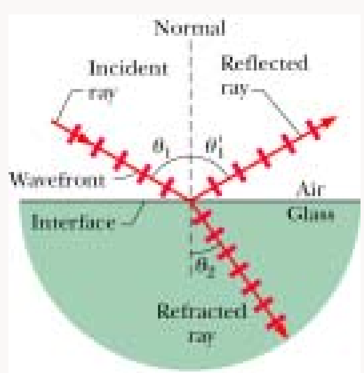
Today's lecture

Geometric optics

Reflection and refraction:

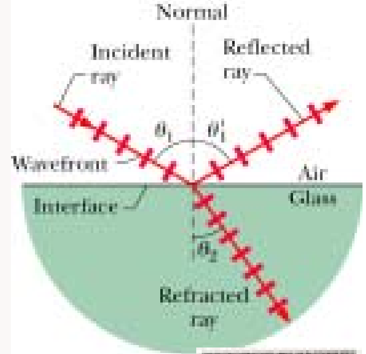
Although we saw that generically light from a source spreads out as it gets away from the source, there are many situations in which we can consider light waves as travelling along a straight line. This can be achieved, for instance, by focussing the rays as headlights of cars or flashlights do. The branch of physics that studies this kind of optical phenomena is called geometric optics. It is geometric because as we will see, the laws will refer to the trajectory of the light and will not involve its wave nature.

When light reaches the boundary between two materials, its direction of travel changes. This phenomenon is called refraction.



(b)

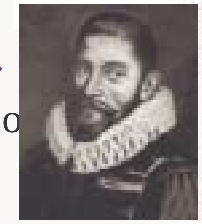
Experiments show that reflection and refraction keep the outgoing rays in the same plane as the ingoing rays and the normal of the surface and are governed by two laws:



Law of reflection: the angle of incidence θ_1 equals the angle of reflection θ'_1.

Law of refraction: $n_2 \sin\theta_2 = n_1 \sin\theta_1$ Snell’s law.

Where n_1 and n_2 are called the “index of refraction” o media 1 and 2 respectively. These quantities are determined experimentally and listed in tables. For air n is very approximately 1. All other substances have larger indices of refraction.



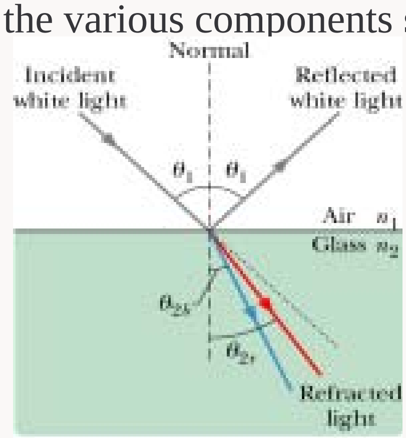
Willebrord Snell 1580-1626 René Descartes 1596-1650

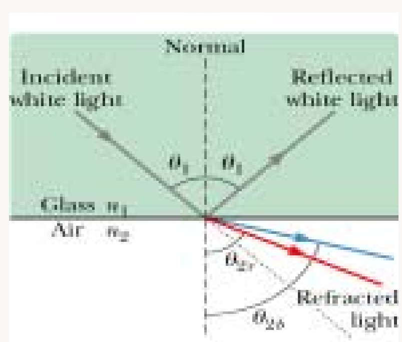
If n_1 equals n_2 then light travels straight. If n_1 is smaller than n_2 then the refracted angle is larger than the incident. It can be so large that the light is actually reflected. It can never be so large that it will go beyond the normal.

Chromatic dispersion:

The index of refraction of a medium in general depends on the wavelength of the light. Therefore if one has a beam of light that is composed of waves of more than one frequency, the various waves will refract at different angles.

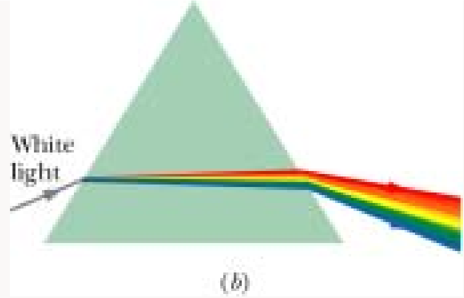
White light is composed of waves of (nearly) all the frequencies in the visible spectrum. Therefore when white light is refracted, the various components separate.



