Unit 6 Parent Guide: Waves, Sound, and Light

What is a wave?

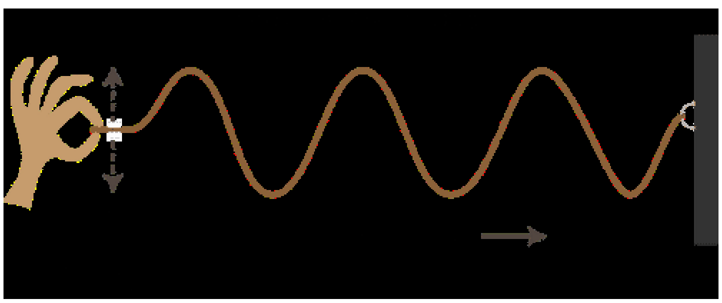
A wave is a disturbance or vibration that carries energy from one location to another. Some waves require a medium to transmit the energy whereas others can travel in a vacuum. Waves can be generated in regular, repeating patterns or a wave can be a single pulse.

How are waves classified?

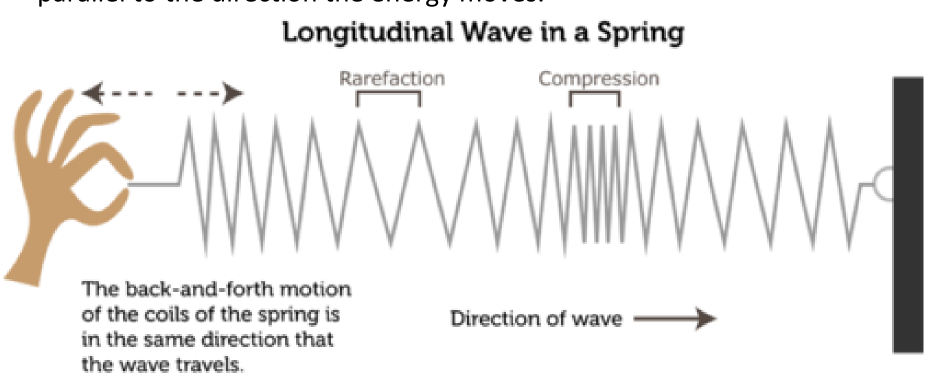
Waves can be classified primarily in one of two ways: the direction in which particles vibrate or whether the wave can transfer energy independent of a medium. A medium is synonym for "matter." A medium is a collection of particles. The medium is the material through which the energy of the wave travels. Steel, water and air are all examples of different types of media.

<u>Transverse v. longitudinal</u>

When the particles in a medium are disturbed, the energy of the vibration travels from one place to another. When the particles vibrate in a direction that is perpendicular to the direction the energy is transferred, it is a transverse wave.



In a longitudinal wave, the particles vibrate parallel to the direction of the energy movement. The pulse travels horizontally in the same direction the vibration was created. The displacement of the particles is parallel to the direction the energy moves.



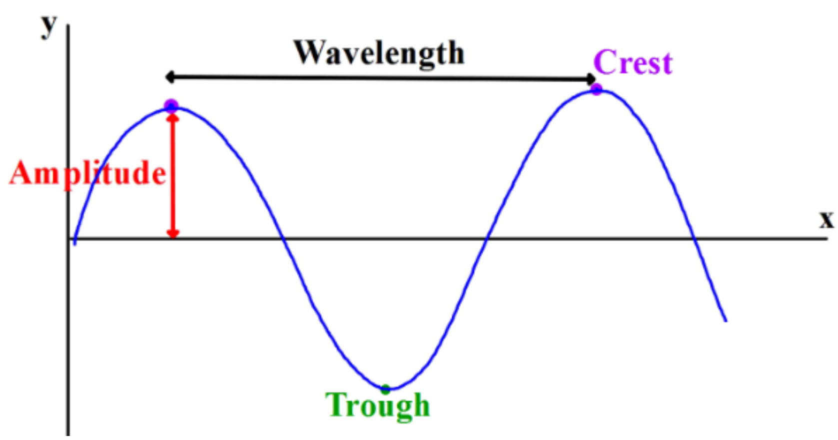
Electromagnetic versus Mechanical

Mechanical waves are waves that require a medium to be able to transfer energy from one location to another. For the energy of the initial disturbance to be transmitted, there must be particles interacting/colliding with other particles. Sound waves and water waves are examples of mechanical waves because without a medium, the energy cannot be transferred. Electromagnetic waves, however, do not require a medium. They can travel through a vacuum (empty space). Electromagnetic waves, such as light, are produced from the movement of charged particles versus the disturbance of a medium.

What are the properties of a wave?

Amplitude: The height of the peak (or depth of the trough) is the magnitude of the amplitude (A). The "y axis" represents the displacement of the medium from the resting position. The vertical distance from peak to trough would be twice the amplitude. For sound waves, the amplitude is equated with loudness and is usually measured in decibels.

Wavelength: The horizontal distance between successive peaks (or between successive troughs) is the wavelength. This distance will be the same, no matter which two peaks, or troughs, are measured. The symbol for the wavelength is the Greek letter lambda, λ.



