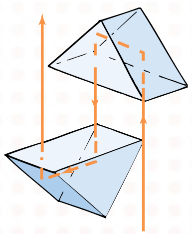


THE BIG IDEA

When waves interact with matter, they can be reflected, transmitted, or a combination of both. Waves that are transmitted can be refracted.

Light doesn't travel through a mirror, but is returned by the mirror's surface. These waves are *reflected*. When waves strike the surface of a medium at an angle, their direction changes. These waves are *refracted*. Usually waves are partly reflected and partly refracted when they fall on a transparent medium.

29.1 Reflection

When a wave reaches a boundary between two media, usually some or all of the wave bounces back into the first medium.

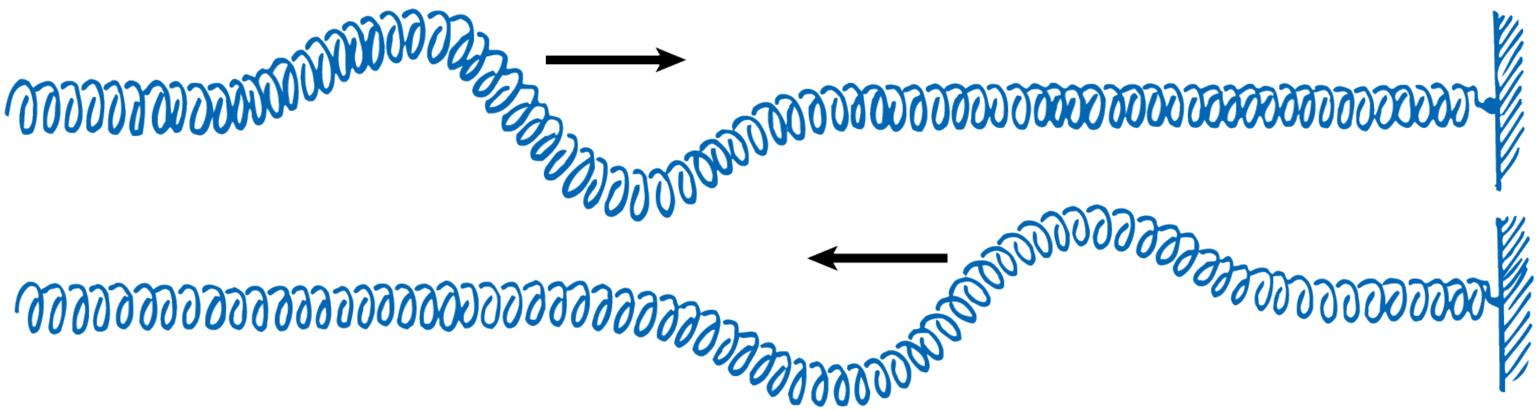
29.1 Reflection

The return of a wave back to its original medium is called **reflection.**

Fasten a spring to a wall and send a pulse along the spring's length.

The wall is a very rigid medium compared with the spring, so all the wave energy is reflected back along the spring.

Waves that travel along the spring are almost *totally reflected* at the wall.

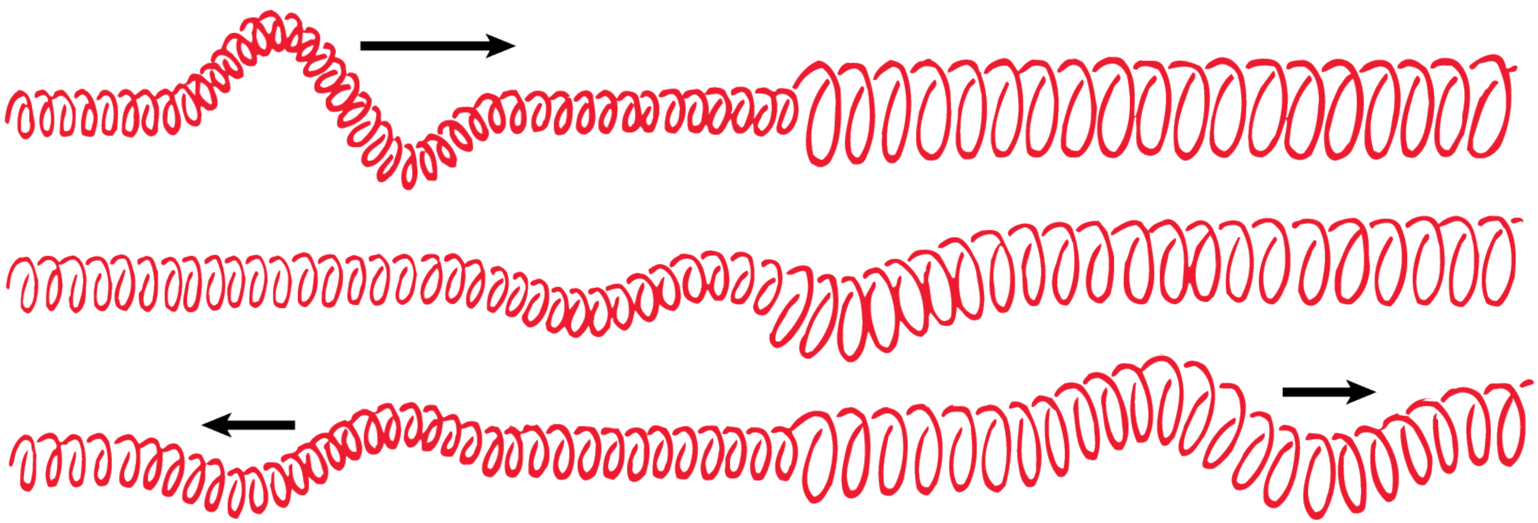


29.1 Reflection

If the wall is replaced with a less rigid medium, such as a heavy spring, some energy is transmitted into the new medium.

Some of the wave energy is still reflected.

The incoming wave is *partially reflected.*



29.1 Reflection

A metal surface is rigid to light waves that shine upon it.

Light energy does not propagate into the metal, but instead is returned in a reflected wave.

This is why metals such as silver and aluminum are so shiny. They reflect almost all the frequencies of visible light.

29.1 Reflection

Materials such as glass and water are not as rigid to light waves.

- When light shines perpendicularly on the surface of still water, about 2% of its energy is reflected and the rest is transmitted.
- When light strikes glass perpendicularly, about 4% of its energy is reflected.
- Except for slight losses, the rest is transmitted.

29.1 Reflection

CONCEPT CHECK

What happens when a wave reaches a boundary between two media?

29.2 The Law of Reflection

The law of reflection states that the angle of incidence and the angle of reflection are equal to each other.

29.2 The Law of Reflection

In one dimension, reflected waves simply travel back in the direction from which they came.

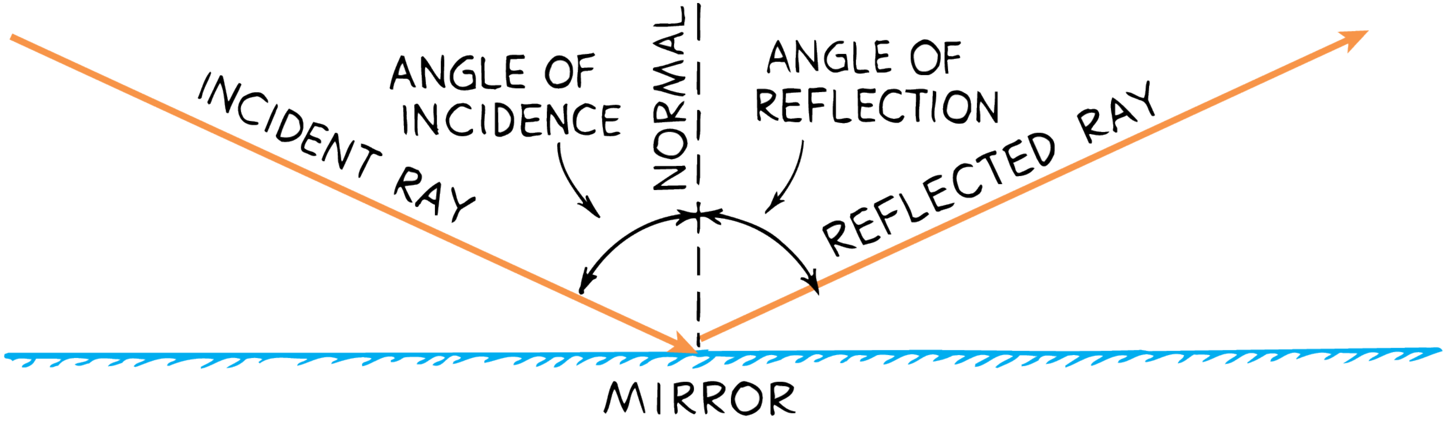
In two dimensions, the situation is a little different.

The direction of incident and reflected waves is described by straight-line *rays.*

29.2 The Law of Reflection

Incident rays and reflected rays make equal angles with a line perpendicular to the surface, called the **normal**.

- The angle between the incident ray and the normal is the **angle of incidence.**
- The angle between the reflected ray and the normal is the **angle of reflection.**
- Angle of incidence = Angle of reflection



29.2 The Law of Reflection

The **law of reflection** states that the angle of incidence and the angle of reflection are equal to each other.

The incident ray, the normal, and the reflected ray all lie in the same plane.

The law of reflection applies to both partially reflected and totally reflected waves.

29.2 The Law of Reflection

think!

If you look at your blue shirt in a mirror, what is the color of its image? What does this tell you about the frequency of light incident upon a mirror compared with the frequency of the light after it is reflected?

29.2 The Law of Reflection

think!

If you look at your blue shirt in a mirror, what is the color of its image? What does this tell you about the frequency of light incident upon a mirror compared with the frequency of the light after it is reflected?

Answer:

The color of the image will be the same as the color of the object because the frequency of light is not changed by reflection.

29.2 The Law of Reflection

CONCEPT CHECK

What is the law of reflection?

29.3 Mirrors

Mirrors produce only virtual images.

29.3 Mirrors

If a candle flame is placed in front of a plane (flat) mirror, rays of light from the candle are reflected from the mirror in all directions.

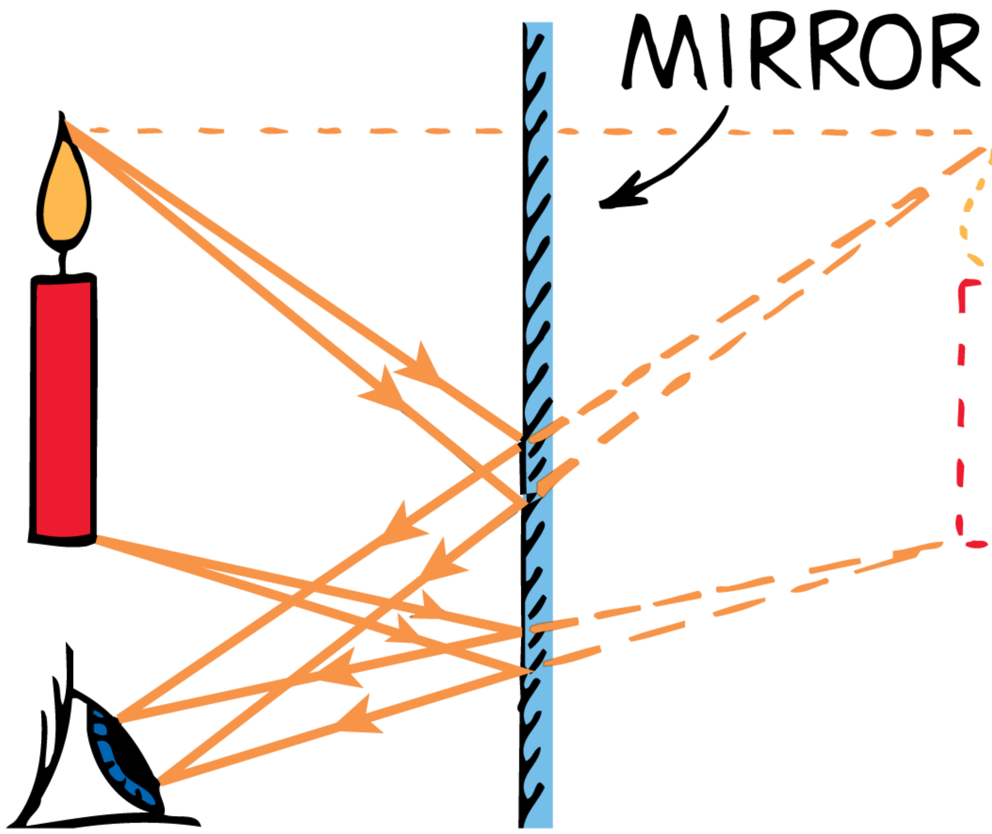
- Each of the infinite number of rays obeys the law of reflection.
- The rays diverge (spread apart) from the tip of the flame, and continue diverging from the mirror upon reflection.
- These divergent rays *appear* to originate from a point located behind the mirror.

