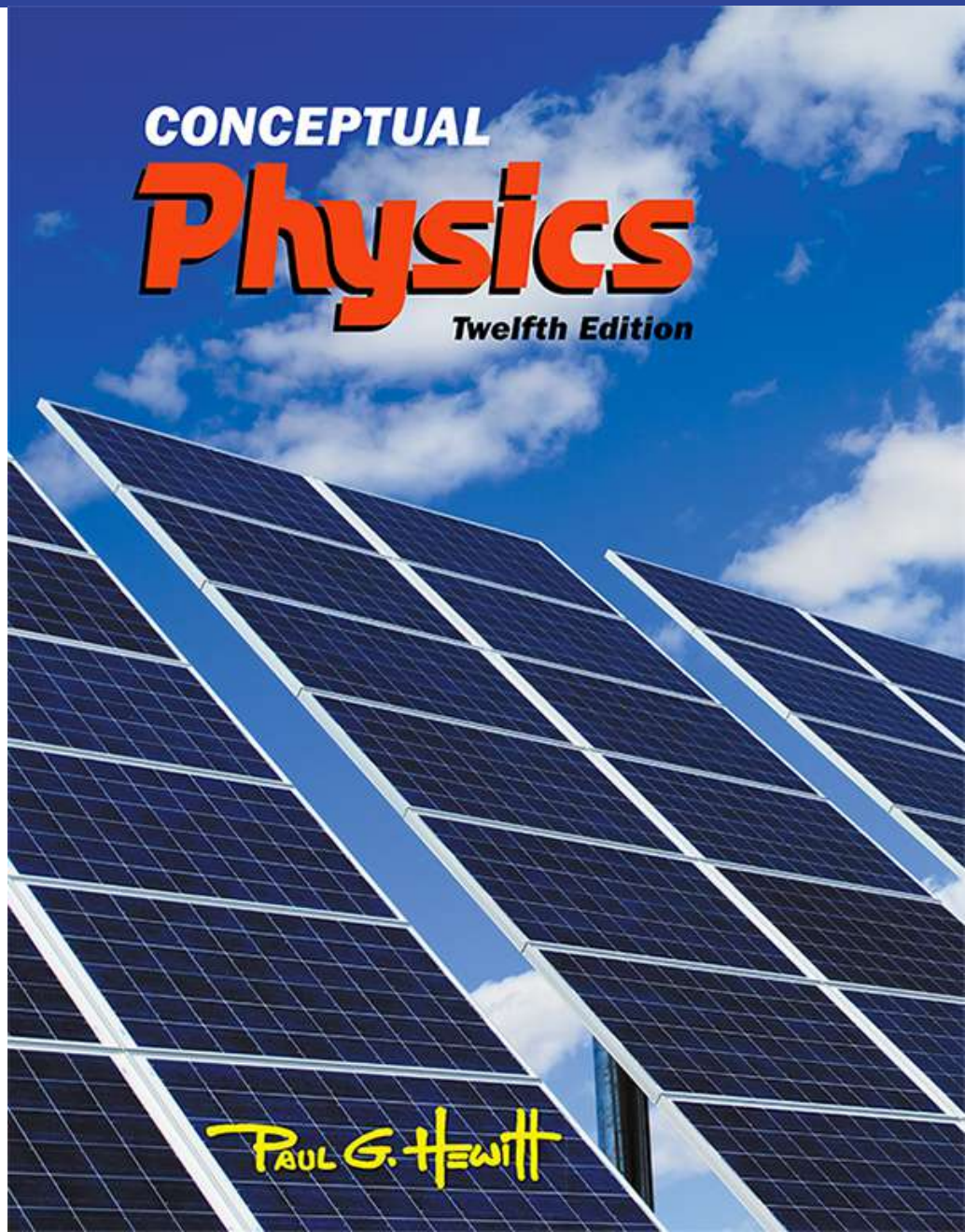
Lecture Outline



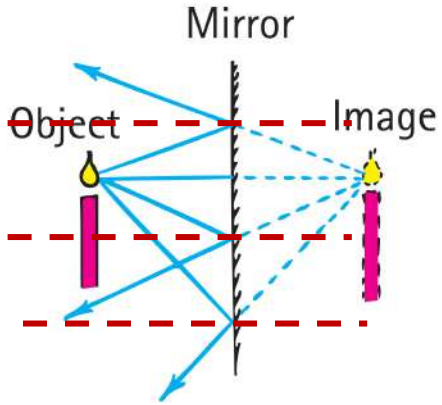
Chapter 28: Reflection and Refraction

Part 2

Classwork

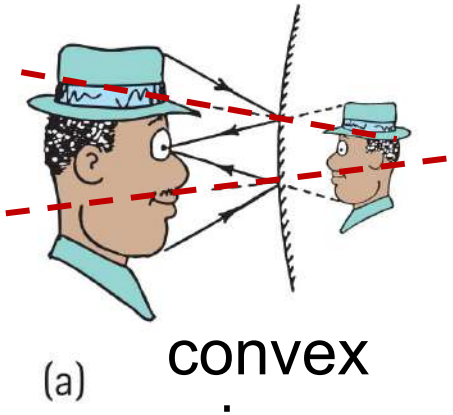
11. Does the law of reflection hold for curved mirrors? Explain.

Law is obeyed.



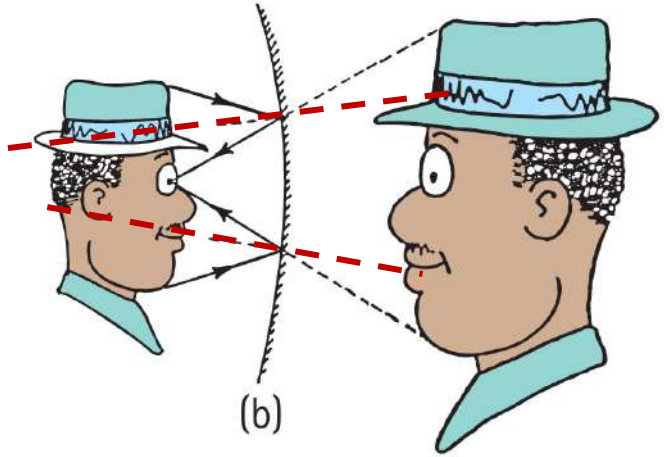
plane mirror

Is Law is obeyed?



convex mirror

Is Law is obeyed?