Period: The Period is the time it takes for a wave to complete one full cycle. In other words, the time for the completion of one wavelength referenced to some fixed point. The Period of the wave is denoted with the symbol T.

Frequency: Whereas the Period is the time for the completion of one cycle (or wavelength), the frequency (ƒ) is how many cycles are completed in a second – or how many wavelengths would pass a fixed point per second. Frequency is the inverse of the Period, with units of Hertz (Hz).
The frequency of sound can be thought of as the rate of vibration (of a guitar string, drum head, etc.).

$$\text{Frequency} = \frac{1}{\text{Periodic time}} \quad \text{or} \quad f = \frac{1}{T}\ \text{Hz}$$

$$\text{Periodic time} = \frac{1}{\text{Frequency}} \quad \text{or} \quad T = \frac{1}{f}\ \text{sec}$$

Speed: A wave will travel one wavelength, λ, in one Period, T. Speed is distance over time, therefore the speed of the wave, v, is equal to the wavelength divided by the Period. Because of the relationship between frequency and Period, speed is also equal to frequency multiplied by the wavelength.

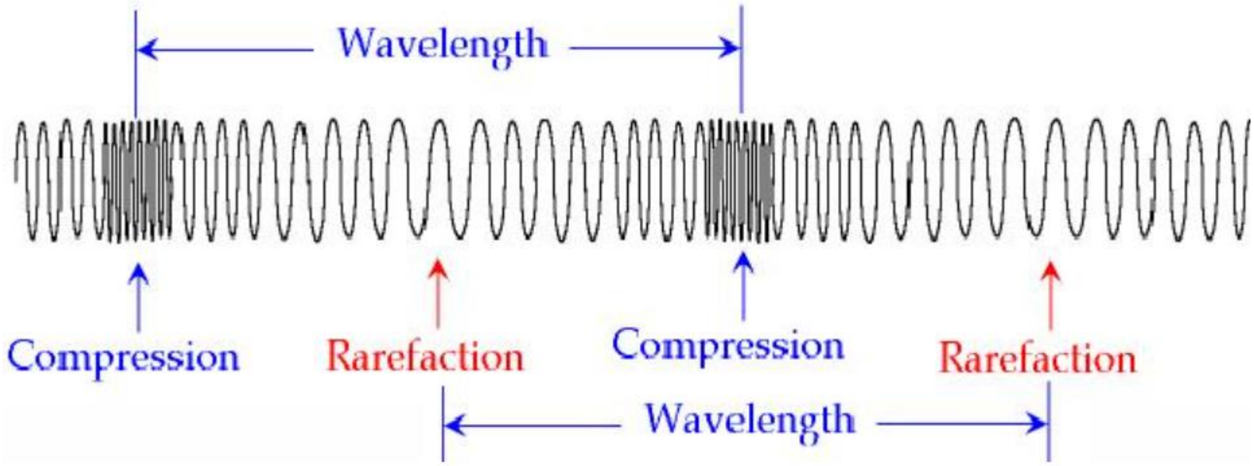
$$\boxed{v = f\lambda}$$

v = velocity
f = frequency
λ = wavelength

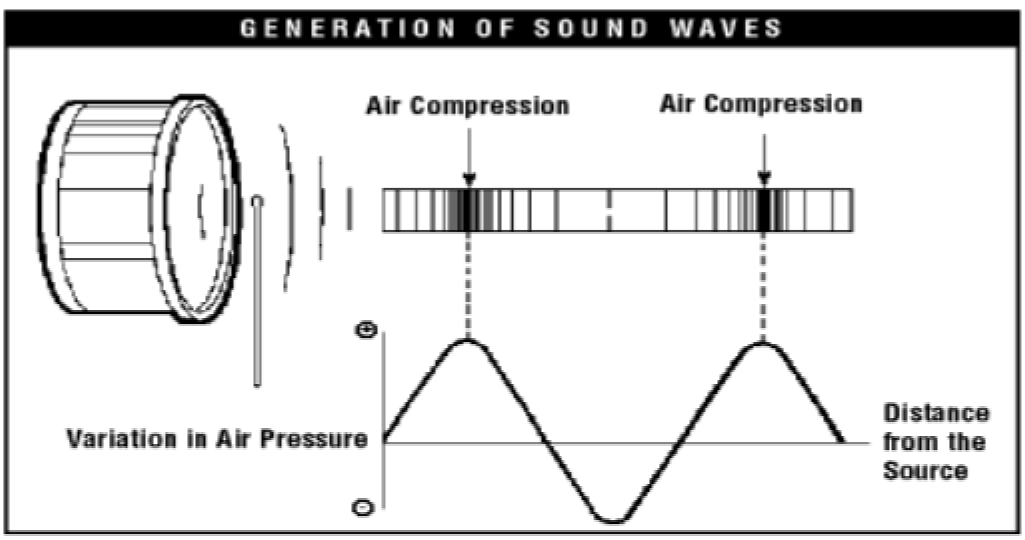
When traveling in a vacuum, all EM radiation travels at the speed of light, c (where c ≈ 3 x 10 8 m/sec). Light will have a slower speed when traveling in translucent or transparent material. This speed can be calculated utilizing the refractive index of the material through which it travels. The speed of sound in air is ≈ 344 m/sec at 70 F. The speed varies with the temperature of air, such that sound travels slower on colder days, due to the air's resulting molecular changes.

