Phys 100: The Physical World

Chapters 28 & 29

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Reflection

- We say light is **reflected** when it is returned into the medium from which it came—the process is **reflection**.
- When light illuminates a material, electrons in the atoms of the material move more energetically in response to the oscillating electric fields of the illuminating light.
- The energized electrons reemit the light by which you see the material.

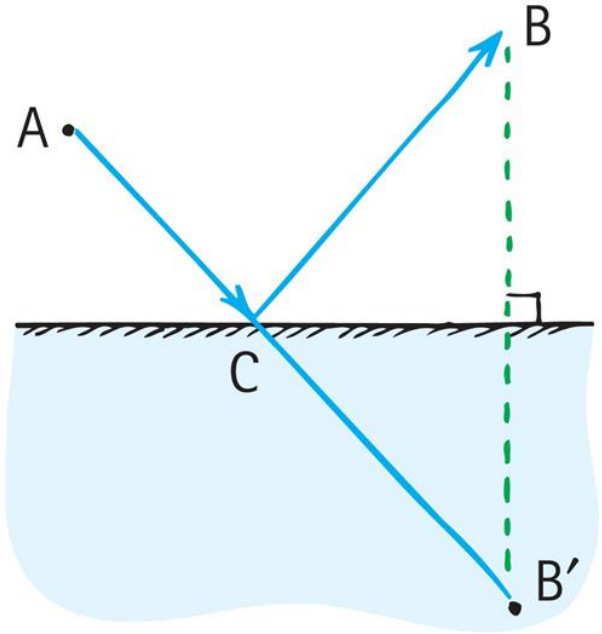
Principle of Least Time

- The idea that light takes the quickest path in going from one place to another is called **Fermat's principle of least time.**
- The principle of least time provides a link between **ray optics** and **wave optics**. It can be derived from Maxwell's equations.
- We can treat light, or any wave for that matter, as a collection of rays if the obstacles encountered by the wave are much larger than the wavelength.
- Fermat's principle states that the path taken by a ray between two given points is the path that can be traveled in the least amount of time.

Pierre de Fermat

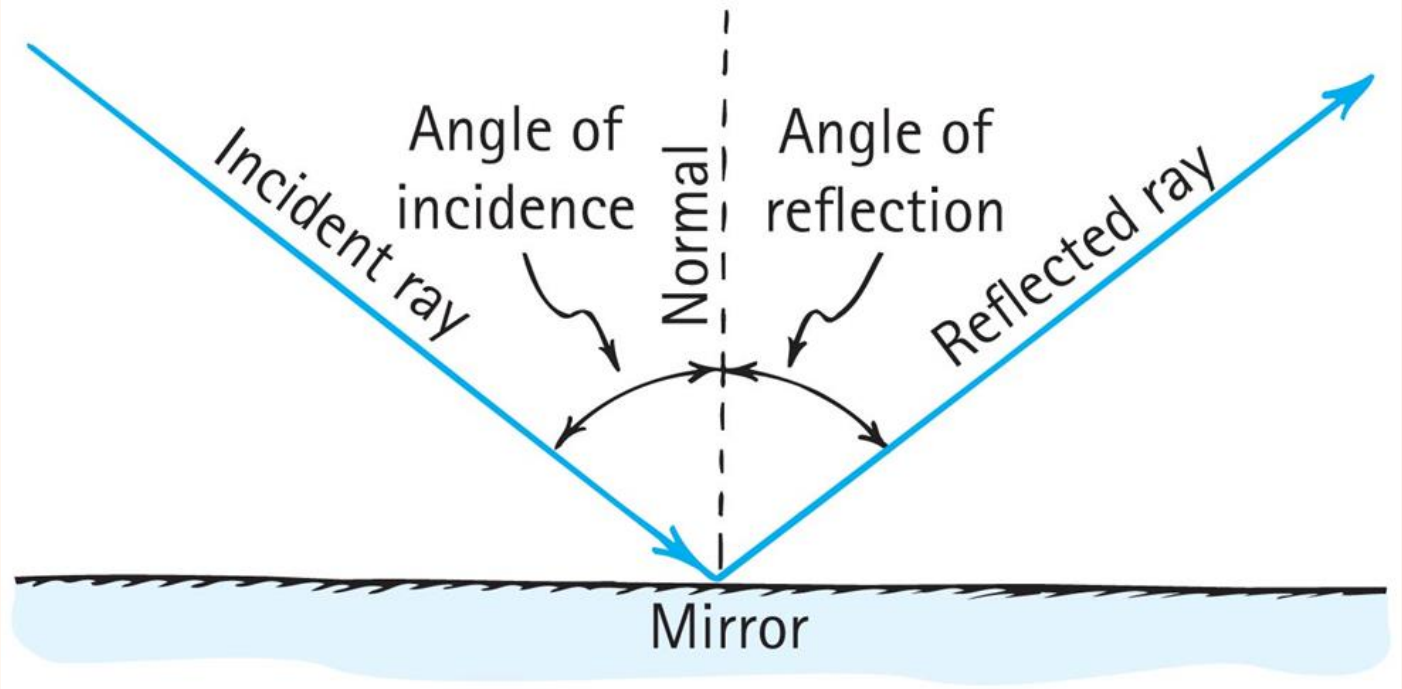
Least Time for Reflection

- Finding the shortest time for light to go from A to B by reflecting off the mirror.
- Construct, on the opposite side of the mirror, an artificial point, which is the same distance “through” and below the mirror as the point B is above the mirror.
- The shortest distance between A and this artificial point is a straight line.
- This straight line intersects the mirror at a point C, the precise point of reflection for least time from A to B.



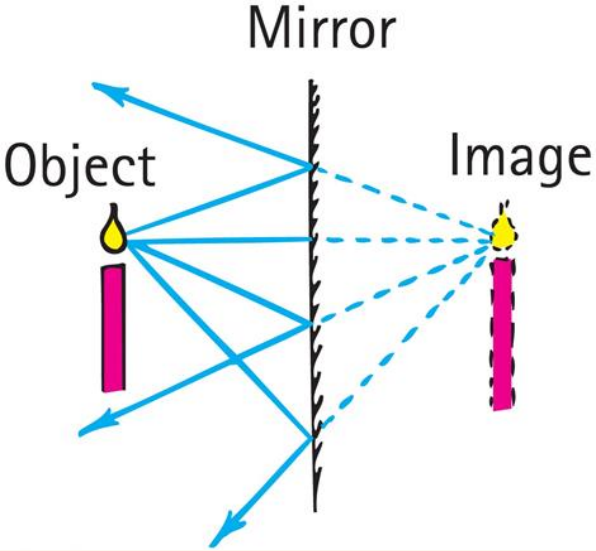
Law of Reflection

- **The angle of reflection equals the angle of incidence.**



Plane Mirrors

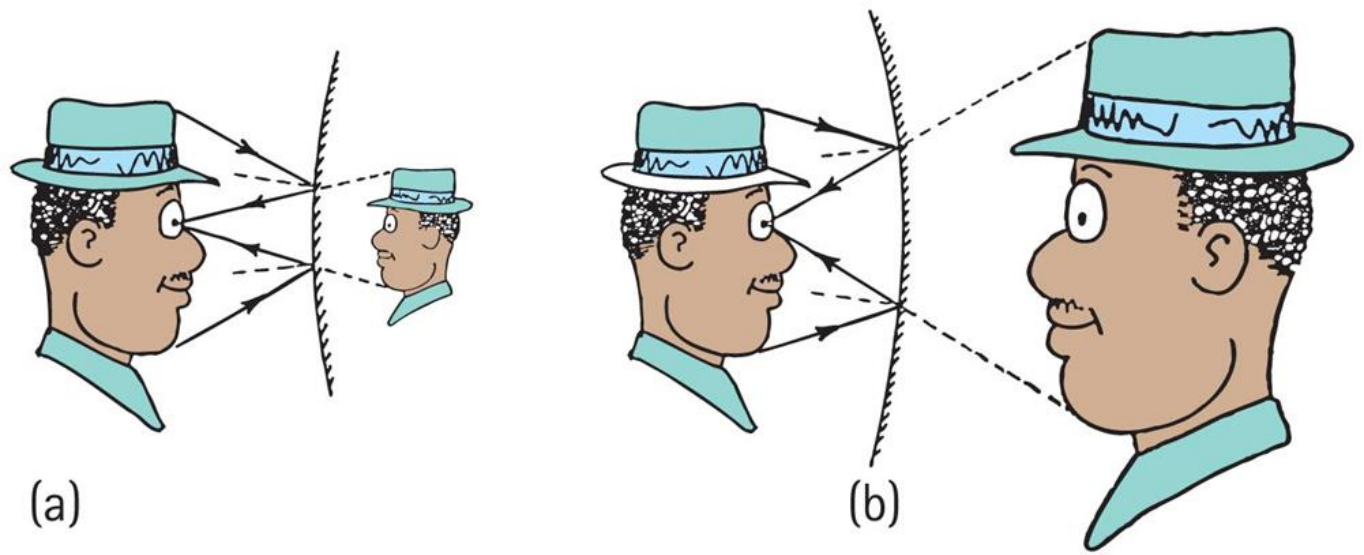
- A plane mirror creates a **virtual image**
  - is the same size as object, formed behind a mirror, and located at the position where the extended reflected rays converge.
  - is as far behind the mirror as the object is in front of the mirror.