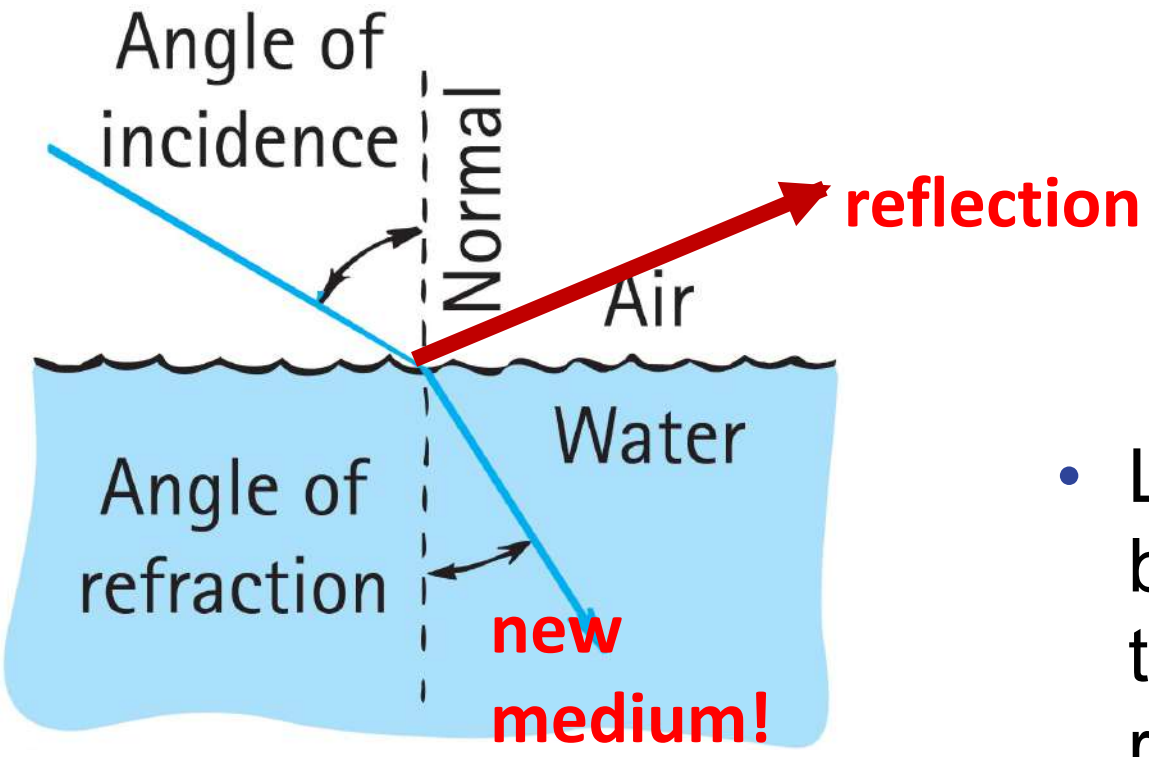


concave mirror

Law is obeyed, but the normals have different directions.

Refraction

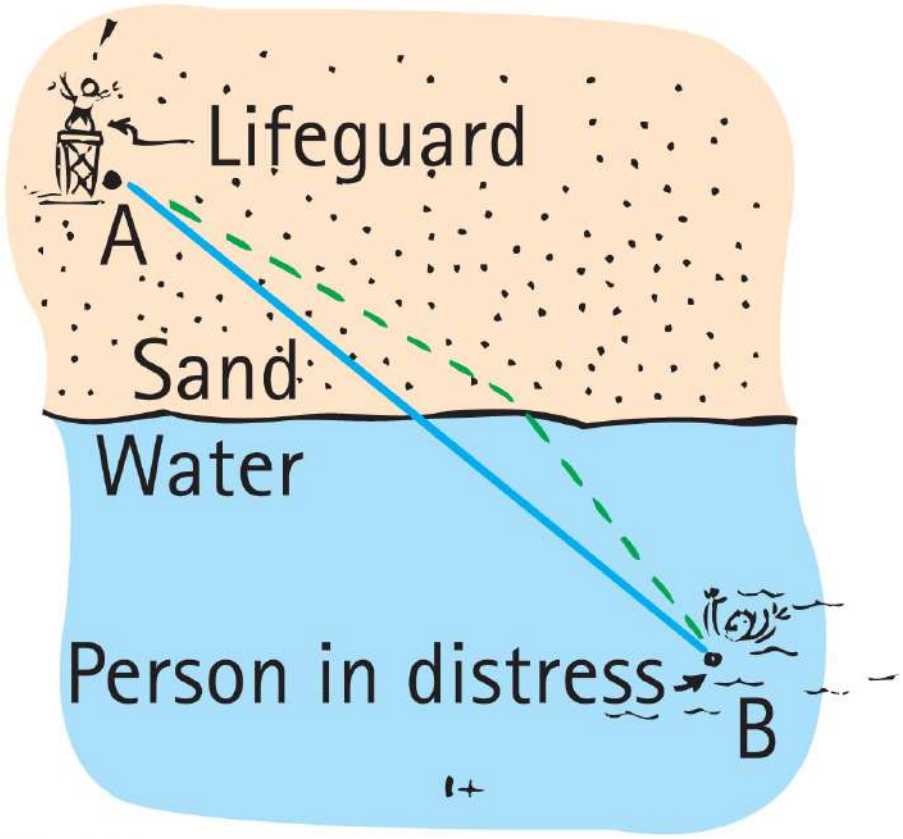
- When light bends in going obliquely (at an angle) from one medium to another, we call this process *refraction*.



- Light still *reflects*, but we ignore this to concentrate on refraction.

Refraction and Fermat's Principle:

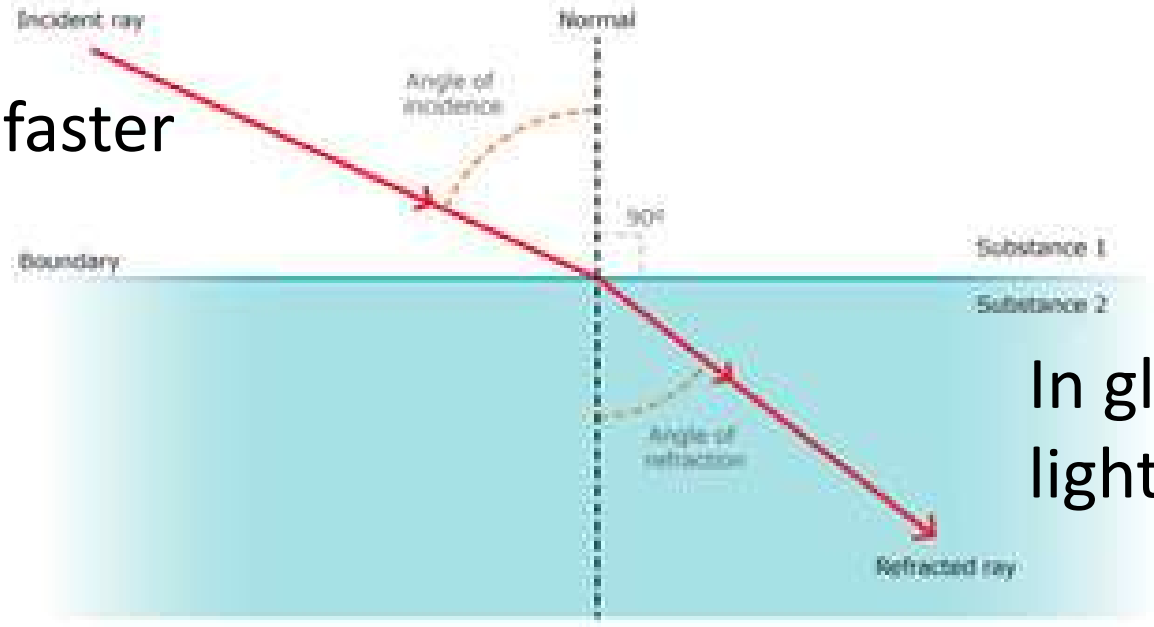
- Refraction occurs to minimize the time taken by light to travel from A to B.
- For a lifeguard, the quickest path is not be a straight line – it would be the dashed path shown.
- You spend extra time in the medium in which you are faster (the sand), but *less time overall.*



Fast to Slow

- When light passes from a fast medium to a slower medium, it bends *towards the normal*.
- Angle of refraction < angle f incidence.

