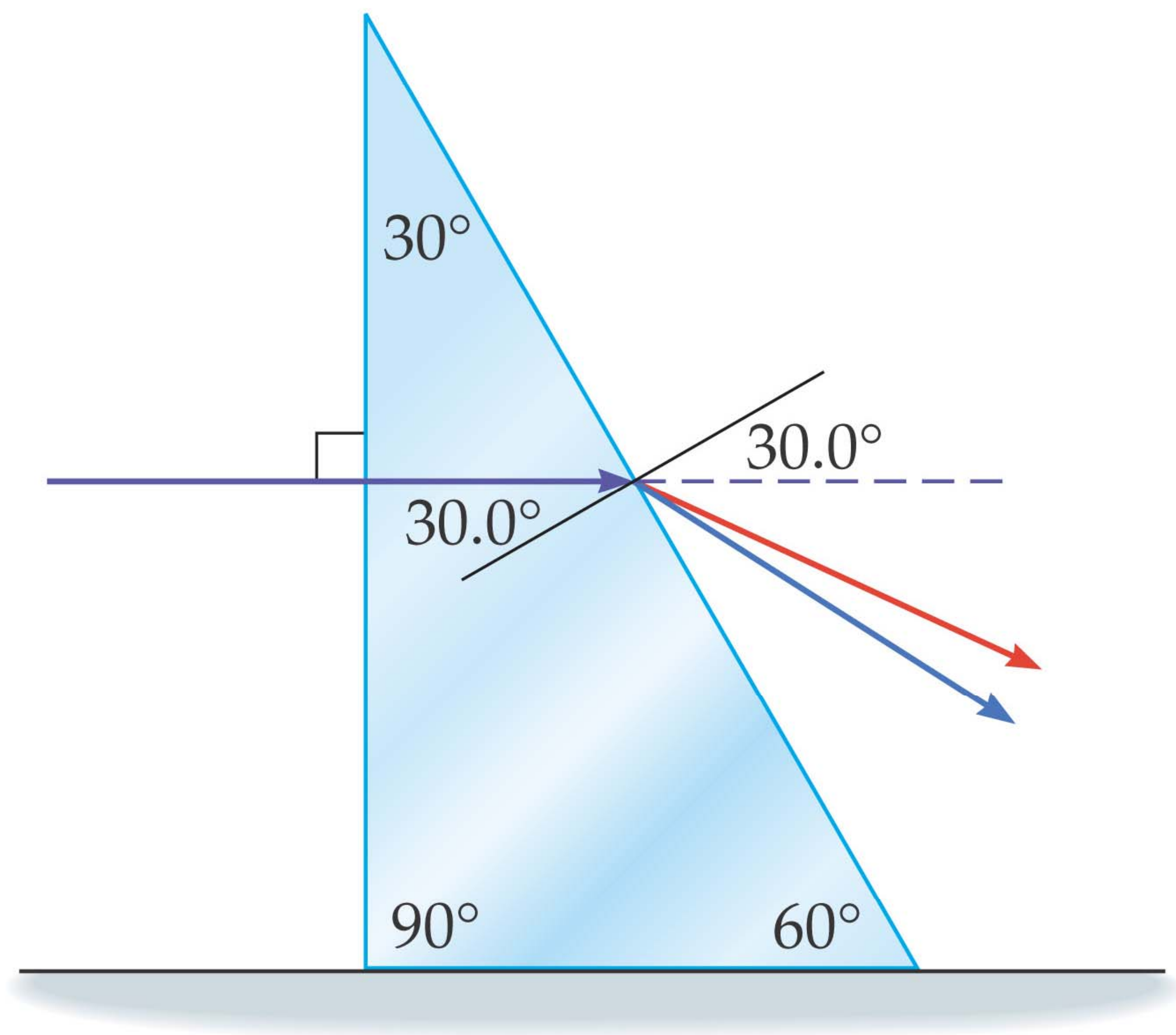
When the ray enters the prism it is bent toward the normal, which deflects it *downward*, as shown below. When it leaves through the opposite side of the prism, it is bent away from the normal. Because the sides of a prism are angled in opposite directions, however, bending away from the normal in the second refraction also causes a *downward* deflection.

The net result, then, is a downward deflection of the ray.

Answer:

(c) The ray deflects downward.

