Light rays slow and bend as they pass through the curved glass lens. In this case, the result is a magnified image.

Index of Refraction of Light

- **What causes light to refract?**
- **When light enters a new medium at an angle, the change in speed causes the light to bend, or refract.**

Index of Refraction of Light

Light usually travels in straight lines. In a vacuum, light travels at a speed of 3.00×10^8 meters per second.

- The speed of light in a different medium depends on the material of the new medium.
- Air allows light to pass through almost as fast as it would through a vacuum.

Index of Refraction of Light

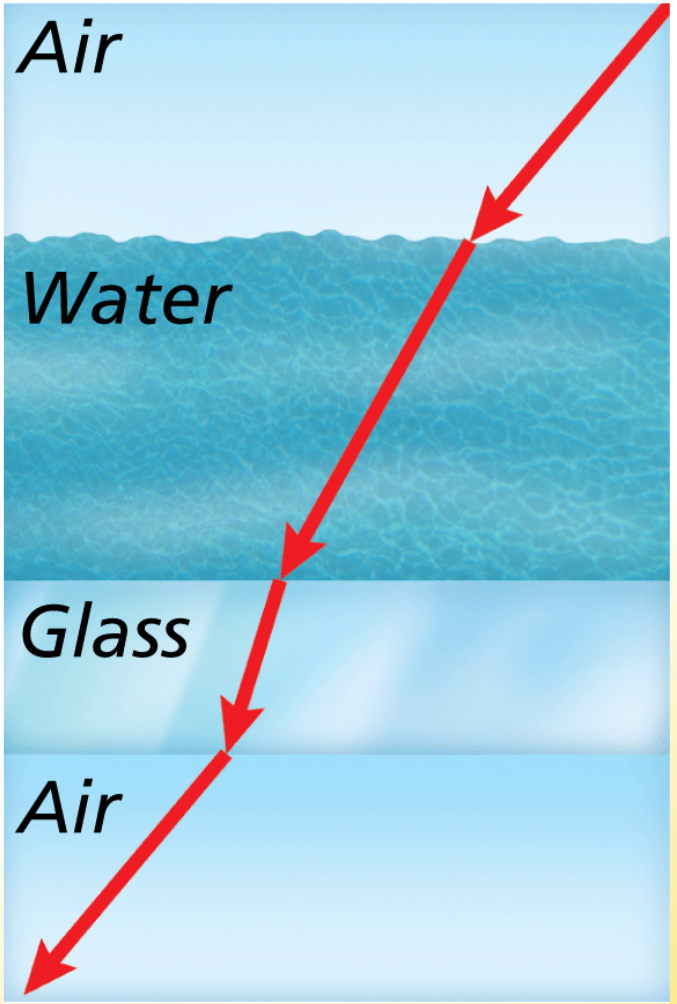
The speed of light in water is 2.25×10^8 meters per second. The speed of light in glass is 2.00×10^8 meters per second.

- When light passes from air into glass or water, it slows down.
- When light passes from glass or water into air, it speeds up.

Index of Refraction of Light

A light ray bends (refracts) as it passes through media with different indices of refraction.

The ray again travels in its original direction when it reenters the air.



Index of Refraction of Light

The amount of refraction depends upon the difference between the speeds of light in the two media. The **index of refraction** for a material is the ratio of the speed of light in a vacuum to the speed of the light in the material.

- A low index of refraction (near 1) causes light to slow and refract very little.
- Diamond (index of refraction = 2.42), causes significant refraction.

Properties of Gemstones

Data Analysis

Gemstones used in jewelry are known for several of their physical properties—primarily luster and optical brilliance. Luster is a measure of the amount of light that strikes a gemstone's surface and is reflected. Flat and smooth surfaces increase a gemstone's luster.

Properties of Gemstones

Data Analysis

Like luster, the brilliance of a gemstone involves reflected light. Light that is not reflected by a gem's lustrous surface passes into the stone. The brilliance of a gemstone is a measure of the amount of light entering the gem that is reflected back to the viewer.

Precise techniques are used to cut gemstones into shapes that produce maximum brilliance. The combination of a specialized shape and the gemstone's inherent high index of refraction gives gems their brilliance.