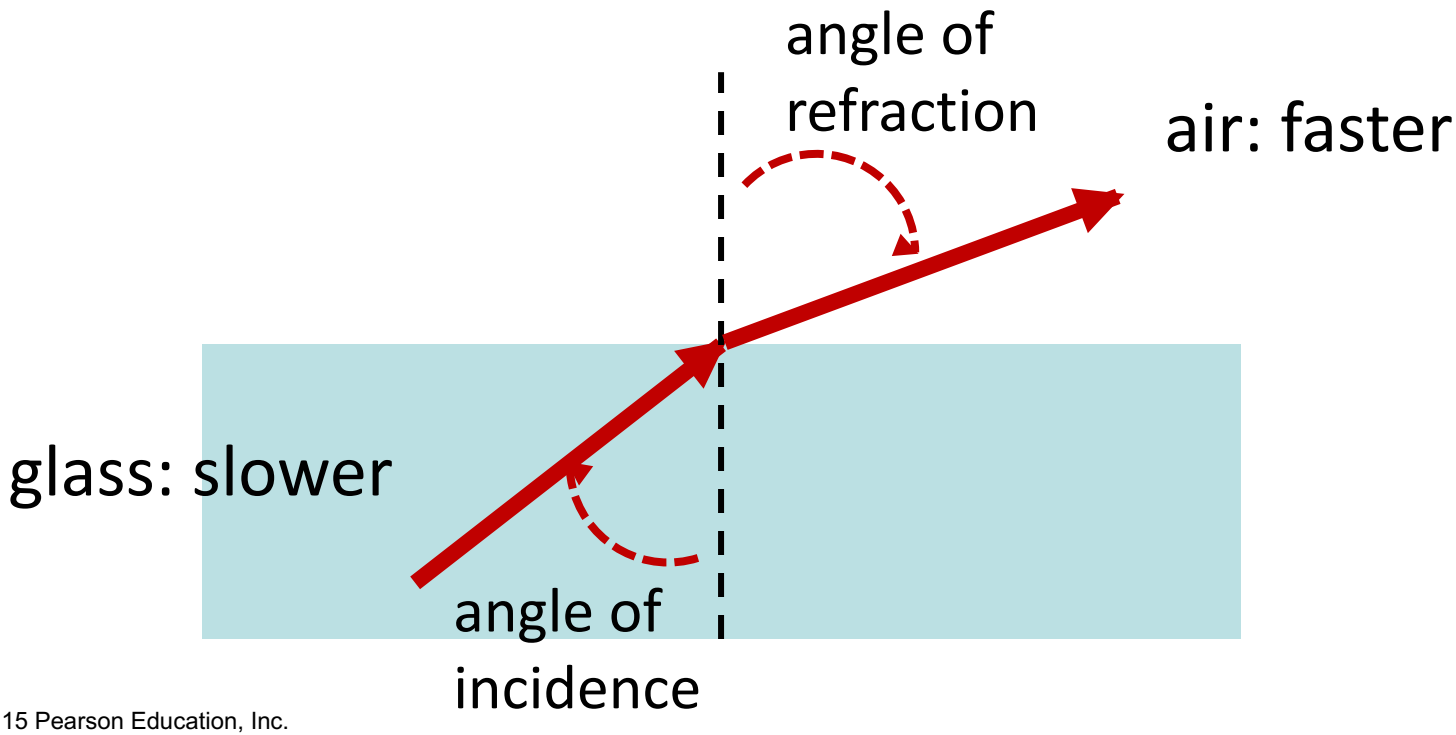
In air:
light is faster



In glass:
light is slower

Slow to fast

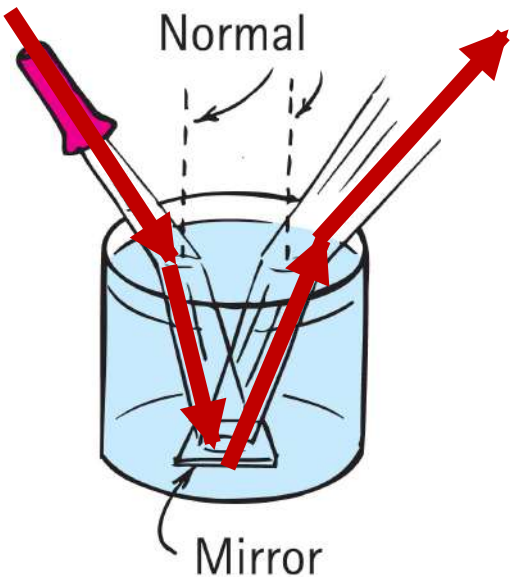
- When light passes from a slow medium to a faster medium, it bends *away from the normal.*
- Angle of refraction > angle of incidence.

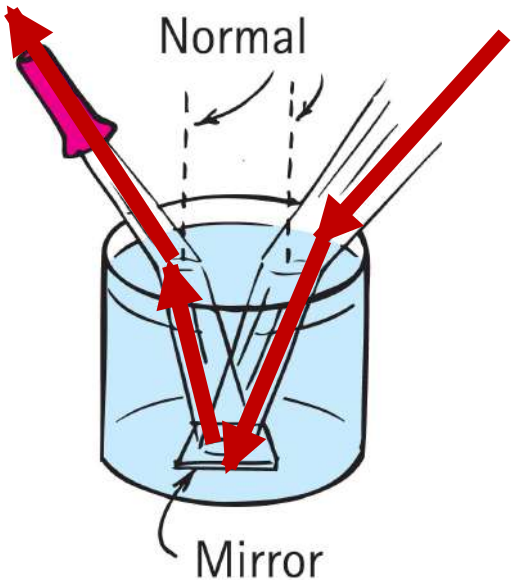


Glass of water

- Light rays pass from air into water and water into air.
- → Bent towards normal going in.
- → Bent away from normal coming out.

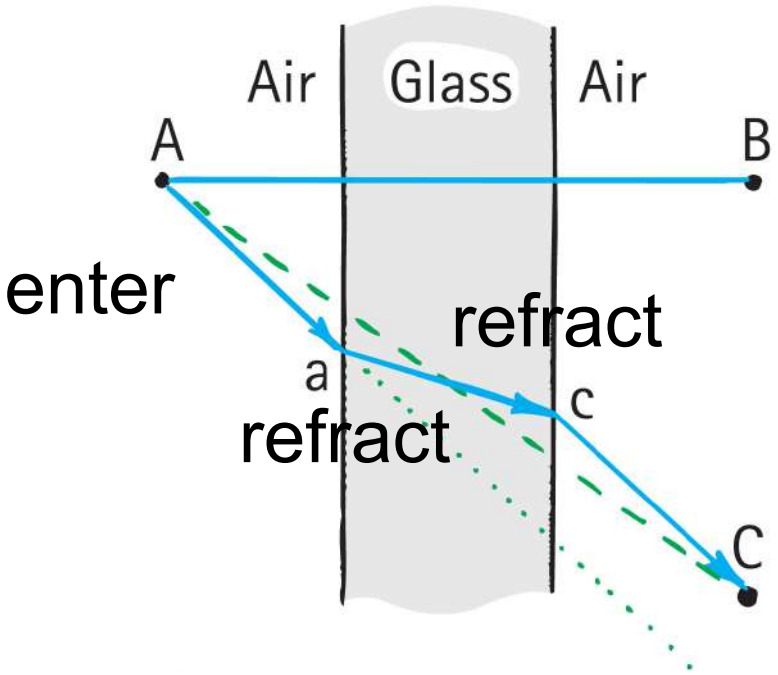
Pathways are *reversible* for both reflection and refraction.