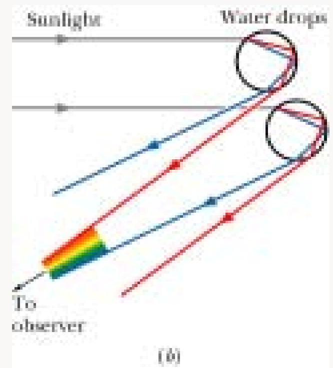


(b)

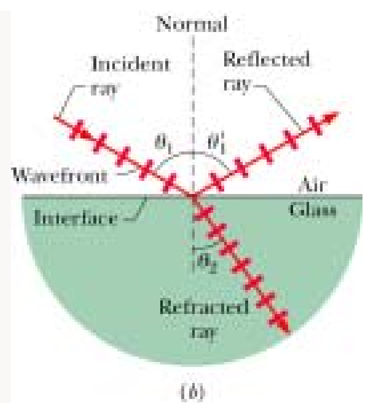
The two previous effects can amplify each other in a prism,



Another example is given by rainbows. Here the water droplets act as “prisms”.



Total internal reflection:

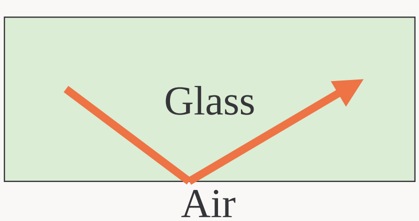


When we discussed the law of refraction:

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

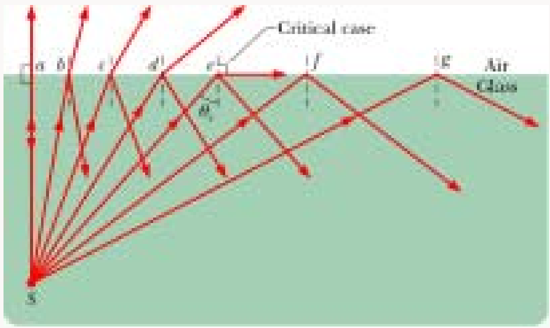
We made clear that it could happen that θ_2 gets bigger than 90°. In such case the ray does not enter the medium at the bottom but actually is “reflected” back to the top. Such phenomenon is called “total internal reflection”. Why “internal”? For this to happen we need to at least have,

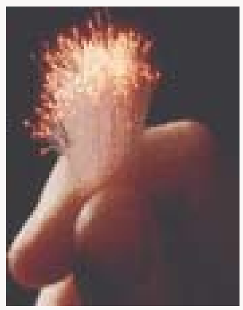
$$\theta_2 = \frac{\pi}{2} \Rightarrow \sin\theta_1 = \frac{n_2}{n_1}$$



Since sin is always less than one, then $n_2<n_1$. Therefore this can only happen if the ray comes through a medium of an index of refraction larger into one that is smaller, for instance within glass onto air. The reflection is therefore “internal” in the glass.

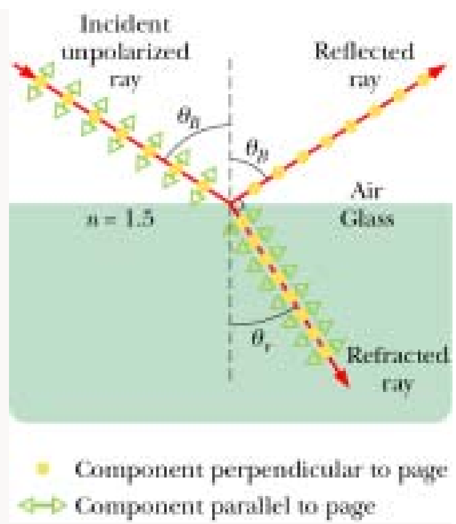
The angle $\theta_1=\sin^{-1}(n_2/n_1)$ at which total internal reflection starts to happen is called "critical" angle. For angles of incidence larger than the critical angle light is reflected and not refracted.





This phenomenon has a huge technological application: fiber optics. These are cylinders of flexible material that "guide" light by bouncing it around via total internal reflection. They have had a huge impact in medical imaging (they can be bent into various places) and communications (they are immune to radio interference and many light rays can share a single fiber).

Polarization by reflection:



We argued that one way of polarizing light was through reflection. More precisely, if we decompose the incoming wave into two directions, one perpendicular and one parallel to the plane of incidence, they will be reflected with different amplitudes.

Light therefore is partially polarized by reflection in general.

However, when the incident angle has a particular value, called Brewster angle $\theta_{B,}$ then the parallel component is not reflected.

It is experimentally observed that at the Brewster angle, the reflected and refracted rays form a straight angle,

$$\theta_B + \theta_R = 90^o$$

If we combine the previous observation with Snell's law,

$$n_1 \sin\theta_B = n_2 \sin(90^o - \theta_B) = n_2 \cos\theta_B$$

$$\tan\theta_B = \frac{n_2}{n_1}$$

If we take n_1=1, as is the case of air, we get $\theta_B = \tan^{-1} n_2$

Which is known as Brewster's law, and n_2 is the refraction index of a material in air.

Summary:

- Light rays deviate when entering a medium. Refraction is governed by Snell's law.
- The deviation can be such that the ray is reflected.
- Light rays are polarized by reflection, this is governed by Brewster's law.