THE BIG IDEA

Lenses change the paths of light.

A light ray bends as it enters glass and bends again as it leaves. Light passing through glass of a certain shape can form an image that appears larger, smaller, closer, or farther than the object being viewed.

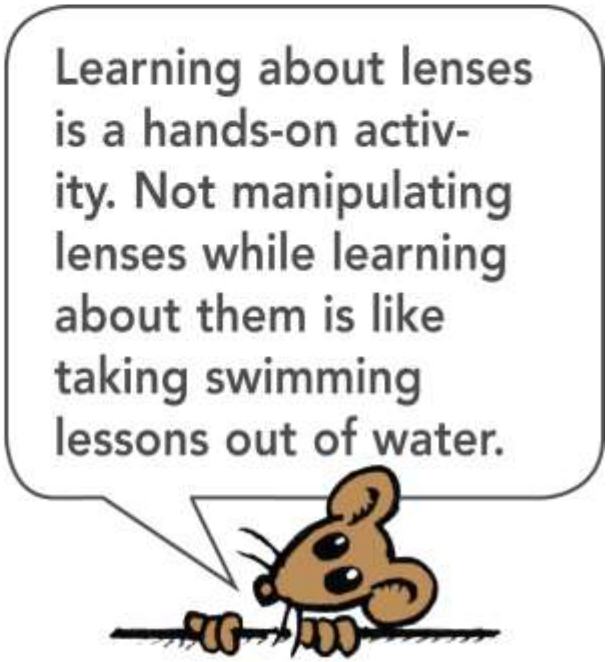
30.1 Converging and Diverging Lenses

A lens forms an image by bending parallel rays of light that pass through it.

30.1 Converging and Diverging Lenses

A **lens** is a piece of glass or plastic that refracts light.

A lens forms an image by bending parallel rays of light that pass through it.

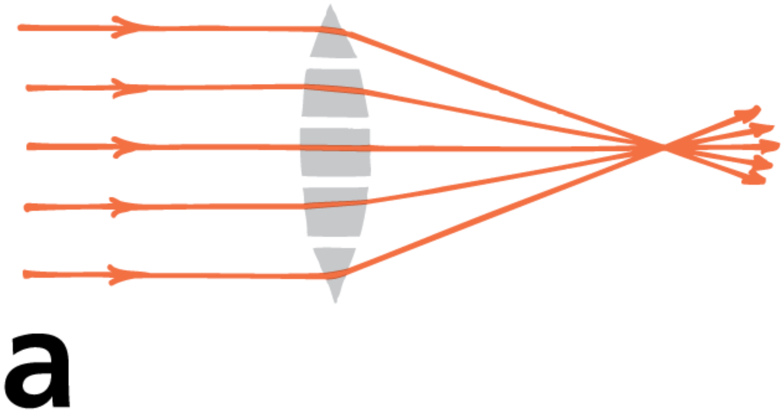


30.1 Converging and Diverging Lenses

Shapes of Lenses

The shape of a lens can be understood by considering a lens to be a large number of portions of prisms.

a. The incoming parallel rays converge to a single point.



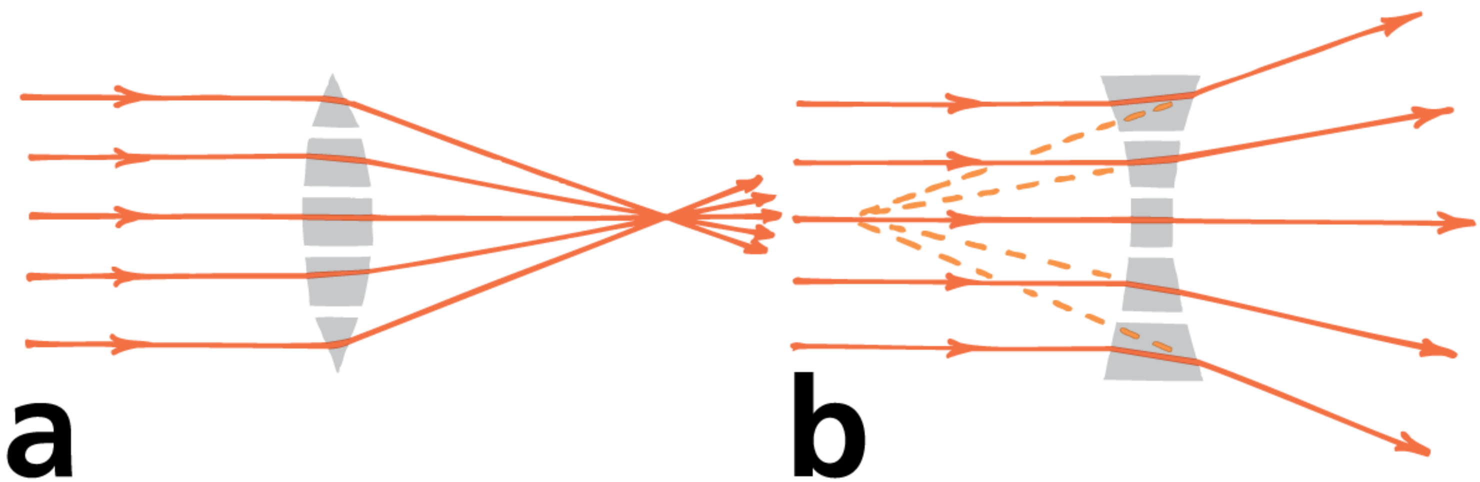
30.1 Converging and Diverging Lenses

Shapes of Lenses

The shape of a lens can be understood by considering a lens to be a large number of portions of prisms.

a. The incoming parallel rays converge to a single point.

b. The incoming rays diverge from a single point.



30.1 Converging and Diverging Lenses

The most net bending of rays occurs at the outermost prisms, for they have the greatest angle between the two refracting surfaces.

No net bending occurs in the middle “prism,” for its glass faces are parallel and rays emerge in their original direction.

30.1 Converging and Diverging Lenses

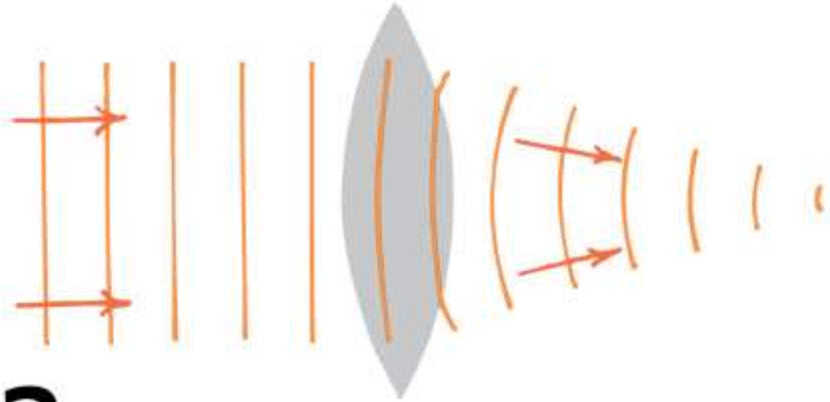
Real lenses are made not of prisms, but of solid pieces of glass or plastic with surfaces that are usually ground to a spherical shape.

- A **converging lens,** also known as a **convex lens,** is thicker in the middle, causing rays of light that are initially parallel to meet at a single point.
- A **diverging lens,** also known as a **concave lens,** is thinner in the middle, causing the rays of light to appear to originate from a single point.

30.1 Converging and Diverging Lenses

Wave fronts travel more slowly in glass than in air.

a. In the converging lens, the wave fronts are retarded more through the center of the lens, and the light converges.



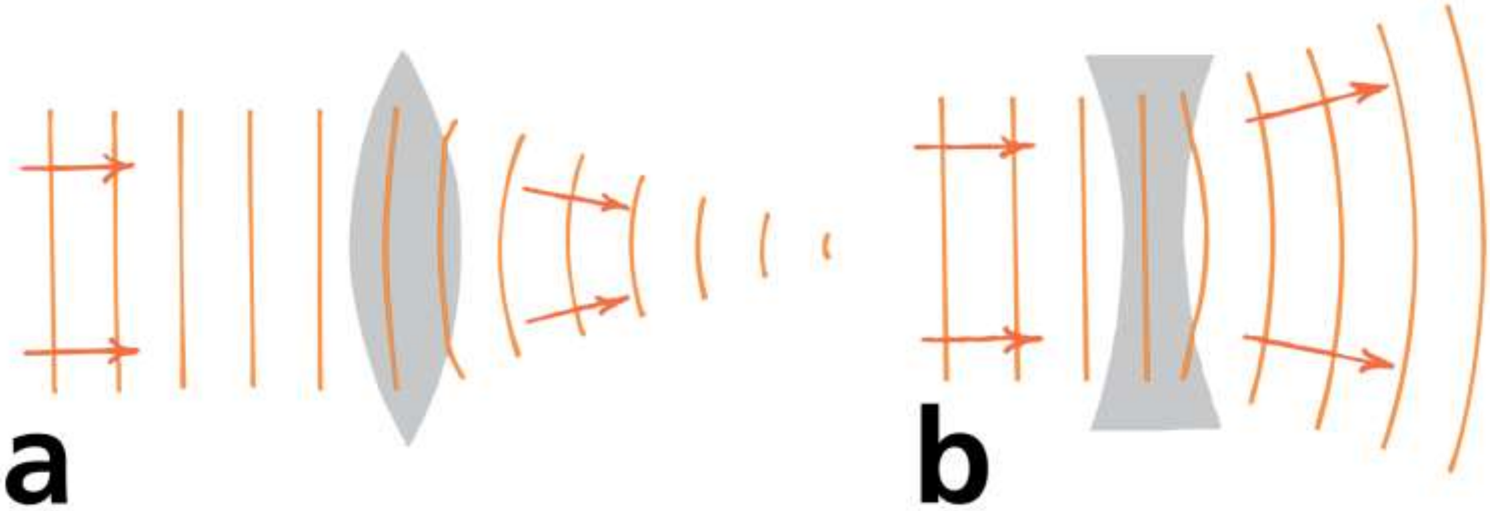
a

30.1 Converging and Diverging Lenses

Wave fronts travel more slowly in glass than in air.

a. In the converging lens, the wave fronts are retarded more through the center of the lens, and the light converges.

b. In the diverging lens, the waves are retarded more at the edges, and the light diverges.