29.3 Mirrors

You perceive the candle flame to be located behind the mirror.

A **virtual image** appears to be in a location where light does not really reach.

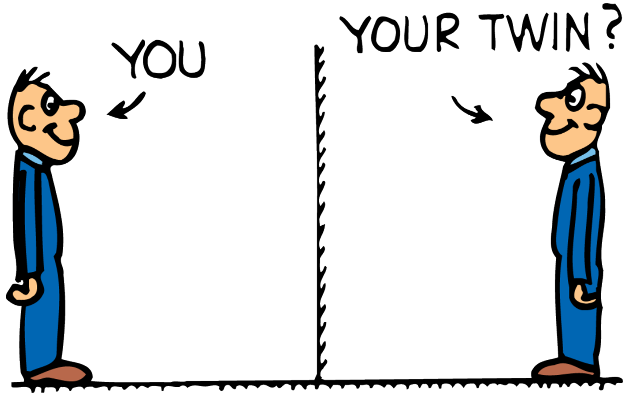
Mirrors produce only virtual images.



29.3 Mirrors

Your eye cannot ordinarily tell the difference between an object and its virtual image.

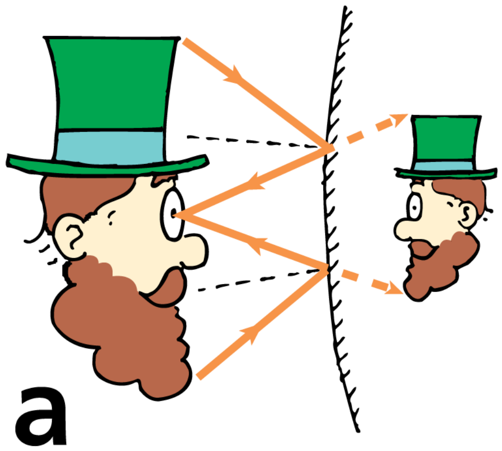
- The light enters your eye in exactly the same manner as it would if there really were an object where you see the image.
- The image is the same distance behind the mirror as the object is in front of it.
- The image and object are the same size.



29.3 Mirrors

The law of reflection holds for curved mirrors. However, the sizes and distances of object and image are no longer equal.

The virtual image formed by a *convex* mirror (a mirror that curves outward) is smaller and closer to the mirror than the object is.

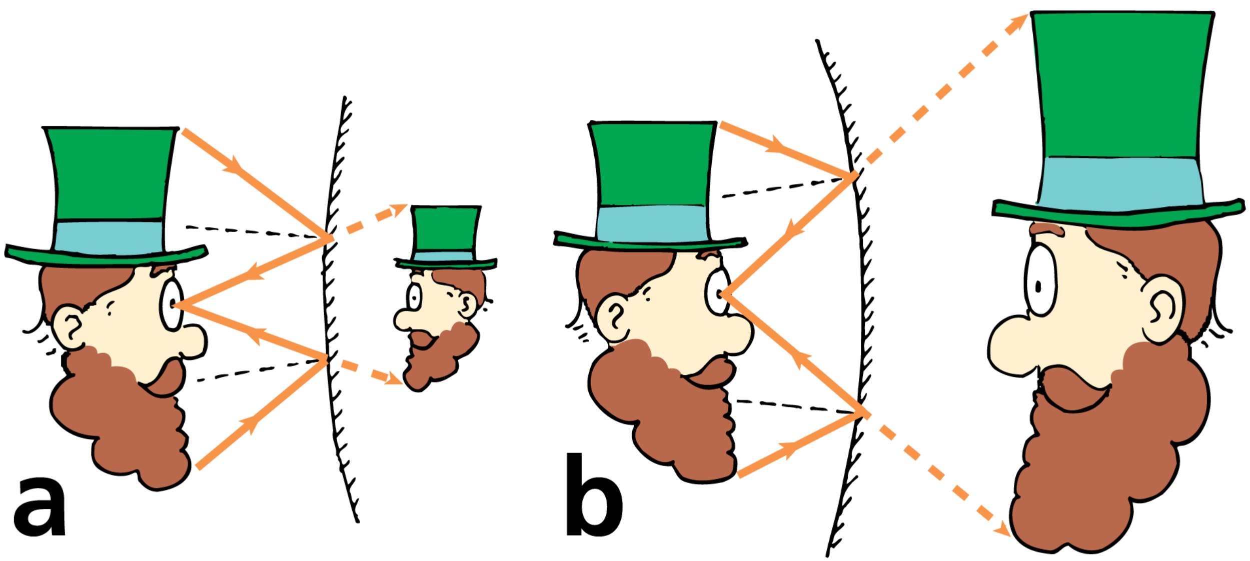


29.3 Mirrors

The law of reflection holds for curved mirrors. However, the sizes and distances of object and image are no longer equal.

The virtual image formed by a *convex* mirror (a mirror that curves outward) is smaller and closer to the mirror than the object is.

When an object is close to a *concave* mirror (a mirror that curves inward), the virtual image is larger and farther away than the object is.



29.3 Mirrors

CONCEPT CHECK

What kind of images do mirrors produce?

29.4 Diffuse Reflection

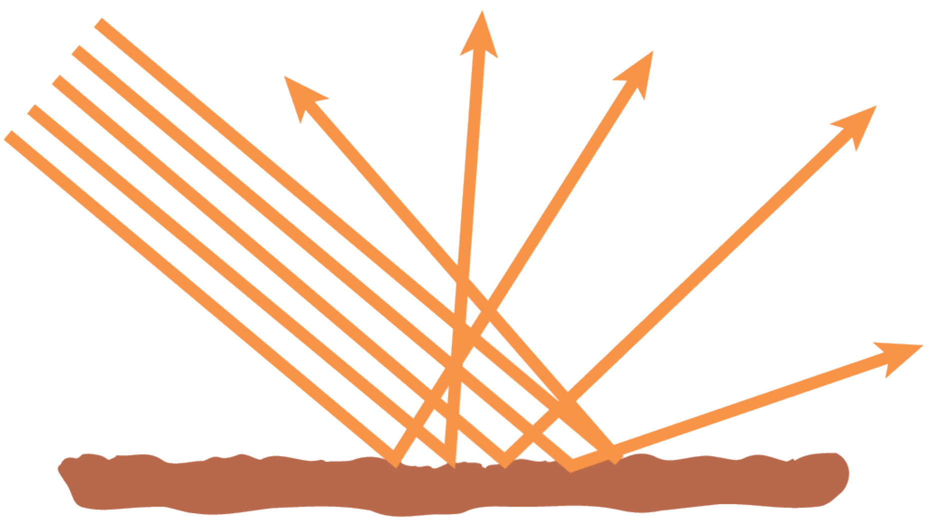
When light is incident on a rough surface, it is reflected in many directions.

29.4 Diffuse Reflection

Diffuse reflection is the reflection of light from a rough surface.

Each ray obeys the law of reflection.

The many different angles that incident light rays encounter at the surface cause reflection in many directions.



29.4 Diffuse Reflection

If the differences in elevations in a surface are small (less than about one eighth the wavelength of the light that falls on it), the surface is considered polished.

A surface may be polished for long wavelengths, but not polished for short wavelengths.

Whether a surface is a diffuse reflector or a polished reflector depends on the wavelength of the waves it reflects.

29.4 Diffuse Reflection

Visible light that reflects from a sheet of paper is diffusely reflected.

Rays of light incident on paper encounter millions of tiny flat surfaces facing in all directions, so they are reflected in all directions.

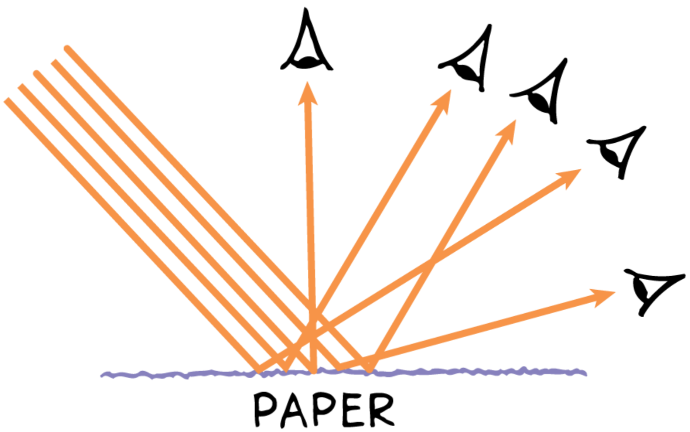
Diffuse reflection allows us to read the page from any direction or position. We see most of the things around us by diffuse reflection.

Ordinary paper has a rough surface when viewed with a microscope.

29.4 Diffuse Reflection

Diffuse reflection allows us to see most things around us.

a. Light is diffusely reflected from paper in many directions.



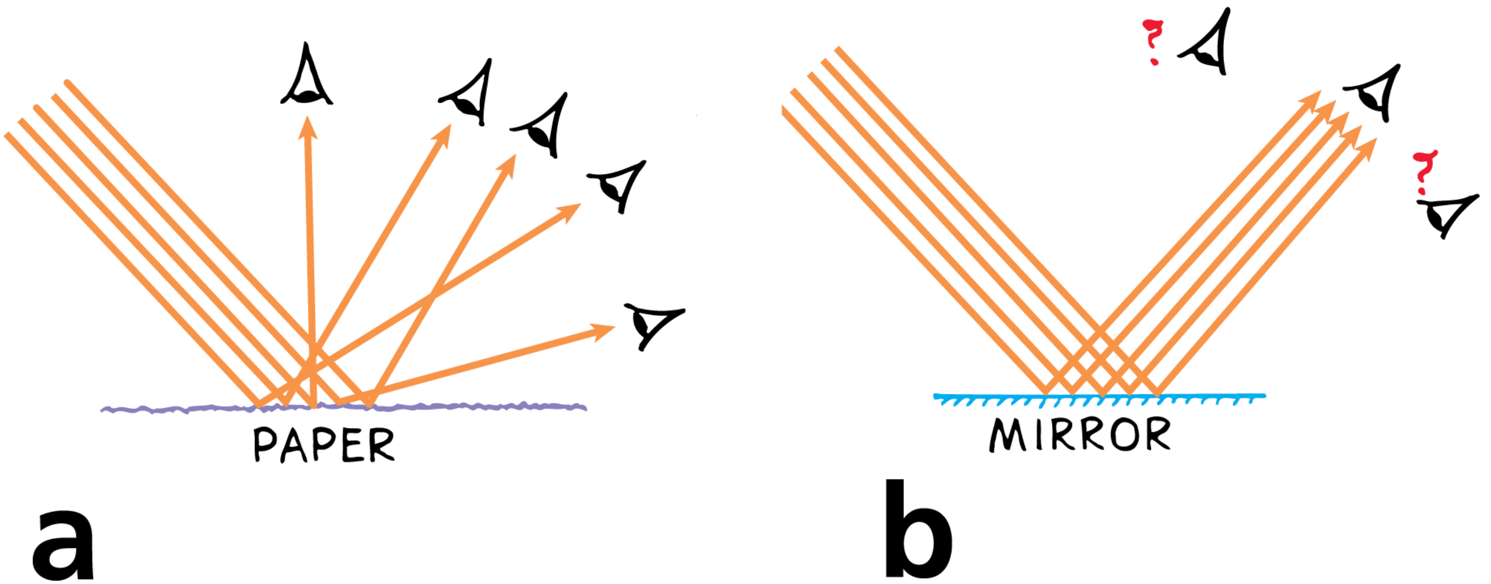
a

29.4 Diffuse Reflection

Diffuse reflection allows us to see most things around us.

a. Light is diffusely reflected from paper in many directions.

b. Light incident on a smooth mirror is only reflected in one direction.



29.4 Diffuse Reflection

CONCEPT CHECK

What happens when light is incident on a rough surface?

29.5 Reflection of Sound

Sound energy not reflected is absorbed or transmitted.

29.5 Reflection of Sound

An echo is reflected sound.

More sound energy is reflected from a rigid and smooth surface than from a soft and irregular surface.

Sound energy not reflected is absorbed or transmitted.

The study of the reflective properties of surfaces is *acoustics.*

29.5 Reflection of Sound

When walls are too reflective, the sound becomes garbled because of multiple reflections of sound waves called **reverberations.**

When the reflective surfaces are more absorbent, the sound level is lower, and the hall sounds dull and lifeless.

In the design of an auditorium or concert hall, a balance between reverberation and absorption is desired.