How does the mirror know?

Curved Mirrors

- Convex mirror (that curves outward): Virtual image is smaller and closer to the mirror than the object.
- Concave mirror (that curves inward): Virtual image of a *close object* is larger and farther away than the object.



Concave Mirrors

Conceptual Question 1

Light reflecting from a smooth surface undergoes a change in

A. frequency.

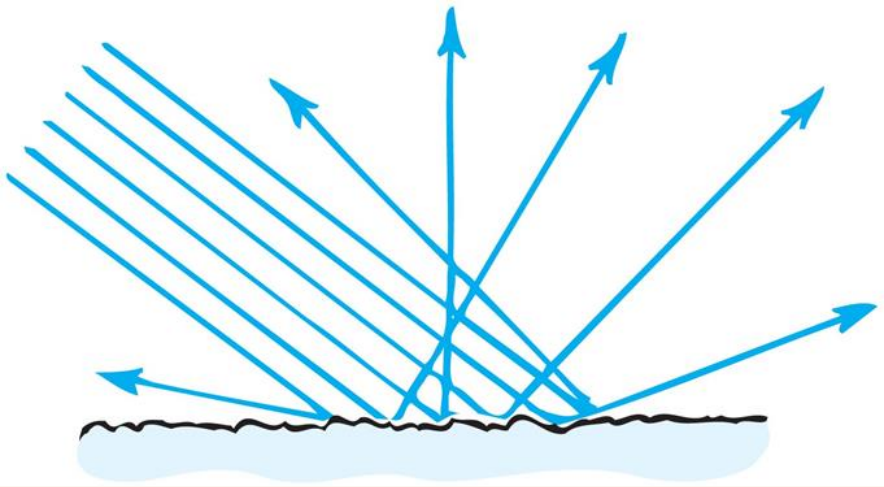
B. speed.

C. wavelength.

D. None of the above is correct.

Diffuse Reflection

- Diffuse reflection
  - occurs when light strikes a rough or an irregular surface and reflects in many directions.
  - is what allows us to see most objects from various angles.



Conceptual Question 2

Diffuse reflection occurs when the sizes of surface irregularities are

A. small compared with the wavelength of reflected radiation.

B. large compared with the wavelength of reflected radiation.

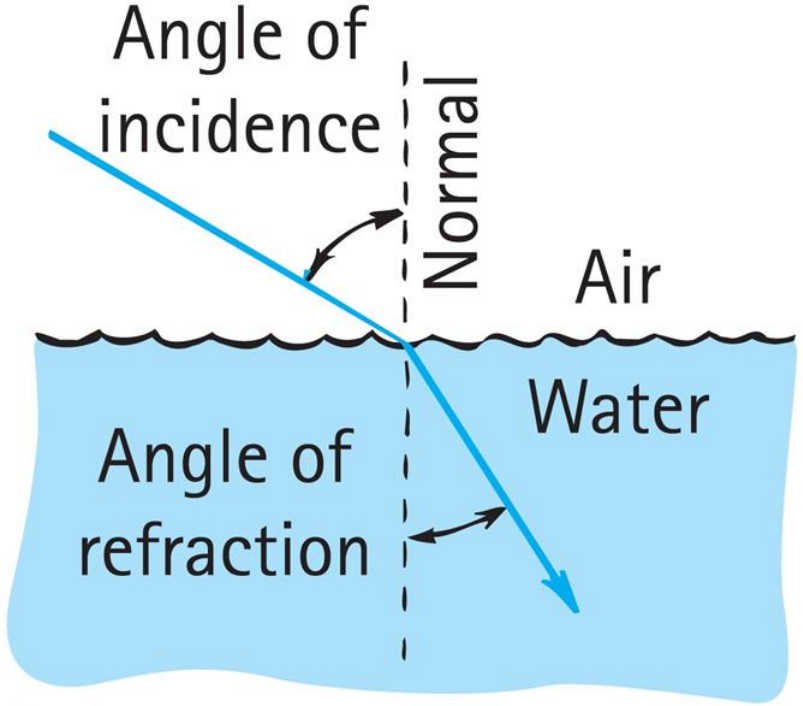
C. Both A and B are correct.

D. None of the above is correct.

Hikaru Dorodango

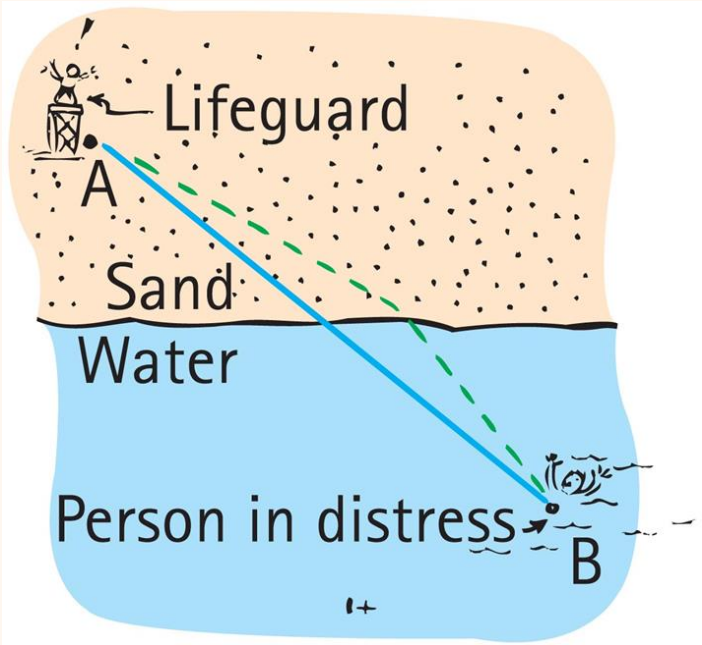
Refraction

- **Refraction** is the bending of light rays after passing obliquely from one medium to another.



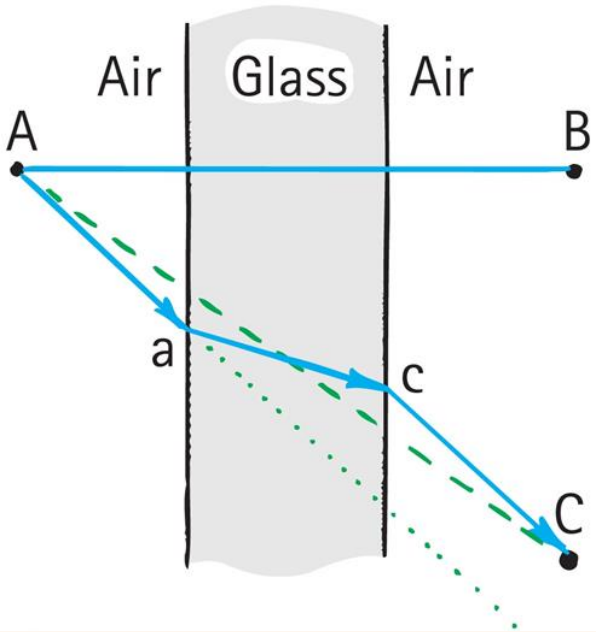
Least Time for Refraction

- Refraction occurs to minimize the time taken for light to travel from A to B, using a different light speed in different media.
- Similarly: To save someone from drowning, the quickest path would not be the straight line—it would be the dashed path shown.