Passing in and out of a Plane of Glass

- Light refracts as it enters and leaves the glass.
  - Light travels slower in glass than in air, so it minimizes the time it spends in the glass.



- Notice ray leaves parallel to the original because the angles are the same…it slows down as much as it speeds up.
- It has only been displaced.

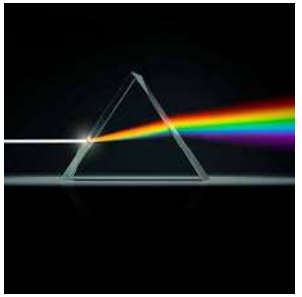
exiting ray parallel to original and back to original speed

Classwork

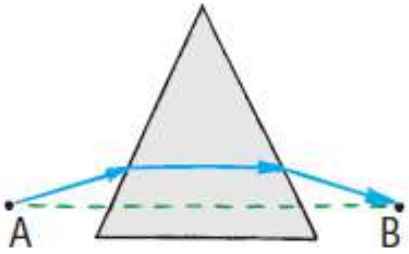
8. How does the angle at which a ray of light strikes a pane of window glass compare with the angle at which the light passes out the other side?

Prisms

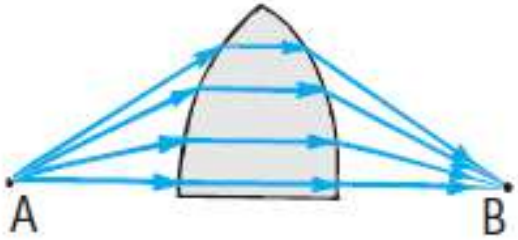
- Light does not come out parallel because sides are not parallel



Path of least time from A to B refracts at both surfaces:

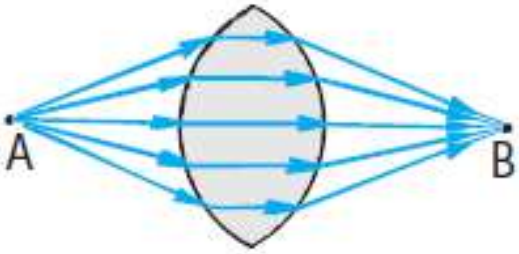


A *curved* prism has many least-time paths, so it collects more light



A lens is simply two curved prisms back-to-back.

So it collects 2x more light than 1.

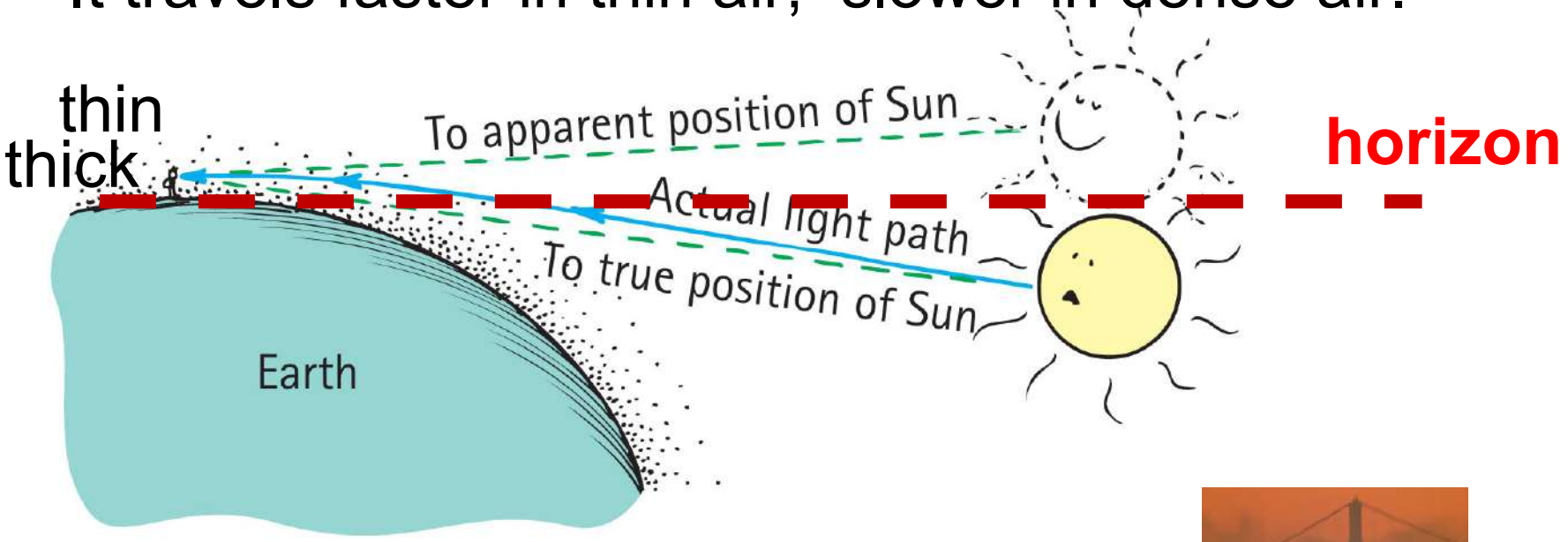


Classwork

9. When is the angle at which a ray of light strikes glass not the same as the angle at which it exits?

Sunset and Sunrise

- When Sun is below horizon, light bends gradually due to changing density of atmosphere.
- It travels faster in thin air; slower in dense air.



- Daylight lasts longer!
- Parts of Sun closer to horizon refract more, so image is flattened:

Classwork

10. In which medium does light travel faster: thin air or dense air? How does this affect the period of daylight?

- Refractive index:

- Index of refraction, *n*, of a material
  - indicates how much the speed of light differs from its speed in a vacuum.
  - indicates the extent of bending of rays
  - ratio of speed of light in a vacuum to the speed in a material:

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

Refractive Index:

Bigger n → slower light in that medium

Material	Index of Refraction (n)
Vacuum	1.000
Air	1.000277
Water	1.333333
Ice	1.31
Glass	About 1.5
Diamond	2.417

fastest

slowest

For light passing from air into another medium, the higher n is, the

1. more the slowing of light.
2. the more the refraction (bending)

Classwork

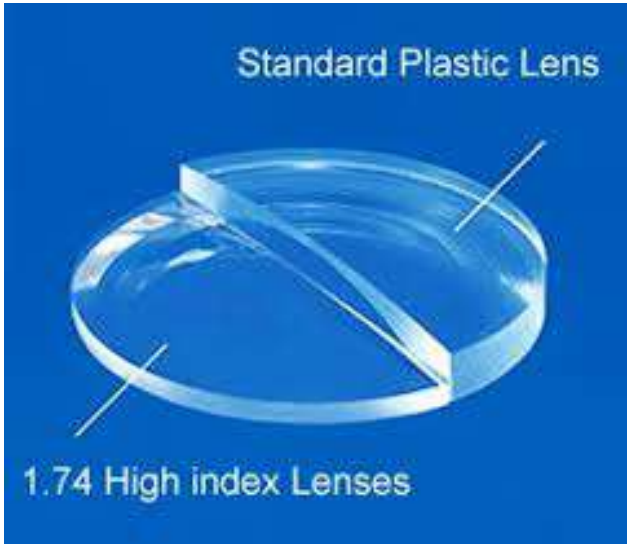
15. What is the relationship between refraction and the speed of light?