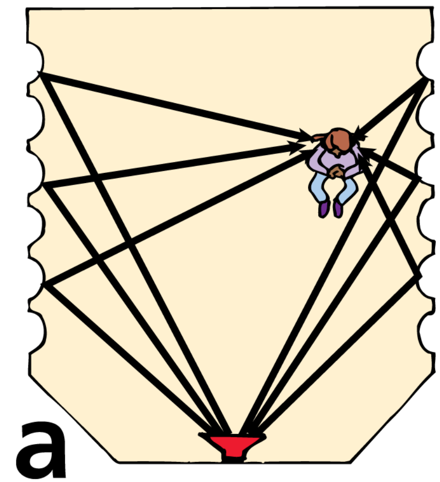
29.5 Reflection of Sound

The walls of concert halls are often designed with grooves so that the sound waves are diffused.

A person in the audience receives a small amount of reflected sound from many parts of the wall.

29.5 Reflection of Sound

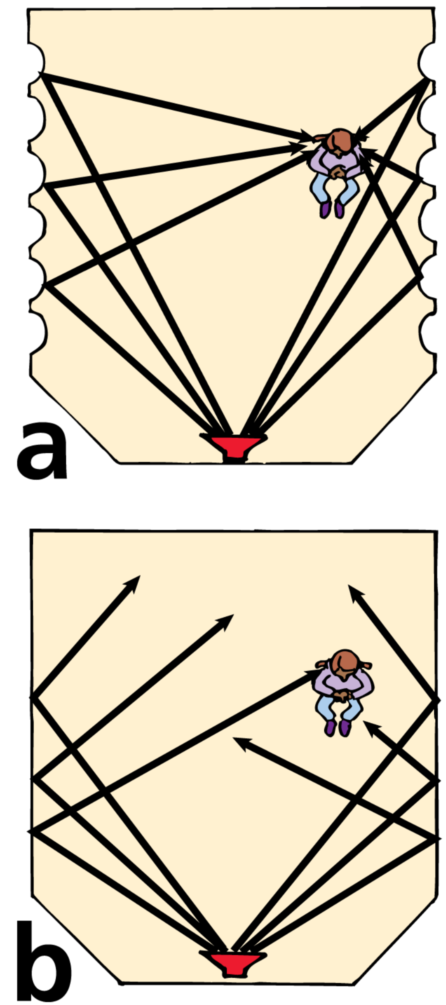
a. With grooved walls, sound reflects from many small sections of the wall to a listener.



29.5 Reflection of Sound

a. With grooved walls, sound reflects from many small sections of the wall to a listener.

b. With flat walls, an intense reflected sound comes from only one part of the wall.



29.5 Reflection of Sound

Reflective surfaces are often placed behind and above the stage to direct sound out to an audience.

Both sound and light obey the same law of reflection.

If a reflector is oriented so that you can *see* a particular musical instrument, you will *hear* it also.

Sound from the instrument will follow the line of sight to the reflector and then to you.

29.5 Reflection of Sound

The shiny plates above the orchestra in Davies Symphony Hall in San Francisco reflect both light and sound.

29.5 Reflection of Sound

CONCEPT CHECK

What happens to sound energy that is not reflected?

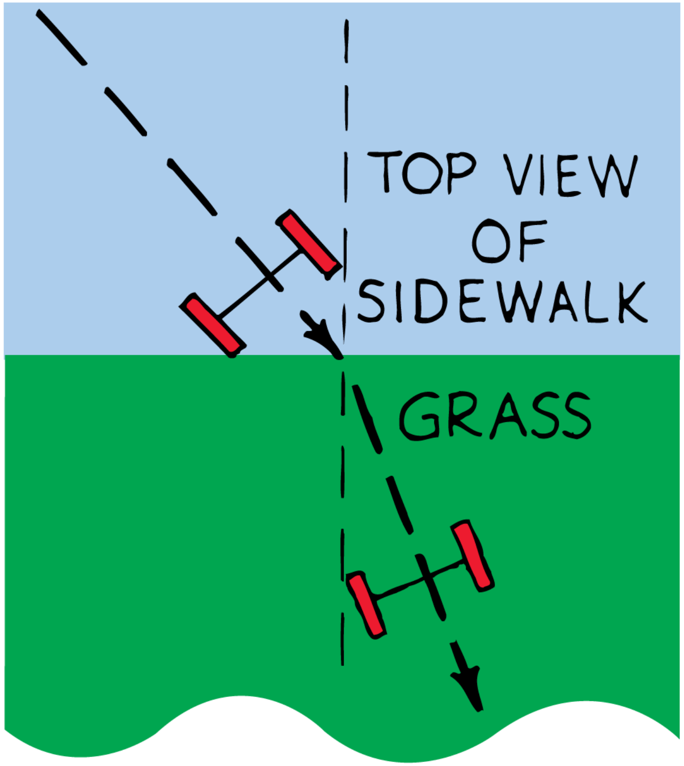
29.6 Refraction

When a wave that is traveling at an angle changes its speed upon crossing a boundary between two media, it bends.

29.6 Refraction

Let an axle with two wheels roll along a pavement that slopes downward onto a downward-sloping mowed lawn.

- It rolls more slowly on the lawn due to interaction of the wheels with the blades of grass.
- Rolled at an angle, it will be deflected from its straight-line course.
- The wheel that first meets the lawn slows down first.
- The axle pivots, and the path bends toward the normal.
- When both wheels reach the grass, it continues in a straight line at reduced speed.



29.6 Refraction

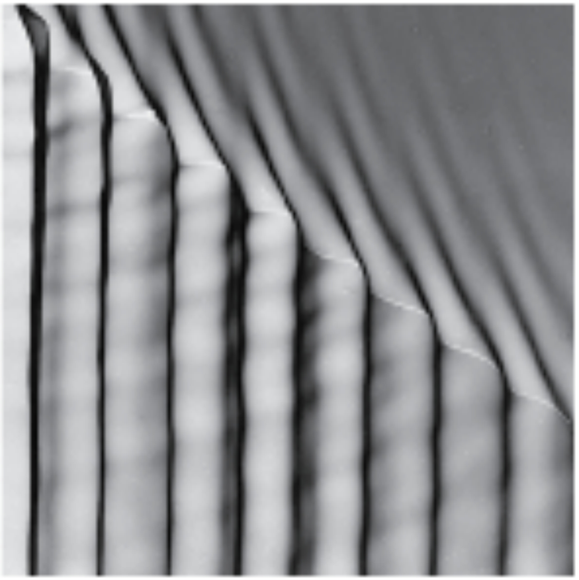
When a wave that is traveling at an angle changes its speed upon crossing a boundary between two media, it bends.

Refraction is the bending of a wave as it crosses the boundary between two media at an angle.

29.6 Refraction

Water waves travel faster in deep water than in shallow water.

a. The wave refracts at the boundary where the depth changes.



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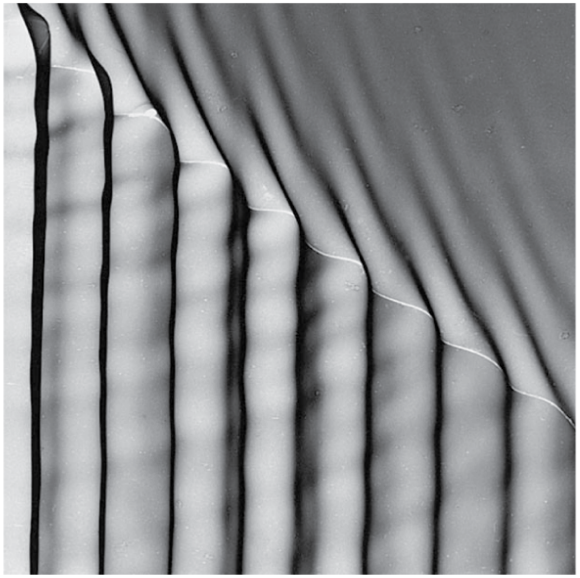
29.6 Refraction

Water waves travel faster in deep water than in shallow water.

a. The wave refracts at the boundary where the depth changes.

b. The sample ray is perpendicular to the wave front it intersects.



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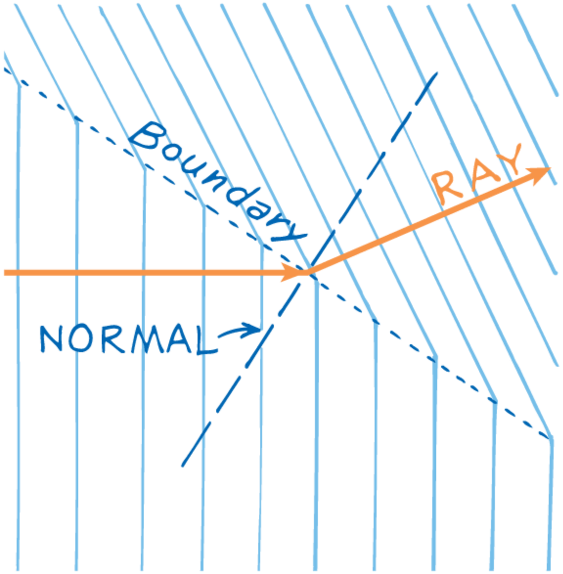

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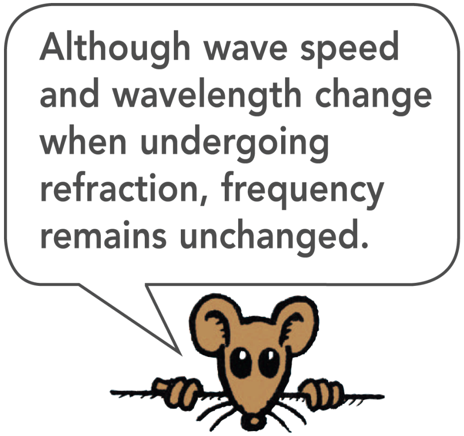
29.6 Refraction

In drawing a diagram of a wave, it is convenient to draw lines, called **wave fronts**, that represent the positions of different crests.

- At each point along a wave front, the wave is moving perpendicular to the wave front.
- The direction of motion of the wave is represented by rays that are perpendicular to the wave fronts.
- Sometimes we analyze waves in terms of wave fronts, and at other times in terms of rays.



29.6 Refraction

CONCEPT CHECK

What causes a wave to bend?

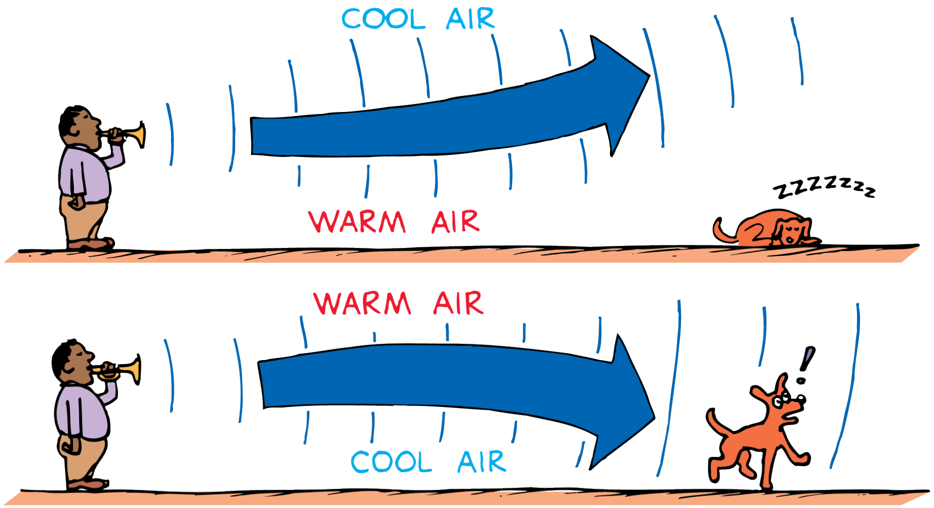
29.7 Refraction of Sound

Sound waves are refracted when parts of a wave front travel at different speeds.

29.7 Refraction of Sound

Sound refraction occurs in uneven winds or when sound is traveling through air of uneven temperature.

- On a warm day the air near the ground may be appreciably warmer than the air above.
- Sound travels faster in warmer air, so the speed of sound near the ground is increased.
- The refraction is not abrupt but gradual.
- Sound waves tend to bend away from warm ground, making it appear that the sound does not carry well.