Example 26-8
Prism Dispersion, and Rainbow



Total Internal Reflection

The angel of total internal reflection can be calculated as (when $n_1 > n_2$):

$$n_1 \sin\theta_c = n_2 \sin 90° = n_2$$

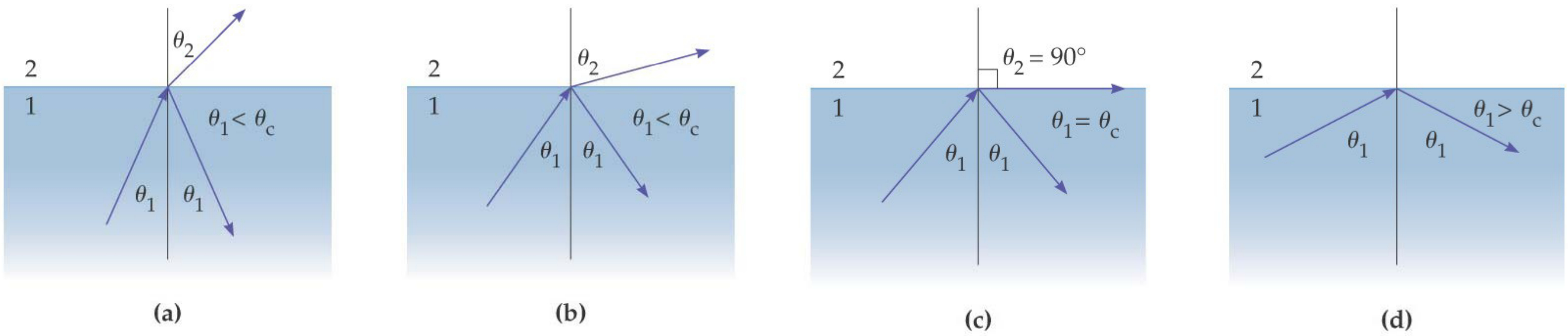


Figure 26-25
Total Internal Reflection

Critical Angle for Total Internal Reflection, θ_c

$$\sin\theta_c = \frac{n_2}{n_1} \qquad (26-12)$$

Note:

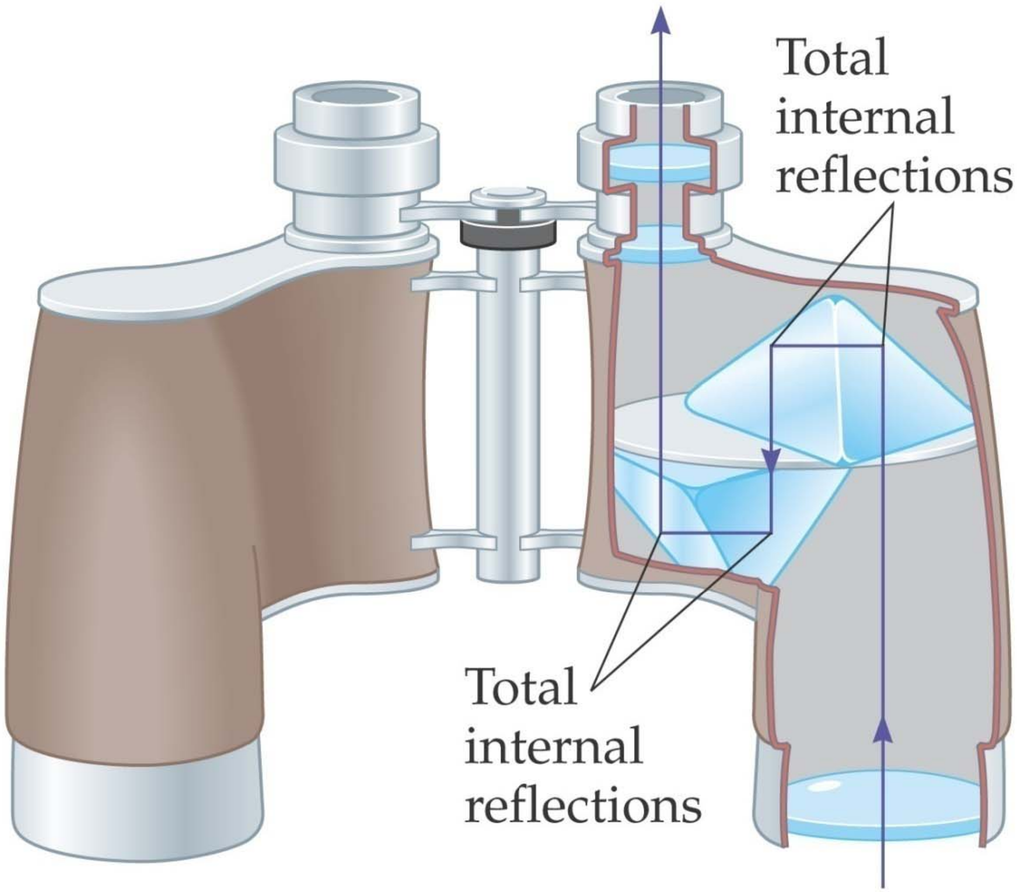
1) $n_1 > n_2$

2) Total internal reflection happens when $\theta_i >= \theta_c$

3) 100% reflection for total internal reflection: no light loss

An example of total internal reflection

Figure 26-26 Prisms and Binocular



Example 26-6

Find the critical angle for light traveling from glass (n=1.50) to (a) air (n=1.00), and (b) water (n=1.33).