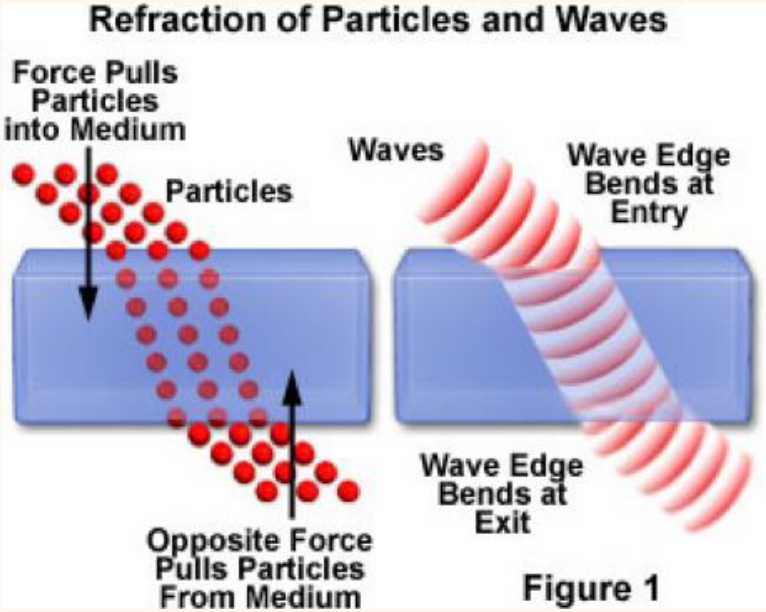
Refraction by Glass

- Light travels slower in glass than in air, so it bends when passing from *a* to *c*, to minimize the time it spends in the glass.



Newton's Corpuscular Model

- Newton's corpuscular model proposed that light consists of tiny particles that speed up when entering a denser medium, like glass, due to an attractive force.
- This increase in speed causes the light to bend toward the normal, explaining refraction. Later experiments showed that *light actually slows down in denser media*, contradicting Newton's model.



Index of Refraction

- The **refractive index** of a material
  - is the ratio of speed of light in vacuum to the speed of light in the material.
  - determines the extent of bending of refracted light rays.
  - Medium with a high index means high bending effect and greatest slowing of light.
  - is typically denoted **n**.
  - is also known as the **index of refraction** of the material.

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

Conceptual Question 3

Refracted light that bends toward the normal is light that has

A. slowed down.

B. speed up.

C. nearly been absorbed.

D. diffracted.

Conceptual Question 4

Refracted light that bends away from the normal is light that has

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B. speed up.

C. nearly been absorbed.

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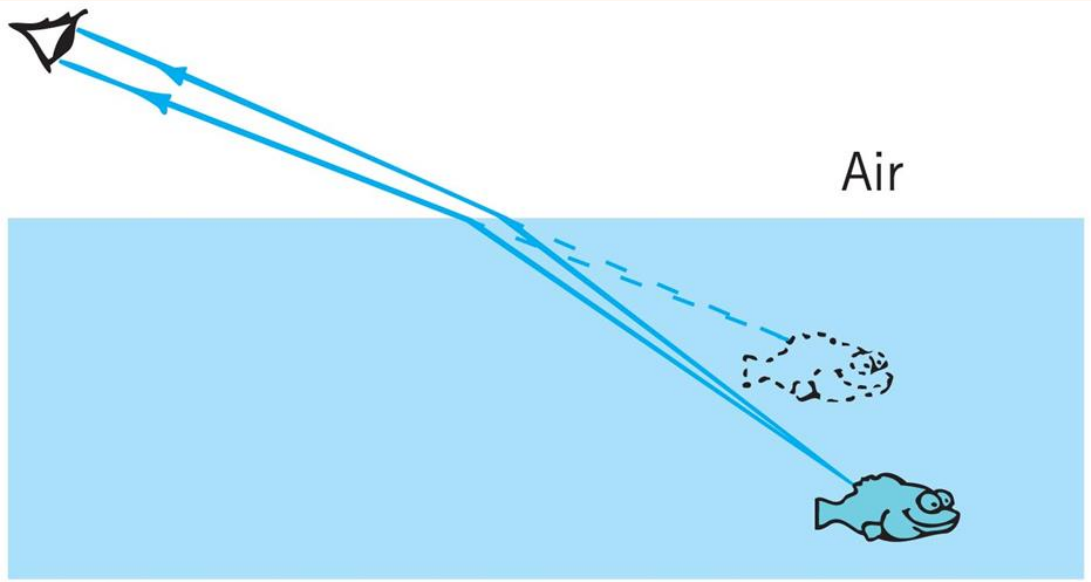
Illusions caused by refraction

- **Objects submerged in water appear closer to the surface.**
- Objects such as the Sun seen through air are displaced because of atmospheric refraction.
- Atmospheric refraction is the cause of mirages.



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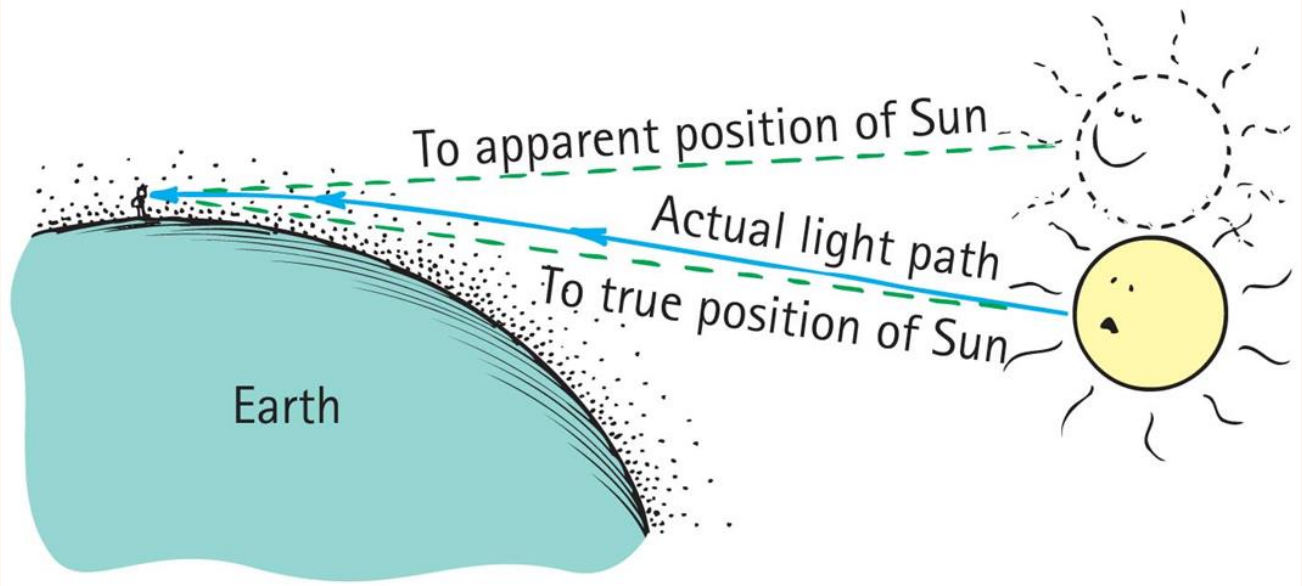

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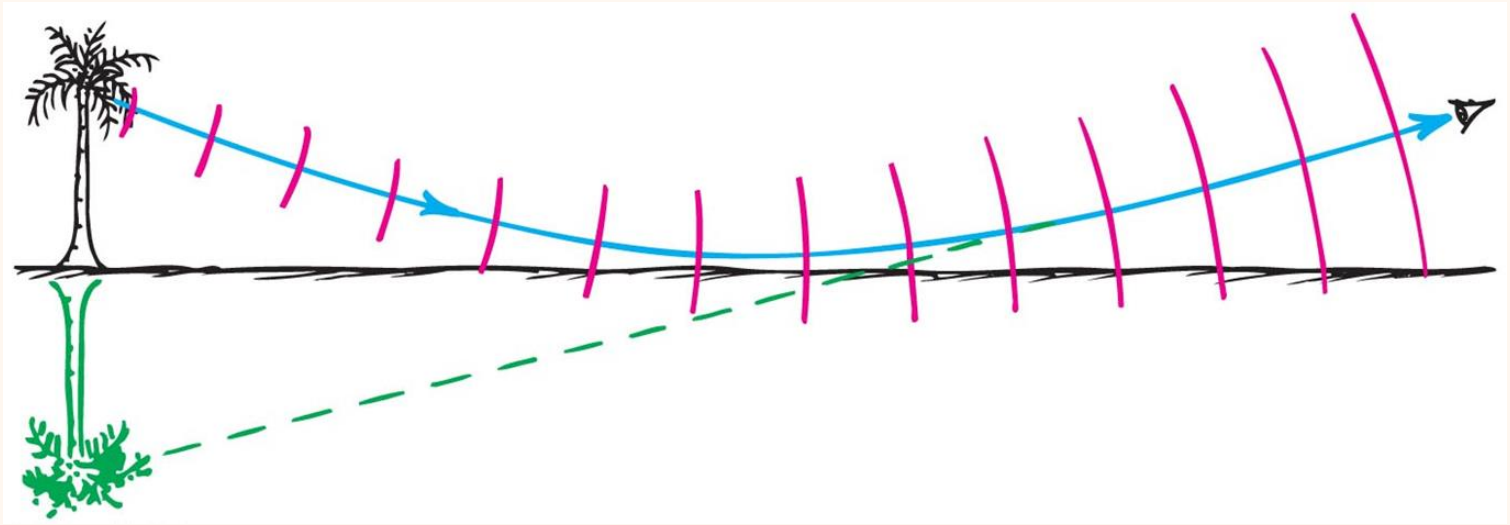