29.7 Refraction of Sound

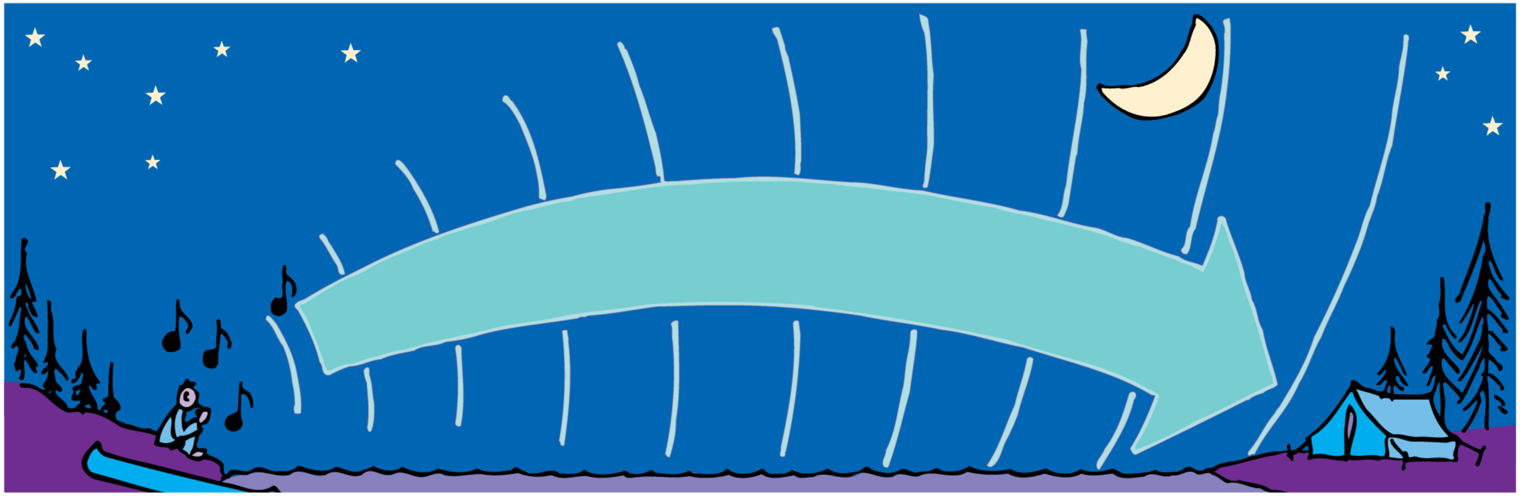
When the layer of air near the ground is colder than the air above, the speed of sound near the ground is reduced.

The higher speed of the wave fronts above causes a bending of the sound toward Earth.

Sound can then be heard over considerably longer distances.

29.7 Refraction of Sound

At night, when the air is cooler over the surface of the lake, sound is refracted toward the ground and carries unusually well.



29.7 Refraction of Sound

think!

Suppose you are downwind from a factory whistle. In which case will the whistle sound louder—if the wind speed near the ground is more than the wind speed several meters above the ground, or if it is less?

29.7 Refraction of Sound

think!

Suppose you are downwind from a factory whistle. In which case will the whistle sound louder—if the wind speed near the ground is more than the wind speed several meters above the ground, or if it is less?

Answer:

You'll hear the whistle better if the wind speed near the ground is less than the wind speed higher up. For this condition, the sound will be refracted toward the ground.

29.7 Refraction of Sound

CONCEPT CHECK

What causes sound waves to refract?

29.8 Refraction of Light

Changes in the speed of light as it passes from one medium to another, or variations in the temperatures and densities of the same medium, cause refraction.

29.8 Refraction of Light

Due to the refraction of light:

- swimming pools appear shallower,
- a pencil in a glass of water appears bent,
- the air above a hot stove seems to shimmer, and
- stars twinkle.

The directions of the light rays change because of refraction.

29.8 Refraction of Light

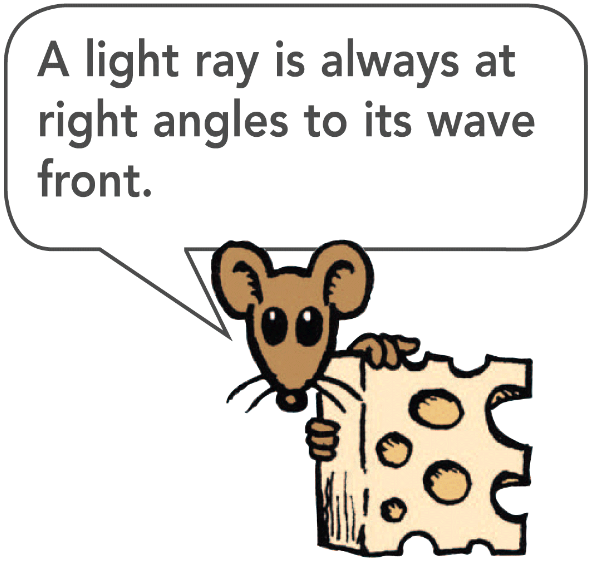
Rays and wave fronts of light refract as they pass from air into water.

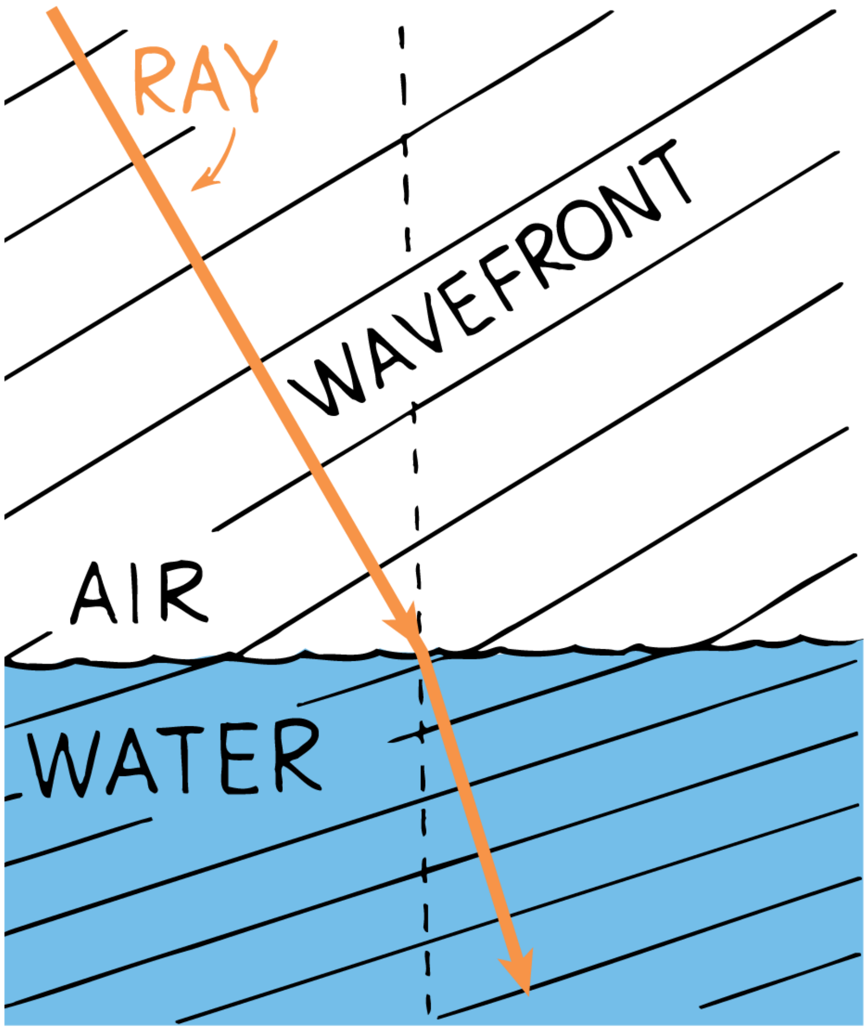
Wave fronts that enter the water first are the first to slow down.

The refracted ray of light is closer to the normal than is the incident ray.

29.8 Refraction of Light

As a light wave passes from air into water, its speed decreases.





29.8 Refraction of Light

When light rays enter a medium in which their speed decreases, as when passing from air into water, the rays bend toward the normal.

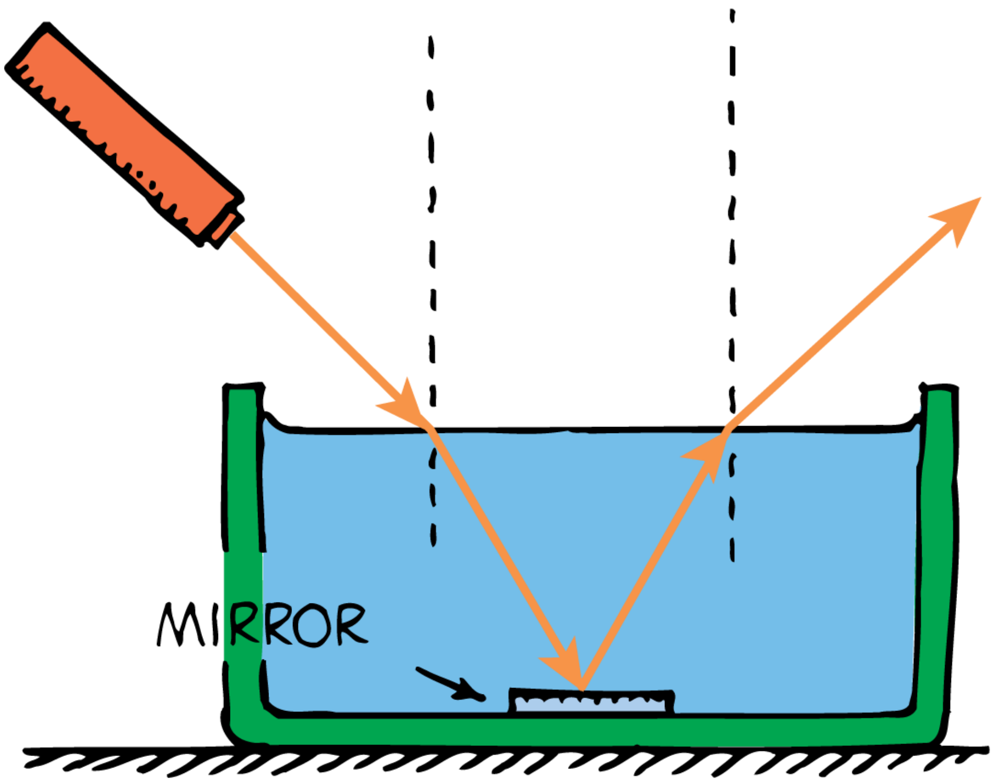
When light rays enter a medium in which their speed increases, such as from water into air, the rays bend away from the normal.

The light paths are reversible for both reflection and refraction.

If you can see somebody in a reflective or refractive device, such as a mirror or a prism, then that person can see you by looking through the device also.

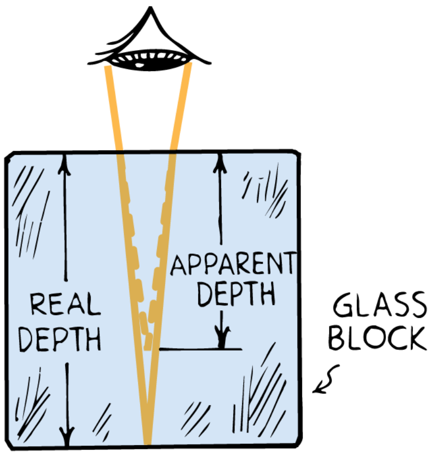
29.8 Refraction of Light

The laser beam bends toward the normal when it enters the water, and away from the normal when it leaves.



29.8 Refraction of Light

a. The apparent depth of the glass block is less than the real depth.

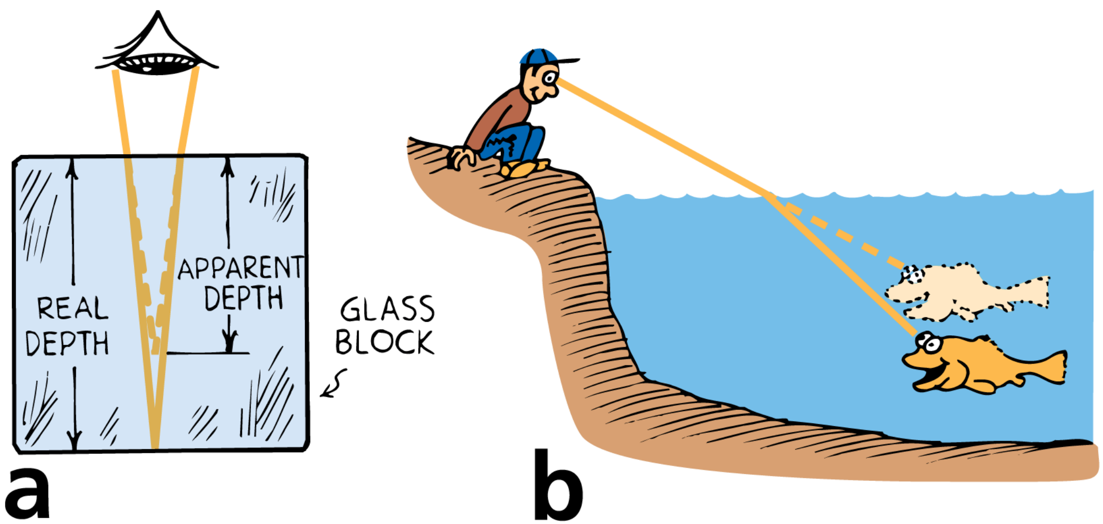


a

29.8 Refraction of Light

a. The apparent depth of the glass block is less than the real depth.