Solution:

Part (a)

$$\sin\theta_c = \frac{n_2}{n_1} = \frac{1.0}{1.50}, \qquad \theta_c = 41.5°$$

Part (b)

$$\sin\theta_c = \frac{n_2}{n_1} = \frac{1.33}{1.50}, \qquad \theta_c = 62.5°$$

Total Polarization

Light reflected from a nonmetallic surface is generally polarized to some degree. At a special angle of incidence, Brewster's angle, θ_B is :

Complete Polarized reflection: Reflected light is completely polarized when the refracted beams are at a right angle with the reflection beam. The direction of polarization is parallel to the reflection surface.

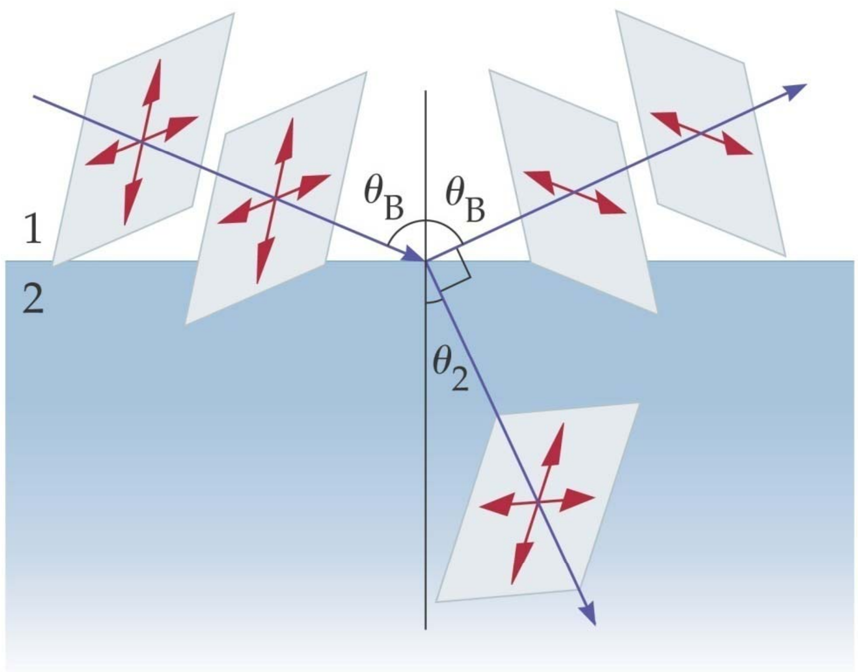


Figure 26-28
Brewster's Angle
note the 90º at Brewster angle

Derive of Brewster's angle:

According to Snell's Law,

$$n_1 \sin\theta_B = n_2 \sin\theta_2 \qquad (a)$$

Also, for complete polarization reflection, we have

$$\theta_B + 90 + \theta_2 = 180°; \quad \textit{that is} \quad \theta_B + \theta_2 = 90°$$

therefore,

$$\sin\theta_2 = \sin(90° - \theta_B) = \cos\theta_B \qquad (b)$$

Combining (a) and (b), we have

Brewster's Angle, θ_B

$$\tan\theta_B = \frac{n_2}{n_1} \qquad (26-13)$$

Exercise 26-5

Find the Brewster's angle for light reflected in the air from the top of glass (n= 1.50) coffee table.

26-6 Ray Tracing for Lenses (Find the image position)

Lens: a lens is a piece of glass or other transparent material that converges or diverges the light beams for imaging purpose.

Two kinds of lenses: Converging lens and Diverging lens (identifying by comparing the thicknesses of the center and edge)