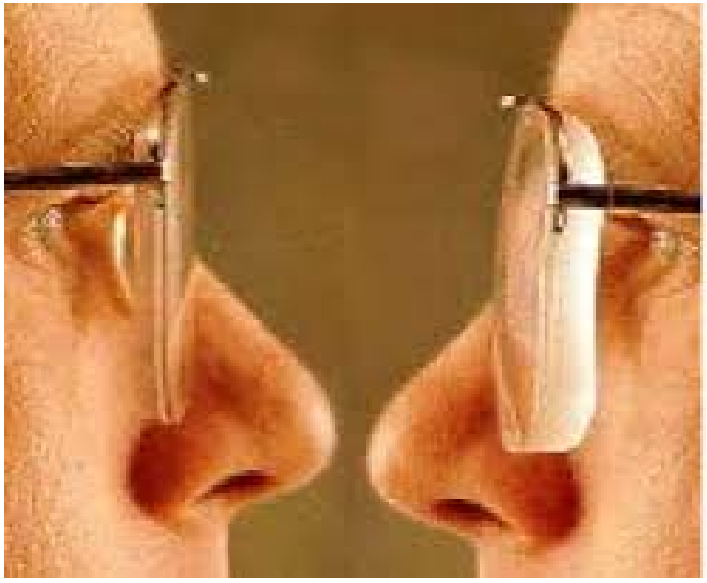
High index plastic lenses

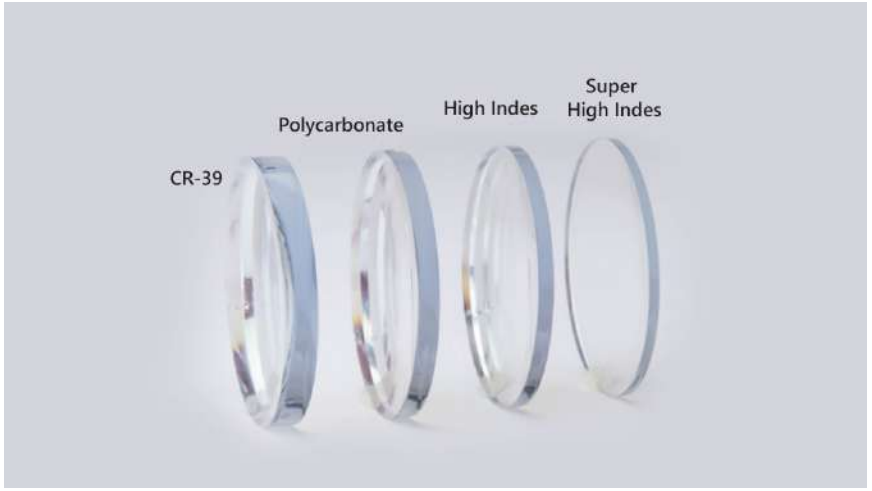
Light slows in them more.

Light refracts more.

So they can be thinner, lighter and more comfortable.





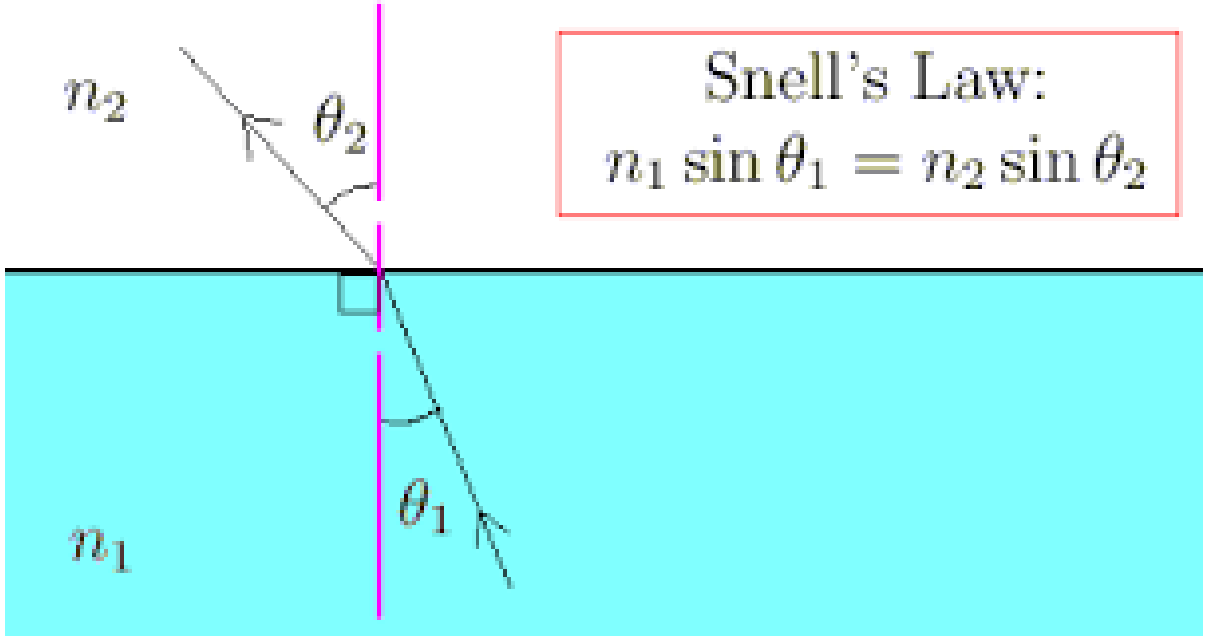


Classwork

16. Are eyeglasses made with "high index of refraction" materials thin or thick?

Snell's Law:

Gives the mathematical relationship between the refraction angles and the indices of refraction



You will not be tested on this law.