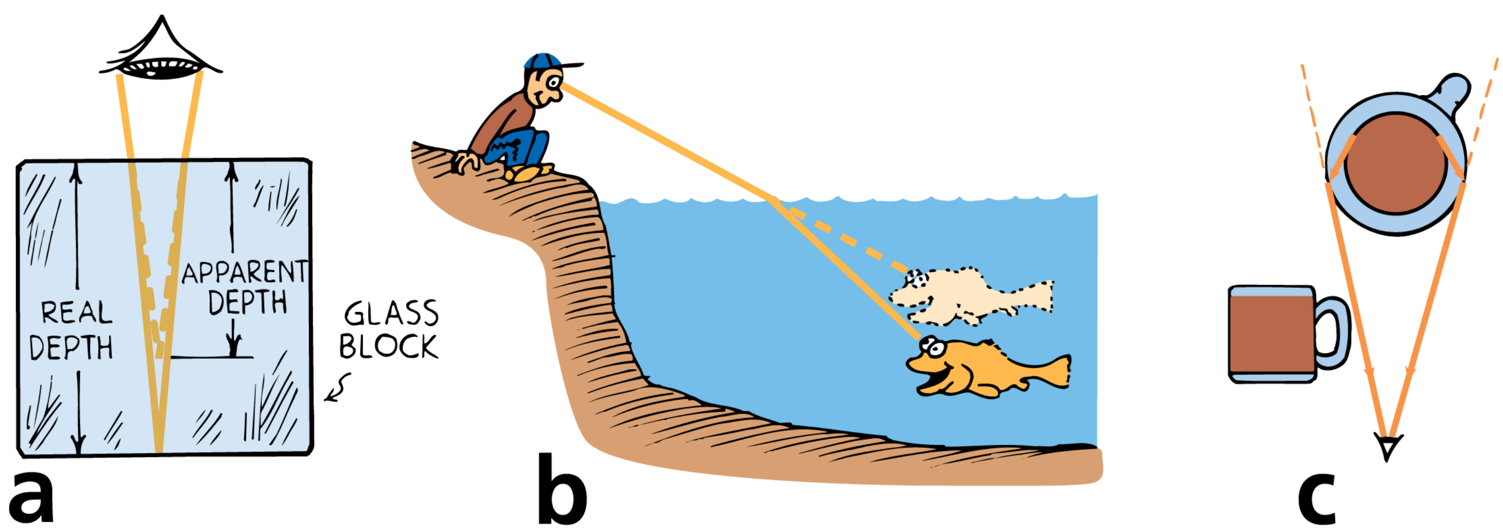
b. The fish appears to be nearer than it actually is.



29.8 Refraction of Light

a. The apparent depth of the glass block is less than the real depth.
b. The fish appears to be nearer than it actually is.
c. The full glass mug appears to hold more root beer than it actually does.

These effects are due to the refraction of light whenever it crosses a boundary between air and another transparent medium.



29.8 Refraction of Light

CONCEPT CHECK

What causes the refraction of light?

29.9 Atmospheric Refraction

A mirage is caused by the refraction of light in Earth's atmosphere.

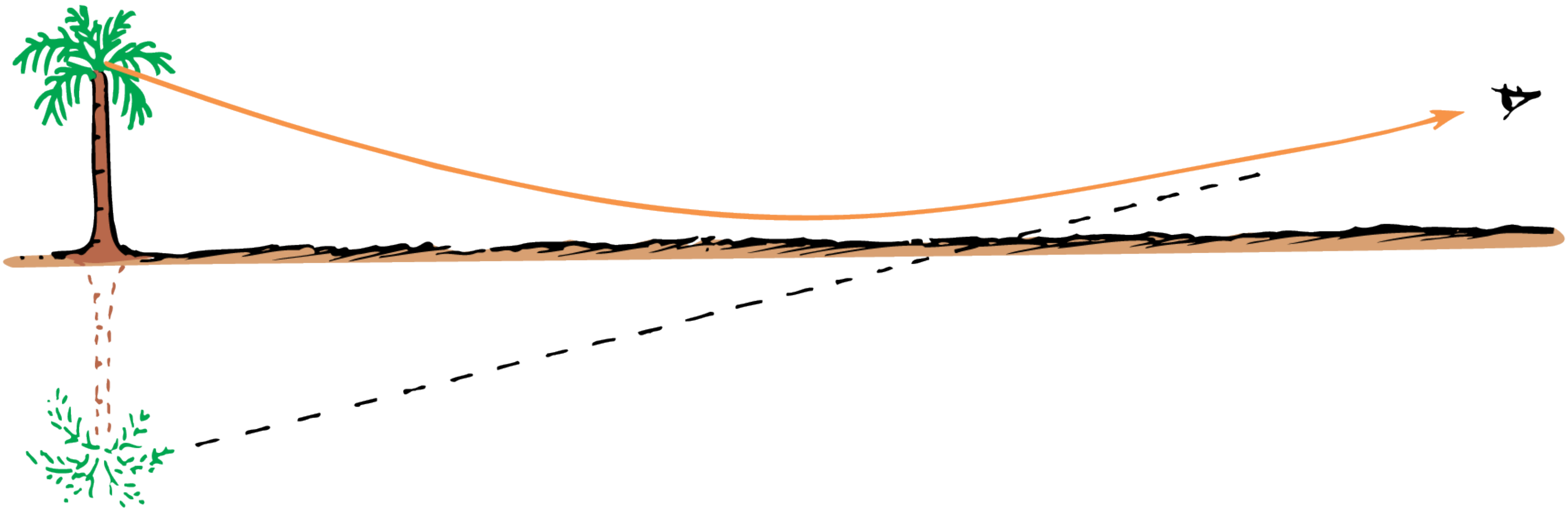
29.9 Atmospheric Refraction

The speed of light in air is only 0.03% less than *c*, but in some situations, atmospheric refraction is quite noticeable.

A distorted image, called a **mirage,** is caused by refraction of light in Earth's atmosphere**.**

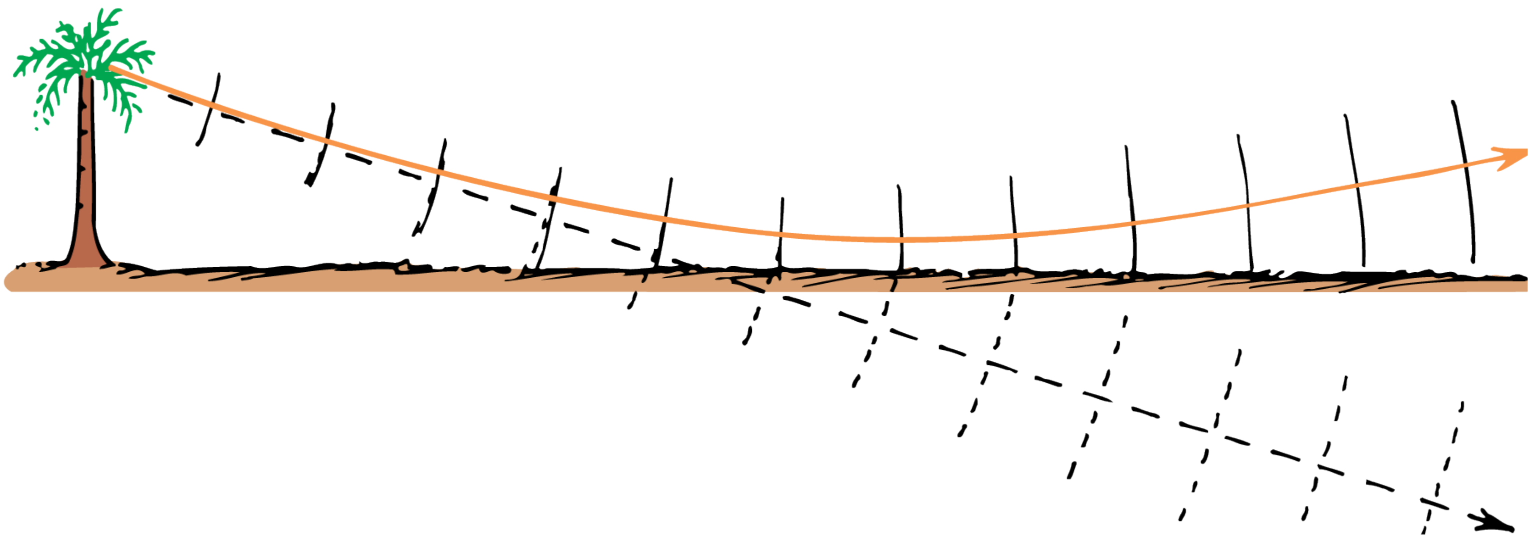
- A layer of very hot air is in contact with the ground on very hot days.
- Light travels faster through it than through the cooler air above.
- The speeding up of the part of the wave nearest the ground produces a gradual bending of the light rays.
- Light is refracted.

29.9 Atmospheric Refraction



29.9 Atmospheric Refraction

Wave fronts of light travel faster in the hot air near the ground, thereby bending the rays of light upward.



29.9 Atmospheric Refraction

A motorist experiences a similar situation when driving along a hot road that appears to be wet ahead.

The sky appears to be reflected from a wet surface, but, in fact, light from the sky is being refracted through a layer of hot air.

A mirage is not a “trick of the mind.”

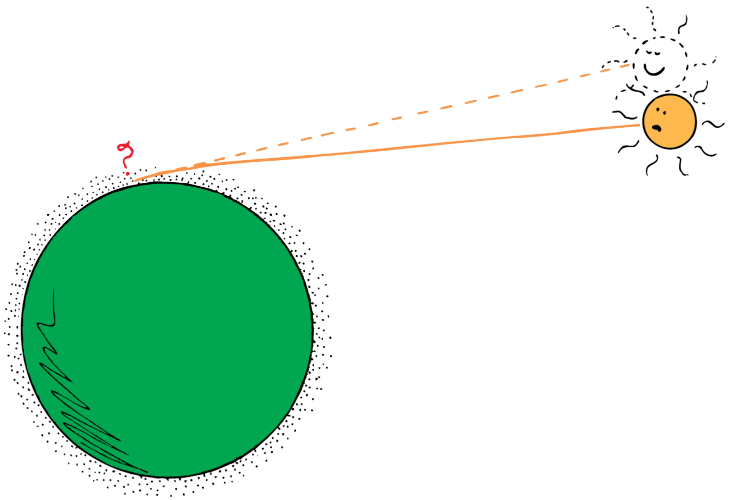
A mirage is formed by real light and can be photographed.

29.9 Atmospheric Refraction

When you watch the sun set, you see the sun for several minutes after it has really sunk below the horizon.

Since the density of the atmosphere changes gradually, refracted rays bend gradually to produce a curved path.

The same thing occurs at sunrise, so our daytimes are about 5 minutes longer because of atmospheric refraction.



29.9 Atmospheric Refraction

When the sun is near the horizon, the rays from the lower edge are bent more than the rays from the upper edge.

This produces a shortening of the vertical diameter and makes the sun look elliptical instead of round.

Atmospheric refraction produces a “pumpkin” sun.

29.9 Atmospheric Refraction

think!

If the speed of light were the same for the various temperatures and densities of air, would there still be mirages?

29.9 Atmospheric Refraction

think!

If the speed of light were the same for the various temperatures and densities of air, would there still be mirages?

Answer:

No! There would be no refraction if light traveled at the same speed in air of different temperatures and densities.

29.9 Atmospheric Refraction

CONCEPT CHECK

What causes the appearance of a mirage?

29.10 Dispersion in a Prism

Since different frequencies of light travel at different speeds in transparent materials, they will refract differently and bend at different angles.

29.10 Dispersion in a Prism

The average speed of light is less than *c* in a transparent medium.

How much less depends on the medium and the frequency of light.

- Light of frequencies closer to the natural frequency of the electron oscillators in a medium travels more slowly in the medium.
- The natural frequency of most transparent materials is in the ultraviolet part of the spectrum.
- Visible light of higher frequencies travels more slowly than light of lower frequencies.