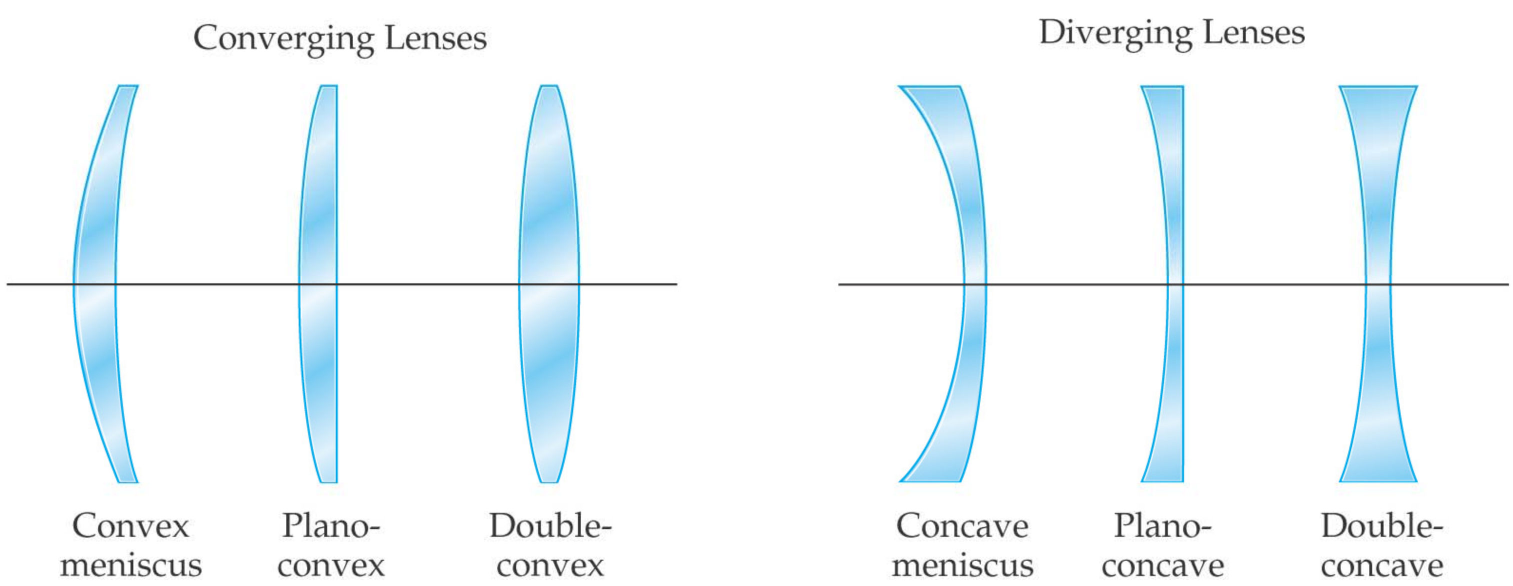


Figure 26-29
A Variety of Converging and Diverging Lenses

Figure 26-30
A Converging lens Lens Compared with a Pair of Prisms

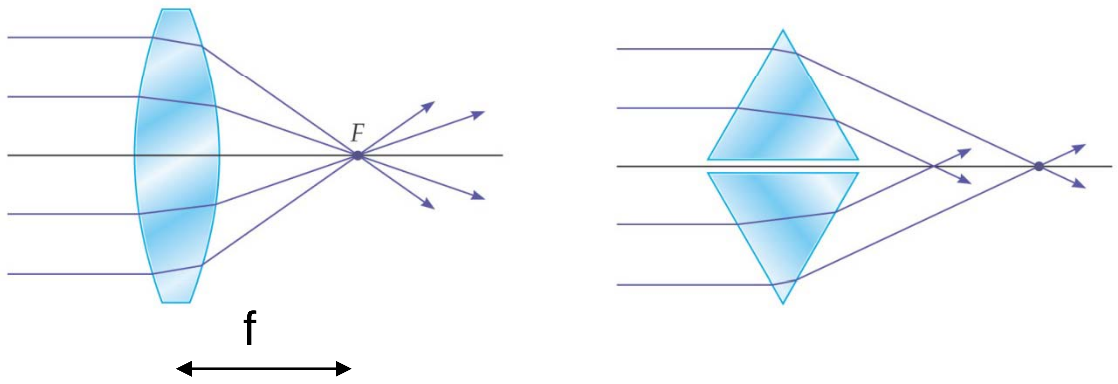
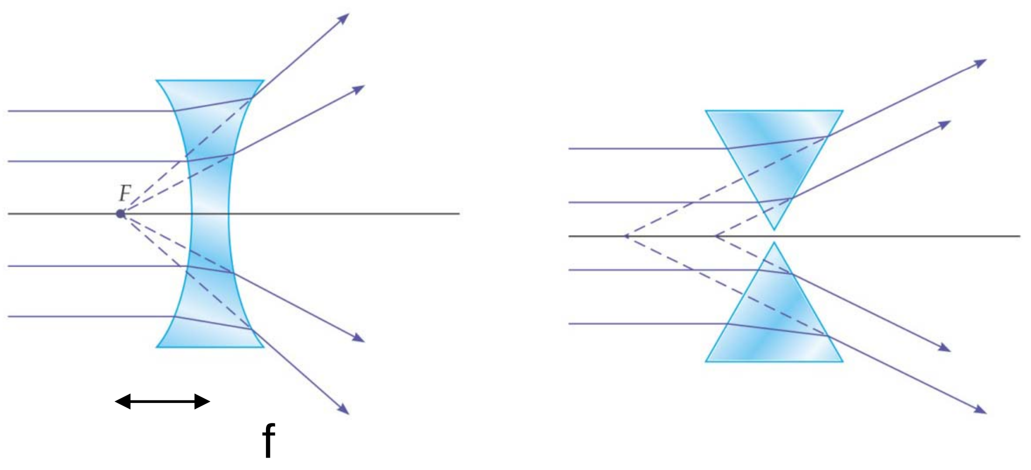