Conceptual Question 5

A change in the speed of light when passing from one medium to another explains which of the following phenomena

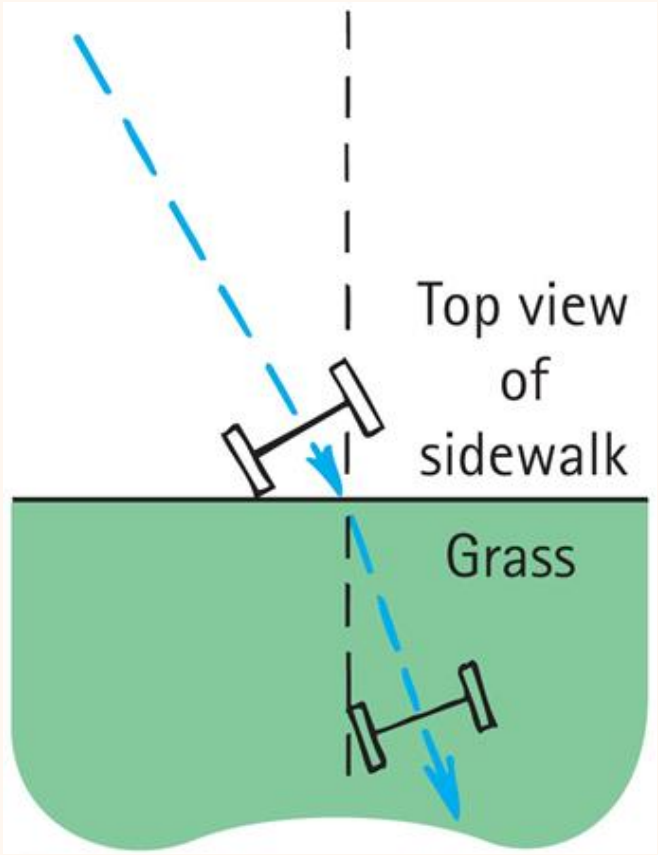
A. reflection.

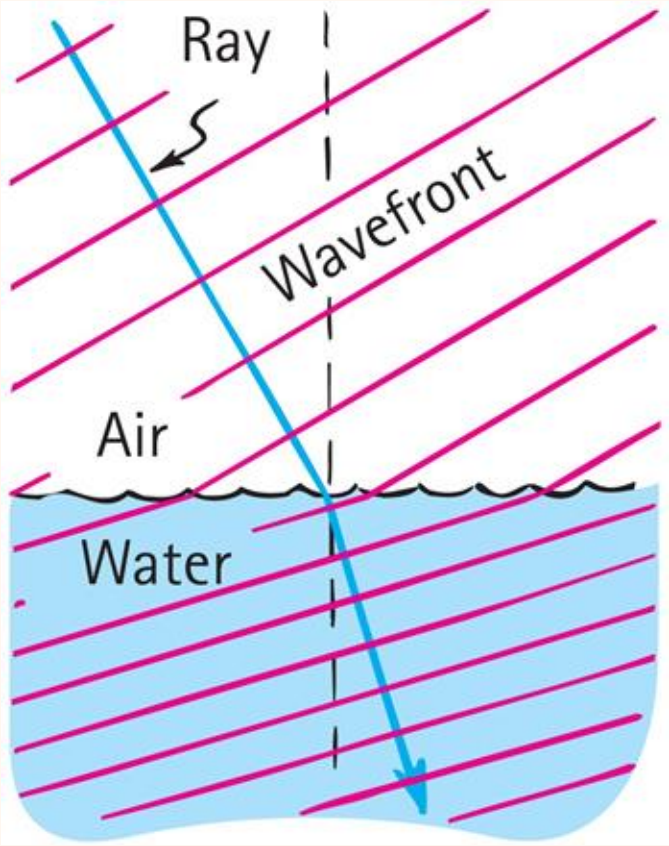
B. interference.

C. dispersion.

D. refraction.

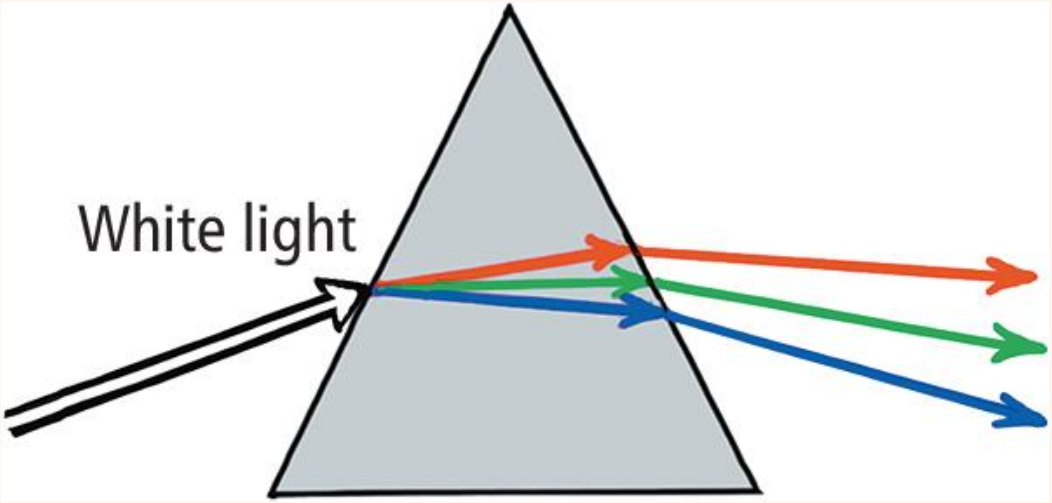
Cause of Refraction





Dispersion

- Separation of light into colors arranged by frequency
- Dispersion is ultimately a resonance effect—some frequencies of light move slower than others because they interact more with the material.



Conceptual Question 6

When white light passes through a prism, green light is bent more than

A. blue light.

B. violet light.

C. red light.

D. None of the above is correct.

Conceptual Question 7

Compared to the speed of green light passing through a prism, red light passing through the same prism