30.1 Converging and Diverging Lenses

Key Features of Lenses

The **principal axis** of a lens is the line joining the centers of curvature of its surfaces.

For a converging lens, the **focal point** is the point at which a beam of light parallel to the principal axis converges.

The **focal plane** is a plane perpendicular to the principal axis that passes through either focal point of a lens.

30.1 Converging and Diverging Lenses

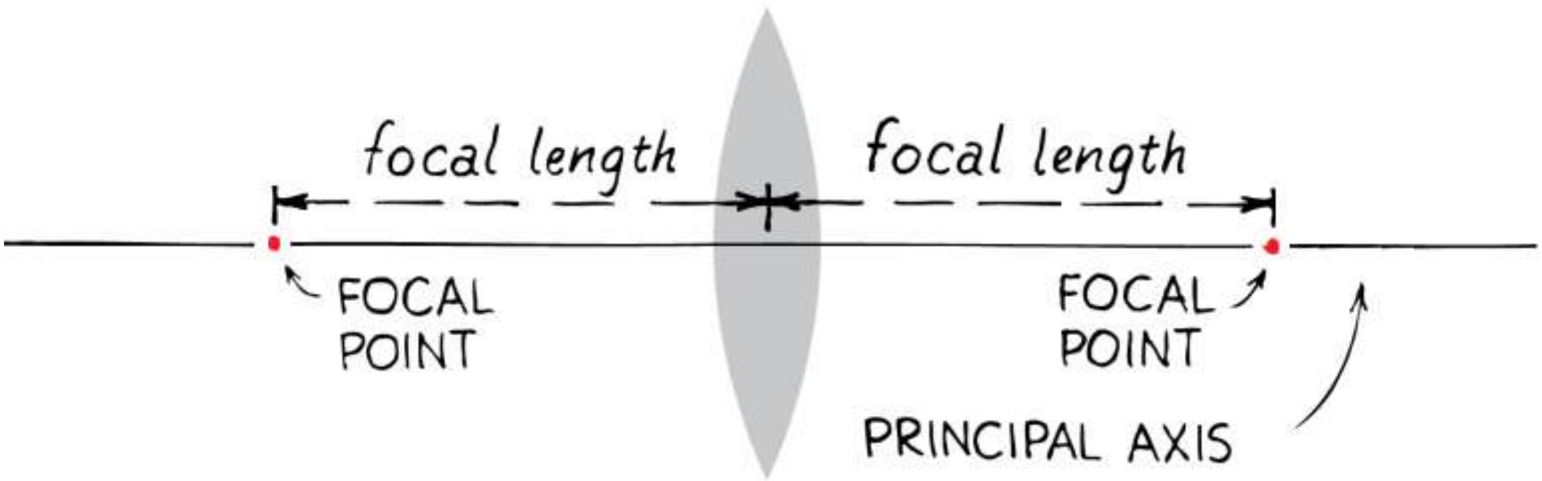
For a converging lens, any incident parallel beam converges to a point on the focal plane.

A lens has two focal points and two focal planes.

When the lens of a camera is set for distant objects, the film is in the focal plane behind the lens in the camera.

30.1 Converging and Diverging Lenses

The key features of a converging lens include the principal axis, focal point, and focal plane.



30.1 Converging and Diverging Lenses

For a diverging lens, an incident beam of light parallel to the principal axis is diverged so that the light appears to originate from a single point.

The **focal length** of a lens, whether converging or diverging, is the distance between the center of the lens and its focal point.

When the lens is thin, the focal lengths on either side are equal, even when the curvatures on the two sides are not.

30.1 Converging and Diverging Lenses

CONCEPT CHECK

How does a lens form an image?

30.2 Image Formation by a Lens

The type of image formed by a lens depends on the shape of the lens and the position of the object.

30.2 Image Formation by a Lens

With unaided vision, a far away object is seen through a relatively small angle of view.

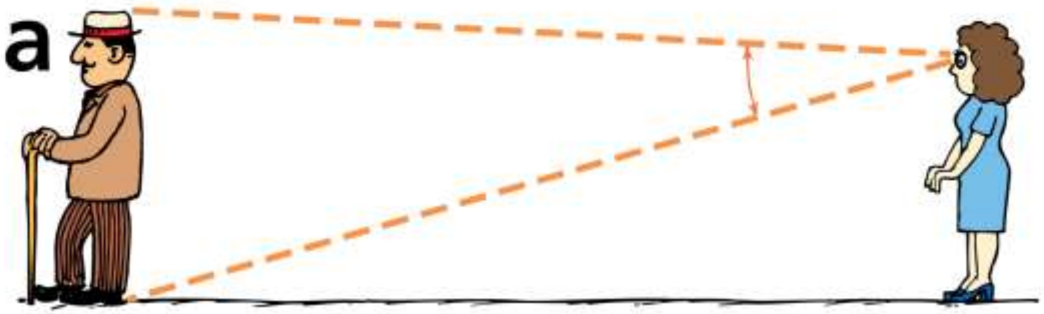
When you are closer, the object is seen through a larger angle of view.

Magnification occurs when the use of a lens allows an image to be observed through a wider angle than would be observed without the lens.

A magnifying glass is simply a converging lens that increases the angle of view and allows more detail to be seen.

30.2 Image Formation by a Lens

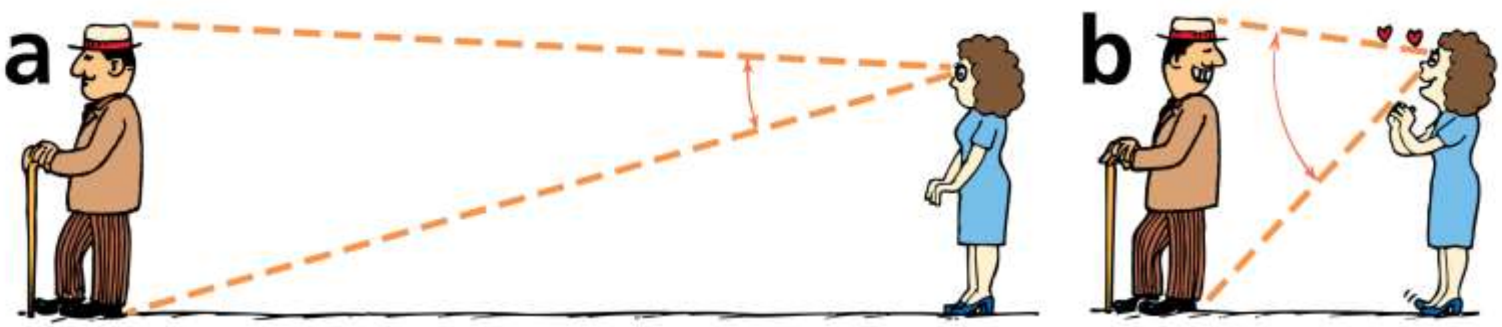
a. A distant object is viewed through a narrow angle.



30.2 Image Formation by a Lens

a. A distant object is viewed through a narrow angle.

b. When the same object is viewed through a wide angle, more detail is seen.



30.2 Image Formation by a Lens

Images Formed by Converging Lenses

When you use a magnifying glass, you hold it close to the object you wish to see magnified.

A converging lens will magnify only when the object is between the focal point and the lens.

The magnified image will be farther from the lens than the object and right-side up.