Figure 26-31
A Diverging Lens Compared with a Pair of Prisms



Ray Tracing

The P ray: the parallel ray. It is parallel to the principle axis and will pass the focal point of a lens (or extended line will pass the focus point).

The F ray: the ray that pass the focus point of a lens (or extended line pass the focus point). It is parallel to principle axis after going through the lens.

The midpoint Ray (M ray): the ray that go through the middle of a lens. It is a straight line for a thin lens.

Rays can be inversed !!!

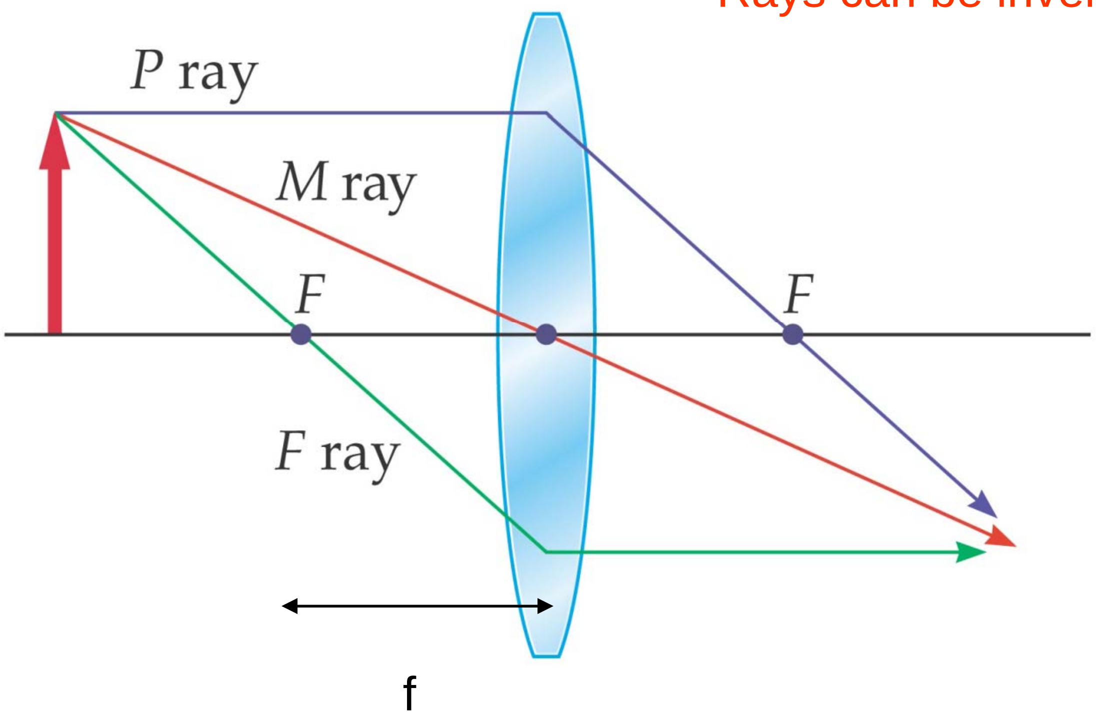


Figure 26-32
The Three Principal Rays Used for Ray Tracing with Converging Lenses