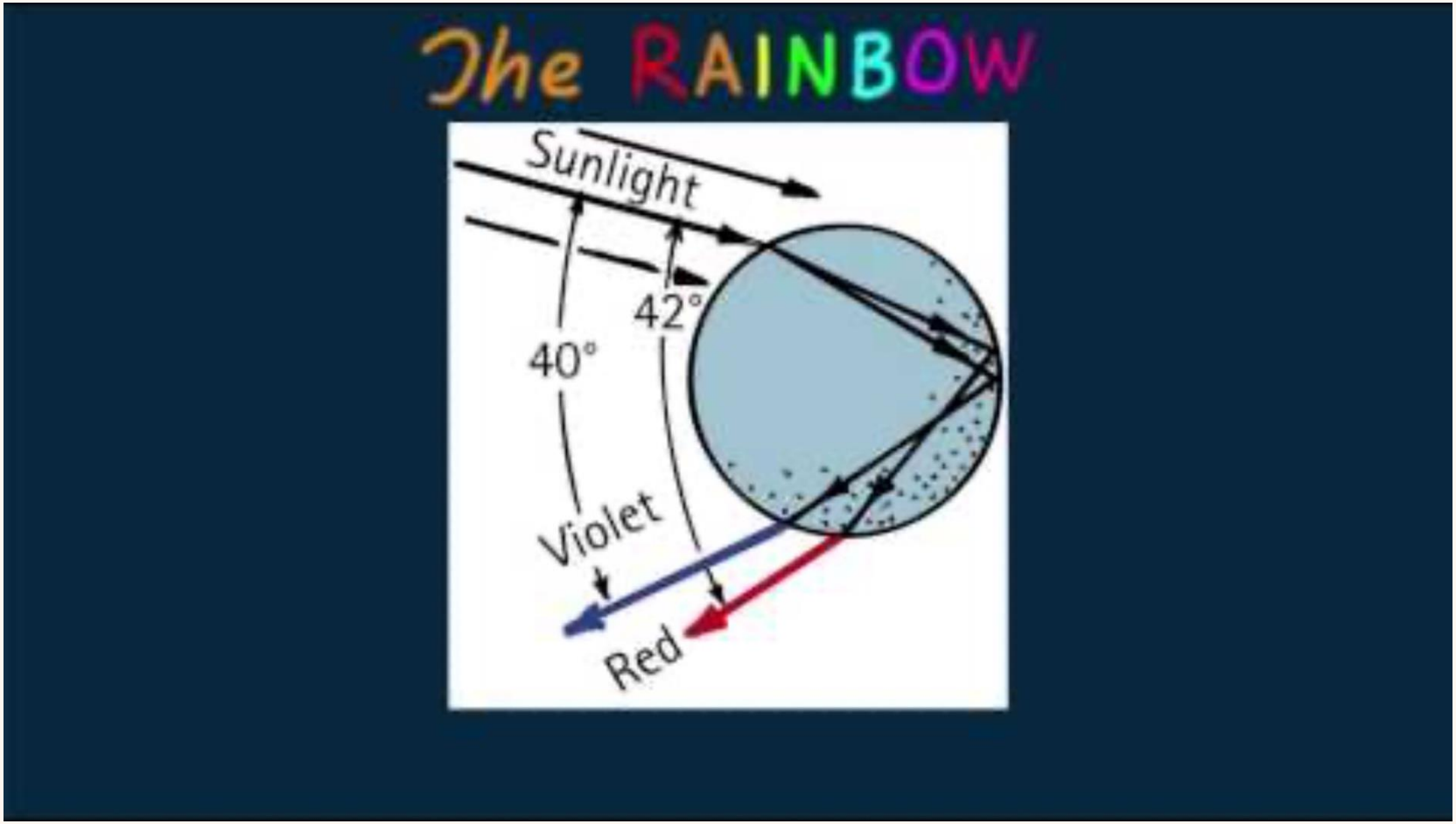
A. Moves faster

B. Moves slower

C. Moves at the same speed

D. Need more information

Rainbows



Conceptual Question 8

Compared with the primary rainbow, the secondary bow

A. is dimmer.

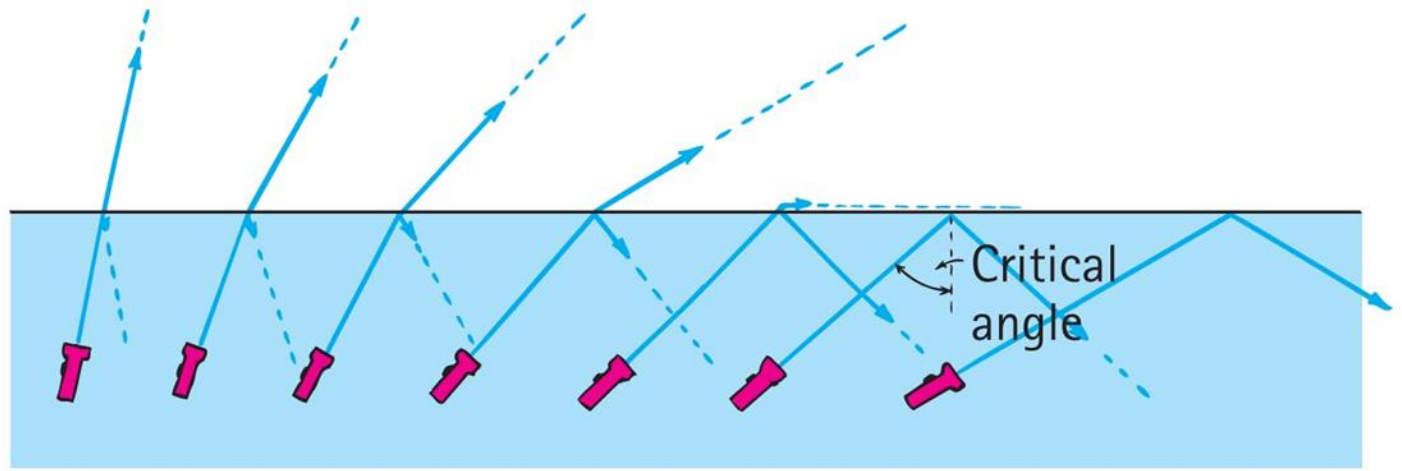
B. has colors reversed.

C. is caused by two internal reflections.

D. All of the above are correct.

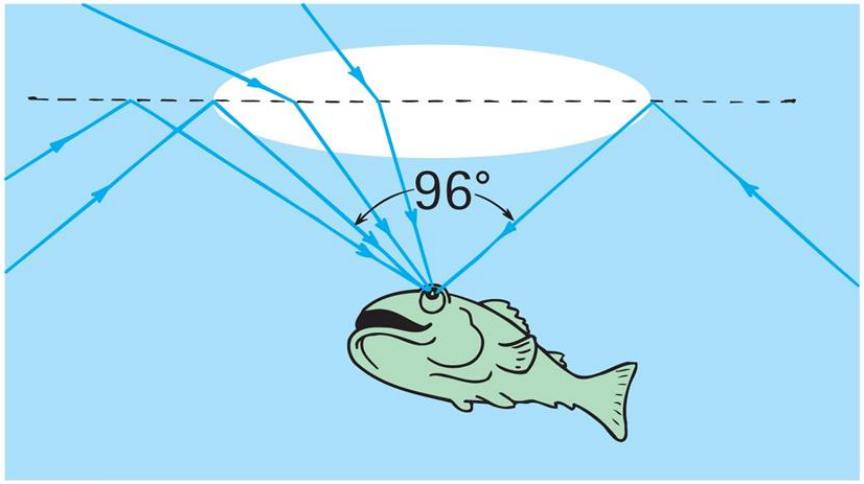
Total Internal Reflection

- Total internal reflection:
  - Total reflection of light traveling within a medium that strikes the boundary of another medium at an angle at, or greater than, the critical angle.



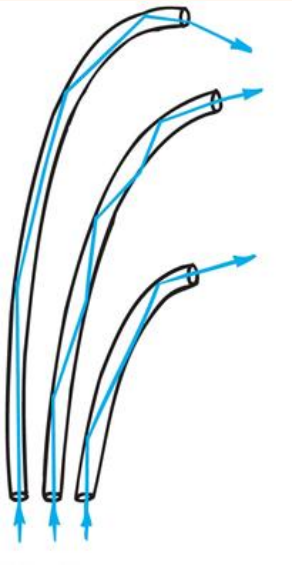
Total Internal Reflection

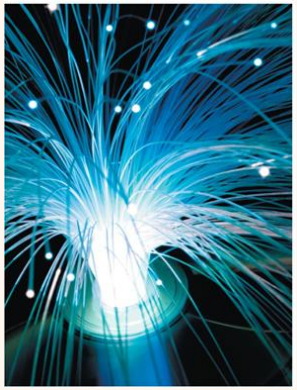
- Critical angle for light rays beneath a material/air interface
  - minimum angle at which a light beam does not emerge into the air above the surface
  - varies for different materials