Properties of Gemstones

Data Analysis

The table summarizes the index of refraction and luster of several common gemstones. Note that moissanite is a manufactured material used to simulate diamond.

Properties of Natural and Synthetic Gemstones

Material	Index of Refraction	Luster
Diamond	2.42	17.2%
Moissanite	2.65	20.4%
Ruby	1.77	7.4%
Sapphire	1.77	7.4%
Emerald	1.58	4.8%

Properties of Gemstones

Data Analysis

- **Interpreting Tables** Which material is the most lustrous? The least lustrous?

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Answer: Moissanite is the most lustrous (20.4%); emerald is the least lustrous (4.8%).

Properties of Gemstones

Data Analysis

- **Calculating** What percentage of light striking a sapphire gemstone enters it?

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Answer: 96.2% of the light striking a sapphire enters the gemstone.

Properties of Gemstones

Data Analysis

- **Applying Concepts** If a light ray strikes each material at an angle, in which material would the light ray bend the most?

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Answer: Light bends the most in moissanite because it has the greatest index of refraction.

Properties of Gemstones

Data Analysis

• **Applying Concepts** The speed of light through an unknown gemstone is 1.69 × 108 m/s. Identify the gemstone.

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Answer: Index of refraction = speed of light in vacuum/speed of light in gemstone; index of refraction = (3.00 × 108 m/s)/ (1.69 × 108 m/s) = 1.77; the gemstone could be either a ruby or a sapphire.

Concave and Convex Lenses

- **What type of images do concave and convex lenses form?**
- **Concave lenses always cause light rays to spread out and can only form virtual images.**
- **Convex lenses form either real or virtual images.**

Concave and Convex Lenses

Concave Lenses

A **lens** is an object made of transparent material that has one or two curved surfaces that can refract light.

A concave lens is curved inward at the center and is thickest at the outside edges.

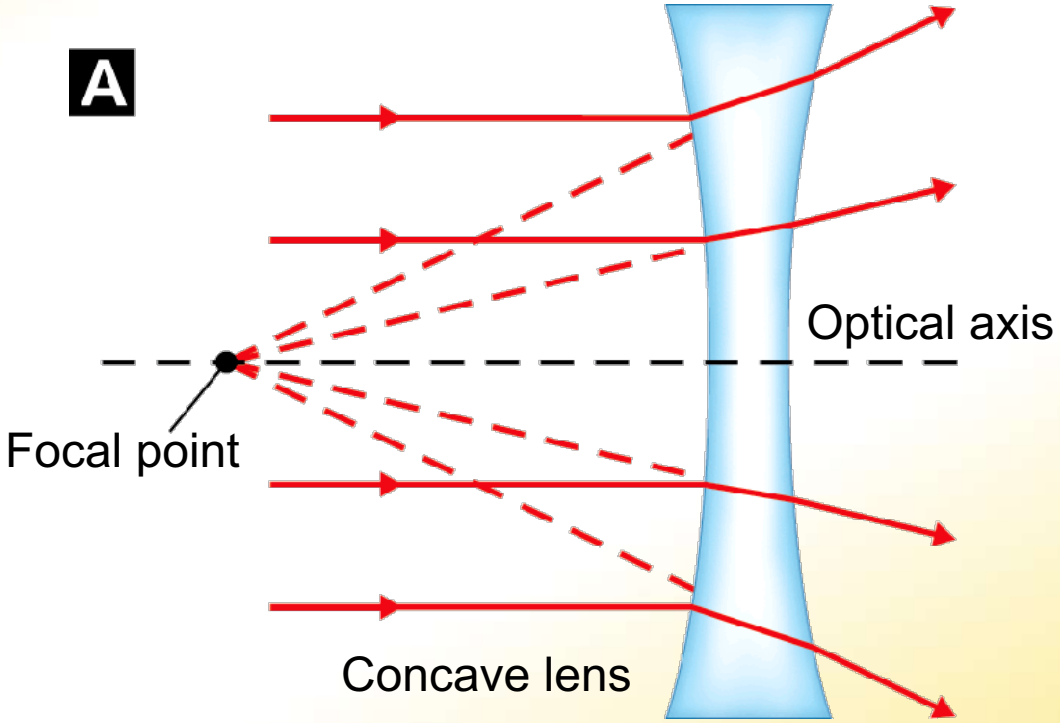
Concave and Convex Lenses

The rays enter the lens at different angles, and so they emerge from the lens at different angles.