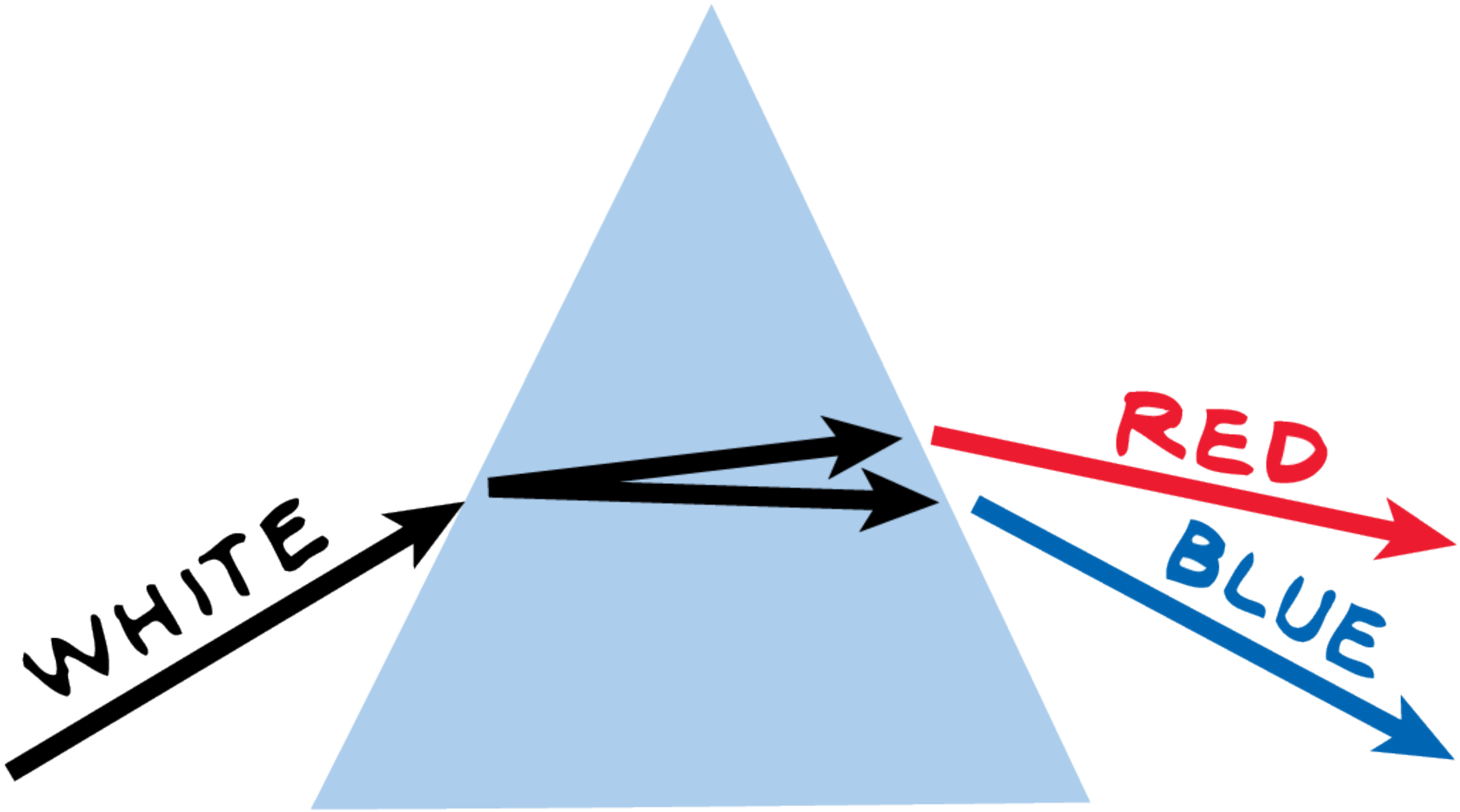
29.10 Dispersion in a Prism

Different frequencies of light travel at different speeds in transparent materials so they bend at different angles.

The separation of light into colors arranged according to their frequency is called **dispersion.**

29.10 Dispersion in a Prism

Dispersion through a prism occurs because different frequencies of light travel at different speeds.



29.10 Dispersion in a Prism

CONCEPT CHECK

What causes dispersion of light?

29.11 The Rainbow

In order for you to see a rainbow, the sun must be shining in one part of the sky, and the water droplets in a cloud or in falling rain must be in the opposite part of the sky.

29.11 The Rainbow

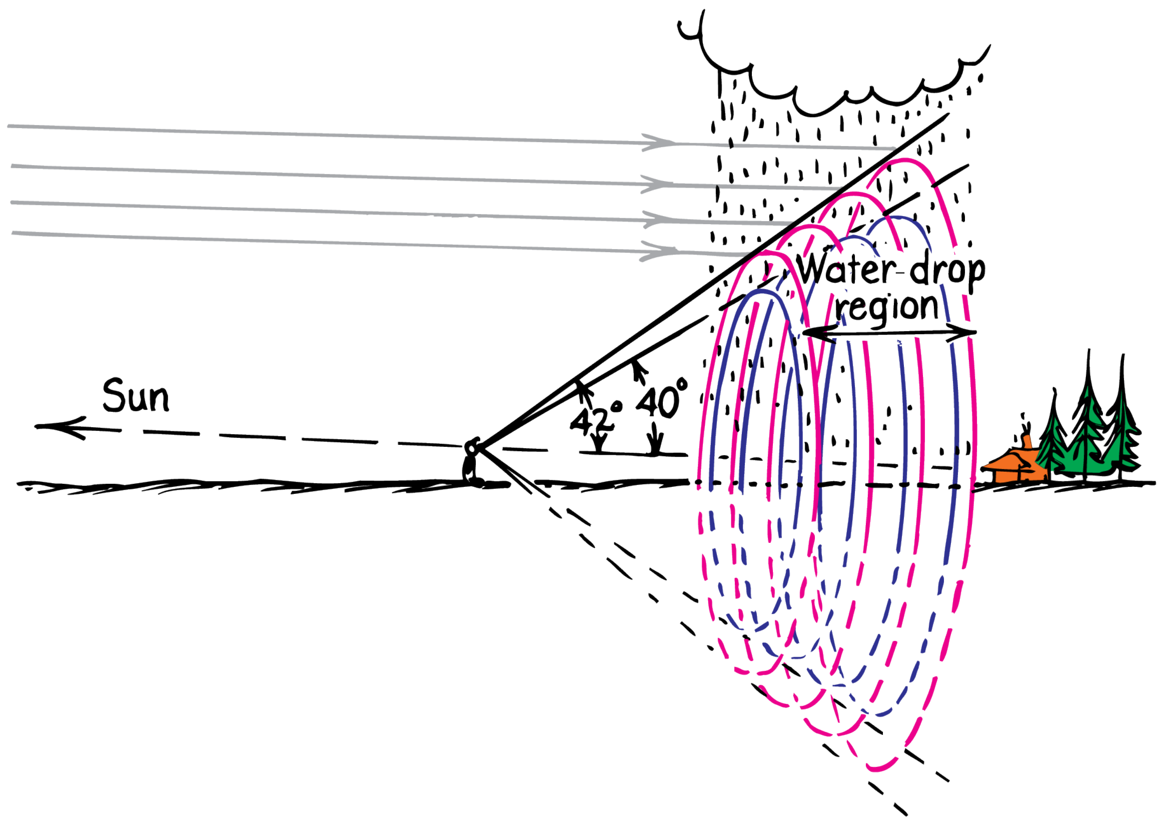
A rainbow is an illustration of dispersion.

Water droplets in a cloud or in falling rain must be in the opposite part of the sky as the sun.

All rainbows would be completely round if the ground were not in the way.

29.11 The Rainbow

The rainbow is seen in a part of the sky opposite the sun and is centered on the line extending from the sun to the observer.



29.11 The Rainbow

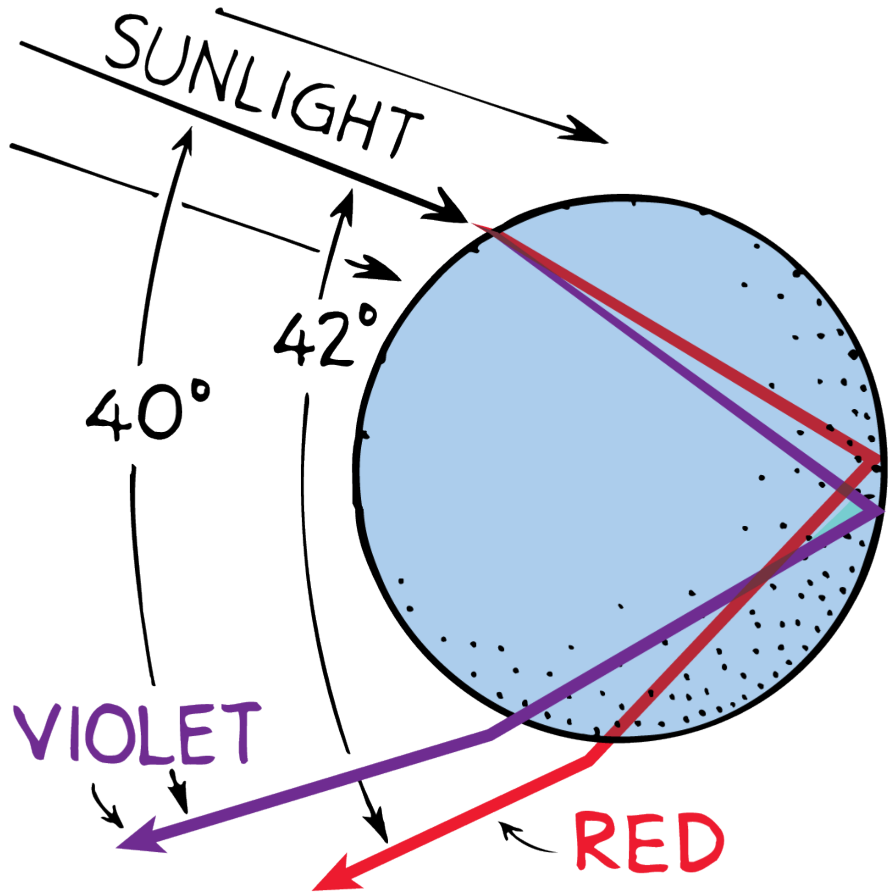
Dispersion by a Raindrop

As the ray of sunlight enters a spherical raindrop near its top surface, some of the light is refracted.

- The light is dispersed into its spectral colors. Violet is bent the most and red the least.
- At the opposite part of the drop, rays are partly reflected back into the water.
- Some rays are refracted into the air. This second refraction is similar to that of a prism.
- Refraction at the second surface increases the dispersion produced at the first surface.

29.11 The Rainbow

Dispersion of sunlight by a water drop produces a rainbow.



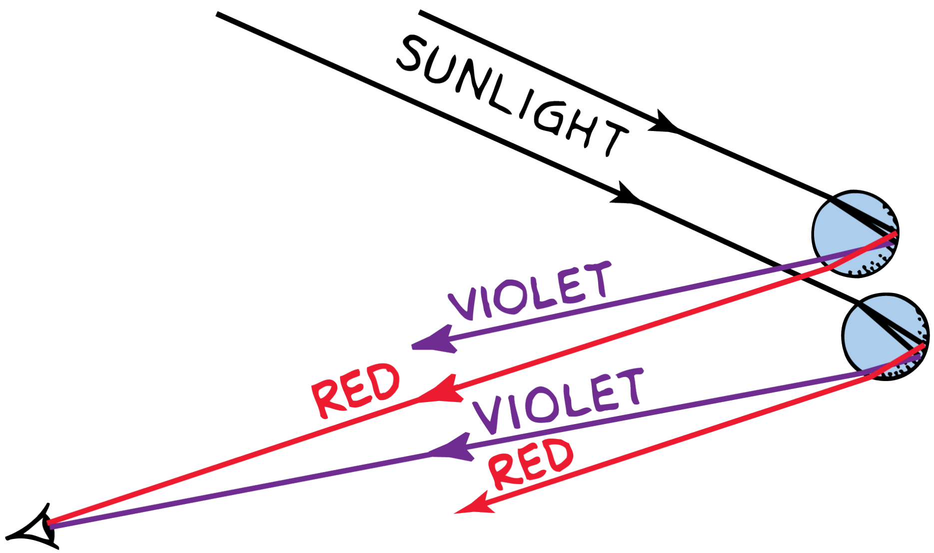
29.11 The Rainbow

Observing a Rainbow

Each drop disperses a full spectrum of colors.

An observer sees only a single color from any one drop.

By observing several drops, the arcs for each color form the familiar rainbow shape.