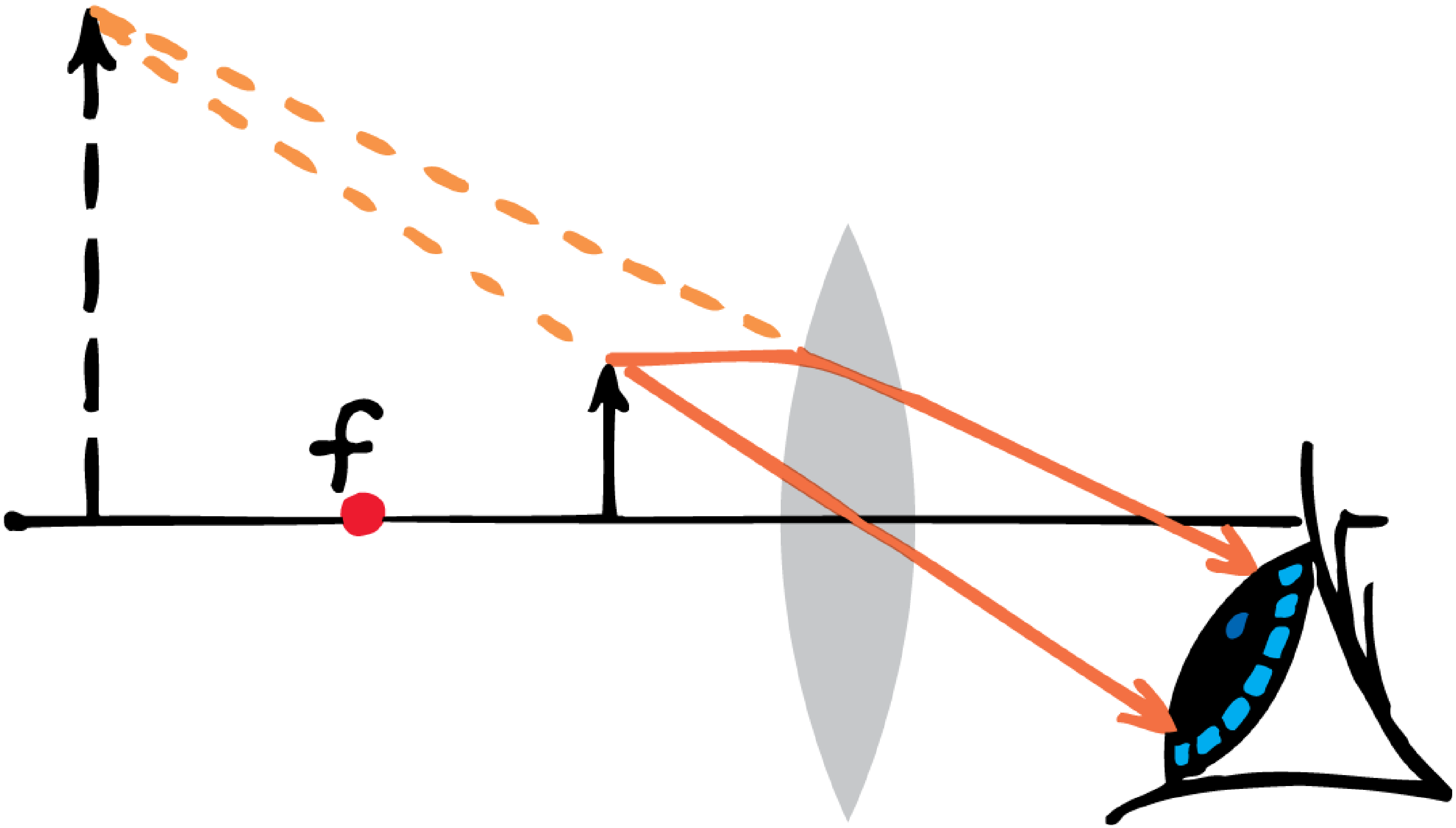
30.2 Image Formation by a Lens

If a screen were placed at the image distance, no image would appear on the screen because no light is actually directed to the image position.

The rays that reach your eye, however, behave *as if* they came from the image position, so the image is a virtual image.

30.2 Image Formation by a Lens

A converging lens can be used as a magnifying glass to produce a virtual image of a nearby object.



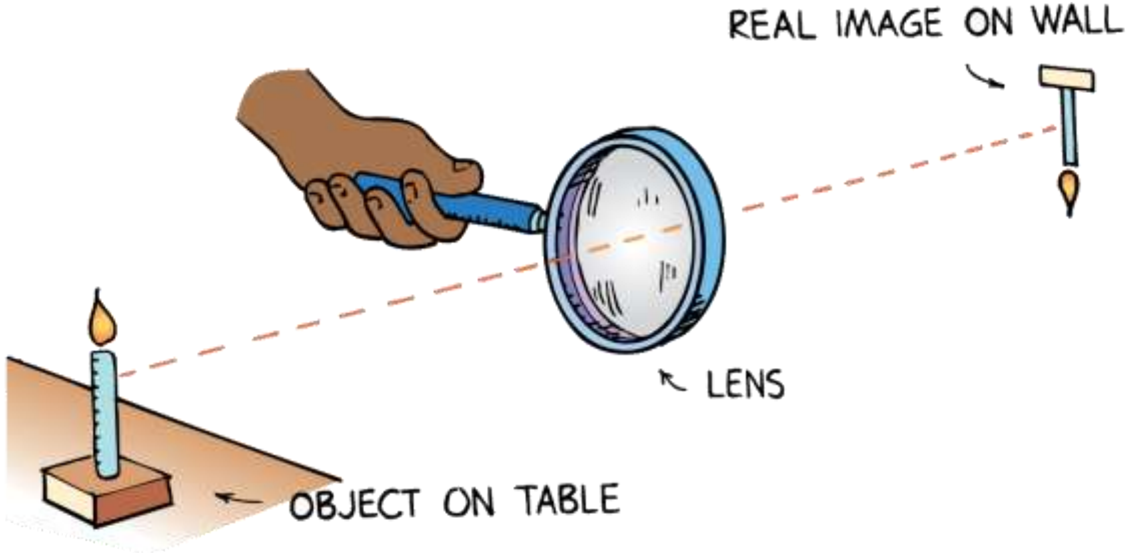
30.2 Image Formation by a Lens

When the object is beyond the focal point of a converging lens, light converges and can be focused on a screen.

An image formed by converging light is called a **real image.**

A real image formed by a single converging lens is upside down.

Converging lenses are used for projecting pictures on a screen.



30.2 Image Formation by a Lens

Images Formed by Diverging Lenses

When a diverging lens is used alone, the image is always virtual, right-side up, and smaller than the object.

It makes no difference how far or how near the object is.

A diverging lens is often used for the viewfinder on a camera.

30.2 Image Formation by a Lens

think!

Why is the greater part of the photograph out of focus?

30.2 Image Formation by a Lens

think!

Why is the greater part of the photograph out of focus?

Answer:

Both Jamie and his cat and the virtual image of Jamie and his cat are “objects” for the lens of the camera that took this photograph. Since the objects are at different distances from the camera lens, their respective images are at different distances with respect to the film in the camera. So only one can be brought into focus.

30.2 Image Formation by a Lens

CONCEPT CHECK

What determines the type of image formed by a lens?

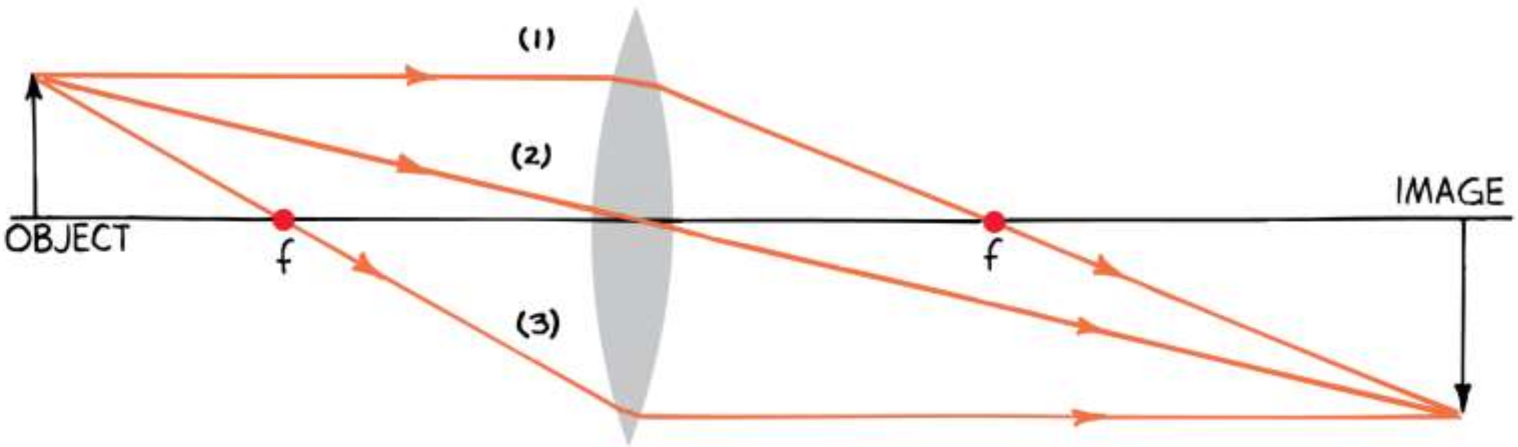
30.3 Constructing Images Through Ray Diagrams

The size and location of the object, its distance from the center of the lens, and the focal length of the lens are used to construct a ray diagram.

30.3 Constructing Images Through Ray Diagrams

Ray diagrams show the principal rays that can be used to determine the size and location of an image.