- Concave lenses cause incoming parallel rays to spread out, or diverge. The diverging rays appear to come from the focal point, on the same side of the lens as the object.
- A concave lens forms a virtual image. The image formed by a concave lens is always smaller than the object.

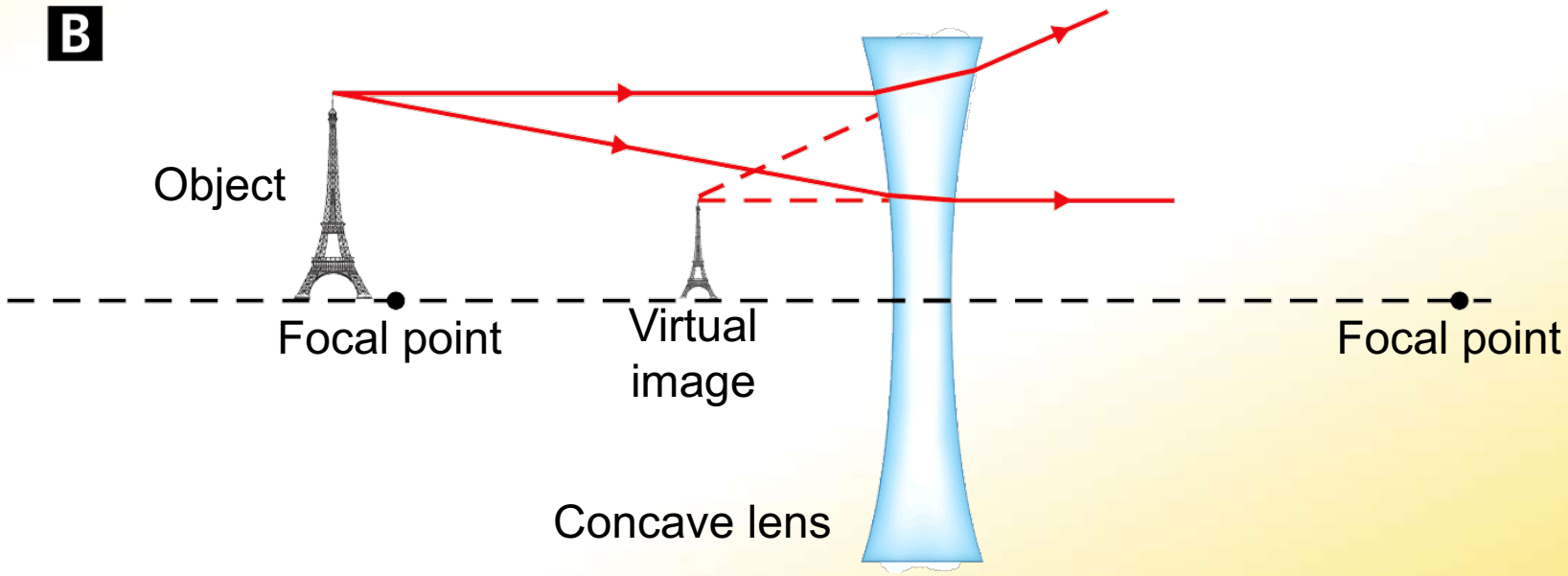
Concave and Convex Lenses

- When parallel incoming rays strike a concave lens, they are refracted away from one another.



Concave and Convex Lenses

- As the light rays diverge after passing through the concave lens, they form a virtual image of the object.



Concave and Convex Lenses

Concave lenses are often used in the viewfinders of cameras. Concave lenses are also combined with mirrors or other lenses to form images in optical instruments such as telescopes.

Concave and Convex Lenses

Convex Lenses

A **convex lens** is curved outward at the center and is thinnest at the outer edges.

- As the rays pass through the lens, each one is refracted, and they emerge at different angles.
- Convex lenses cause incoming parallel rays to come together, or converge.