29.11 The Rainbow

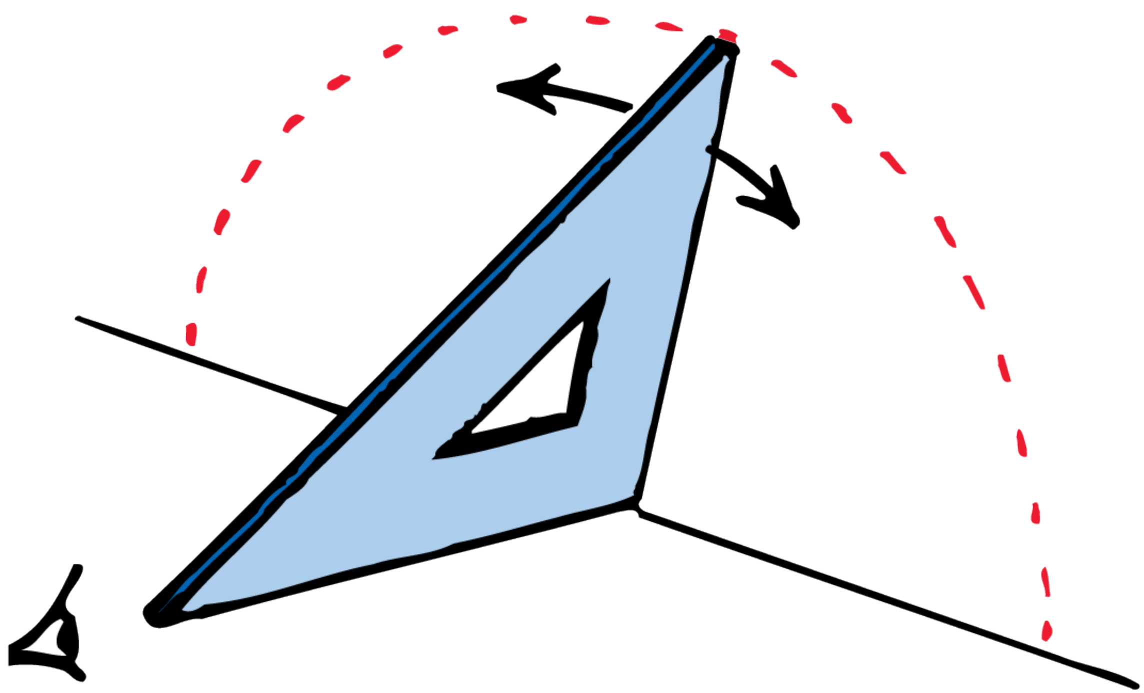
At a particular angle, you sweep out the portion of a cone, with your eye at the apex.

The raindrops that disperse light to you lie at the far edges of such a cone.

The thicker the region of water drops, the thicker the conical edge you look through, and the more vivid the rainbow.

29.11 The Rainbow

Only raindrops along the dashed arc disperse red light to the observer at a 42° angle.



29.11 The Rainbow

Your cone of vision that intersects the raindrops creating your rainbow is different from that of a person next to you.

Everybody sees his or her own personal rainbow, so when you move, your rainbow moves with you.

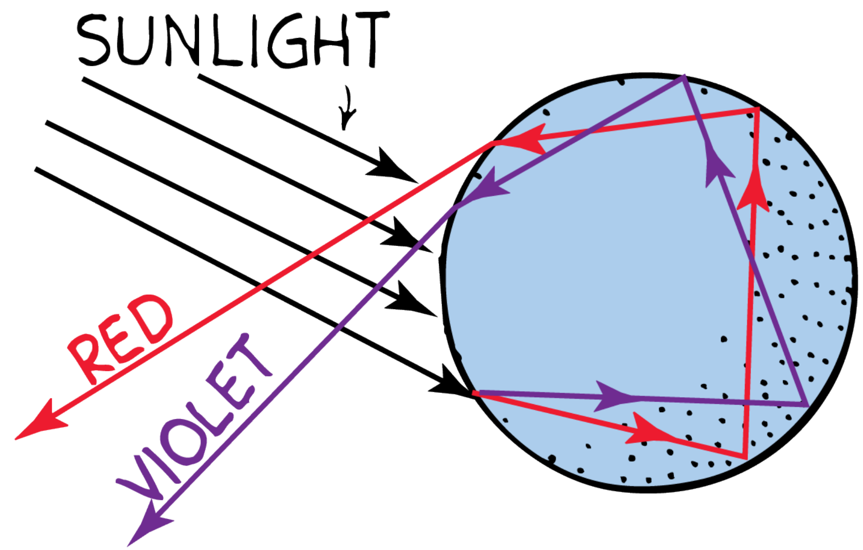
This means you can never approach the side of a rainbow, or see it end-on. You *can't* get to its end.

29.11 The Rainbow

Often a larger, secondary bow with colors reversed can be seen arching at a greater angle around the primary bow.

The secondary bow is formed by similar circumstances and is a result of double reflection within the raindrops.

Most of the light is refracted out the back of the water drop during the extra reflection, so the secondary bow is much dimmer.



29.11 The Rainbow

Light from droplets inside the rainbow form a bright disk with the colored rainbow at its edge. The sky appears darker outside the rainbow because there is no light exiting raindrops in the way that produces the main rainbow.

29.11 The Rainbow

think!

If light traveled at the same speed in raindrops as it does in air, would we still have rainbows?

29.11 The Rainbow

think!

If light traveled at the same speed in raindrops as it does in air, would we still have rainbows?

Answer:

No. If there is no change in speed, there is no refraction. If there is no refraction, there is no dispersion of light and hence, no rainbow!

29.11 The Rainbow

think!

Point to a wall with your arm extended to approximate a 42° angle to the normal of the wall. Rotate your arm in a full circle while keeping the same 42° angle. What shape does your arm describe? What shape on the wall does your finger sweep out?

29.11 The Rainbow

think!

Point to a wall with your arm extended to approximate a 42° angle to the normal of the wall. Rotate your arm in a full circle while keeping the same 42° angle. What shape does your arm describe? What shape on the wall does your finger sweep out?

Answer:

Your arm describes a cone, and your finger sweeps out a circle. Likewise with rainbows.

29.11 The Rainbow

CONCEPT CHECK

What are the conditions necessary for seeing a rainbow?

29.12 Total Internal Reflection

Total internal reflection occurs when the angle of incidence is larger than the critical angle.

29.12 Total Internal Reflection

The Critical Angle

Fill a bathtub with water and shine a submerged waterproof flashlight straight up and then slowly tip it.

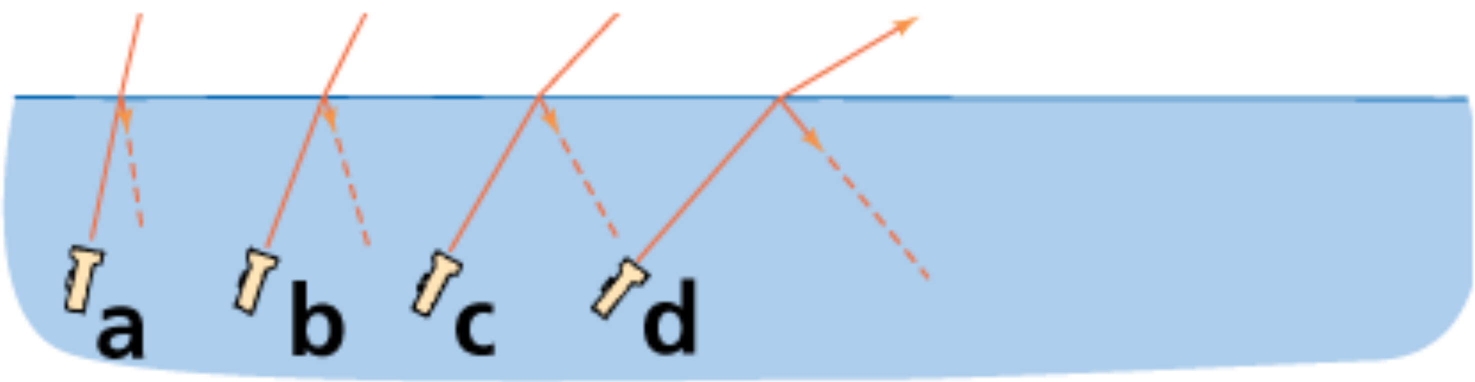
- The intensity of the emerging beam diminishes and more light is reflected from the water surface to the bottom of the tub.
- At a certain angle, the beam no longer emerges into the air.
- The **critical angle** is the angle of incidence at which the light is refracted at an angle of 90° with respect to the normal.
- The intensity of the emerging beam reduces to zero.

29.12 Total Internal Reflection

- Beyond the critical angle (48° from the normal in water), the beam cannot enter the air; it is only reflected.
- The beam is experiencing **total internal reflection,** which is the complete reflection of light back into its original medium.
- Total internal reflection occurs when the angle of incidence is larger than the critical angle.

29.12 Total Internal Reflection

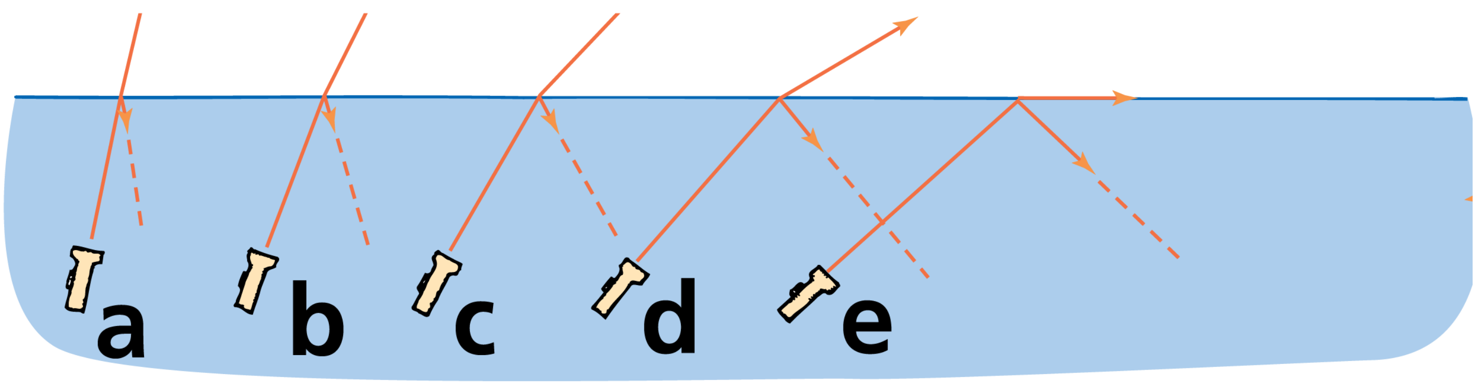
a-d. Light emitted in the water at angles below the critical angle is partly refracted and partly reflected at the surface.



29.12 Total Internal Reflection

a-d. Light emitted in the water at angles below the critical angle is partly refracted and partly reflected at the surface.

e. At the critical angle, the emerging beam skims the surface.

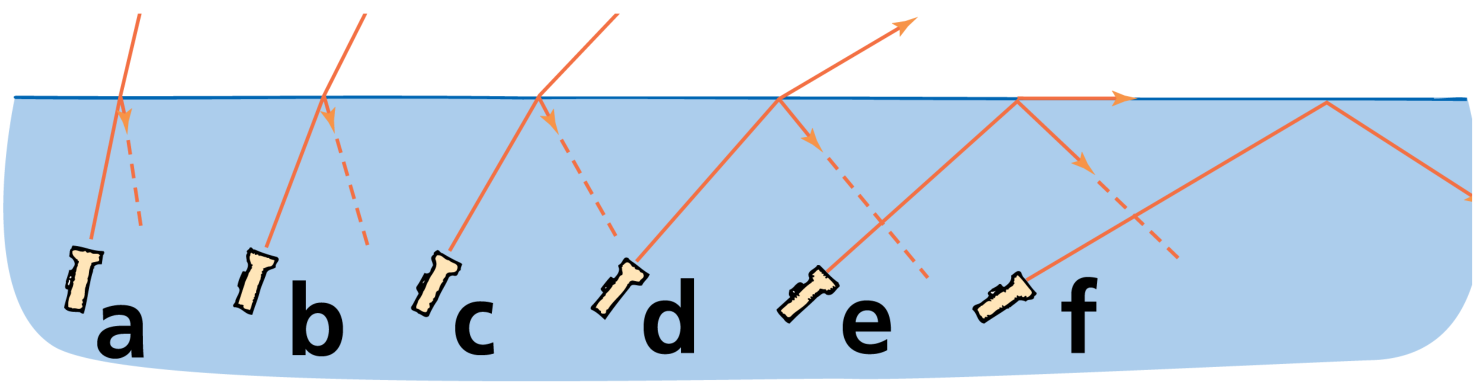


29.12 Total Internal Reflection

a-d. Light emitted in the water at angles below the critical angle is partly refracted and partly reflected at the surface.

e. At the critical angle, the emerging beam skims the surface.

f. Past the critical angle, there is total internal reflection.



29.12 Total Internal Reflection

The critical angle for glass is about 43°, depending on the type of glass.

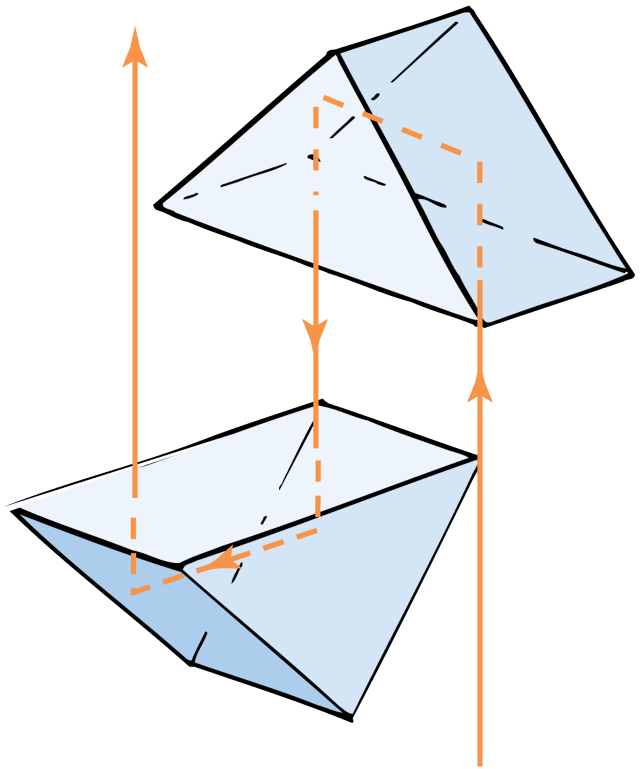
This means that within the glass, rays of light that are more than 43° from the normal to a surface will be totally internally reflected.

