Wave Model of Light

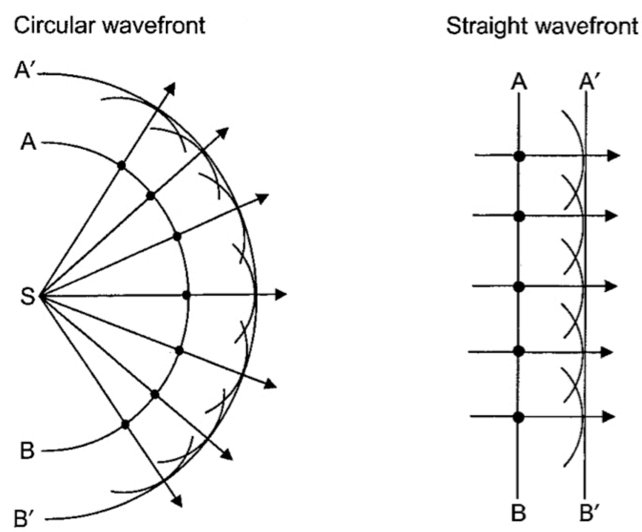
This lesson will focus on the wave model of light, and how it explains the behavior of light.

Huygens' Principle and Rectilinear Propagation

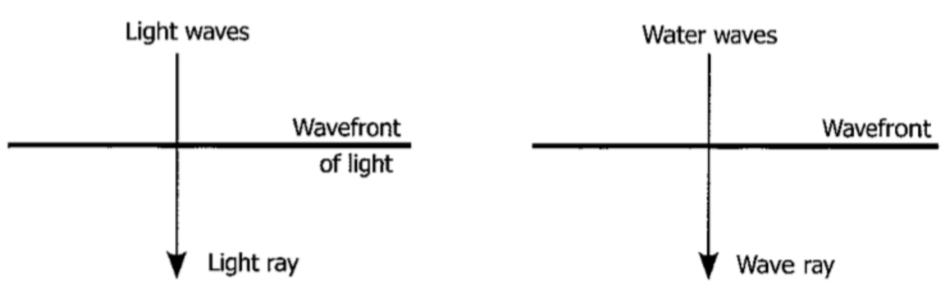
The wave theory of light was proposed by Robert Hooke in 1665. Twenty years later, it was improved by Christiaan Huygens. He developed a technique for predicting the future position of a wave front based on an earlier position of the same wave. His explanation became known as Huygens' Principle.

Huygens' Principle states that every point on a wave front can be considered as a point source of tiny secondary wavelets that spread out in front of the wave at the same speed as the wave itself. The surface envelope, tangent to all the wavelets, constitutes the new wavefront.

As an example, consider the wavefront AB that is traveling away from the source S at some moment in time. The points on the wavefront represent the centers of the new wavelets, seen as a series of small circles. The common tangent to all these wavelets, the line $A'B'$, is the new position of the wavefront a short time later.



The wave theory treats light as a series of wavefronts perpendicular to the light rays.

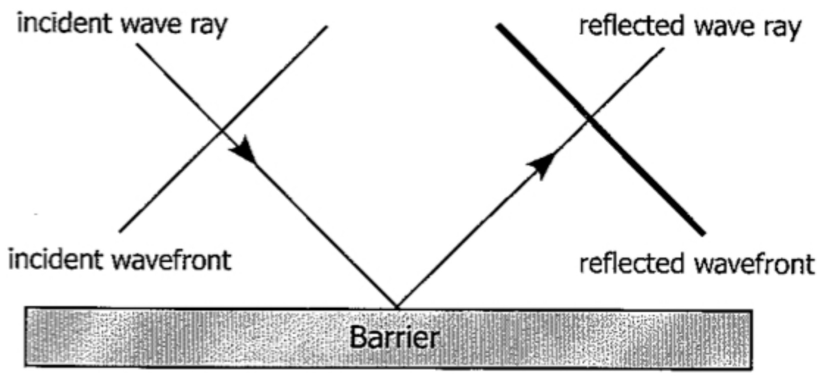


Huygens thought of the rays as simply representing the direction of motion of a wavefront. This was how the wave theory explained the rectilinear propagation of light.