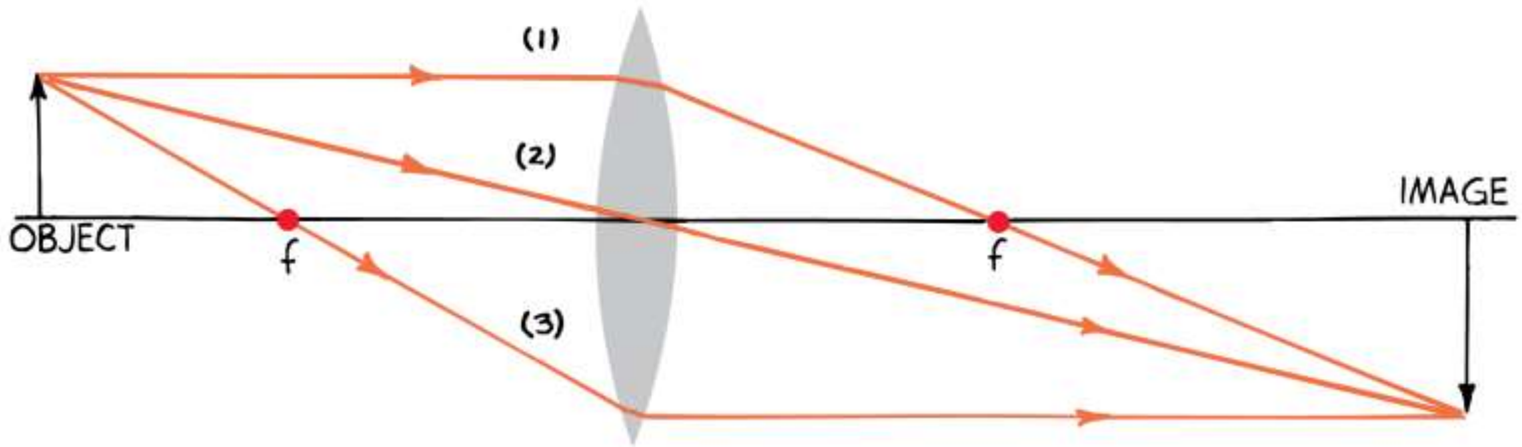
The size and location of the object, distance from the center of the lens, and the focal length are used to construct the ray diagram.



30.3 Constructing Images Through Ray Diagrams

An arrow is used to represent the object.

For simplicity, one end of the object is placed right on the principal axis.



30.3 Constructing Images Through Ray Diagrams

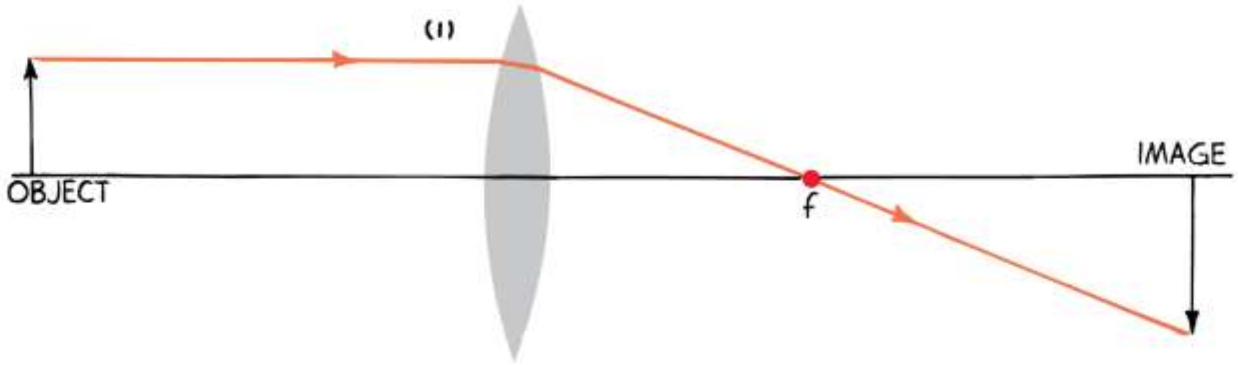
The Three Principal Rays

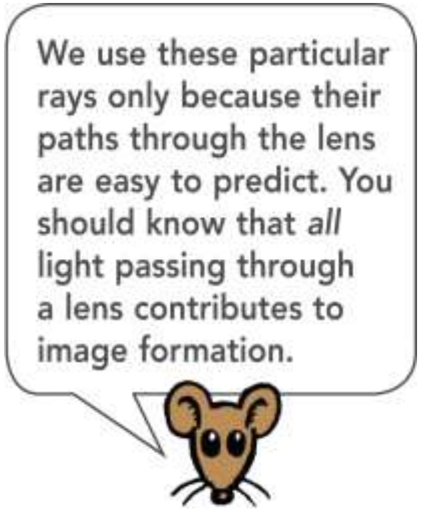
To locate the position of the image, you only have to know the paths of two rays from a point on the object.

Any point except for the point on the principal axis will work, but it is customary to choose a point at the tip of the arrow.

30.3 Constructing Images Through Ray Diagrams

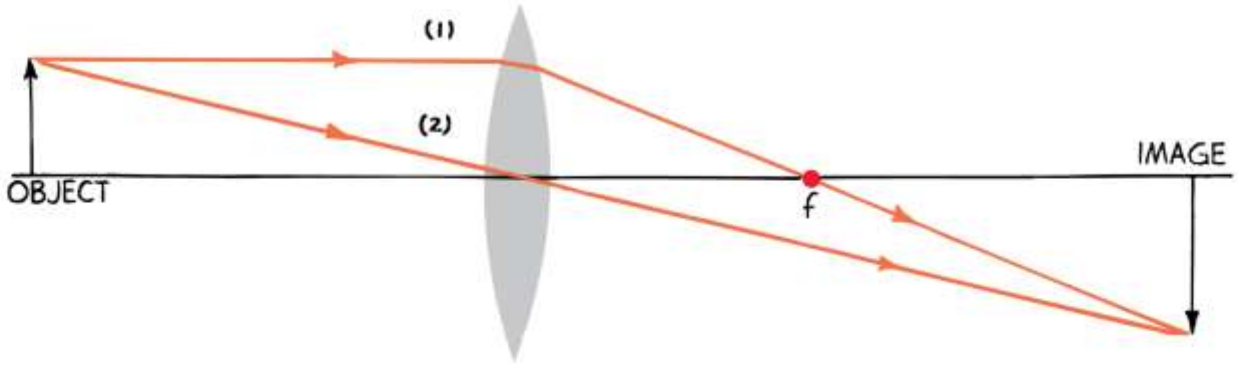
- A ray parallel to the principal axis will be refracted by the lens to the focal point.

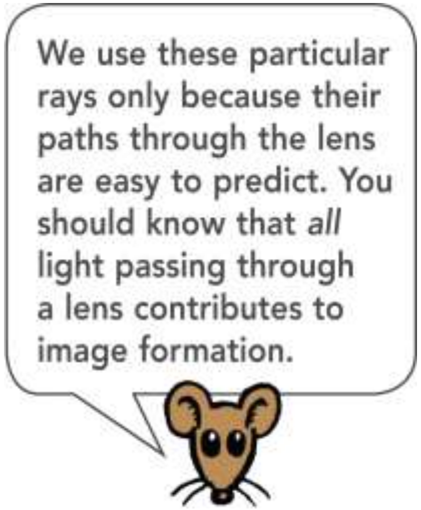




30.3 Constructing Images Through Ray Diagrams

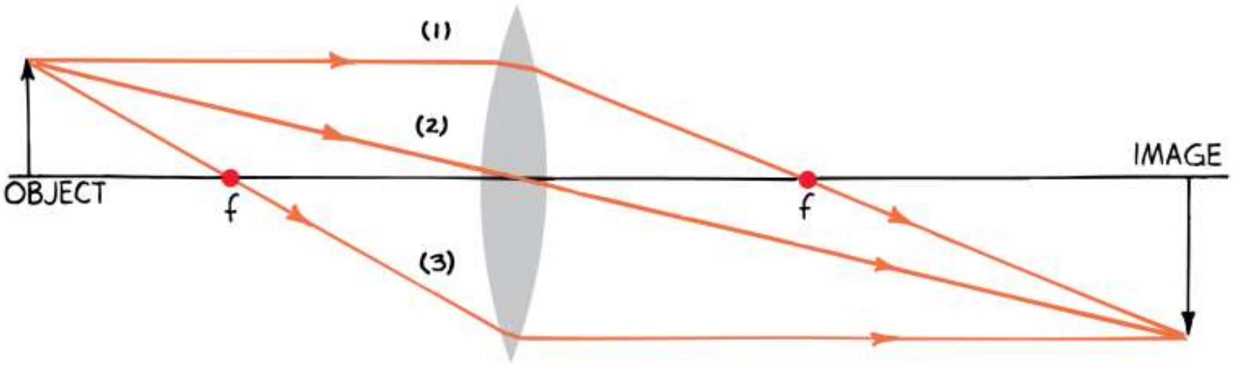
- A ray parallel to the principal axis will be refracted by the lens to the focal point.
- A ray will pass through the center with no appreciable change in direction.