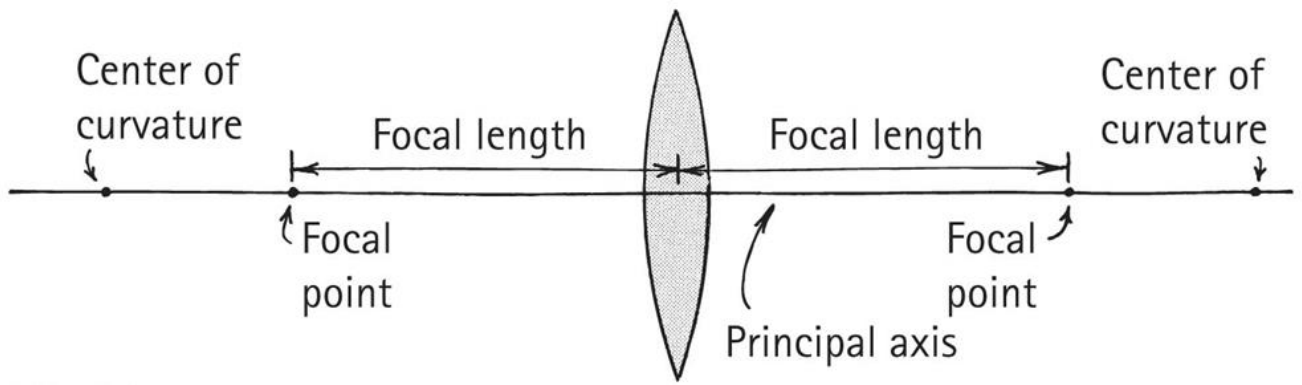
Optical Fibers

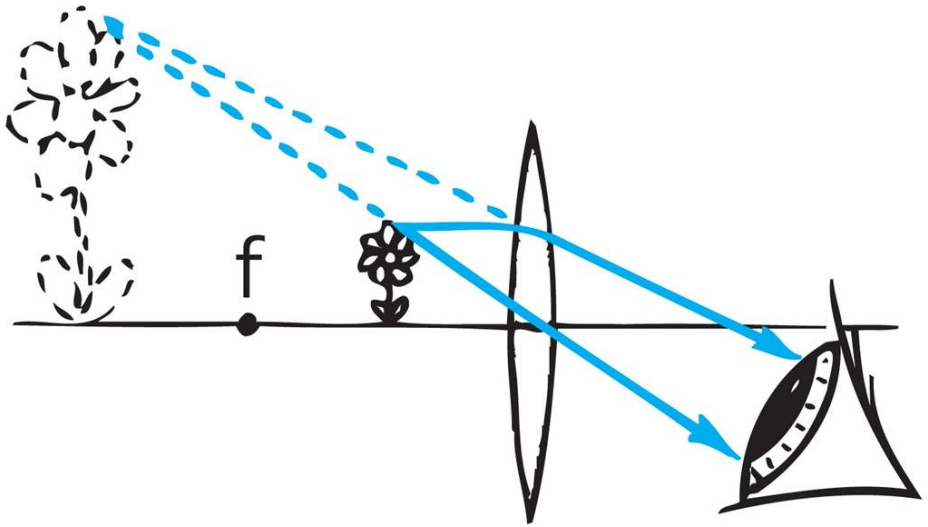
- Optical fibers or light pipes:
  - Thin, flexible rods of special glass or transparent plastic.
  - Light from one end of the fiber is total internally reflected to the other end, resulting in nearly the same brightness of light emerging as entering
- Used in
  - illuminating instrument displays
  - concentrating light in dental procedures
  - viewing of inaccessible regions of organs and other devices
  - communications





Lenses


Center of curvature
Focal length
Focal length
Center of curvature
Focal point
Focal point
Principal axis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Conceptual Question 9

The action of lenses depends mainly on

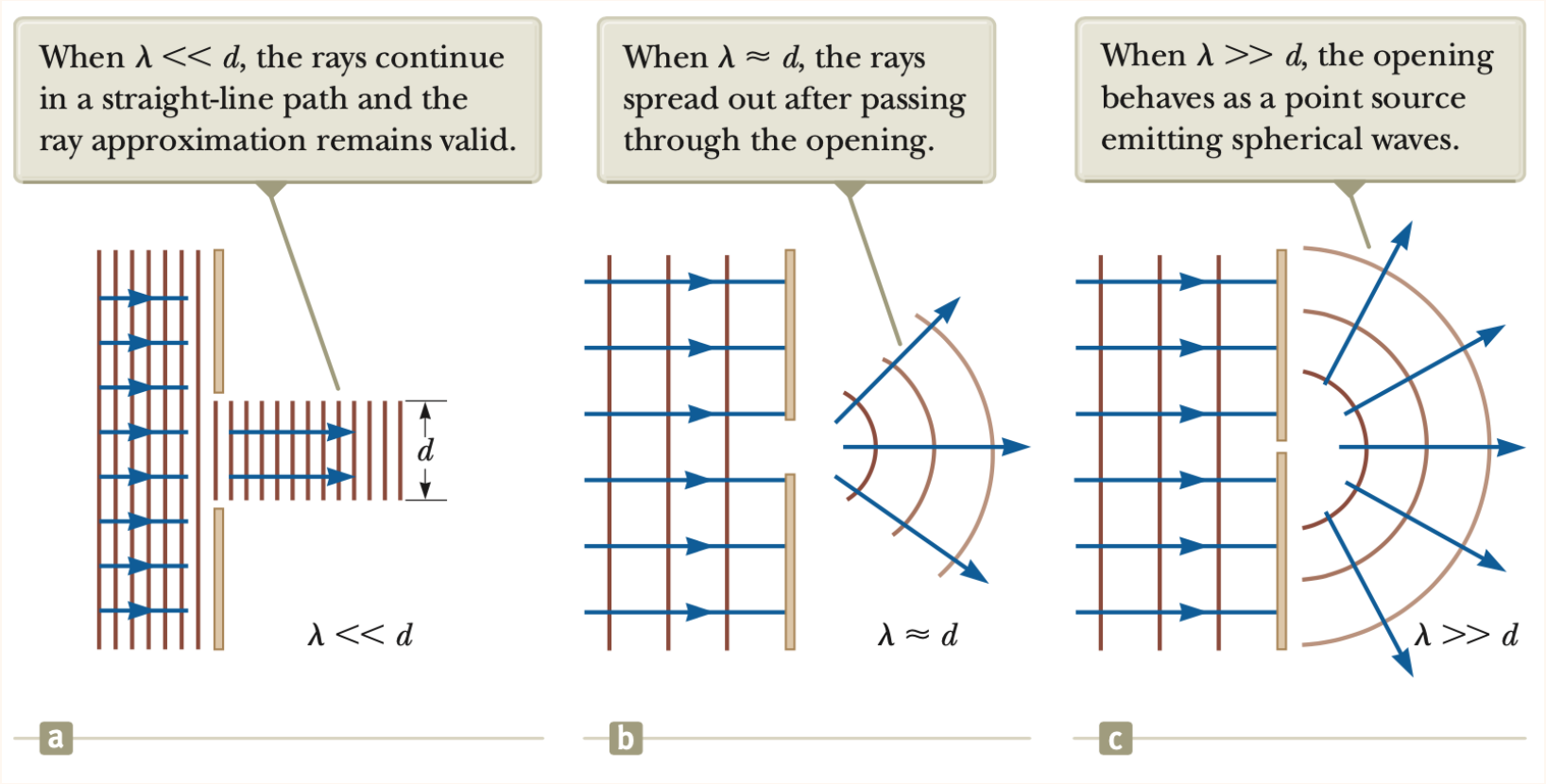
A. reflection.

B. refraction.

C. Both A and B are correct.

D. Neither A nor B is correct.

Wave Optics


When λ << d, the rays continue in a straight-line path and the ray approximation remains valid.
d
λ << d
a
When λ ≈ d, the rays spread out after passing through the opening.
λ ≈ d
b
When λ >> d, the opening behaves as a point source emitting spherical waves.
λ >> d
c

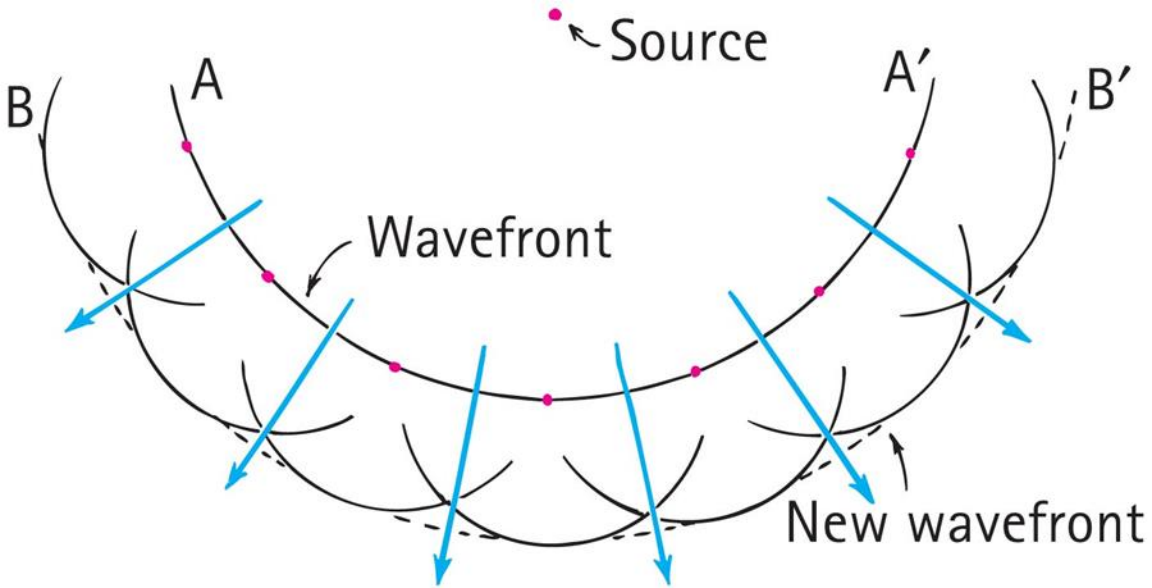
Christiaan Huygens

- Throw a rock in a quiet pool, and waves appear along the surface of the water.
- Huygens proposed that the wavefronts of light waves spreading out from a point source can be regarded as the overlapped crests of tiny secondary waves.
- Wavefronts are made up of tinier wavefronts—this idea is called **Huygens' principle** and like Fermat's principle of least time, it can be derived from Maxwell's equations!