Figure 26-33
The Three Principal Rays
Used for Ray Tracing with Diverging Lenses

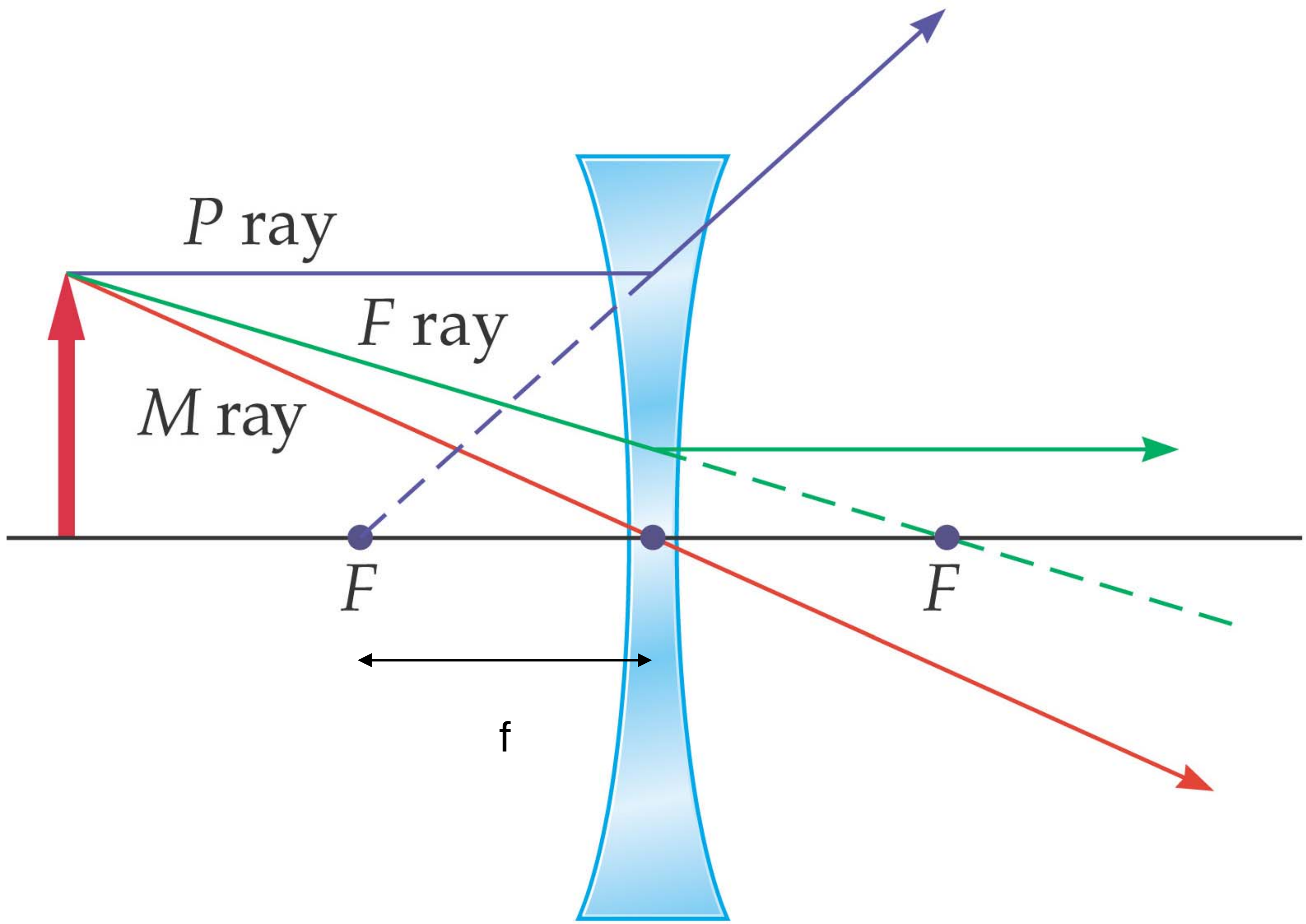


Figure 26-34
The Image Formed by a Diverging (Concave) Lens

Virtual image !

