The Nature of Light

For centuries there has been debate about whether the properties of light could best be explained using a particle model of light or a wave model. This lesson will focus primarily on the particle model of light. We will begin, however, with a brief summary of how the model of light has changed in the last two thousand years.

Early Greece to 20th Century

The earliest views on the nature of light came to us from the Greeks. Plato thought that light consisted of filaments (think tentacles), emitted by the eye. When these filaments came into contact with an object, it was possible to see the object. We refer to this as the **tactile theory** of light.

Not all Greeks agreed with Plato. The Pythagoreans believed that light traveled as a stream of fast-moving particles. According to this **emission theory**, objects sent out beams of light that would ricochet off objects and enter the eye.

One Greek, Empedocles, believed that light traveled as a wave-like disturbance. So as early as ancient Greece, we see a debate between a particle theory of light and a wave theory.

By the 17th century, the contradictory views of light placed scientists in two camps. Newton was the principle advocate of the **particle**, or **corpuscular theory**. Newton's theory stated that light consisted of particles that traveled in straight lines.

The **wave theory** was supported principally by Christiaan Huygens of Holland. Huygens' wave theory stated that light consisted of waves and exhibits wave-like properties in its behavior.

At the end of the 19th century, James Clerk Maxwell combined electricity, magnetism, and light into one theory. According to Maxwell's **electromagnetic theory**, light was an electromagnetic wave with the same properties as other electromagnetic waves. Maxwell's theory was flawed, however. It was unable to explain all of the properties of light, including one called the photoelectric effect.

In 1900, Max Planck proposed the **quantum hypothesis**, suggesting that light was transmitted and absorbed in small bundles of energy called quanta. Albert Einstein agreed with Planck's theory and used it to explain the photoelectric effect using the particle model of light.

The theory of **quantum mechanics**, developed over several years in the early 1900s, combines the two major theories of light by suggesting that light sometimes behaves as a particle and sometimes behaves as a wave.

Newton's Corpuscular Theory

In the remainder of this lesson, we will learn the details of Newton's particle model of light. Specifically, we will examine the arguments that could be used to support the particle theory.

Rectilinear Propagation

One argument was the rectilinear propagation of light that is, light travels in straight lines. Newton argued that, since the path of light has no noticeable curve, the speed of light must be extremely high. He also argued that since light does not exert any noticeable pressure, the mass of the particles must be extremely small.

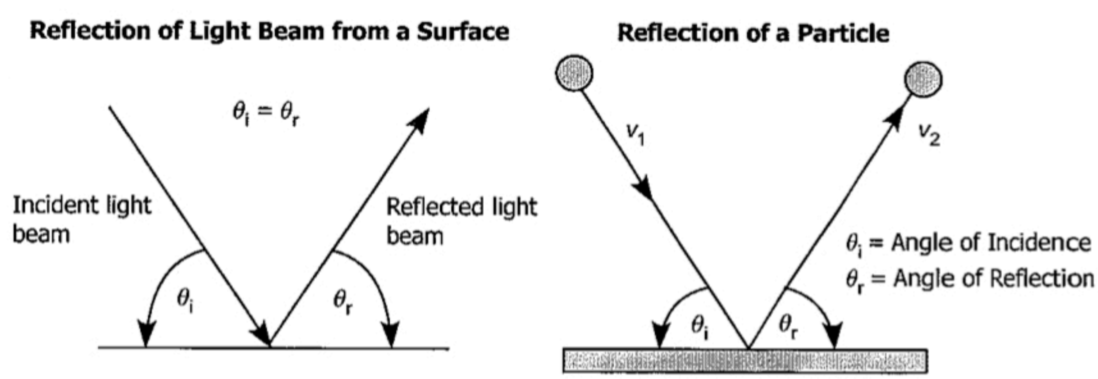
Newton also noticed that two beams of light pass through each other without reflecting to the side. This indicated to Newton that the particles must also be extremely small in size.

It is primarily because of rectilinear propagation that Newton rejected the wave theory. Newton argued that a wave should spread (diffract) out a great deal as it passes through an opening, filling almost the whole region beyond the opening. He felt, therefore, that waves could not possibly produce a narrow beam. He also argued that waves would diffract around objects to fill the area behind them, resulting in there being no shadows.

We know today that the reason light doesn't diffract noticeably has to do with its wavelength. Waves with small wavelengths diffract less – light has a very small wavelength, and so it diffracts very little.