Total internal reflection is as the name implies: total—100%.

Mirrors reflect only 90 to 95% of incident light, so prisms are used instead of mirrors in many optical instruments.

29.12 Total Internal Reflection

Prisms are more efficient at reflecting light than mirrors because of total internal reflection.



29.12 Total Internal Reflection

Total Internal Reflection in Diamonds

The critical angle for a diamond is 24.6°, smaller than in other common substances.

This small critical angle means that light inside a diamond is more likely to be totally internally reflected than to escape.

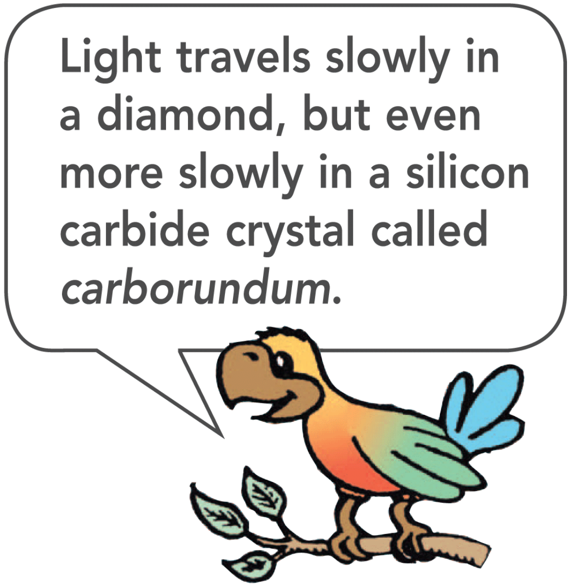
All light rays more than 24.6° from the normal to a surface in a diamond are kept inside by total internal reflection.

29.12 Total Internal Reflection

In a cut diamond, light that enters at one facet is usually totally internally reflected several times, without any loss in intensity.

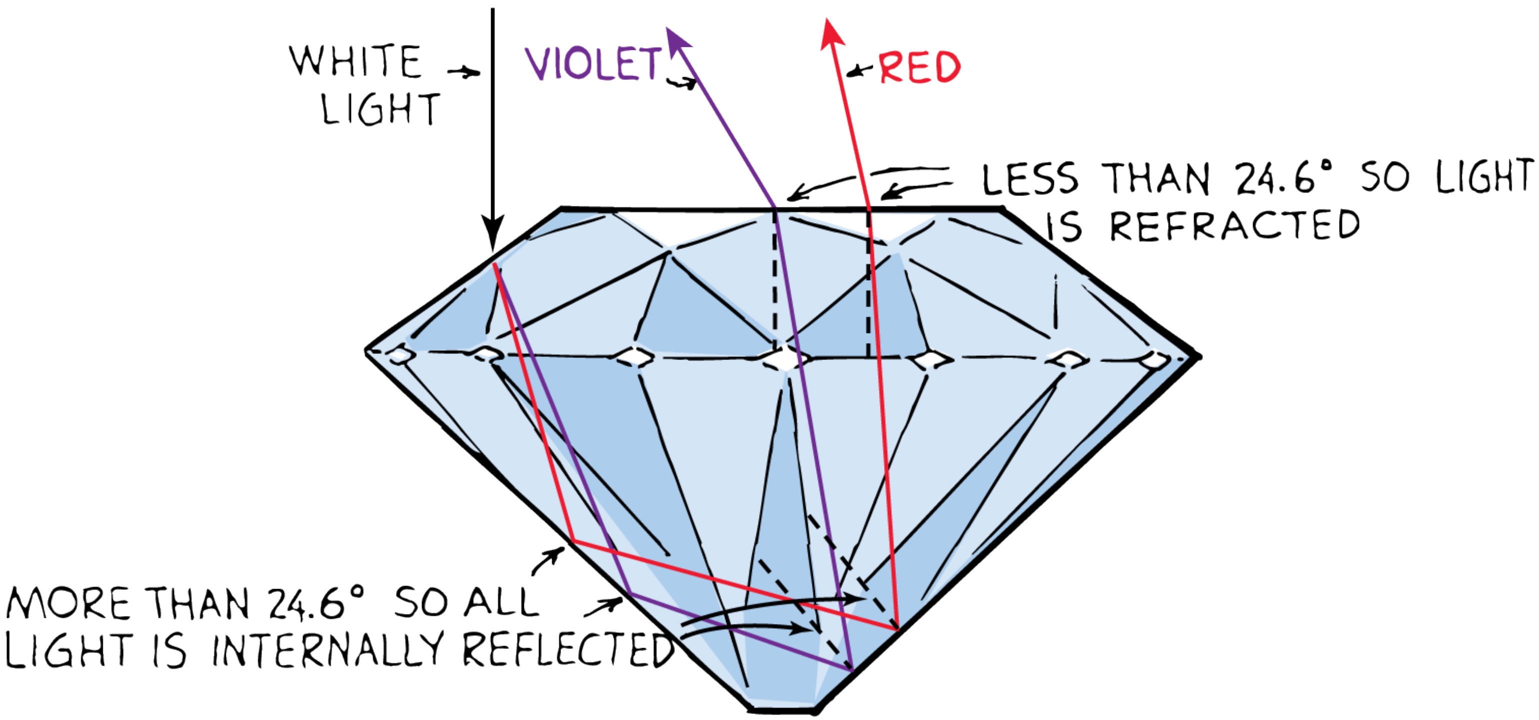
It then exits from another facet in another direction.

A small critical angle, plus high refraction, produces wide dispersion and a wide array of brilliant colors.



29.12 Total Internal Reflection

The brilliance of diamonds is a result of total internal reflection.



29.12 Total Internal Reflection

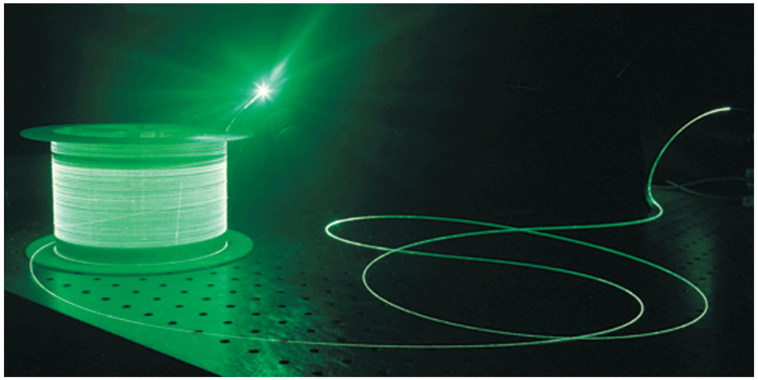
Optical Fibers

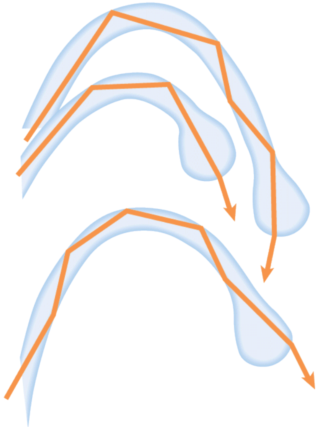
Optical fibers, sometimes called *light pipes,* are transparent fibers that pipe light from one place to another.

They do this by a series of total internal reflections.

Optical fibers are useful for getting light to inaccessible places.

Mechanics and machinists use them to look at the interiors of engines, and physicians use them to look inside a patient’s body.





29.12 Total Internal Reflection

Light that shines down some of the fibers illuminates the scene and is reflected back along others.

Optical fibers are important in communications, replacing bulky and expensive copper cables to carry telephone messages.

More information can be carried in the high frequencies of visible light than in the lower frequencies of electric current.

29.12 Total Internal Reflection

CONCEPT CHECK

What causes total internal reflection to occur?

Assessment Questions

1. When a wave reaches a boundary it
   a. can partially or totally reflect.
   b. cannot reflect into the first medium.
   c. scatters.
   d. is absorbed into the second medium.

Assessment Questions

1. When a wave reaches a boundary it
   a. can partially or totally reflect.
   b. cannot reflect into the first medium.
   c. scatters.
   d. is absorbed into the second medium.

Answer: A

Assessment Questions

2. The law of reflection applies to
   a. only partially reflected waves.
   b. only totally reflected waves.
   c. only normal waves.
   d. both partially and totally reflected waves.

Assessment Questions

2. The law of reflection applies to
   a. only partially reflected waves.
   b. only totally reflected waves.
   c. only normal waves.
   d. both partially and totally reflected waves.

Answer: D

Assessment Questions

3. Your image behind a plane mirror is at a distance equal to
   a. half your height.
   b. half your distance from the mirror.
   c. your distance in front of the mirror.
   d. slightly more than your distance in front of the mirror.

Assessment Questions

3. Your image behind a plane mirror is at a distance equal to
   a. half your height.
   b. half your distance from the mirror.
   c. your distance in front of the mirror.
   d. slightly more than your distance in front of the mirror.

Answer: C

Assessment Questions

4. A surface may be a polished reflector or a diffuse reflector depending on the
   a. color of light.
   b. brightness of light.
   c. wavelength of light.
   d. angle of incoming light.

Assessment Questions

4. A surface may be a polished reflector or a diffuse reflector depending on the
   a. color of light.
   b. brightness of light.
   c. wavelength of light.
   d. angle of incoming light.

Answer: C

Assessment Questions

5. Sound energy can be
   a. reflected.
   b. absorbed.
   c. transmitted.
   d. all of these

Assessment Questions

5. Sound energy can be
   a. reflected.
   b. absorbed.
   c. transmitted.
   d. all of these

Answer: D

Assessment Questions

6. Refraction occurs when a wave crosses a boundary and changes
   a. speed and direction.
   b. intensity.
   c. frequency.
   d. amplitude.

Assessment Questions

6. Refraction occurs when a wave crosses a boundary and changes
   a. speed and direction.
   b. intensity.
   c. frequency.
   d. amplitude.

Answer: A

Assessment Questions

7. Changes in wind speed and temperature cause sound waves to
   a. reflect.
   b. reverberate.
   c. refract.
   d. scatter.

Assessment Questions

7. Changes in wind speed and temperature cause sound waves to
   a. reflect.
   b. reverberate.
   c. refract.
   d. scatter.

Answer: C

Assessment Questions

8. Refracted light that bends away from the normal is light that has
   a. slowed down.
   b. speeded up.
   c. nearly been absorbed.
   d. diffracted.

Assessment Questions

8. Refracted light that bends away from the normal is light that has
   a. slowed down.
   b. speeded up.
   c. nearly been absorbed.
   d. diffracted.

Answer: B

Assessment Questions

9. Atmospheric refraction occurs with changes in
   a. wind speed.
   b. air temperature.
   c. the presence of water.
   d. both wind speed and air temperature.

Assessment Questions

9. Atmospheric refraction occurs with changes in
   a. wind speed.
   b. air temperature.
   c. the presence of water.
   d. both wind speed and air temperature.

Answer: B

Assessment Questions

10. When light incident on a prism separates into a spectrum, we call the process
    a. reflection.
    b. interference.
    c. diffraction.
    d. dispersion.

Assessment Questions

10. When light incident on a prism separates into a spectrum, we call the process
    a. reflection.
    b. interference.
    c. diffraction.
    d. dispersion.

Answer: D

Assessment Questions

11. A rainbow is the result of light in raindrops that undergoes
    a. internal reflection.
    b. dispersion.
    c. refraction.
    d. all of these

Assessment Questions

11. A rainbow is the result of light in raindrops that undergoes
    a. internal reflection.
    b. dispersion.
    c. refraction.
    d. all of these

Answer: D

Assessment Questions

12. The critical angle in total internal reflection occurs when incident light on a surface is
    a. refracted at 90° to the normal.
    b. reflected at 90° to the normal.
    c. at maximum diffraction.
    d. totally absorbed.

Assessment Questions

12. The critical angle in total internal reflection occurs when incident light on a surface is
    a. refracted at 90° to the normal.
    b. reflected at 90° to the normal.
    c. at maximum diffraction.
    d. totally absorbed.

Answer: A