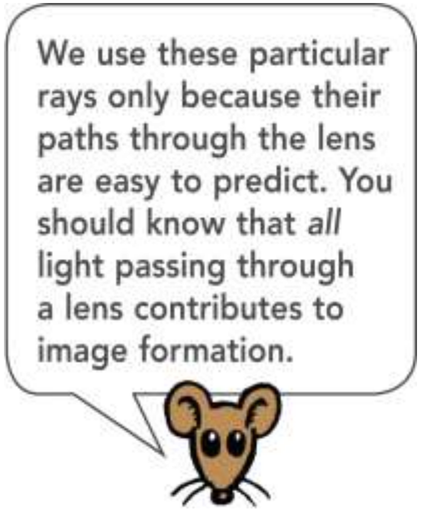




30.3 Constructing Images Through Ray Diagrams

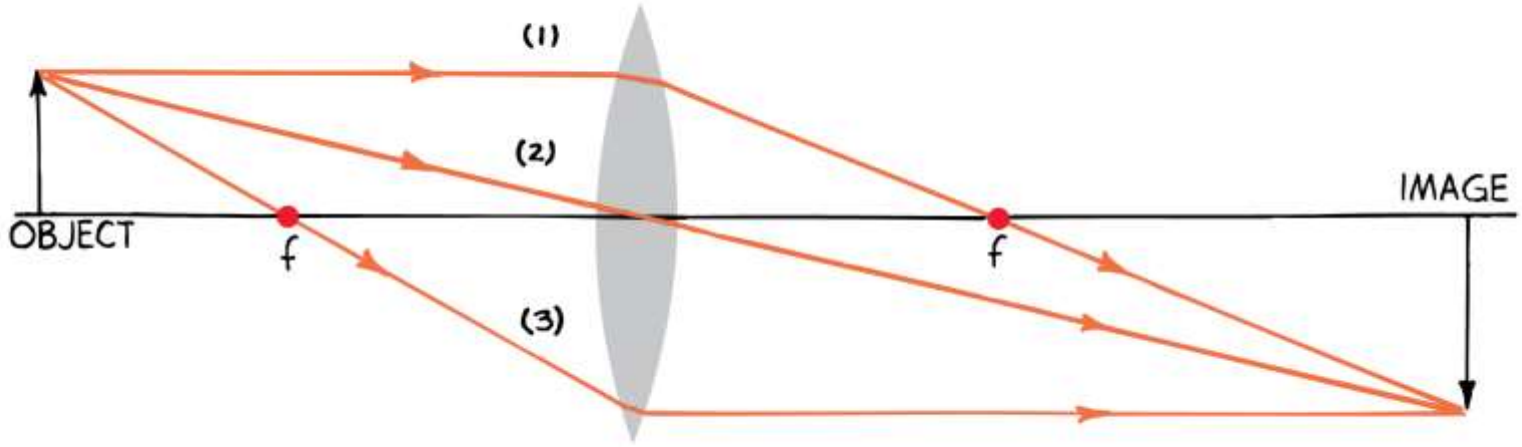
- A ray parallel to the principal axis will be refracted by the lens to the focal point.
- A ray will pass through the center with no appreciable change in direction.
- A ray that passes through the focal point in front of the lens emerges from the lens parallel to the principal axis.





30.3 Constructing Images Through Ray Diagrams

The image is located where the three rays intersect. Any two of these three rays is sufficient to locate the relative size and location of the image.

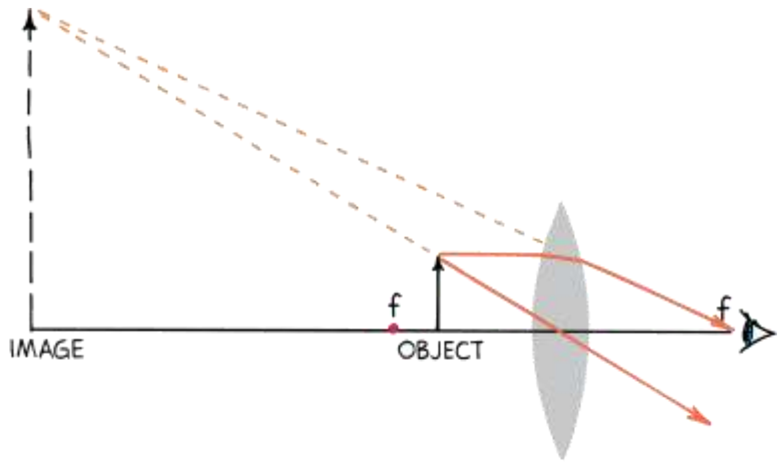


30.3 Constructing Images Through Ray Diagrams

If the distance from the lens to the object is less than the focal length, the rays diverge as they leave the lens.

The rays of light appear to come from a point in front of the lens.

The location of the image is found by extending the rays backward to the point where they converge.



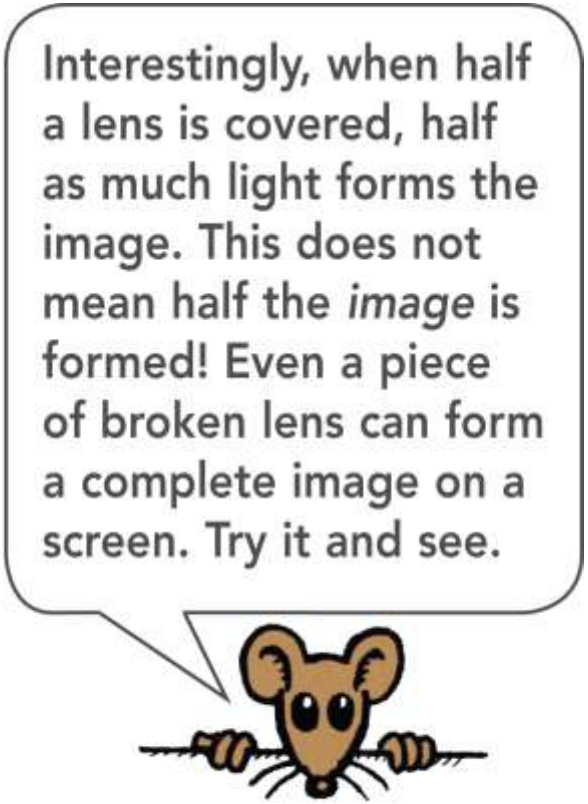
30.3 Constructing Images Through Ray Diagrams

The virtual image that is formed is magnified and right-side up.

30.3 Constructing Images Through Ray Diagrams

The three rays useful for the construction of a ray diagram are:

1. A ray parallel to the principal axis that passes through the focal point on the opposite side.
2. A ray passing through the center of the lens that is undeflected.
3. A ray through the focal point in front of the lens that emerges parallel to the principal axis after refraction by the lens.

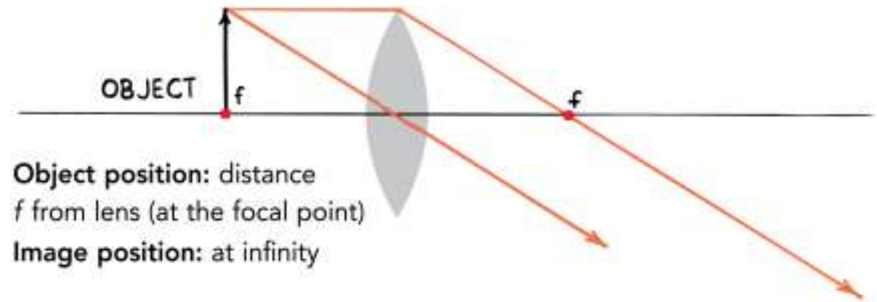


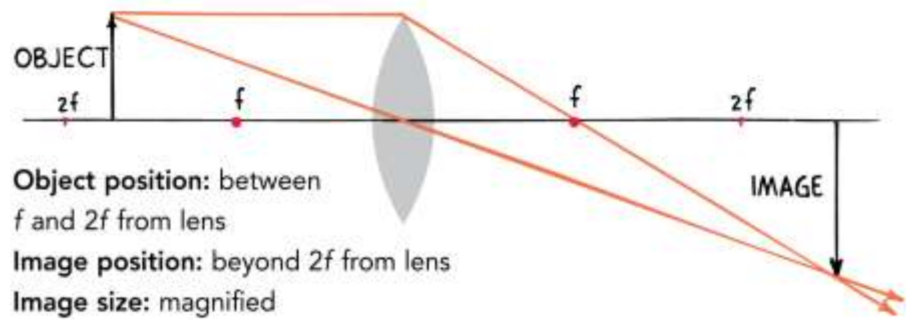
30.3 Constructing Images Through Ray Diagrams

Ray Diagrams for Converging and Diverging Lenses

For a converging lens, as an object, initially at the focal point, is moved away from the lens along the principal axis, the image size and distance from the lens changes.

For a converging lens, if the object is not located between the focal point and the lens, the images that are formed are real and inverted.





30.3 Constructing Images Through Ray Diagrams

The method of drawing ray diagrams applies to diverging lenses.

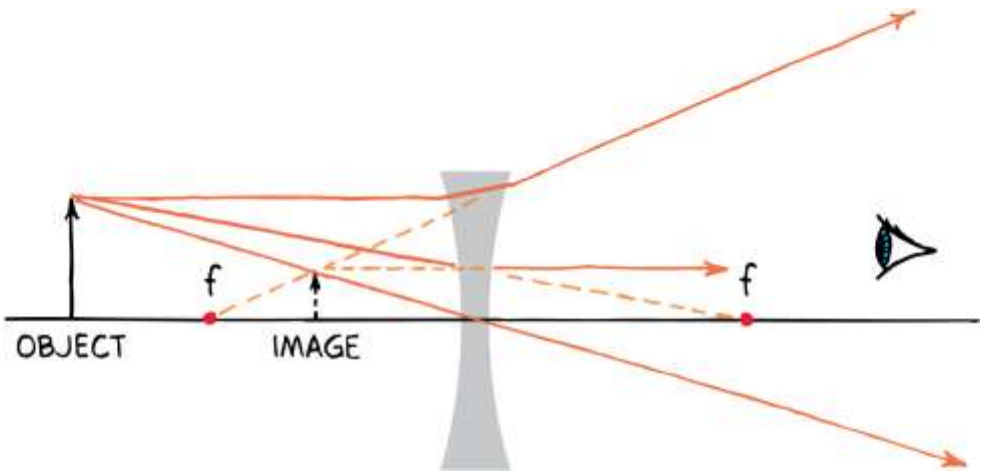
- A ray parallel to the principal axis from the tip of the arrow will be bent by the lens as if it had come from the focal point.
- A ray through the center goes straight through.
- A ray heading for the focal point on the far side of the lens is bent so that it emerges parallel to the axis of the lens.

