Light, Images, and Reflection

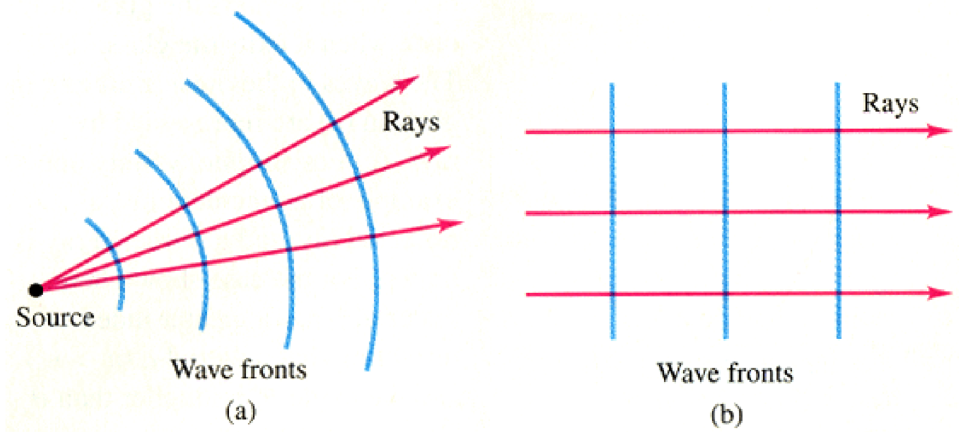
Light is one of the most studied topics in the history of physics, and has fascinated us for millennia. Our view of light has changed drastically from the ancient picture of light as being emitted by the observer's eye. In the 17th century there was a great debate over whether light was a wave phenomena, like sound, or a particle phenomenon, whereby rays of light are composed of particles, light bullets fired from a machine gun. The debate was finally settled in the 19th century when interference and diffraction phenomena demonstrated that light moved through space as waves. By the middle of that century Maxwell proved that light waves were *electromagnetic waves*, sinusoidally oscillating electric and magnetic fields that travel through space at 3×10^8 m/s.

All was right with the theory until the 20th century, when Einstein expanded on the work of Planck and showed that light waves did behave as collections of individual particles in certain circumstances. This led to the birth of quantum physics, and the essential "wave/particle duality" that applies to all types of matter. This is a fascinating story, best told in my Modern Physics (PH301) and Optical Physics (PH303) courses.

Light Rays

For our purposes in this class, we will only focus on *ray optics*, a mathematical construction that can be used in both wave and particle models and works especially well when studying mirror and lens systems. You are familiar with light rays when observing light passing through smoky or cloudy air and, of course, when playing with laser pointers.

It should be obvious how the ray construction works for a particle model of light: imagine a light ray as a stream of particles like bullets from a machine gun. The ray model is harder to visualize for waves. Imagine wave fronts moving through space like ocean ripples approaching the shore, the "ray" will be perpendicular to these wave fronts and move in the direction of the wave:

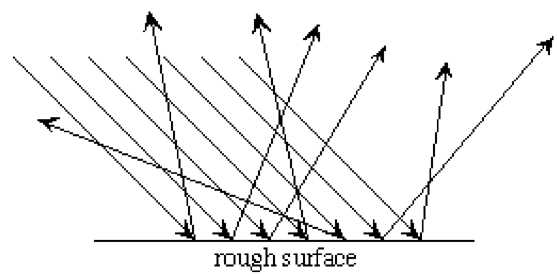


Some ancient scholars believed that people see because their eyes emit light, illuminating the target. We now know, of course, that it is the object we are observing that emits (or reflects) light that enters our eye. When we see an object, we essentially trace the rays that enter our eyes back to their origin. In the picture above left, we see three rays emanating from a "point source." In reality, there are countless rays. If you imagine those rays entering your eyes, the "object" that you see is located by tracing the rays back to where they meet. In the image above right, the rays are parallel and never meet back to a single originating point. We say that the source of these rays is "infinitely" far (or just really far) from the eye.

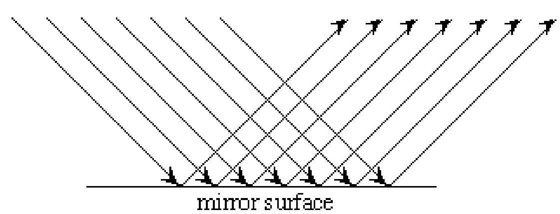
Reflection

Light rays in a vacuum (and in any constant medium) travel in straight lines. If that were all there was to light, optics wouldn't be very interesting. In reality, light rays can be bent from a straight path in a number of ways. For example, light rays in one medium will tend to change direction as they enter and transmit through another medium. this phenomenon, known as **refraction**, is the subject of the next lesson.

