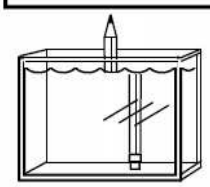
Name: _____

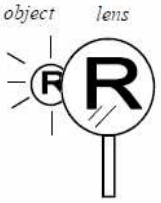
Period: _____

Refraction

Refraction



A pencil is put into water and viewed from the side. The pencil seems to be split at the surface of the water. Why? Because the light from the pencil refracted when it passed from water to air. The position in air is correct (the object). The position in water is where it seems to be (the image).

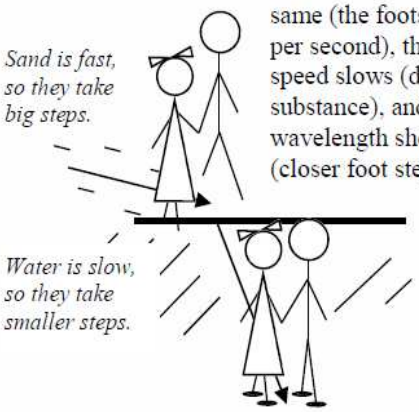


Light (like all waves) refracts when it passes into a different substance at an angle. This is how a magnifying glass, glasses, and contacts work.

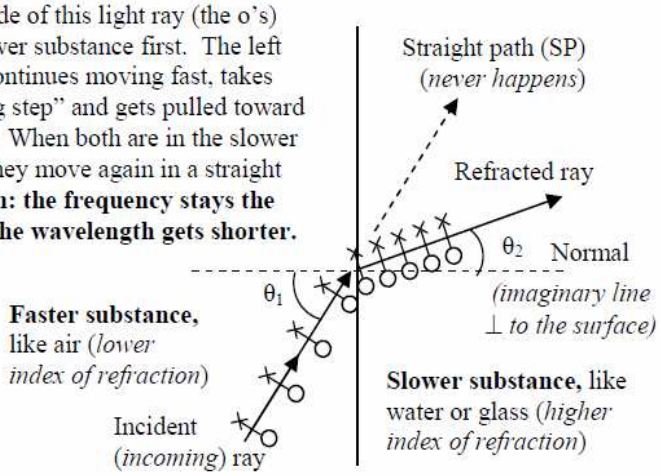
Why Light Refracts

In denser mediums, light bumps into more particles and slows down. This causes refraction.

Imagine Slim Jim and Slim Kim running on the beach. Kim reaches the water first and slows down. Jim, still moving fast on the sand, gets pulled towards the water. Light works just like this: the frequency stays the same (the footsteps per second), the speed slows (denser substance), and the wavelength shortens (closer foot steps).



The right side of this light ray (the o's) hits the slower substance first. The left side (x's) continues moving fast, takes another "big step" and gets pulled toward the normal. When both are in the slower substance they move again in a straight line. **Again: the frequency stays the same, but the wavelength gets shorter.**



When passing from fast to slow mediums light always bends toward the normal (between the straight path and the normal). Light will follow the exact opposite path if it starts in the slow substance.

Index of Refraction (n)

The index of refraction lets you calculate the speed of light in a substance.

Index of refraction (no units) → $n = \frac{c}{v}$ ← *Speed of light in a vacuum (3×10^8 m/s)*; ← *Speed of light in any substance (in m/s)*

As n increases, light moves slower and refracts more.

faster ↑ / ↓ *slower*

Vacuum	n = 1
Air	n = 1.000293 (use 1)
Ice	n = 1.309
Water	n = 1.33
Glass	n = 1.52
Diamond	n = 2.419

Example: Find the speed of light in glass.

$c = 3 \times 10^8$ m/s

$n_{glass} = 1.52$

$v_{glass} =$ _____

$n = \frac{c}{v}$

$v = \frac{c}{n} = \frac{3 \times 10^8}{1.52}$

$v = 1.97 \times 10^8$ m/s

Snell's Law

Snell's Law allows you to calculate how much light will refract when it crosses a boundary.

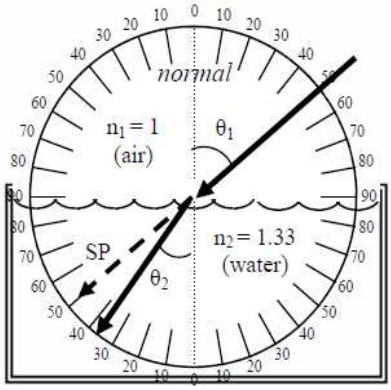
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

Incident ray (1st substance) — Refracted ray (2nd substance)

For all optics equations: ALL angles must be measured from the normal!

Ex: A light ray in air enters water at 50°, as shown in the diagram at the right. At what angle does the light refract in the water?