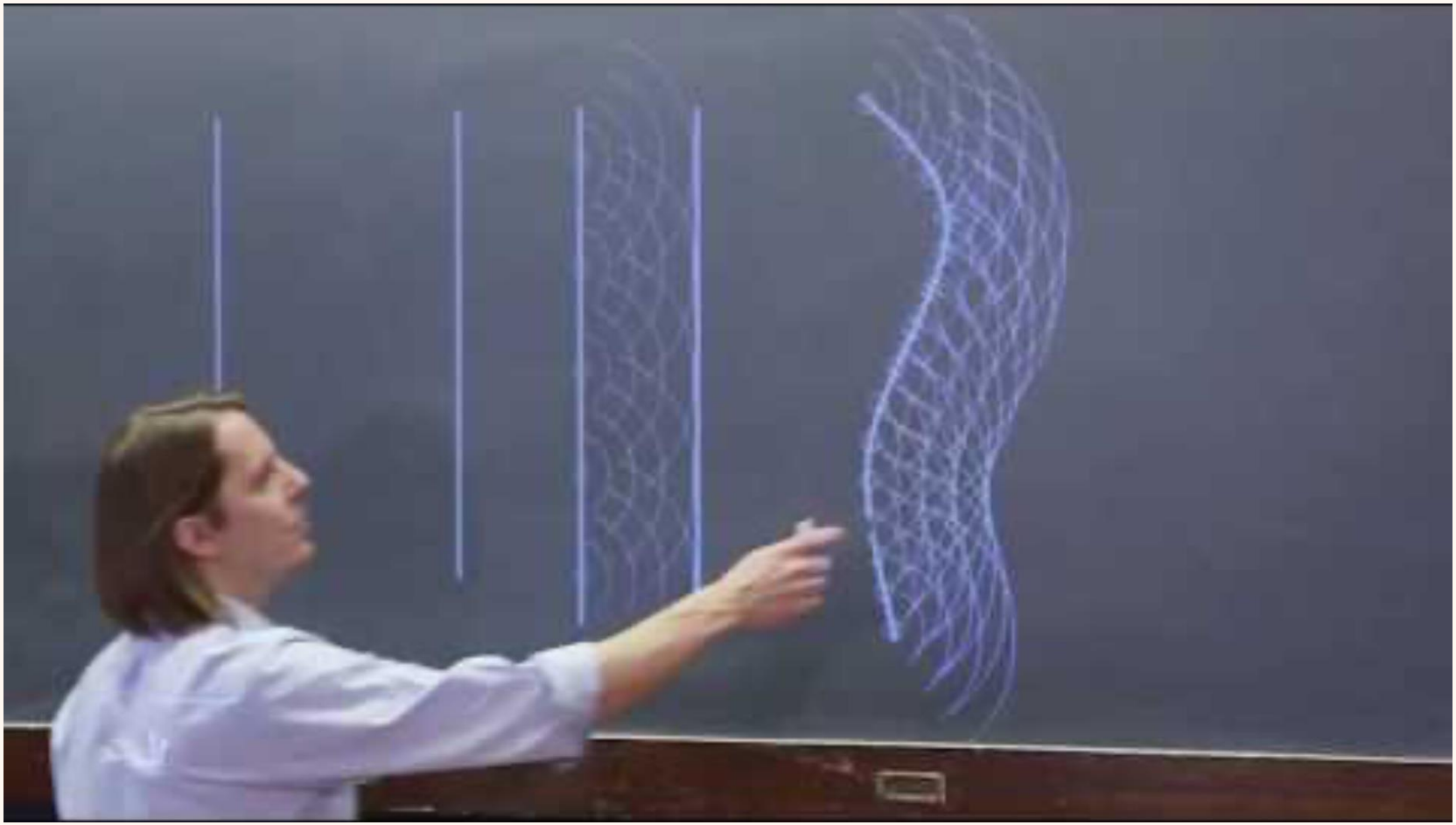
Christiaan Huygens

Huygens' Principle

- Every point of a wavefront may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the waves.

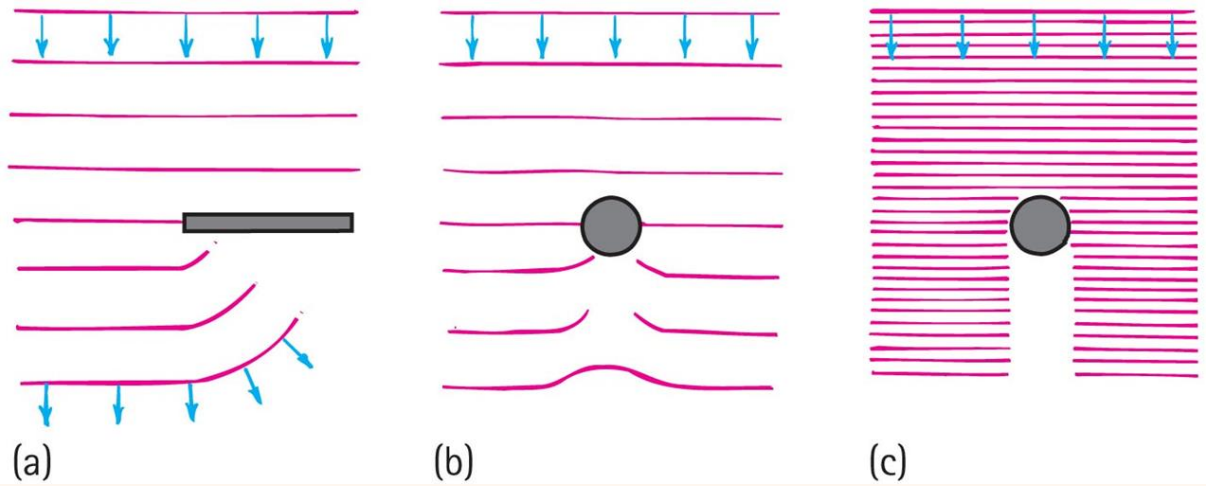


Huygens' Principle



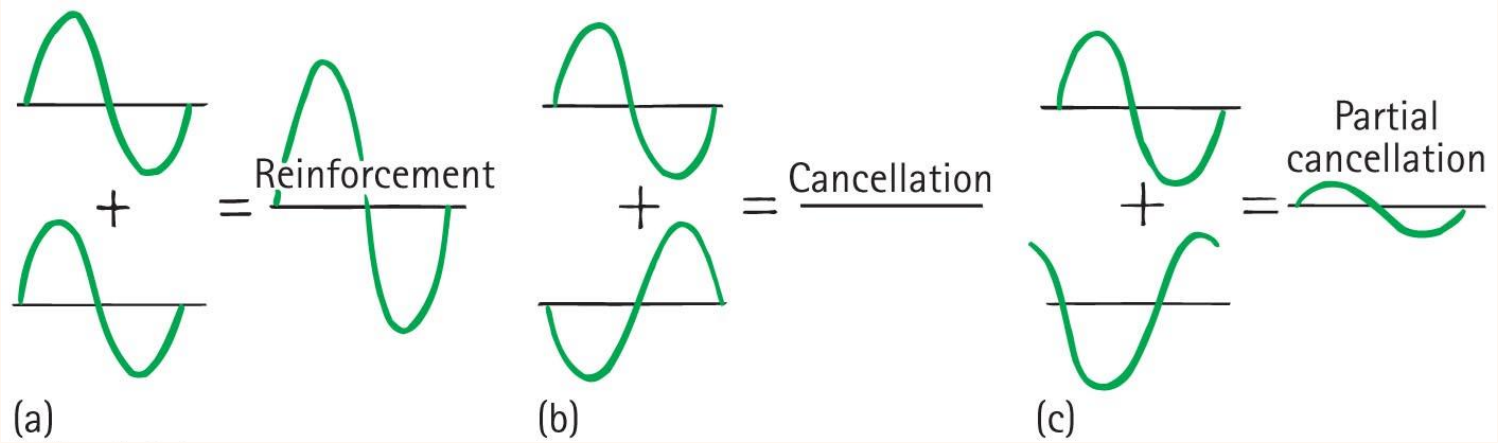
Diffraction

- Bending of waves by means other than reflection and refraction
  - Property of **all** kinds of waves
  - Seen around edges of many shadows
- Amount of diffraction depends on wavelength of the wave compared to the size of the obstruction that casts the shadow.
  - Resolution is limited by wavelengths!