Newton felt that the wave theory did not adequately explain the rectilinear propagation of light since waves emitted from a point source spread out in all directions.

Reflection

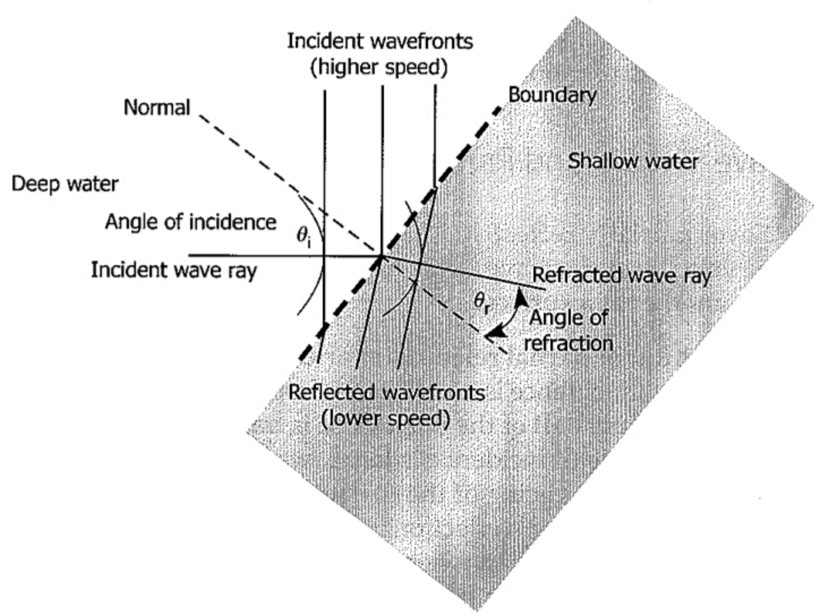
In our previous study of waves, we saw that waves reflect according to the law of reflection.



Since light also reflects according to the law of reflection, it is reasonable to infer that light could be a wave.

Refraction

In our study of waves in two dimensions, we studied a diagram similar to the one shown below.



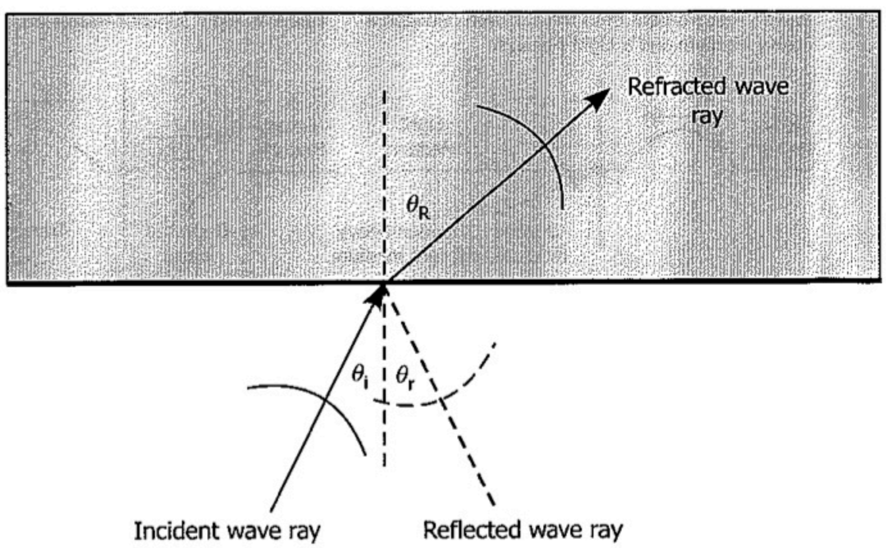
The diagram shows incident wavefronts in deep water. This corresponds to light moving in a low density material like air. The direction of the wavefronts is indicated by the incident wave ray. One of the wavelets is included on this ray. Note that the wavefront is tangent to the wavelet.

After the wavefronts move into shallow water, they refract in such a way that the angle of refraction is smaller than the angle of incidence. The wave ray in shallow water corresponds to light moving in a higher density material like water or glass.