Concave and Convex Lenses

- The converging rays meet at the focal point, on the side of the lens opposite to the object.
- Whether an image is real or virtual depends upon how far the object is from the lens.

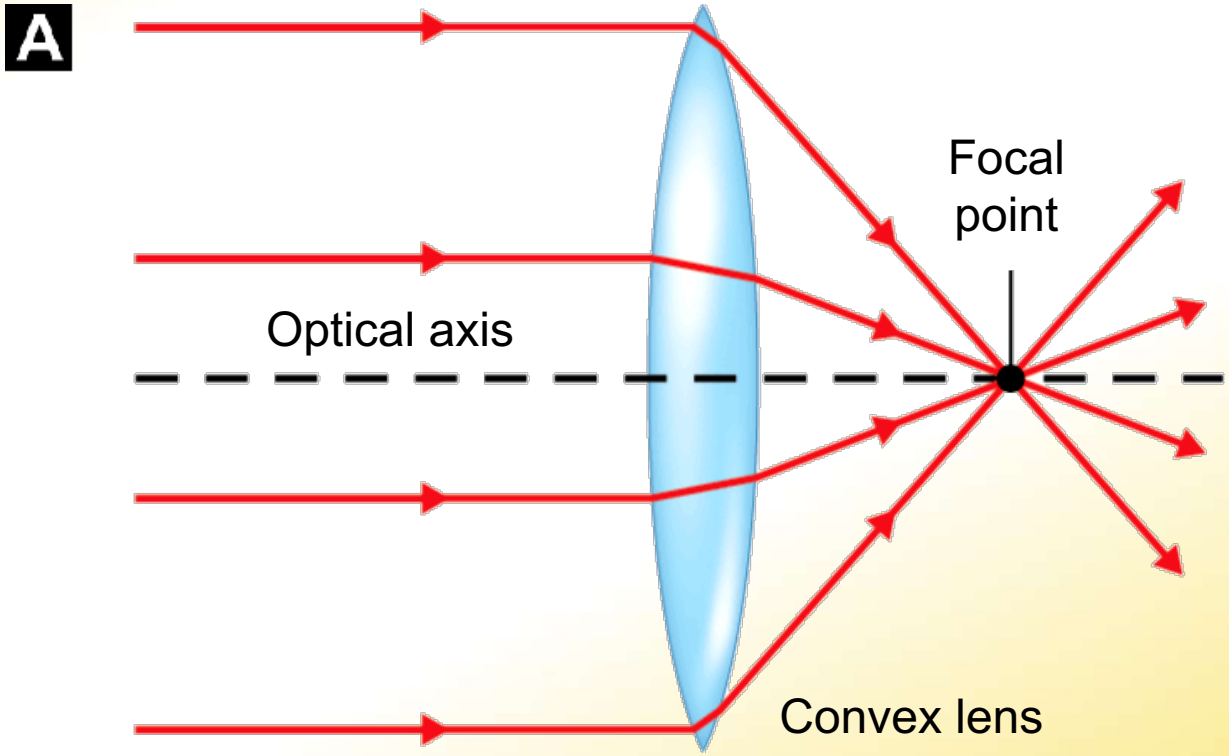
Concave and Convex Lenses

Each of the housefly's eyes is made up of thousands of tiny individual eyes called facets.

The outer surface of each facet is convex. The eyes give the fly a nearly 360-degree field of view.