30.3 Constructing Images Through Ray Diagrams

On emerging from the lens, the three rays appear to come from a point on the same side of the lens as the object.

This is the position of the virtual image. The image is nearer to the lens than the object.

The image formed by a diverging lens is always virtual, reduced, and right-side up.



30.3 Constructing Images Through Ray Diagrams

CONCEPT CHECK

What information is used to construct a ray diagram?

30.4 Image Formation Summarized

A converging lens forms either a real or a virtual image. A diverging lens always forms a virtual image.

30.4 Image Formation Summarized

For a converging lens, when the object is within one focal length of the lens, the image is then virtual, magnified, and right-side up.

When the object is beyond one focal length, a converging lens produces a real, inverted image.

- If the object is close to (but slightly beyond) the focal point, the image is far away.
- If the object is far from the focal point, the image is nearer.
- In all cases where a real image is formed, the object and the image are on opposite sides of the lens.

30.4 Image Formation Summarized

When the object is viewed with a diverging lens, the image is virtual, reduced, and right-side up.

This is true for all locations of the object.

In all cases where a virtual image is formed, the object and the image are on the same side of the lens.

30.4 Image Formation Summarized

think!

Where must an object be located so that the image formed by a converging lens will be (a) at infinity? (b) as near the object as possible? (c) right-side up? (d) the same size? (e) inverted and enlarged?

30.4 Image Formation Summarized

think!

Where must an object be located so that the image formed by a converging lens will be (a) at infinity? (b) as near the object as possible? (c) right-side up? (d) the same size? (e) inverted and enlarged?

Answer:

The object should be (a) at one focal length from the lens (at the focal point); (b) and (c) within one focal length of the lens; (d) at two focal lengths from the lens; (e) between one and two focal lengths from the lens.

30.4 Image Formation Summarized

CONCEPT CHECK

What types of images are produced by lenses?

30.5 Some Common Optical Instruments

Optical instruments that use lenses include the camera, the telescope (and binoculars), and the compound microscope.

30.5 Some Common Optical Instruments

The first eyeglasses were probably invented in Italy in the late 1200s.

The telescope wasn’t invented until some 300 years later.

Today, lenses are used in many optical instruments.

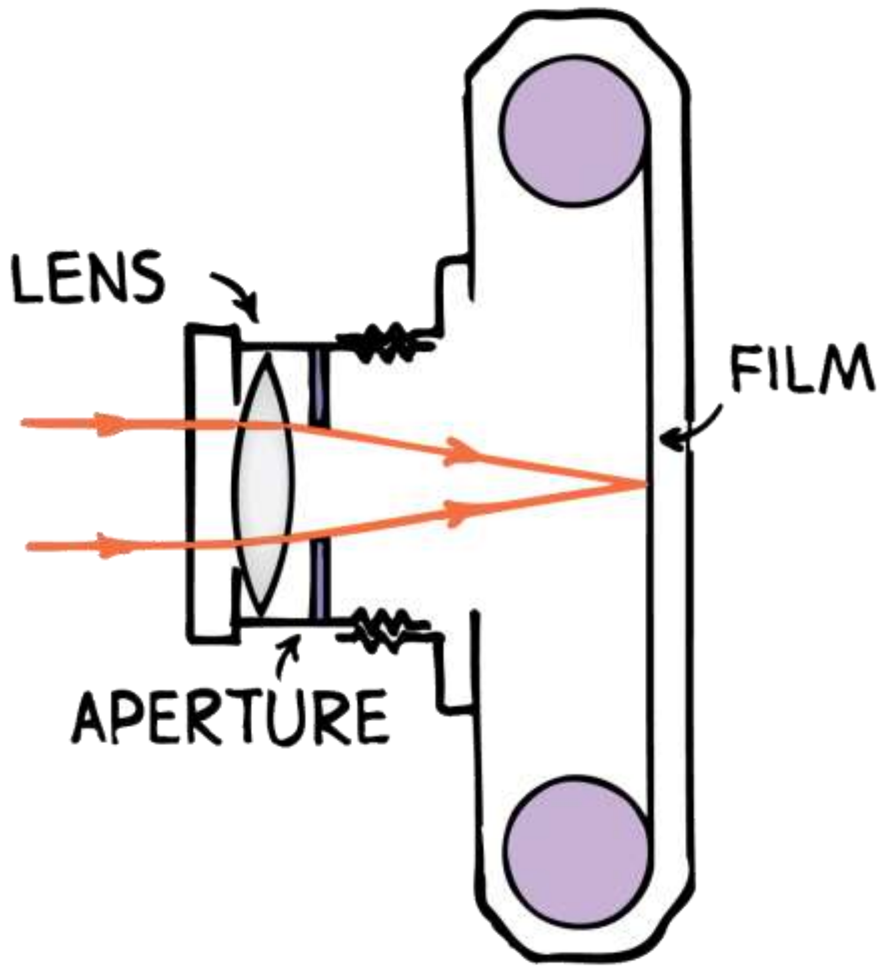
30.5 Some Common Optical Instruments

Camera

A camera consists of a lens and sensitive film (or light-detecting chip) mounted in a light-tight box.

The lens forms a real, inverted image on the film or chip.

In practice, most cameras use compound lenses to minimize distortions called *aberrations.*



30.5 Some Common Optical Instruments

The amount of light that gets to the film is regulated by a shutter and a diaphragm.

The shutter controls the length of time that the film is exposed to light.

The diaphragm controls the opening that light passes through to reach the film.

Varying the size of the opening (aperture) varies the amount of light that reaches the film at any instant.

30.5 Some Common Optical Instruments

Telescope

A simple telescope uses a lens that forms a real image of a distant object.

The real image is projected in space to be examined by another lens, called the **eyepiece,** used as a magnifying glass.

The eyepiece is positioned so that the image produced by the first lens is within one focal length of the eyepiece.

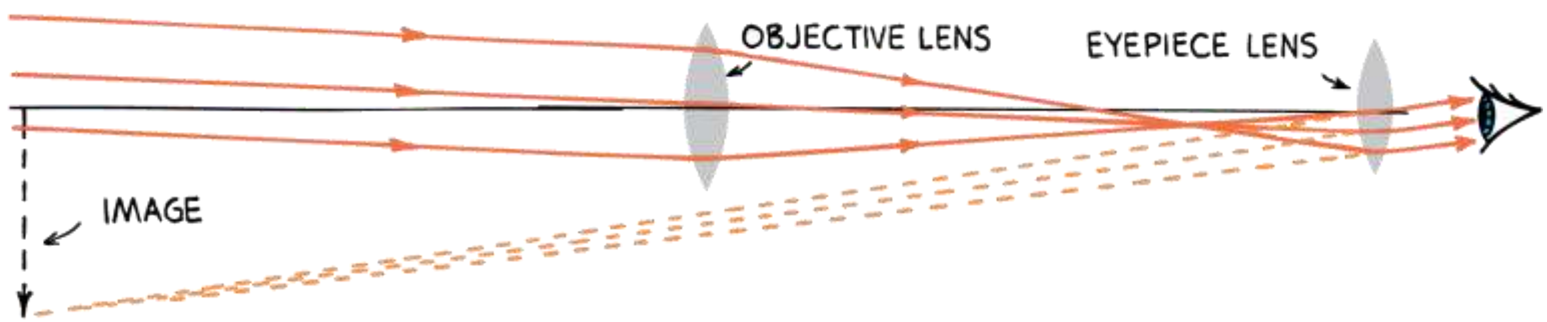
The eyepiece forms an enlarged virtual image of the real image.

30.5 Some Common Optical Instruments

(The image is shown close here; it is actually located at infinity.)

In an *astronomical telescope,* the image is inverted, which explains why maps of the moon are printed with the moon upside down.