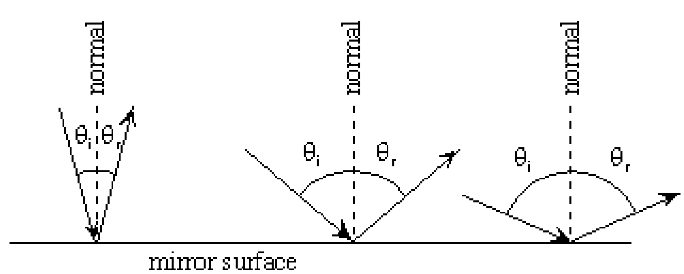
In this lesson we will look at **reflection**, in which light rays actually "bounce back" from the surface. There are two kinds of reflection. **Diffuse reflection** occurs when light scatters off of rough surfaces. An organized bundle of rays incident on the rough surface will reflect off in seemingly random directions. Diffuse reflection is actually the most common kind of reflection you see. When you look at the road, a wall, or your friend, you are observing reflected light. However, you don't ever see a bright reflected image of the sun or whatever other light source illuminates the object.



Shiny surfaces, on the other hand, exhibit the phenomenon of **specular reflection**. In this case, an incoming organized bundle of rays will remain organized after they are reflected. In fact, specular reflection is pretty much the definition of "shiny surface." When you see an image of the light source reflected from the surface, as you will with specular reflection, you think of the surface as shiny.

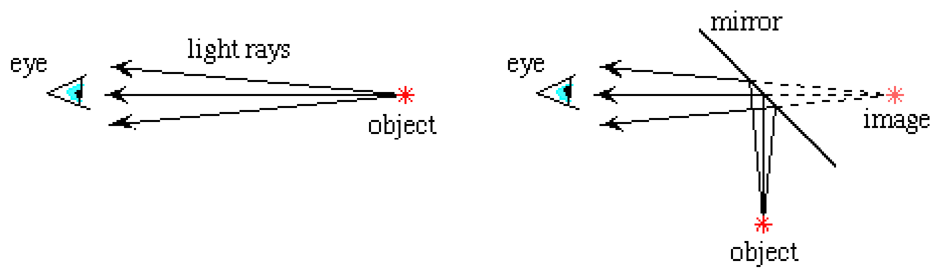


Specular reflection is characterized by the **Law of Reflection**, which states that the "angle of incidence" (the angle at which the incoming ray strikes the surface) is equal to the "angle of reflection" (the angle from which the ray leaves the surface. By convention in ray optics, we actually measure incident and reflected angles not from the surface itself, but from the "normal" to the surface (the line perpendicular to the surface).



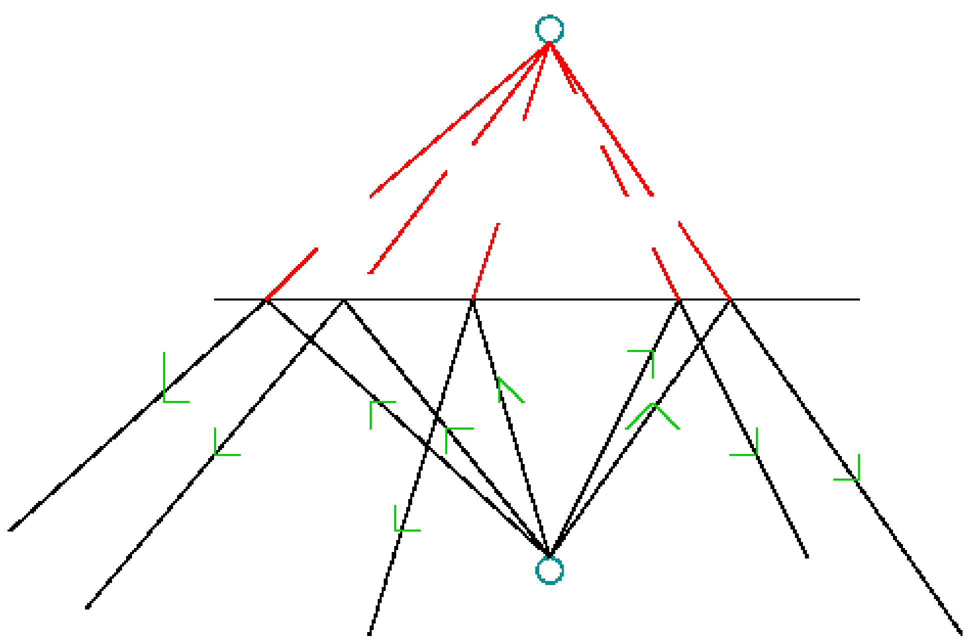
Images

As I mentioned above, we "see" objects by extrapolating the incoming rays to our eye backward to their origin. This works fine for straight rays (below left), but not for rays that are bent (below right).



The diagram above right demonstrates the difference between an object and an image. The light rays emanate from the object, are bent by the mirror, and collected by the eye. However, the rays that enter your eye come in from the mirror on the right, not from the object below the mirror. Extrapolating those rays backward, your eye not see the object, but instead an **image** of the object formed by the mirror.

Here's a clearer image of reflection from a plane surface:



In this case, we consider several rays, more than any one eye would collect, to show how the reflected rays really can be extrapolated backward to form an image.

From the two reflected images above, we can deduce some important rules about images formed by a plane mirror:

- The object and image can be connected by a line that runs perpendicular to the mirror surface.
- The distance from the object to the mirror along this line is equal to the distance from the mirror to the image along the line.
- Then the object is "in front" of the mirror, then the image will be "behind" the mirror. (How can an object not be "in front" of a mirror? If that statement sounds strange to you, wait a couple classes.) We call such an image a **virtual image** because the rays do not truly originate from the image. We'll learn more about virtual images later.