Refraction
CHECK YOUR NEIGHBOR

Refracted light that bends toward the normal is light that has

A. slowed down.
B. sped up.
C. nearly been absorbed.
D. diffracted.

Refraction
CHECK YOUR ANSWER

Refracted light that bends toward the normal is light that has

A. slowed down.

Refraction
CHECK YOUR NEIGHBOR, Continued

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

A. slowed down.
B. sped up.
C. nearly been absorbed.
D. diffracted.

Refraction
CHECK YOUR ANSWER, Continued

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

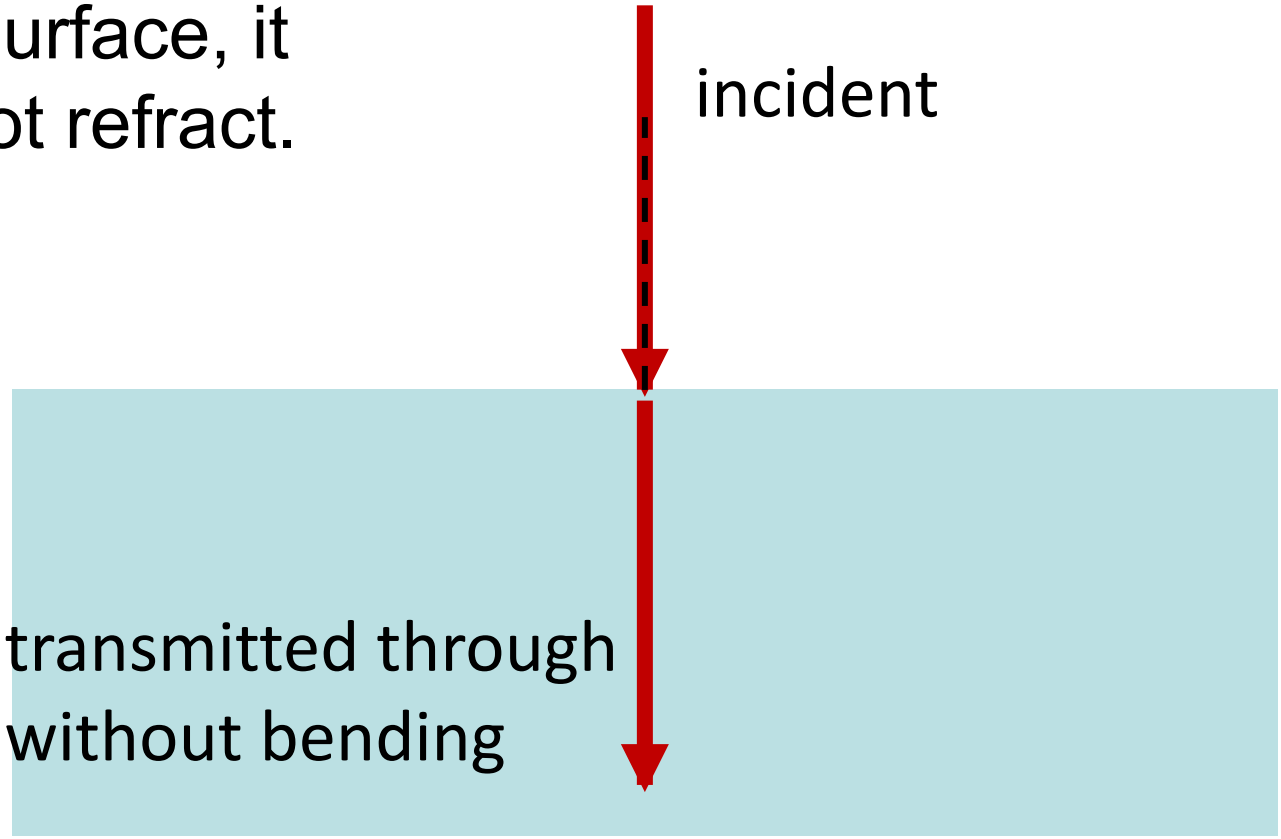
B. sped up.

Explanation:

This question is a consistency check with the question that asks about light bending toward the normal when slowing.

When does light NOT refract?

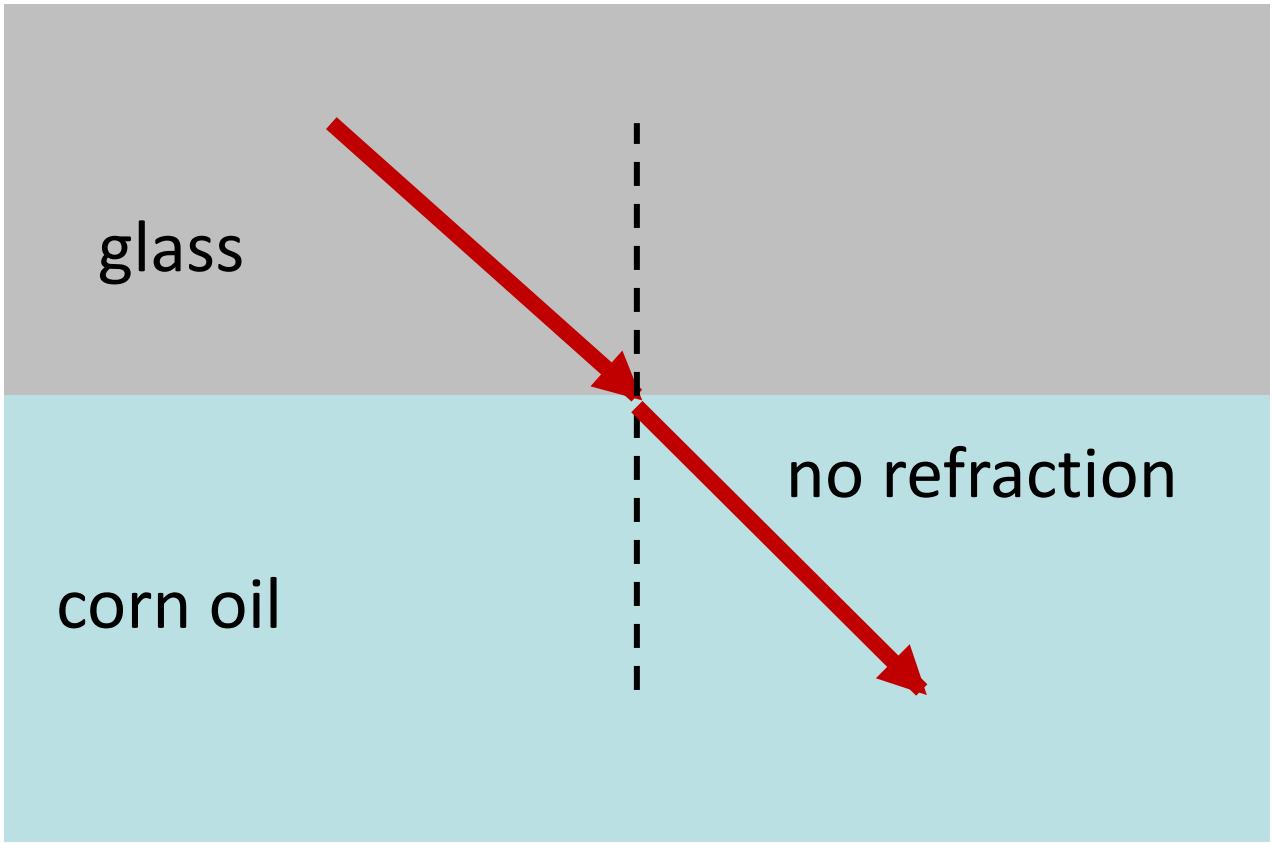
1. If light enters perpendicularly to the surface, it does not refract.



When does light NOT refract?

2. If light does not change speed when it enters

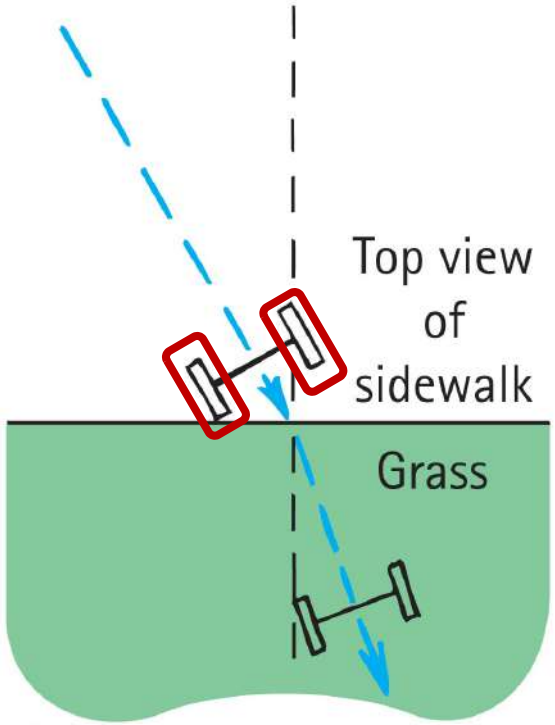
→ Speed of light is the same in both media



Cause of Refraction

- Refraction
  - Bending of light when it passes from one medium to another
  - Caused by *change* in speed of light

  - Analogy: a toy cart moving from a sidewalk (fast) onto grass (slow).
  - Right wheel enters slow grass first
  - Left wheel still on fast sidewalk
  - Wheels bent towards normal