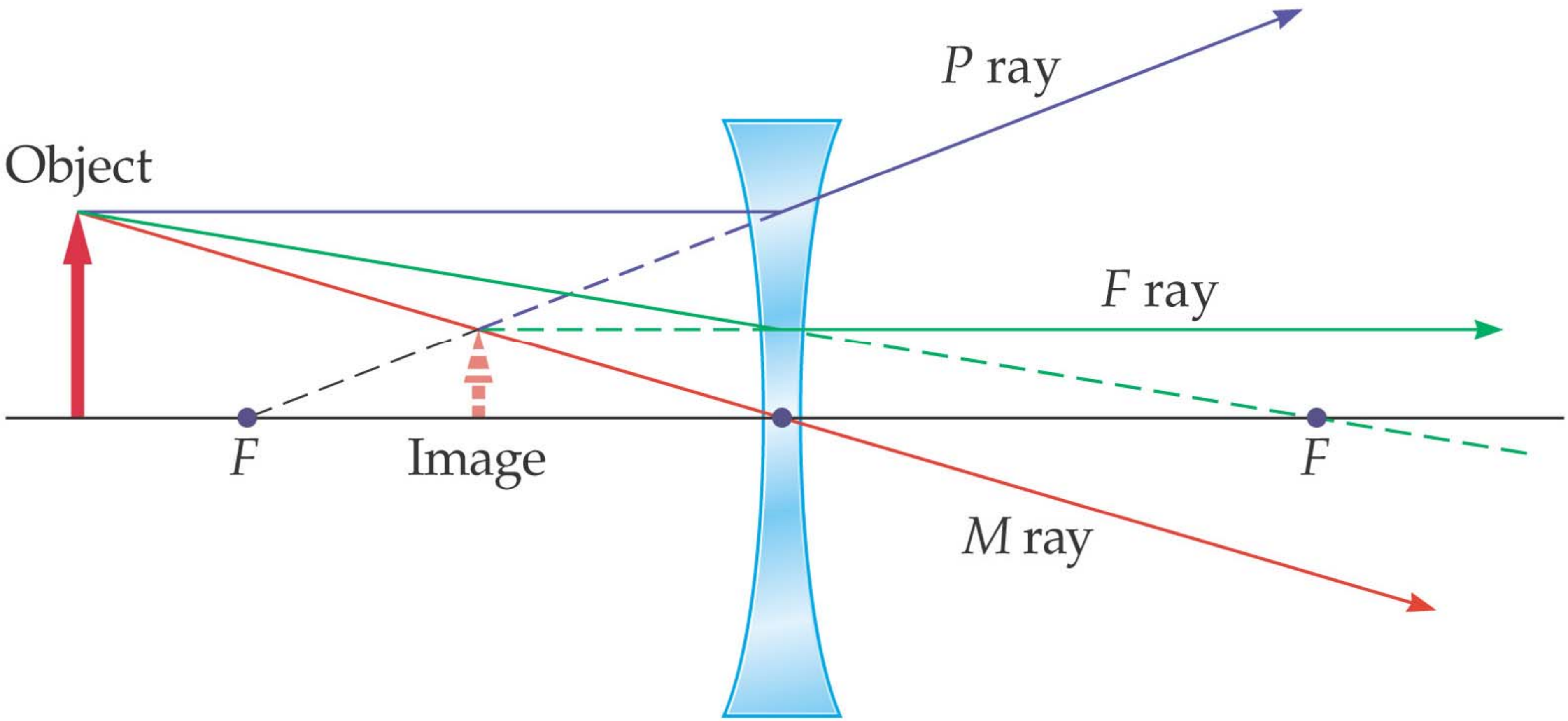
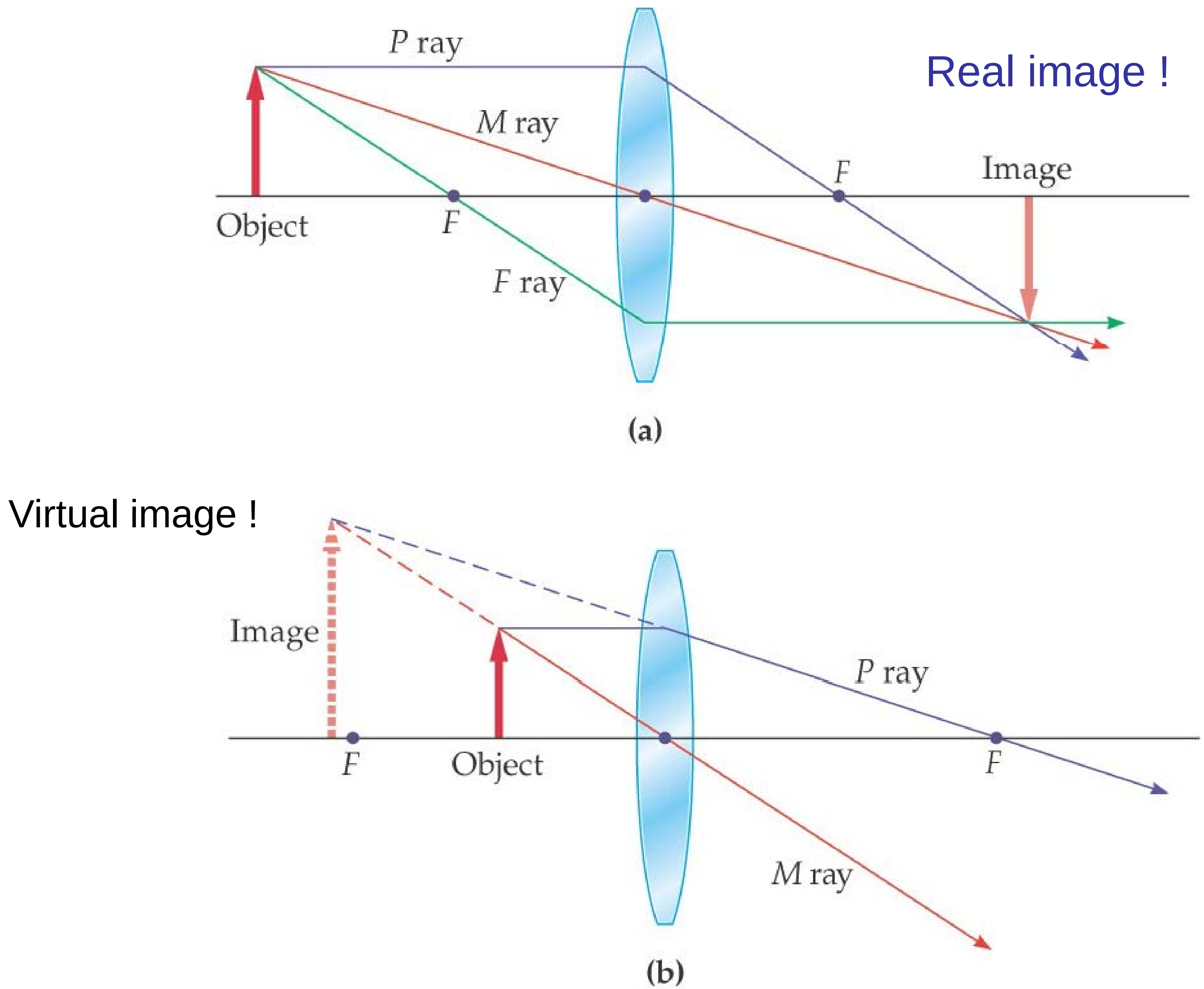
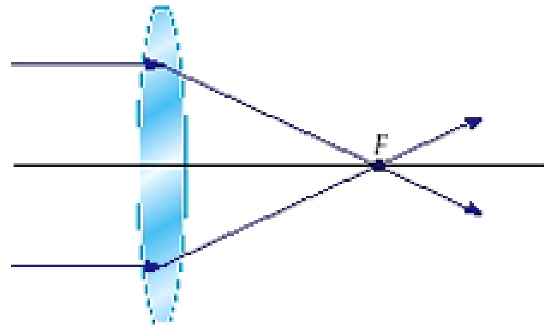