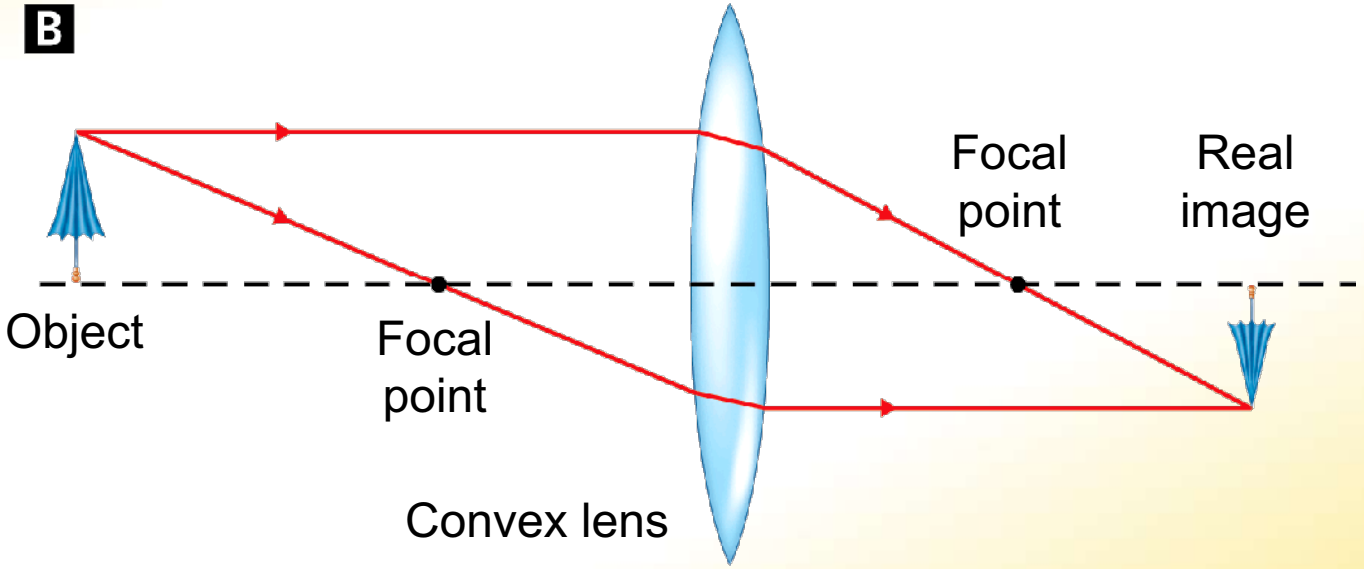
Concave and Convex Lenses

- Parallel rays are refracted and pass through the focal point of a convex lens.



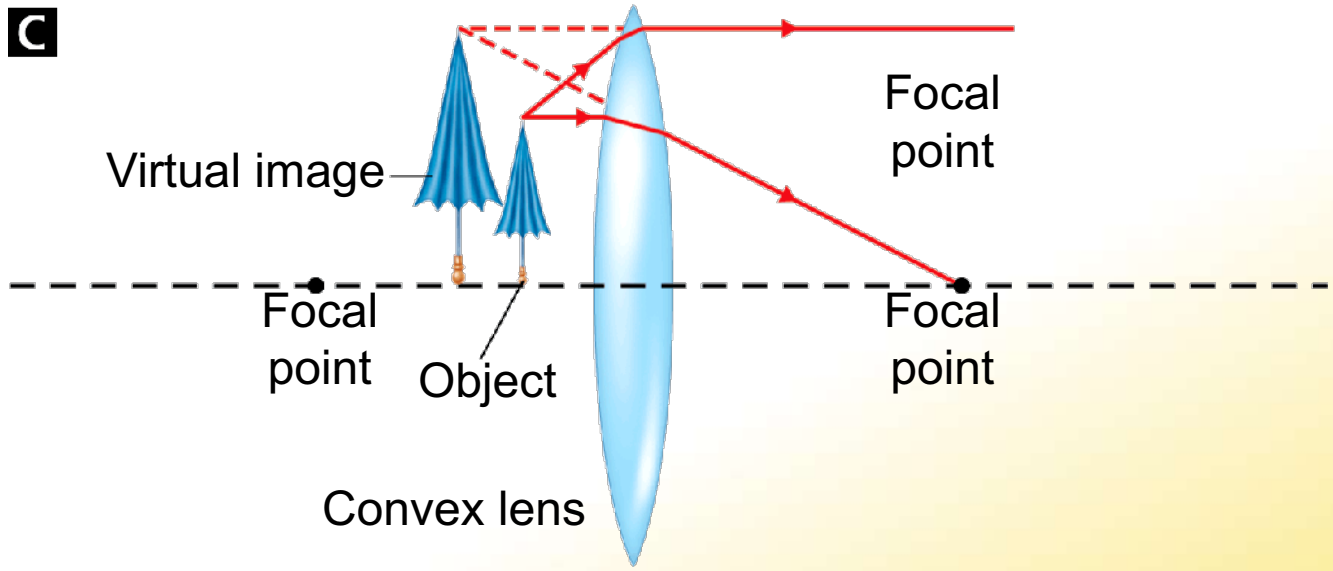
Concave and Convex Lenses

- When an object is located beyond the focal point, a real image is formed.