The distance between the wavefronts in shallow water is less than the wavelength in deeper water. This indicates that the wave speed has decreased as light moves into a denser material. Thus, **the wave theory predicts that light will move more slowly in water than in air**. This is exactly the opposite of what the particle model predicts.

Partial Reflection and Partial Refraction

Waves partially reflect and partially refract whenever there is a change in the velocity of the wave. This happens whenever the waves pass from one medium to another.



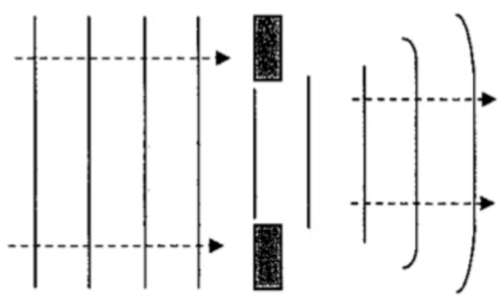
The amount of partial reflection varies with the angel of incidence. When the angle of incidence is small, almost all of the wavefront is transmitted through the surface. When the angle of incidence is large, then the amount of reflection is larger. Partial reflection is also more apparent when there is an increase in velocity than when there is a decrease.

It is easily observable that light partially reflects and partially refracts in exactly the same way that waves do. Thus, the wave model is an excellent model to explain this behavior of light.

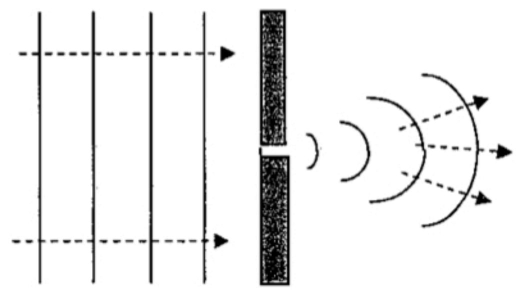
Diffraction

At the time of Newton, it was observed by Grimaldi that light would diffract when directed through two successive narrow slits. Newton criticized Grimaldi's work, saying that if light was a wave, it should diffract much more than was observed by Grimaldi.

In our earlier lessons, we observed that there is considerable diffraction only when the size of the opening is the same size as, or smaller than, the wavelength of the waves. For example, in the left diagram below, the size of the opening is large compared to the wavelength, so there is little diffraction. In the right diagram, the opening size is small, and there is considerable diffraction.

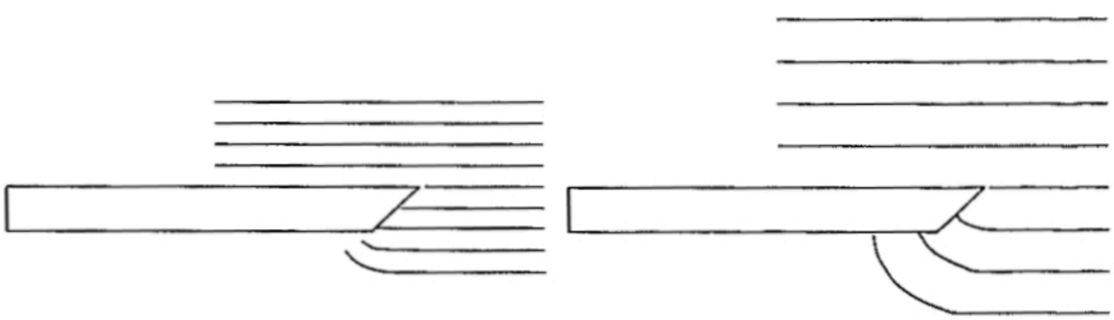


There is little diffraction when waves pass through an opening that is much larger than the wavelength.



There is more diffraction when waves pass through an opening that is about the same size as the wavelength.

The diagram below also shows that diffraction around a sharp barrier is less for shorter wavelengths.



At the time of Huygens and Newton, the wavelength of light was not known. We know today that, because the wavelength of light is so small, the diffraction effects are very small when light passes through the relatively large openings that we typically experience. Upon further investigation, it was discovered that, with a sufficiently tiny opening, light will actually diffract a great deal.

The wave model provided a much better explanation of diffraction than the particle model did.