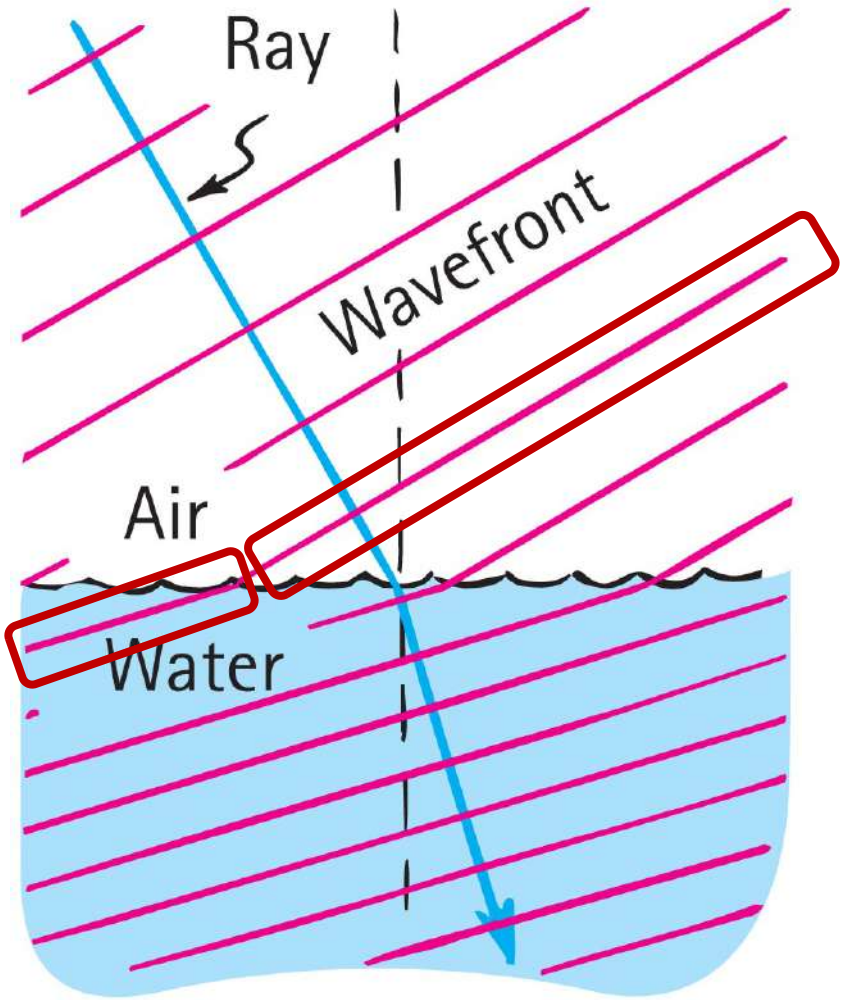
Wavefronts are like the toy cart wheels

Wavefronts are perpendicular to the wave ray.

Left side of wavefront enters slow water first

Right side still in fast air.

Wave bends towards normal.



Classwork

13. When the wheel of a cart rolls from a smooth sidewalk onto a plot of grass, the interaction of the wheel with blades of grass slows the wheel. What slows light when it passes from air into glass or water?

Classwork

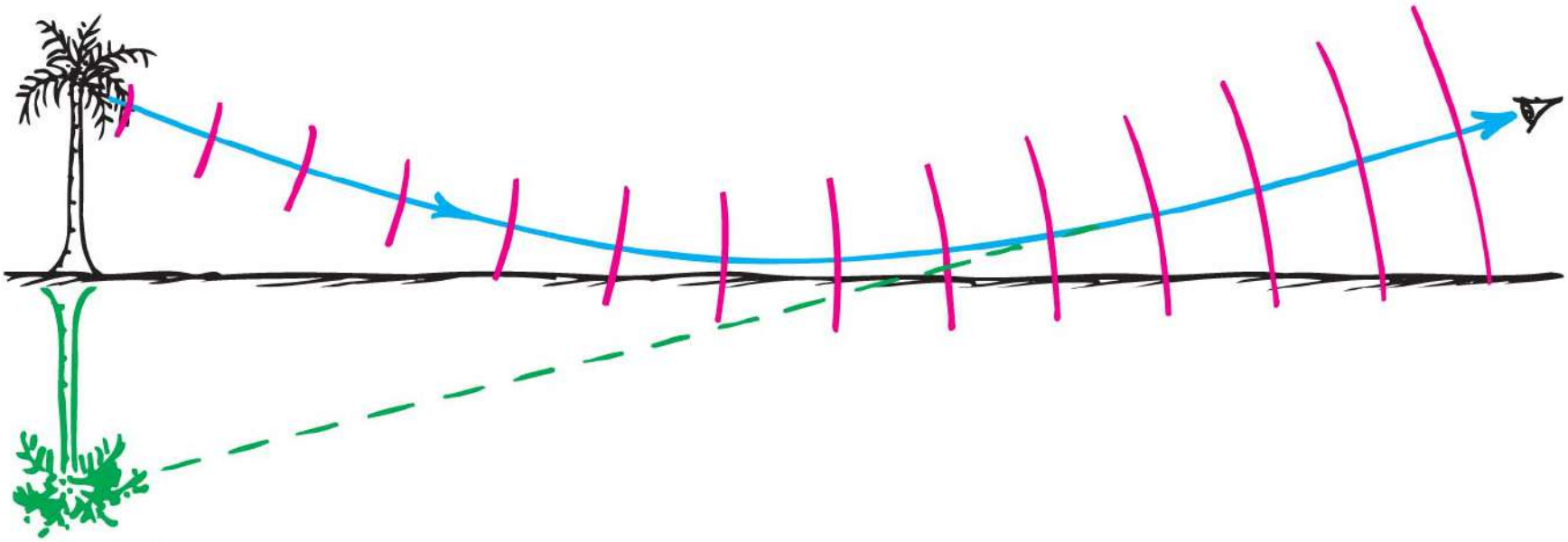
14. What is the angle between a light ray and its wavefront?

Mirages

On hot day, air near ground is warmer.

Light travels faster in warmer air.

Fastest path from tree to you is refracted:



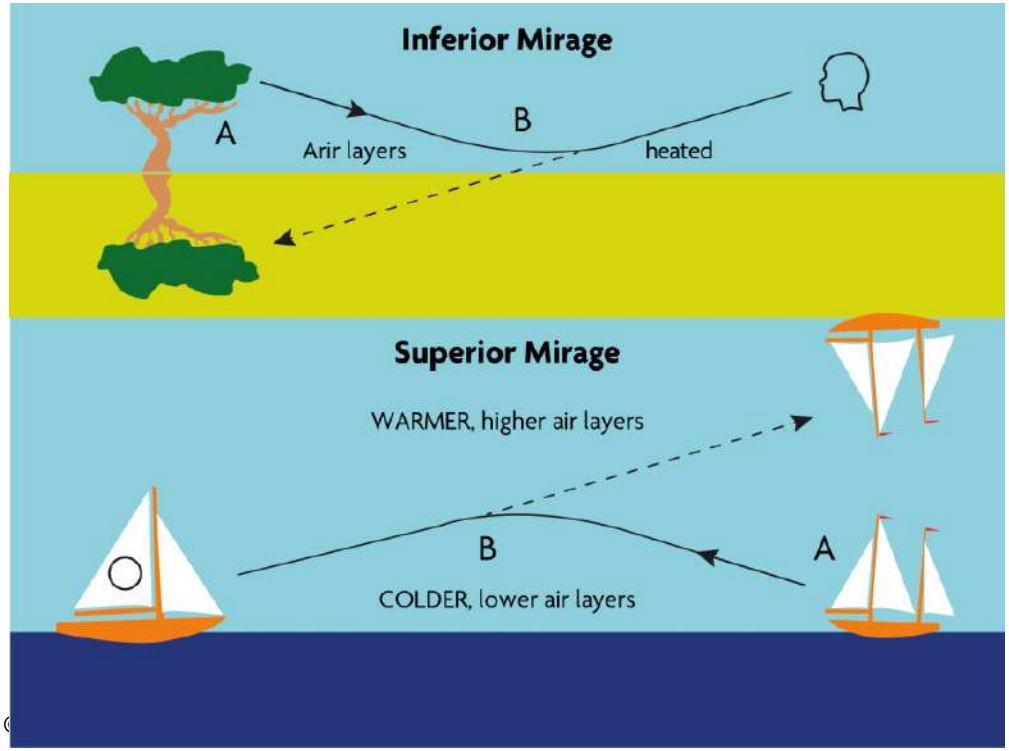
You eye sees tree below ground.

