Study Guide: Reflection and Refraction

Reflection of Light

1. **Light Reflections** occur when light bounces off a reflective surface. Most of what our eyes see in the world is reflected light.
2. **The Law of Reflection:** The *angle of reflection* is equal to the *angle of incidence* about the *normal line*.

The Law of Reflection

3. **Angle of Incidence:** The angle at which a light ray reaches a reflective surface.
4. **Angle of Reflection:** The angle at which a light ray bounces off of a reflective surface.
5. **Normal Line:** An imaginary line perpendicular (0 degrees) to the surface of a reflective surface (at any one point). Think of the normal line as the 0 degree *base line* on which most reflection and refraction calculations are based.
6. The incident ray, reflective ray, and normal line are all on a plane. (*This is a great idea as keeping calculations within two dimensions simplifies the math.*)

Diffuse and Regular Reflection

1. **Diffuse** (or irregular) surfaces bounce light in many different directions. They do not produce recognizable images.
2. **Regular surfaces** produce **regular reflections**, in which light rays bounce in parallel directions. This produces recognizable images.
3. Each individual ray reflects according to the law of reflection.

Refraction of Light

1. Light travels at a different speed in different media.
2. Light changes direction (or bends) as it enters a new medium of a different density if it enters at an angle other than 0 degrees.
3. Optically dense matter slows light.
4. When light enters an optically denser medium (such as from air to water), it travels more slowly, bends **toward** the normal, and the angle of reflection is **less** than the angle of incidence.
5. Although in reflections, the incident and reflective angles are **always** equal, in refractions the angles are **usually not equal**.

Transition	**Δ of Speed**	**Bend**	**Diff. of Angles**
Lighter → Denser	Slower	→ Normal	Reflection is < Incidence
Air → Water	Slower	→ Normal	Reflection is < Incidence
Denser → Lighter	Faster	← Normal	Reflection is > Incidence
Water → Air	Faster	← Normal	Reflection is > Incidence

Snell's Law

Although the angle of incidence clearly affects the angle of refraction, the angle of refraction **does not vary directly** with the angle of incidence. (Note: A direct variance results in a linear equation, such as $y = 2x$. The relationship between incident and refractive angles is not that straightforward.)

The Dutch scientist Willebrord Snell (1591 – 1629) discovered the mathematical relationship now known as Snell's Law. The following equation applies to light traveling from a vacuum into a denser medium.

$$Index\ of\ refraction\ of\ the\ medium = \frac{sin\ of\ the\ angle\ of\ the\ incident\ ray}{sin\ of\ the\ angle\ of\ the\ refractive\ ray} \tag{1}$$

$$n = \frac{sin\ i}{sin\ r} \tag{2}$$

Where

- n = Index of refraction of the medium
- i = Incident ray
- r = Refractive ray

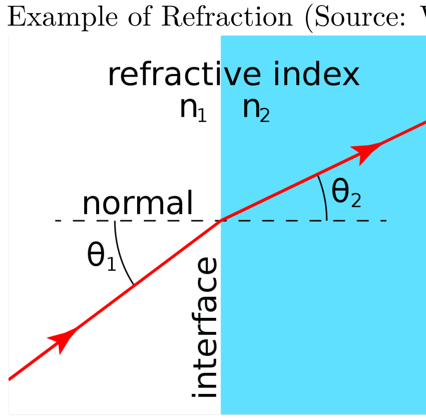
To apply the equation for light traveling from any medium into any other medium, we convert it to the following. If we have any three values, we can find the fouth.

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

Where

- n_1 = Index of refraction of the first medium
- n_2 = Index of refraction of the second medium
- θ_1 = Angle of incidence
- θ_2 = Angle of refraction

Figure 1: Example of Refraction (Source: Wikipedia)



Example Indexes of Refraction

Every medium has an index of refraction. Vacuum has in index of 1. All other matter has a higher index. Here are some commonly used values.

Medium	Index of Refraction
Vacuum	1
Air	1.0003
Carbon dioxide	1.00045
Hydrogen	1.000139
Oxygen	1.000271
Water	1.333
Crown glass	1.517
Dense flint glass	1.655
Diamond	2.417

Example Angles

Angles (In Degrees)	0	30	45	60	90	180	270	360
Angles (In Radians)	0	$\pi/6$	$\pi/4$	$\pi/3$	$\pi/2$	π	$3\pi/2$	2π
sin	0	$1/2$	$1/\sqrt{2}$	$\sqrt{3}/2$	1	0	-1	0
approx. sin			$1/1.414$	$1.732/2$				

Trigonometry Functions

$$sin\ \theta = opp/hyp \quad csc\ \theta = 1/sin\ \theta = hyp/opp$$
$$cos\ \theta = adj/hyp \quad sec\ \theta = 1/cos\ \theta = hyp/adj$$
$$tan\ \theta = opp/adj \quad cot\ \theta = 1/tan\ \theta = adj/opp$$

Example 1

A ray of light traveling through air is incident upon a sheet of crown glass at an angle of 30°. What is the angle of refraction? (Note that the refractive index of air is so close to that of a vacuum that we can round to 1.00.)

Given:

- Refractive index of air: $n_1 \approx 1.00$
- Refractive index of crown glass: $n_2 \approx 1.52$ (rounded to the nearest hundredth)
- Incident angle: $\theta_1 = 30.0°$
- Reflective angle: $\theta_2 = x°$

$$n_1\ sin\ \theta_1 = n_2\ sin\ \theta_2 \qquad \textit{Original equation} \qquad (3)$$

$$sin\ \theta_2 = \frac{n_1\ sin\ \theta_1}{n_2} \qquad \textit{Isolate the unknown value} \qquad (4)$$

$$= \frac{1.00\ sin\ 30.0°}{1.52} \qquad \textit{Replace known values} \qquad (5)$$

$$= \frac{0.5}{1.52} = 0.329 \qquad \textit{Simplify numerator} \qquad (6)$$

$$\theta_2 = 19.2° \qquad \textit{Find } \sin^{-1} \textit{ of } 0.329 \qquad (7)$$

Example 2

A ray of light traveling through air falls on the surface of a transparent glass slab. The ray makes an angle of 45° with the normal. Given that the refractive index of the glass is $\sqrt{2}$, find the angle made by the refracted ray within the slab.

$$\frac{\sin\ 45°}{sin\ r} = \sqrt{2} \qquad (8)$$

$$sin\ r = \frac{1}{\sqrt{2}} \times 45° \qquad (9)$$

$$= \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} = \frac{1}{2} \qquad (10)$$

$$\textit{Thus, as } \sin\ r = \frac{1}{2}, \textit{ the angle of refraction would be, } r = \sin^{-1}\left(\frac{1}{2}\right) = 30° \qquad (11)$$

Practice: Snell's Law and Angles of Refraction

1) A ray of light traveling through water is incident upon a sheet of dense flint glass at an angle of 45°. What is the angle of refraction?

2) A ray of light traveling through air is incident upon water at an angle of 0°. What is the angle of refraction?

3) A ray of light traveling through air falls on the surface of a transparent glass slab. The ray makes an angle of 60° with the normal. Given that the refractive index of the glass is 1.517, find the angle made by the refracted ray within the slab of glass.

4) A light beam makes an angle of 60 degrees to the normal as it strikes a transparent substance with a partially reflective surface. Part of the beam is reflected from the surface into the air and part is refracted through the substance. The reflected and refracted beams make an angle of 90 degrees with each other. What is the index of refraction of the substance? (Use the back side of this page to make a diagram and show your calculations.)