Concave and Convex Lenses

- A magnified, virtual image is formed when the object is located between the focal point and the lens.



Concave and Convex Lenses

Convex lenses are used in slide and movie projectors and cameras.

At the movie theatre, the film is placed upside down in the projector so that the real image is upright.

Concave and Convex Lenses

In the past, lighthouses used a light source placed at the focal point of a convex lens or series of convex lenses to form a beam of parallel light rays.

Total Internal Reflection

- **In what types of materials is total internal reflection likely to occur?**
- **Materials that have small critical angles are likely to cause most of the light entering them to be totally internally reflected.**

Total Internal Reflection

The **critical angle** is the angle of incidence that produces an angle of refraction of 90 degrees.

- At the critical angle, the light ray bends so much that it takes a path along the glass-air boundary.
- At angles larger than the critical angle, the light ray bends so much that it is reflected back into the glass.

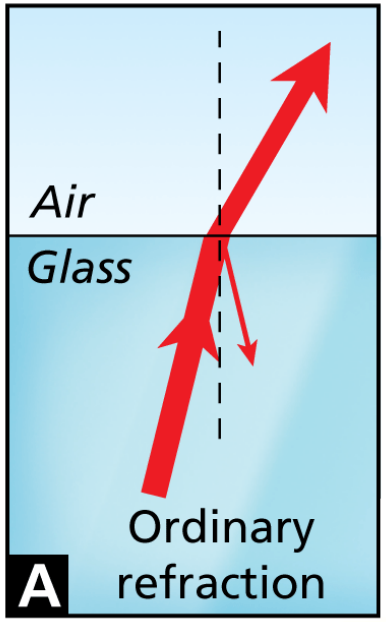
Total Internal Reflection

Total internal reflection is the complete reflection of a light ray back into its original medium. An important application of total internal refraction is fiber optics.

- Light rays are generally unable to exit through the sides of the curving fiber optic strands.
- Fiber optics are able to transmit data in the form of light pulses over large distances with little loss in signal strength.

Total Internal Reflection

- For angles less than the critical angle, light is partly refracted and partly reflected.



