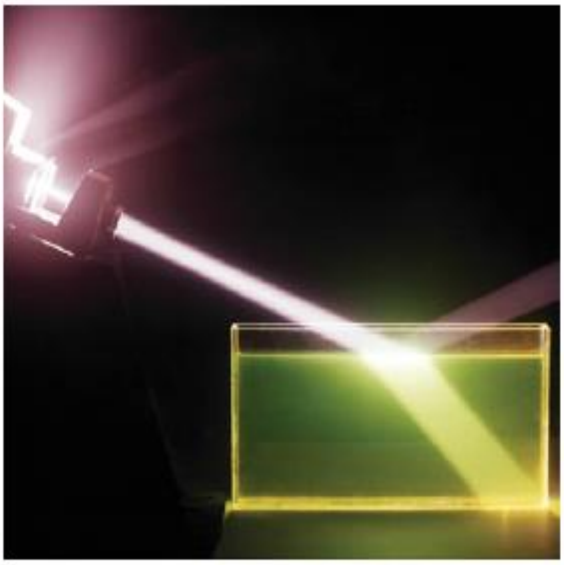
Reflection and Refraction

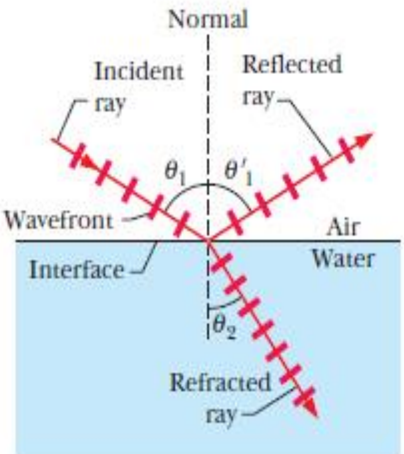
Although a light wave spreads as it moves away from its source, we can often approximate its travel as being in a straight line; we did so for the light waves. The study of the properties of light waves under that approximation is called *geometrical optics.* The photograph in Fig. *a below* shows an example of light waves traveling in approximately straight lines. A narrow beam of light (the *incident* beam), angled downward from the left and traveling through air, encounters a *plane* (flat) water surface. Part of the light is **reflected** by the surface, forming a beam directed upward toward the right, traveling as if the original beam had bounced from the surface. The rest of the light travels through the surface and into the water, forming a beam directed downward to the right. Because light can travel through it, the water is said to be *transparent;* that is, we can see through it.

The travel of light through a surface (or *interface*) that separates two media is called **refraction,** and the light is said to be *refracted.* Unless an incident beam of light is perpendicular to the surface, refraction changes the light's direction of travel. For this reason, the beam is said to be "bent" by the refraction. Note in Fig. *a* that the bending occurs only at the surface; within the water, the light travels in a straight line.

In Figure *b,* the beams of light in the photograph are represented with an *incident ray,* a *reflected ray,* and a *refracted ray* (and wavefronts). Each ray is oriented with respect to a line, called the *normal,* that is perpendicular to the surface at the point of reflection and refraction. In Fig.*b*, the **angle of incidence** is θ_1, the **angle of reflection** is θ_1', and the **angle of refraction** is θ_2, all measured *relative to the normal.* The plane containing the incident ray and the normal is the *plane of incidence*, which is in the plane of the page in Fig. *b*.



(*a*)



(*b*)

Experiment shows that reflection and refraction are governed by two laws:

Law of reflection: A reflected ray lies in the plane of incidence and has an angle of reflection equal to the angle of incidence (both relative to the normal). In Fig.*b*, this means that

$$\theta_1' = \theta_1 \quad \text{(reflection)}.$$

(We shall now usually drop the prime on the angle of reflection.)

Law of refraction: A refracted ray lies in the plane of incidence and has an angle of refraction θ_2 that is related to the angle of incidence θ_1 by

$$n_2 \sin\theta_2 = n_1 \sin\theta_1 \quad \text{(refraction)}.$$

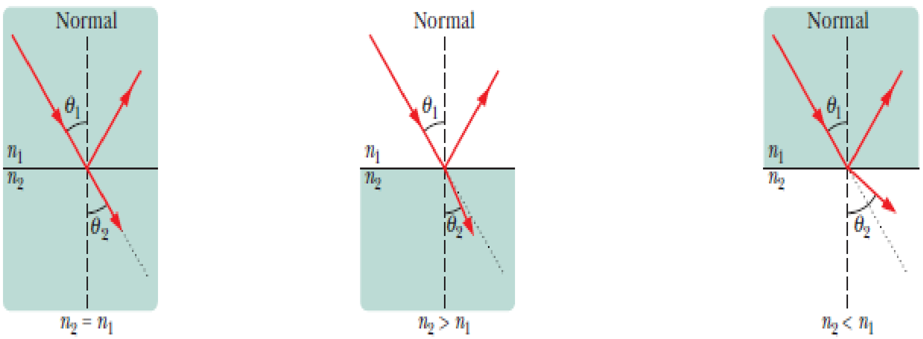
Here each of the symbols n_1 and n_2 is a dimensionless constant, called the **index of refraction,** that is associated with a medium involved in the refraction. We derive this equation, called **Snell's law**, the index of refraction of a medium is equal to c/v, where v is the speed of light in that medium and c is its speed in vacuum.

For vacuum, n is defined to be exactly 1; for air, n is very close to 1.0 (an approximation we shall often make). ***Nothing has an index of refraction below 1.***

We can rearrange above equation as

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1$$

to compare the angle of refraction θ_2 with the angle of incidence θ_1. We can then see that the relative value of θ_2 depends on the relative values of n_2 and n_1:



(*a*) If the indexes match, there is no direction change.

(*b*) If the next index is greater, the ray is bent *toward* the normal.

(*c*) If the next index is less, the ray is bent *away from* the normal.

1. If n_2 is equal to n_1, then θ_2 is equal to θ_1 and refraction does not bend the light beam, which continues in the *undeflected direction,* as in Fig. a

2. If n_2 is greater than n_1, then θ_2 is less than θ_1. In this case, refraction bends the light beam away from the undeflected direction and toward the normal, as in fig.*b*.

3. If n_2 is less than n_1, then θ_2 is greater than θ_1. In this case, refraction bends the light beam away from the undeflected direction and away from the normal, as in Fig. *c*.

Refraction cannot bend a beam so much that the refracted ray is on the same side of the normal as the incident ray.