Classwork

12. Is a mirage the result of reflection or refraction?

"Water" on road is light from the sky refracting.

2 types of mirages:

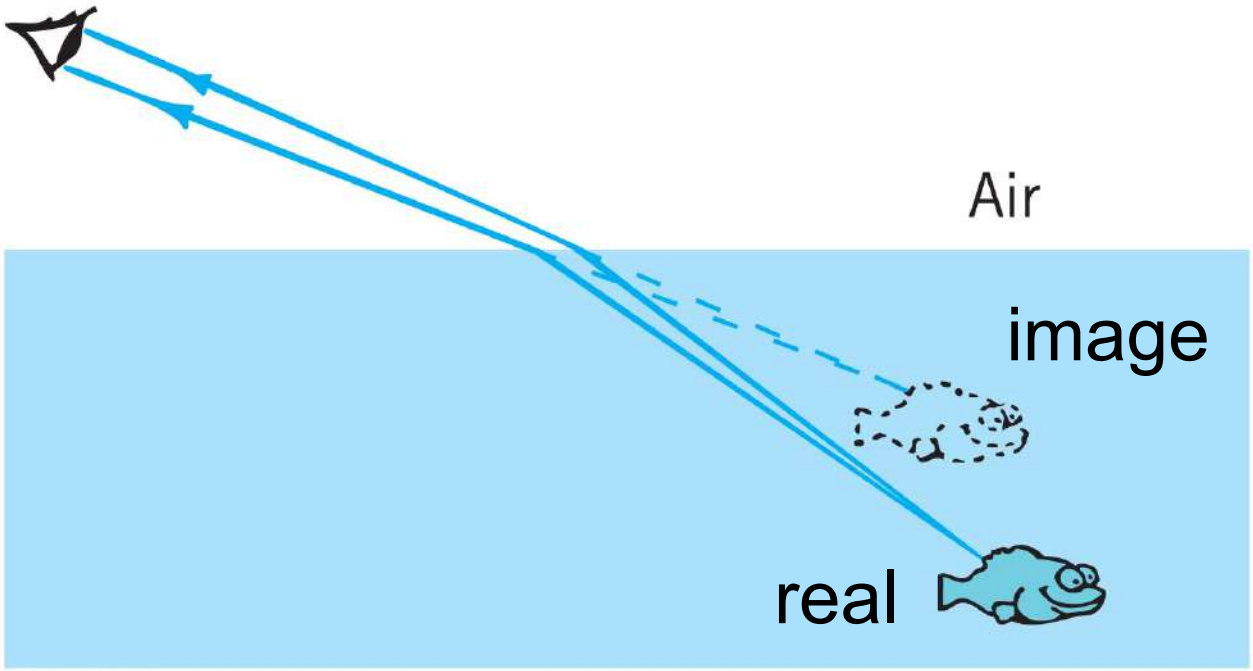


"Floating" mirages are a type of mirage, too.

Refraction Illusions

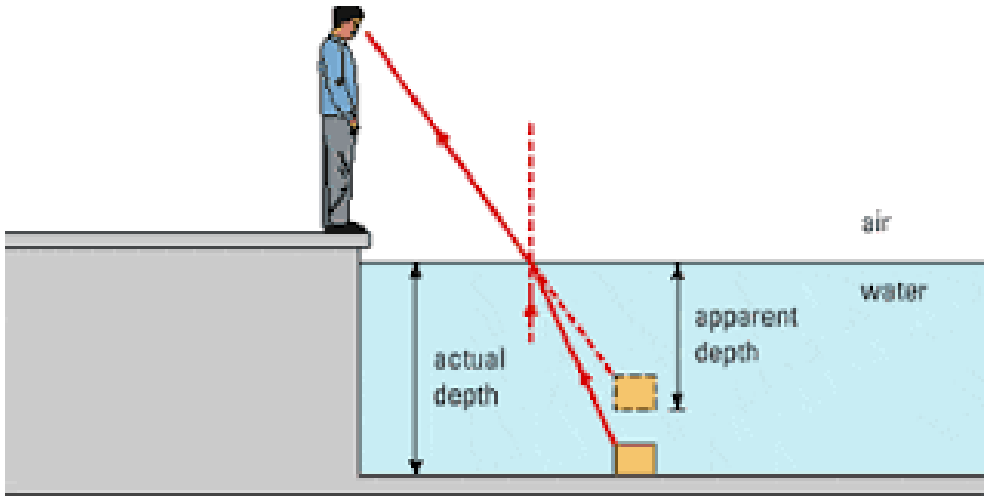
Objects submerged in water appear closer to the surface.

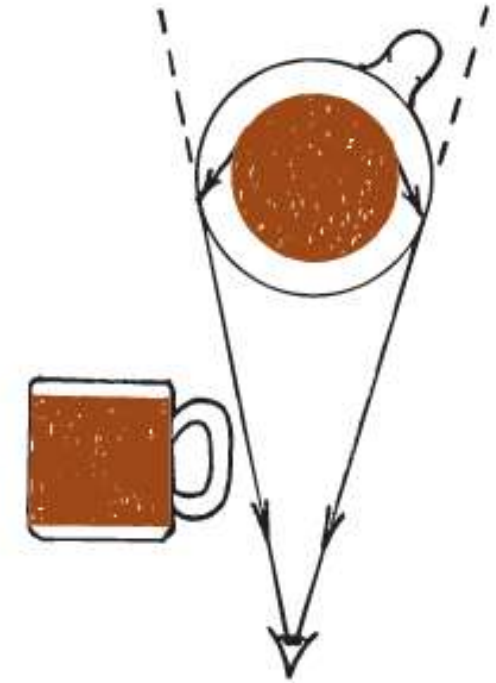
Light from fish takes the path of least time to your eye



Apparent depth:

Pool is *slightly* deeper than it appears.





Mug appears fuller than it really is.

Classwork

17. Does the refraction of light make a swimming pool appear deeper or shallower than it really is?

Refraction
CHECK YOUR NEIGHBOR, Continued-1

When light travels from one medium to another and changes speed in doing so, we call the process

A. reflection.
B. interference.
C. dispersion.
D. refraction.

Refraction
CHECK YOUR ANSWER, Continued-1

When light travels from one medium to another and changes speed in doing so, we call the process

D. refraction.