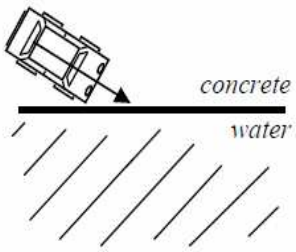
$n_1 = 1$ (*air*) $\theta_1 = 50°$ $n_2 = 1.33$ (*water*) $\theta_2 = ?$	$1(\sin 50°) = 1.33(\sin\theta_2)$ $1(.766) = 1.33(\sin\theta_2)$ $\frac{.766}{1.33} = .616 = \sin\theta_2$ $\sin^{-1}(.5759) = \theta_2 = 35.2°$
$n_1 \sin\theta_1 = n_2 \sin\theta_2$	



Notice: angles are measured from the normal and light bent toward the normal.

1. Imagine a car traveling on concrete hits a puddle of water.

   A. Will the car be faster on concrete or in the water?



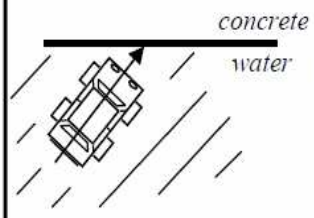
   B. Draw the normal line perpendicular to the water where the car will enter.

   C. Which side of the car hits first?

   D. Use an arrow to draw the path of the car in the water.

2. This time the car starts in the puddle.

   A. Which side of the car gets out of the water first?

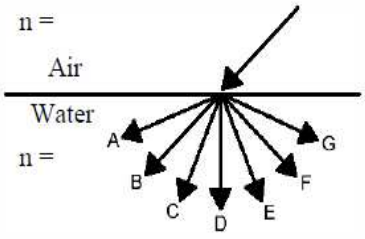


   B. Will the car speed up or slow down when it leaves the water?

   C. Draw the normal line.

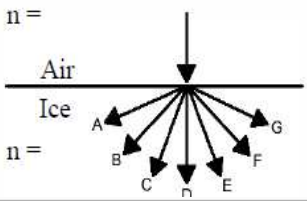
   D. Draw the path of the car after it leaves the water.

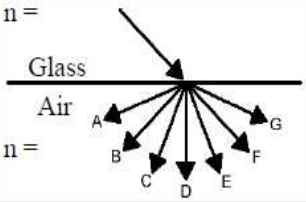
3. A light ray passes from air into water, as shown.

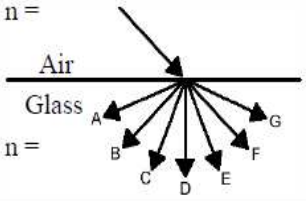


   A. Find the indexes of refraction for both substance from the table on the front.
   B. In which substance does light travel faster?
   (*Hint: notice the arrow on the left of the index of refraction table.*)
   C. Looking from light rays point of view, which side of the light ray hits the water first: left or right? (*If you have trouble seeing this, pretend the car is following the arrow: which wheel hits the water first?*)
   D. Label the "straight path" as "SP" and the normal as "N".
   E. Which of the given paths will the light ray follow in the water?
   F. Did the light ray bend toward or away from the normal?

4. Repeat the previous problem's for the three diagrams at the right. Then decide which path light will take in the second substance.







5. The index of refraction of a substance is 2. Calculate the speed of light in the substance.

   Notice that the speed is half that of the speed in a vacuum.

6. So, if the speed of light in a substance is 1×10^8 m/s, what would its index of refraction be? (*Without calculating.*)

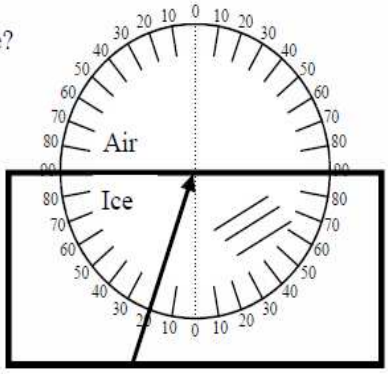
7. Two substances: $n_A = 2.35$; $n_B = 1.65$. In which substance does light have the faster speed?

8. Light travels at 2.06×10^8 m/s in quartz. Calculate the index of refraction for quartz.

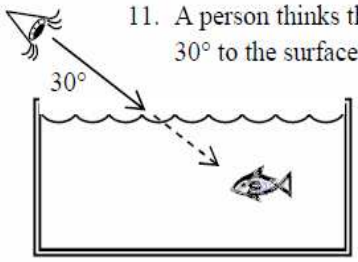
9. Using the table on the front, calculate the speed of light in water.

10. Light travels from a block of ice into air.

    A. Which is the first substance: air or ice?
    B. Calculate and draw the angle in air.



11. A person thinks they see a fish at an angle of 30° to the surface of the water.



    A. Draw where the fish is really (approximately).
    B. Remembering that all angles are from the normal, calculate the actual angle of the fish in the water.