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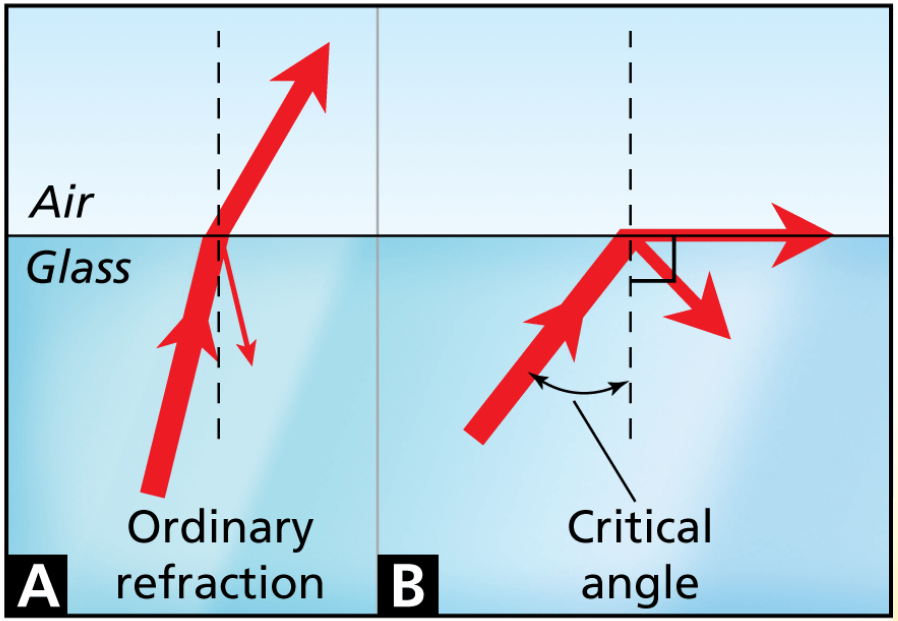
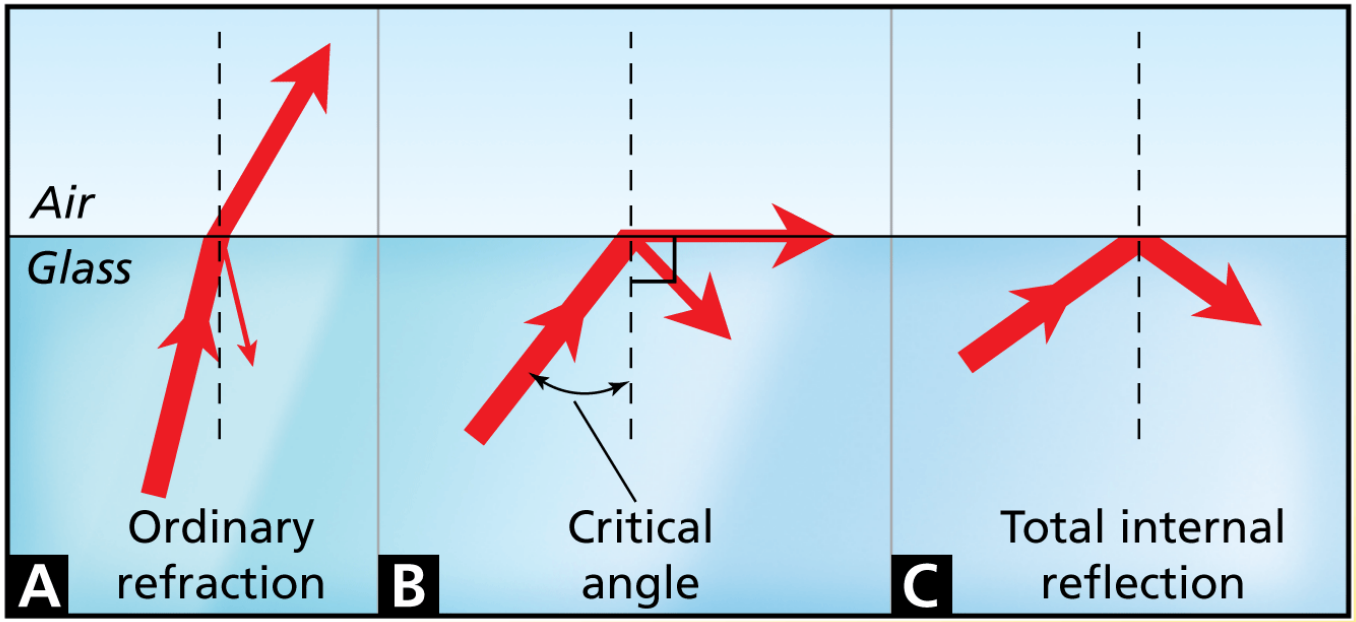


Total Internal Reflection

- For angles less than the critical angle, light is partly refracted and partly reflected.
- At the critical angle, the angle of refraction is 90 degrees.
- For angles greater than the critical angle, all of the light is reflected.



Assessment Questions

- Light refracts when it passes from air to water because
  - the wavelength is different in the two media.
  - the frequency is different in the two media.
  - the speed is different in the two media.
  - the amplitude is different in the two media.

Assessment Questions

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  ANS:C

Assessment Questions

- Which type(s) of lens can form a real image?
  - concave lens only
  - convex lens only
  - both concave and convex lenses
  - neither concave nor convex lenses

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  ANS:B

Assessment Questions

- What will happen to a ray of light if it hits a new medium at an angle greater than the critical angle?
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  - Part of the light will be refracted and part reflected.
  - All the light will be reflected.
  - All the light will be absorbed.

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Assessment Questions

- The index of refraction is the ratio of the speed of light in a vacuum to the speed of light in a material.

  True
  False

-

Assessment Questions

- The index of refraction is the ratio of the speed of light in a vacuum to the speed of light in a material.

  True
  False

- ANS:T