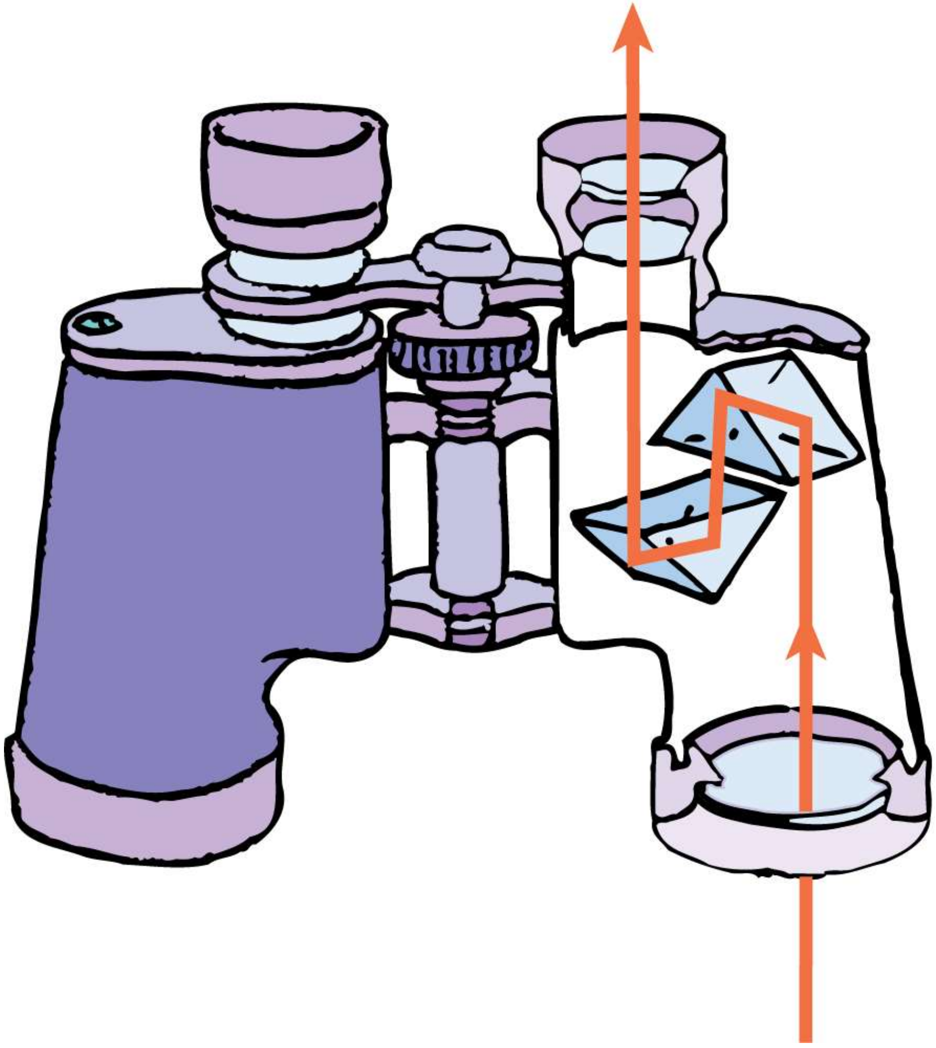
A third lens or a pair of reflecting prisms is used in the terrestrial *telescope,* which produces an image that is right-side up.



30.5 Some Common Optical Instruments

A pair of these telescopes side by side, each with a pair of prisms, makes up a pair of *binoculars*.

Each side of a pair of binoculars uses a pair of prisms that flips the image right-side up.



30.5 Some Common Optical Instruments

No lens transmits 100% of the light so astronomers prefer the brighter, inverted images of a two-lens telescope.

For uses such as viewing distant landscapes or sporting events, right-side-up images are more important than brightness.

30.5 Some Common Optical Instruments

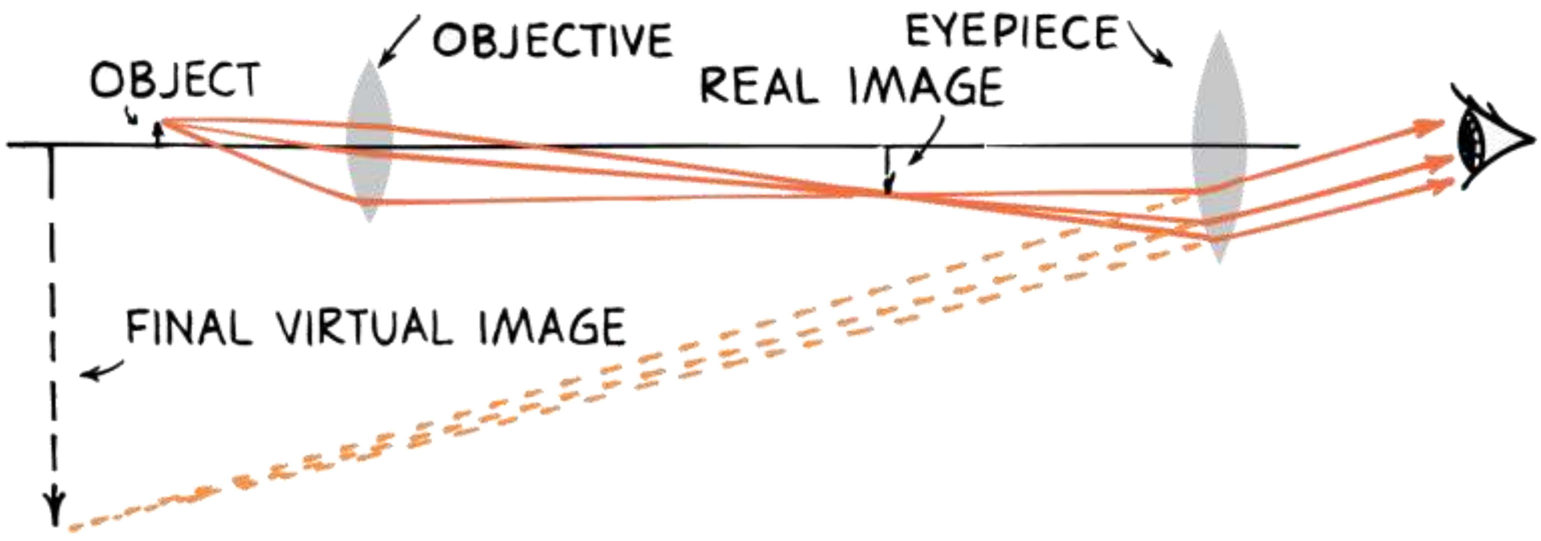
Compound Microscope

A compound microscope uses two converging lenses of short focal length.

The **objective lens** produces a real image of a close object.

The image is farther from the lens than the object so it is enlarged.

The eyepiece forms a virtual image of the first image, further enlarged.



30.5 Some Common Optical Instruments

CONCEPT CHECK

What are some optical instruments that use lenses?

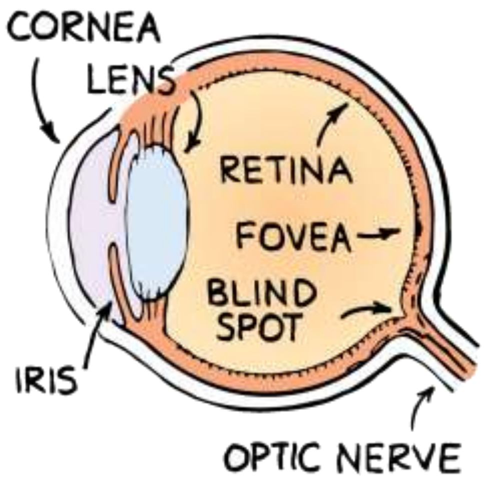
30.6 The Eye

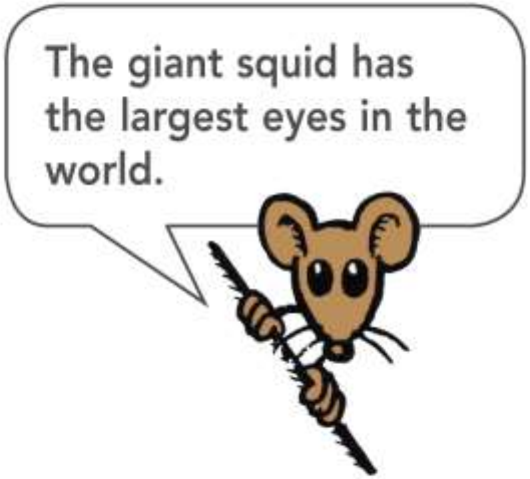
The main parts of the eye are the cornea, the iris, the pupil, and the retina.

30.6 The Eye

In many respects, the human eye is similar to the camera.

- Light enters through the transparent covering, the **cornea.**
- The amount of light that enters is regulated by the **iris,** the colored part of the eye that surrounds the pupil.
- The **pupil** is the opening through which light passes.
- Light passes through the pupil and lens and is focused on a layer of tissue at the back of the eye—the **retina.** Different parts of the retina receive light from different directions.





30.6 The Eye

The Blind Spot

The retina is not uniform. There is a small region in the center of our field of view where we have the most distinct vision.

This spot is called the *fovea.* Much greater detail can be seen here than at the side parts of the eye.

There is also a spot in the retina where the nerves carrying all the information leave the eye in a narrow bundle.

This is the *blind spot.*

30.6 The Eye

The Camera and the Eye

In both the camera and the eye, the image is upside down, and this is compensated for in both cases.

You simply turn the camera film around to look at it.

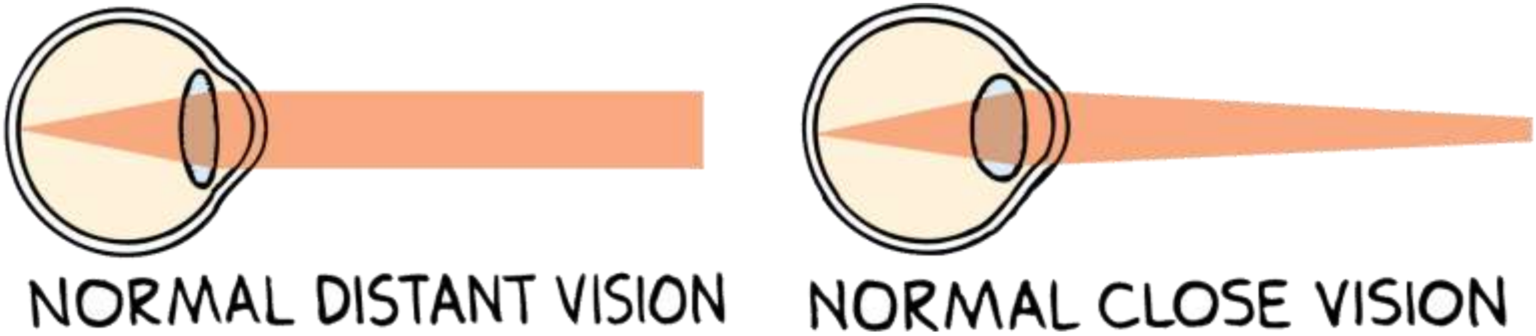
Your brain has learned to turn around images it receives from your retina.