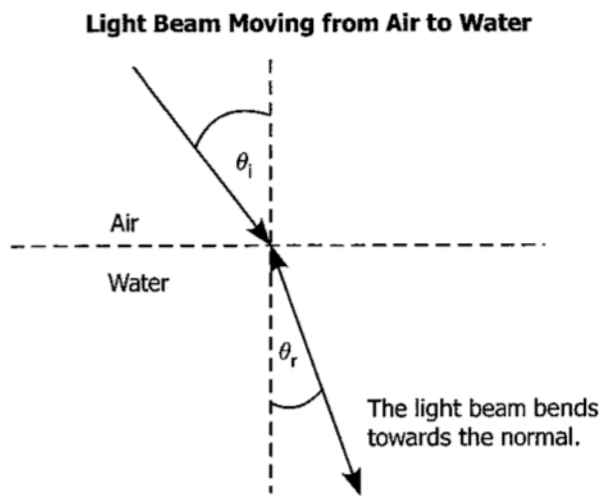
Reflection

When light falls on the smooth surface of a mirror, it reflects in such a way that the angle of incidence is equal to the angle of reflection. Newton demonstrated that very hard spheres collide with very hard surfaces in a similar way. Thus, Newton's corpuscular theory was able to explain reflection – light did indeed appear to act like small, hard bits of matter.



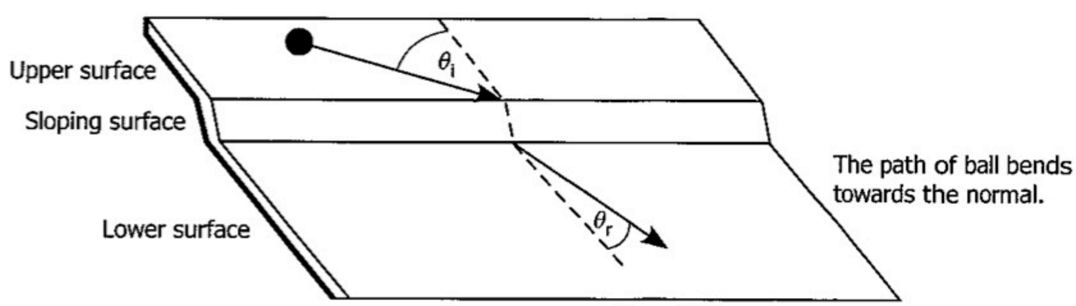
Refraction

When light passes from air into water, it bends (refracts) towards the normal. Rays of light will always bend towards the normal when they pass from a less dense to a more dense material.



Newton was able to explain this behavior using his corpuscular theory. The following analogy illustrates his reasoning.

Consider the motion of a ball that is initially moving along a horizontal, flat surface. This ball then goes down a small slope to another flat, horizontal surface. When the ball is on either horizontal surface, it will experience no net force and so move in a straight line (this is rectilinear propagation). However, when the ball moves from one to the other (by the ramp), it will experience a net force towards the lower surface and so will accelerate and change the direction it is moving. The upper surface represents air and the lower surface represents water.



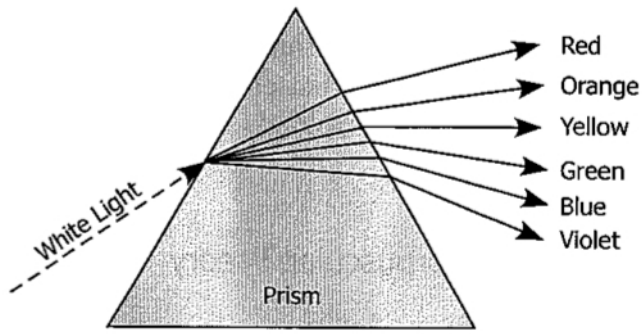
Newton believed that water attracts approaching particles of light in much the same way that gravity acts on a rolling ball on an incline. The rolling ball model shows that particles of light must speed up as they pass from air into water. Thus, **Newton predicted that the speed of light in water must be greater than the speed of light in air**.

At the time of Newton, the speed of light was not known. It was not until 123 years after Newton's death that Foucault was able to successfully determine the speed of light.

Dispersion

When a beam of light passes through a prism, the light can change from white to a range of colors that is most often referred to as "the colors of the rainbow." This is called **dispersion**.

A prism is a transparent material (often glass) typically in the shape of a triangle.



To explain dispersion using the corpuscular theory, Newton hypothesized that the particles of light are not all the same mass: different colors could be explained as differences in the mass of the light particles. Since violet particles are refracted the most, Newton argued that the violet particles must have the smallest mass. Similarly, the particles that correspond to red light must have the largest mass in the visible spectrum.

Difficulties with Newton's Corpuscular Model

Newton's corpuscular theory of light provided a satisfactory explanation for four properties of light:

- rectilinear propagation
- reflection
- refraction
- dispersion

It was weak in its explanation of other effects:

- diffraction
- partial reflection and partial refraction
- speed of light

Diffraction

Newton believed that light travels in straight lines and, therefore, does not diffract around corners. It had been observed, however, that light passing through successive narrow slits produced on a screen a band of light slightly larger than the width of the slits. It was Newton's position that this effect resulted from collisions between the particles of light and the edges of the slit.

Partial Reflection and Partial Refraction

When light refracts, some of the light is reflected. Newton's explanation of this behavior was the so-called "theory of fits." He said that particles of light arrived at the surface sometimes in a "fit" of easy reflection and sometimes in a "fit" of easy refraction. This was obviously a weak explanation, which Newton himself acknowledged.

Speed of Light

Newton predicted that the speed of light would be faster in water than in air. We know today that this is, in fact, not the case.