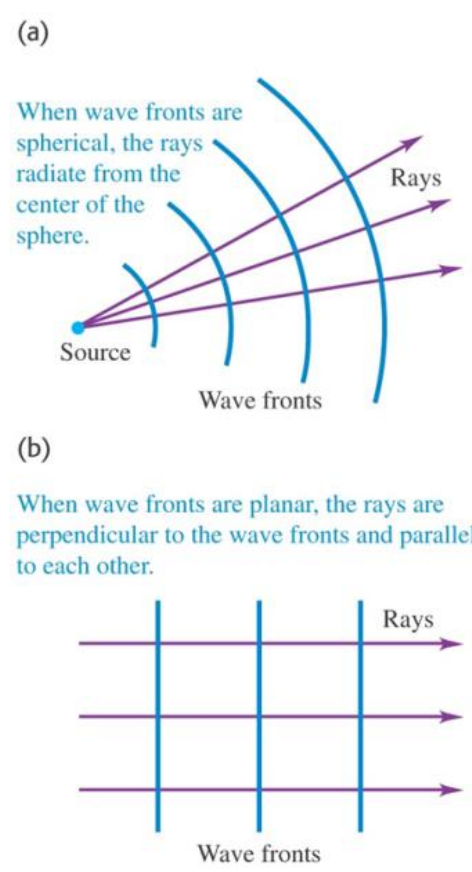
Pre-lecture Notes Section 15:
The Nature and Propagation of Light

I. Introduction to Reflection and Refraction

In this section, we will be primarily concerned with studying the propagation of light as it is incident on a boundary, such as a piece of metal or a dielectric (think water, plastic, glass etc…). We will see that light can be reflected from and/or transmitted into such a material, and we will study what happens to light in each of those two cases.

When a light wave encounters such a boundary (i.e. a new medium), there are two possibilities as to what may happen. It may be reflected back into its original medium, or it may be transmitted into the new medium. In many cases it will do both, with the intensity of the light wave "splitting" up, some of it being reflected and some transmitted! The ratio of the reflected intensity to the transmitted intensity is somewhat complicated to calculate, and we will not do so in this section. We will simply be interested in describing what happens to the part of the wave which is reflected, as well as the part of the wave which is transmitted.



To describe such phenomena, we often do not need to know the frequency or wavelength of the wave (i.e. the specific wave properties) but instead only the ***direction*** of propagation of the wave. The direction of wave propagation can be described simply by a **ray**. The picture to the right shows the propagation of wavefronts and the rays that accompany them.

II. Reflection and the Law of Reflection

When light strikes a boundary, it will often be reflected. A "perfect mirror" is defined as a material for which 100% of the incident wave intensity is reflected back. Conductors, such as silver, form nearly perfect mirrors. However, even glass, which is definitely not a perfect mirror, exhibits reflection.

To describe the incident and reflected rays, we must define the ***normal line*** to be the line that is perpendicular to the boundary surface at the location that the incident ray hits the boundary.

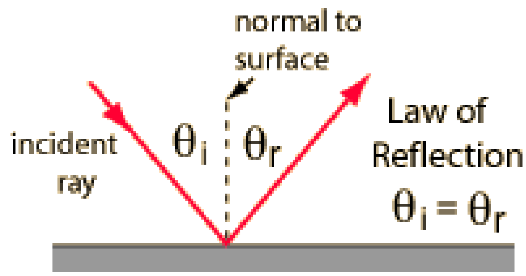
With this definition, we can state the law of reflection.

The Law of Reflection: The angle that the incident ray makes with the normal is always equal to the angle that the reflected ray makes with the normal.

Mathematically, if the incident angle is θ_a and the reflected angle is θ_r, then

$$\theta_r = \theta_a$$

A picture of the incident ray, normal line, and reflected ray is shown to the right. (*Note: In the picture, the incident angle is called θ_i instead of θ_a*).



III. Refraction and Snell's Law

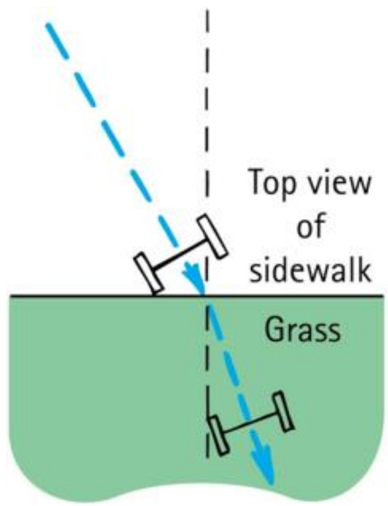
Now we consider what happens to the transmitted portion of the wave. If the wave is transmitted into a dielectric material (i.e. water, glass, plastic etc…), it will change speeds as it enters the new material! Recall that in section 14, we found that the speed of a wave in a material is related to the material's index of refraction, n, such that

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

In other words, for a material with a large index of refraction, the wave speed will be small and vice-versa.