30.6 The Eye

A principal difference between a camera and the human eye has to do with focusing.

- In a camera, focusing is accomplished by altering the distance between the lens and the film or chip.
- In the human eye, most of the focusing is done by the cornea, the transparent membrane at the outside of the eye.
- The image is focused on the retina by changing the thickness and shape of the lens to regulate its focal length. This is called *accommodation* and is brought about by the action of the *ciliary muscle,* which surrounds the lens.

30.6 The Eye



30.6 The Eye

CONCEPT CHECK

What are the main parts of the human eye?

30.7 Some Defects in Vision

Three common vision problems are farsightedness, nearsightedness, and astigmatism.

30.7 Some Defects in Vision

With normal vision, your eye can accommodate to clearly see objects from infinity (the *far point*) down to 25 cm (the *near point*).

Unfortunately, not everyone has normal vision.

30.7 Some Defects in Vision

Farsightedness

A **farsighted** person has trouble focusing on nearby objects.

- The eyeball is too short and images form behind the retina.
- Farsighted people have to hold things more than 25 cm away to be able to focus them.
- The remedy is to increase the converging effect of the eye by wearing eyeglasses or contact lenses with converging lenses.
- Converging lenses converge the rays sufficiently to focus them on the retina instead of behind the retina.

30.7 Some Defects in Vision

Nearsightedness

A **nearsighted** person can see nearby objects clearly, but does not see distant objects clearly.

- Distant objects focus too near the lens, in front of the retina.
- The eyeball is too long.
- A remedy is to wear lenses that diverge the rays from distant objects so that they focus on the retina instead of in front of it.

30.7 Some Defects in Vision

Astigmatism

Astigmatism of the eye is a defect that results when the cornea is curved more in one direction than the other.

Because of this defect, the eye does not form sharp images.

The remedy is cylindrical corrective lenses that have more curvature in one direction than in another.

30.7 Some Defects in Vision

CONCEPT CHECK

What are three common vision problems?

30.8 Some Defects of Lenses

Two types of aberration are spherical aberration and chromatic aberration.

30.8 Some Defects of Lenses

No lens gives a perfect image.

The distortions in an image are called **aberrations.**

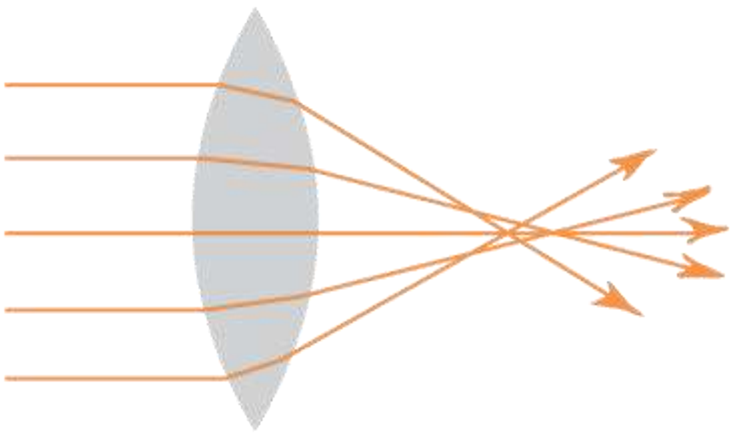
Combining lenses in certain ways can minimize aberrations so most optical instruments use compound lenses.

30.8 Some Defects of Lenses

Aberrations

Spherical aberration results when light passing through the edges of a lens focuses at a slightly different place from light passing through the center of the lens.

Spherical aberration is corrected in good optical instruments by a combination of lenses.

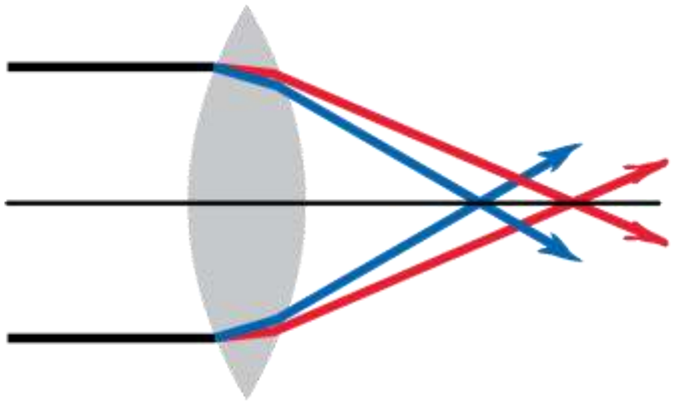


30.8 Some Defects of Lenses

Chromatic aberration is the result of the different speeds of light of various colors, and hence the different refractions they undergo.

In a simple lens red light and blue light bend by different amounts (as in a prism), so they do not come to focus in the same place.

Achromatic lenses, which combine simple lenses of different kinds of glass, correct this defect.



30.8 Some Defects of Lenses

Vision is sharpest when the pupil is smallest.

Light then passes through only the center of the eye's lens, where spherical and chromatic aberrations are minimal.

Also, light bends the least through the center of a lens, so minimal focusing is required for a sharp image.

You see better in bright light because your pupils are smaller.

30.8 Some Defects of Lenses

Methods for Correcting Vision

An alternative to wearing eyeglasses for correcting vision is contact lenses.

One option is LASIK (***l****aser-****a****ssisted in-****si****tu* ***k****eratomileusis*), the procedure of reshaping the cornea using pulses from a laser.

Another procedure is PRK (***p****hoto****r****efractive* ***k****eratectomy*). Still another is IntraLase, where intraocular lenses are implanted in the eye like a contact lens.

30.8 Some Defects of Lenses

think!

Why is there chromatic aberration in light that passes through a lens, but no chromatic aberration in light that reflects from a mirror?

30.8 Some Defects of Lenses

think!

Why is there chromatic aberration in light that passes through a lens, but no chromatic aberration in light that reflects from a mirror?

Answer:

Different frequencies travel at different speeds in a transparent medium, and therefore refract at different angles. This produces chromatic aberration. The angles at which light reflects, on the other hand, have nothing to do with the frequency of light. One color reflects the same as any other.

30.8 Some Defects of Lenses

CONCEPT CHECK

What types of aberrations can occur in images?

Assessment Questions

1. The action of lenses depends mainly on
   a. convexing light in various directions.
   b. changing the direction of light rays or waves.
   c. converging light rays or waves.
   d. diverging light rays or waves.

Assessment Questions

1. The action of lenses depends mainly on
   a. convexing light in various directions.
   b. changing the direction of light rays or waves.
   c. converging light rays or waves.
   d. diverging light rays or waves.

Answer: B

Assessment Questions

2. A real image can be cast on a screen by
   a. converging lens.
   b. diverging lens.
   c. concave lens.
   d. any lens.

Assessment Questions

2. A real image can be cast on a screen by
   a. converging lens.
   b. diverging lens.
   c. concave lens.
   d. any lens.

Answer: A

Assessment Questions

3. The minimum number of light rays necessary to construct the position of an image is
   a. one.
   b. two.
   c. three.
   d. four.

Assessment Questions

3. The minimum number of light rays necessary to construct the position of an image is

   a. one.
   b. two.
   c. three.
   d. four.

Answer: B

Assessment Questions

4. A diverging lens forms
   a. only a real image.
   b. only a virtual image.
   c. both a real image and a virtual image.
   d. a perfect image.

Assessment Questions

4. A diverging lens forms
   a. only a real image.
   b. only a virtual image.
   c. both a real image and a virtual image.
   d. a perfect image.

Answer: B

Assessment Questions

5. The amount of light getting into a camera or your eye is regulated by a(n)
   a. distorter.
   b. diaphragm.
   c. eyepiece.
   d. set of compound lenses.

Assessment Questions

5. The amount of light getting into a camera or your eye is regulated by a(n)
   a. distorter.
   b. diaphragm.
   c. eyepiece.
   d. set of compound lenses.

Answer: B

Assessment Questions

6. To best test for the blind spots in your eyes,
   a. keep your eyes wide open in bright light.
   b. close one eye.
   c. do not use eyeglasses unless you need them.
   d. focus intently on whatever you’re viewing.

Assessment Questions

6. To best test for the blind spots in your eyes,
   a. keep your eyes wide open in bright light.
   b. close one eye.
   c. do not use eyeglasses unless you need them.
   d. focus intently on whatever you're viewing.

Answer: B

Assessment Questions

7. A person who is nearsighted wears
   a. no glasses.
   b. glasses that have a uniform thickness.
   c. glasses that are thicker in the middle.
   d. glasses that are thicker at the edges.

Assessment Questions

7. A person who is nearsighted wears
   a. no glasses.
   b. glasses that have a uniform thickness.
   c. glasses that are thicker in the middle.
   d. glasses that are thicker at the edges.

Answer: D

Assessment Questions

8. Chromatic aberrations are caused by
   a. light passing through a lens.
   b. the use of achromatic lenses.
   c. different colors of light traveling at different speeds.
   d. LASIK.

Assessment Questions

8. Chromatic aberrations are caused by
   a. light passing through a lens.
   b. the use of achromatic lenses.
   c. different colors of light traveling at different speeds.
   d. LASIK.

Answer: C