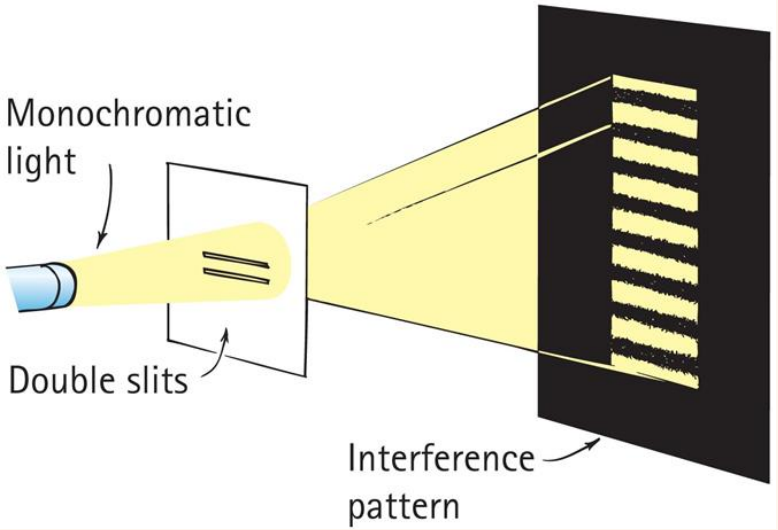


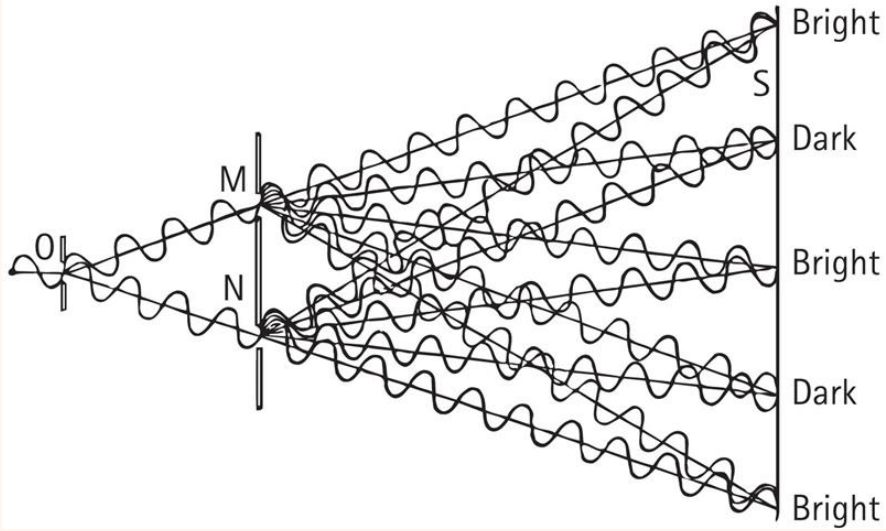
Superposition and Interference

- The principle of superposition states that waves add or subtract whenever they meet.
- Constructive interference is when they add, and destructive interference is when they cancel each other out by subtraction.



Interference Patterns





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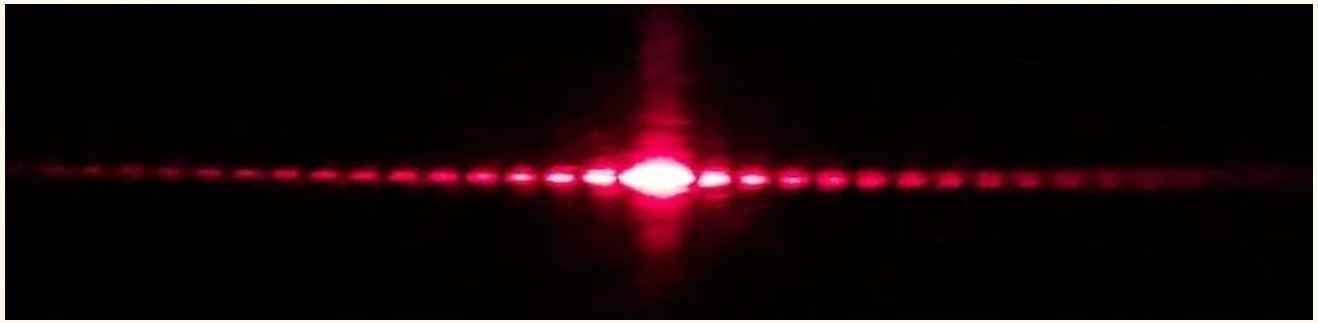
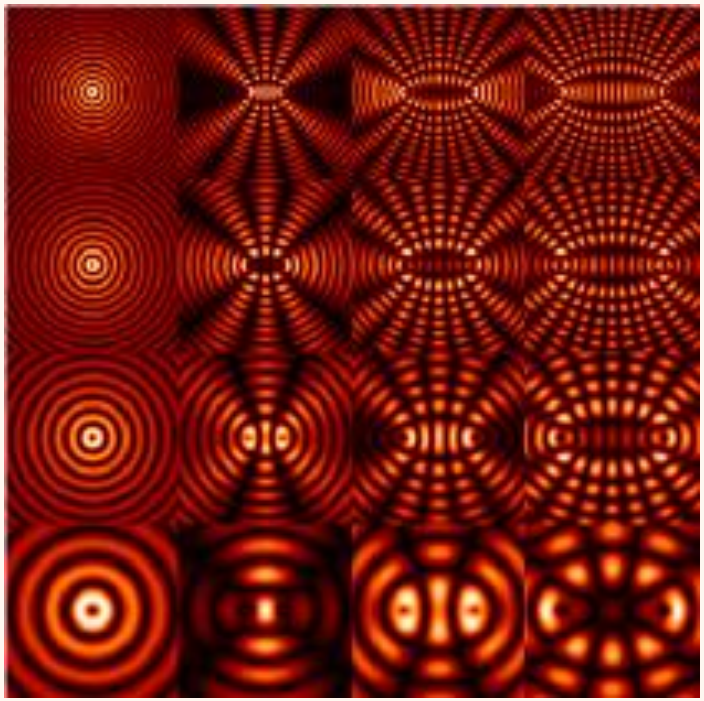




Conceptual Question 10

The phenomenon of interference occurs for

A. sound waves.

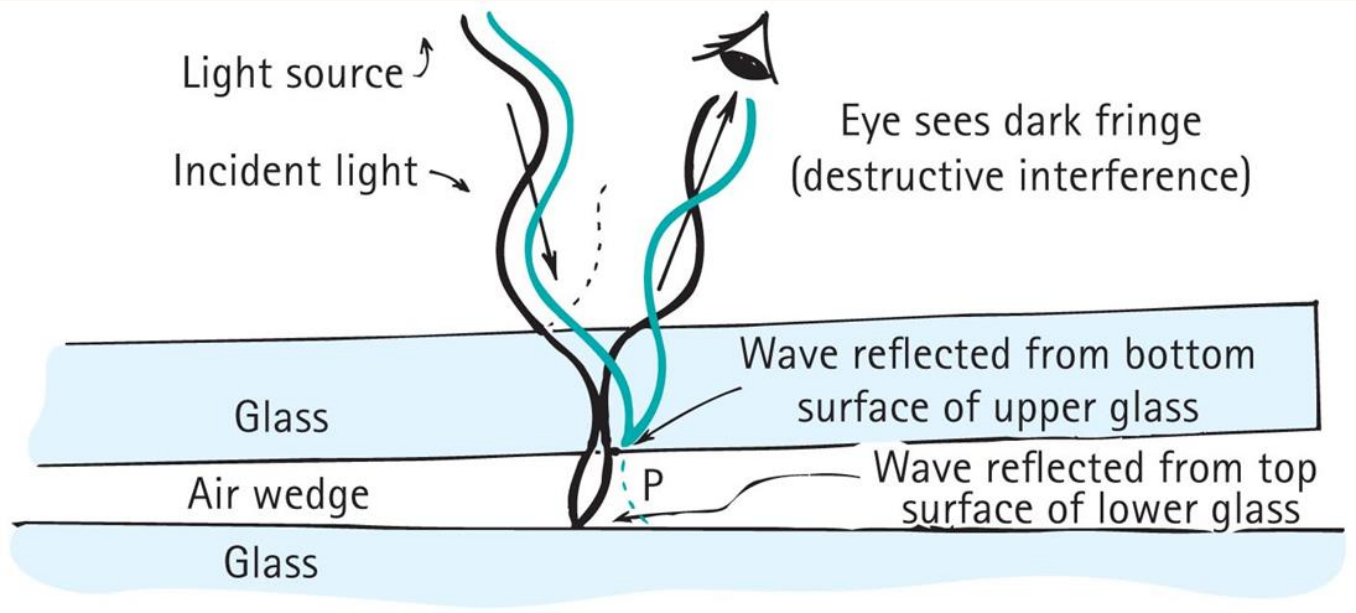
B. light waves.

C. Both A and B are correct.

D. Neither A nor B is correct.

Thin Film Interference

Colors of light that come from a thin film depend on the thickness. Some colors will destructively interfere.



Thin Film Interference