The consequence of this changing of speed is that the light bends upon entering the material! If the light slows down (i.e. the wave enters a higher n material) the light will bend **towards the normal**, while if the light speeds up (i.e. the wave enters a lower n material) the light will bend **away from the normal**.

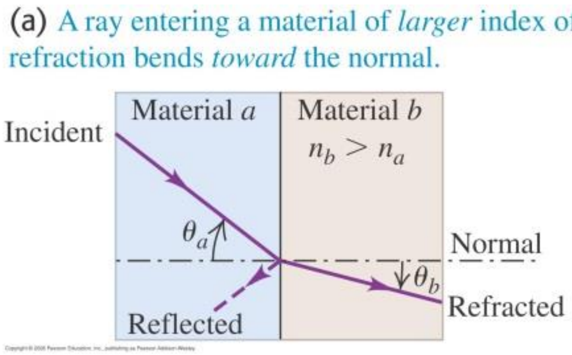
This process has a mechanical analogy (as we will show with a demonstration in class). In the picture to the right, the car slows down upon going from sidewalk to grass, and thus it must bend towards the normal.

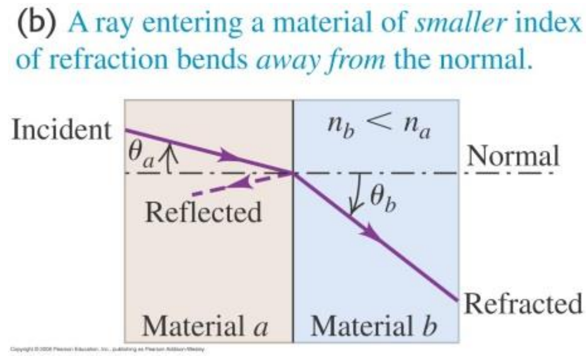


When the light bends, we say it has been **refracted**. Quantitatively, we can figure out the amount by which the light has been refracted using the law of refraction, also called **Snell's Law**:

$$n_a \sin\theta_a = n_b \sin\theta_b$$

Figure (a) below shows the refracted wave in the case that (a) the light enters a "slower" medium (larger n) at some non-zero incident angle and figure (b) shows what happens when the the light enters a "faster" medium (smaller n) at some non-zero incident angle.





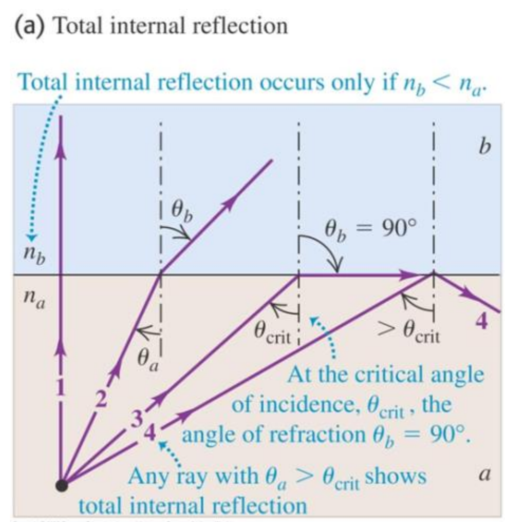
IV. <u>Total Internal Reflection</u>

If a wave is being refracted from a "slow" medium (larger n) into a "fast" medium (smaller n), then according to Snell's law, the wave will be refracted away from the normal line. If the incident angle is large enough for a given pair of materials, then the refracted angle will be at 90° (i.e. right along the boundary of the materials)! The incident angle for which this occurs is called the **<u>critical angle</u>** θ_{crit} for that particular set of materials. Using Snell's law with $\theta_b = 90°$, we find that for a given set of media a and b, the critical angle can be found via

$$\sin\theta_{\text{crit}} = \frac{n_b}{n_a}$$

(*You should be able to "prove" this relation for yourself!!*).

What happens if the incident angle becomes greater than the critical angle? The answer is that the refracted ray ceases to exist, and the entire incident wave becomes reflected! When this occurs, we say that the light wave has undergone **<u>total internal reflection</u>**.



The picture to the right shows a series of incident rays with increasing angles until the critical angle is reached. At any incident angle greater than the critical angle, total internal reflection occurs and 100% of the wave is reflected. This phenomenon is used, for instance, in fiber optic cables, which transmit light via total internal reflection so that none of the electromagnetic energy is "lost" leaving the cable.

Note that this can only happen if the ray moves away from the normal. Therefore, total internal reflection is only possible when light moves within a slower medium towards a boundary with a faster medium.