Figure 26-35 Ray Tracing for a Convex Lens:
Object at different distances.



CONCEPTUAL CHECKPOINT 26–5

The lens shown in the diagram below is generally used in air. If it is placed in water instead, does its focal length **(a)** increase, **(b)** decrease, or **(c)** stay the same?



CONCEPTUAL CHECKPOINT 26–5

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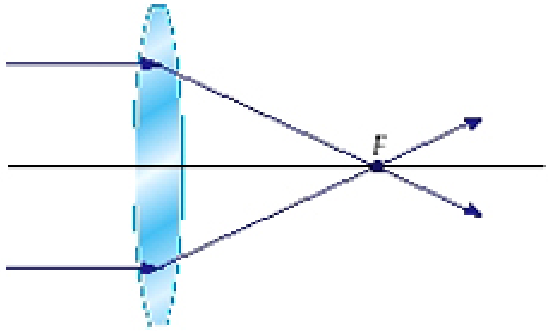
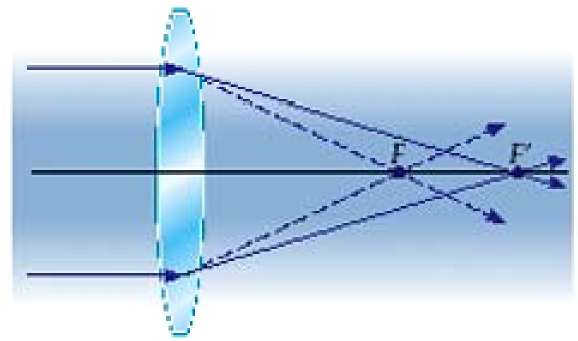


Reasoning and Discussion

In water, the difference in index of refraction between the lens and its surroundings is less than when it is in air. Therefore, recalling the discussion following Exercise 26–4, we conclude that light is bent less by the lens when it is in water, as illustrated in the next diagram.



As a result, the focal length of the lens is increased.

This explains why our vision is so affected by immersing our eyes in water—the focusing ability of the eye is greatly altered by the water, as we can see from the diagram above. On the other hand, if we wear goggles, so that our eyes are still in contact with air, our vision is normal.

Answer:

(a) The focal length increases.

Summary

Snell's Law (Refraction Law)

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 \qquad (26-11)$$

Critical Angle for Total Internal Reflection, θ_c

$$\sin\theta_c = \frac{n_2}{n_1} \qquad (26-12)$$

Brewster's Angle, θ_B

$$\tan\theta_B = \frac{n_2}{n_1} \qquad (26-13)$$

Ray Tracing (find the image position):

The P ray: the parallel ray. It is the parallel to the principle axis and will pass the focal point of a lens.

The F ray: the ray that pass the focus point of a lens.

The midpoint Ray (M ray): the ray that go through the middle of a lens.