Material	**Speed (m/sec)**
Air (0° C, 1 atm)	330
Water	1530
Wood	2000
Steel	5940

For a longitudinal wave there are three basic features. The compression is the part of the wave in which the particles have been pushed or squeezed together and are at a higher density than the medium at equilibrium. The rarefaction is the part of the wave in which the particles have been pulled apart and are at a lower density than equilibrium. For a longitudinal wave, the definition for wavelength is the same, however, the parts are different. In this case, the wavelength can be measured from one compression to the next compression. The amplitude of a longitudinal wave is the maximum change in density relative to the density of the medium at equilibrium.



Sound is an example of a mechanical wave and must propagate through a medium such as air, water, or even solids. Sound waves are a form of pressure disturbance caused by the interaction of neighboring atoms or molecules.



Pitch and loudness.

The frequency of a sound wave describes how quickly the particles within a particular medium vibrate as the wave passes through. The frequency of the waves corresponds to the sound's pitch while sound waves with greater amplitude sound louder. When a sound wave travels through a medium, frequency describes the number of particle vibrations per unit time. Pitch is synonymous with the frequency of sound waves. High frequency (short wavelength) sound waves produce a high pitch whereas low frequency (longer wavelength) sound waves produce low pitch.

How can we describe wave behavior and wave phenomena?

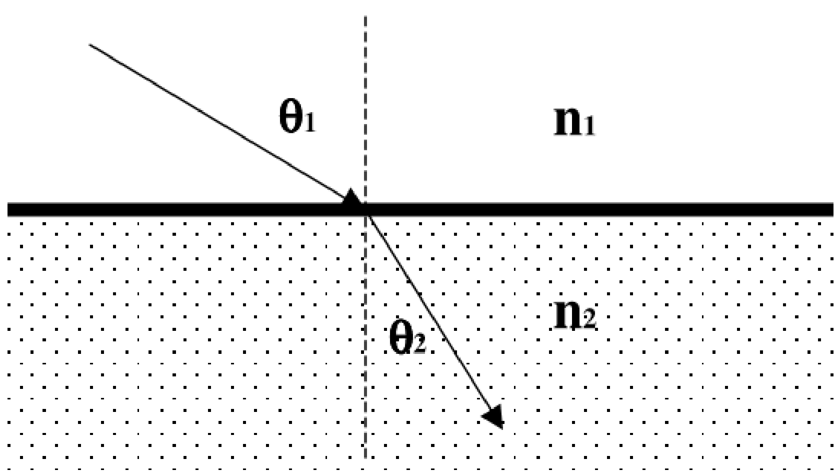
Both mechanical and electromagnetic waves propagate energy and encounter many differing types of medium as they travel. When a wave encounters a new medium or boundary, depending on the properties of the medium and the wave, it will undergo some type of disruption in its propagation. This could result in a change of direction, speed, wavelength, or any combination thereof. Refraction, reflection, scattering, diffraction, and absorption describe the interactions of waves as they contact new medium and/or boundaries.

Visible light is a form of electromagnetic radiation and comprises only a small slice of a much larger spectrum. Visible light itself is composed of a spectrum from red to violet light with differing wavelengths and frequencies. The following discussions are tailored to visible light, but would apply to other types of waves as well.

Refraction. When traversing in a vacuum (i.e. no interactions with matter) light will travel at approximately 3 x 10^8 m/sec. This changes when the light wave enters a medium containing particles of matter. The light interacts with the matter, propagates at a slower speed, and the result is an interesting, observable phenomena – the wave "bends". This bending is called refraction. Refraction not only occurs when light passes from a vacuum to a physical medium, but also between mediums of differing densities.

Snell's Law: this law describes a relationship between the angle of incidence and angle of refraction. This equation also utilizes the index of refraction, n, for a given material. The index of refraction for a material is defined as the ratio of the speed of light, c, to the actual speed of the wave as it travels through the material. In general, as the density of a material increases, so does its index of refraction.

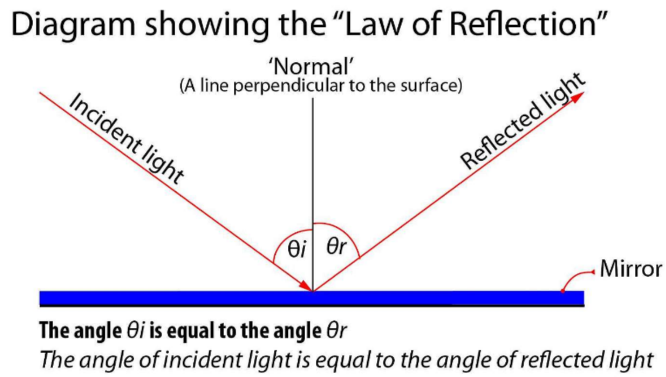
$$n_1 \sin \theta_i = n_2 \sin \theta_r$$



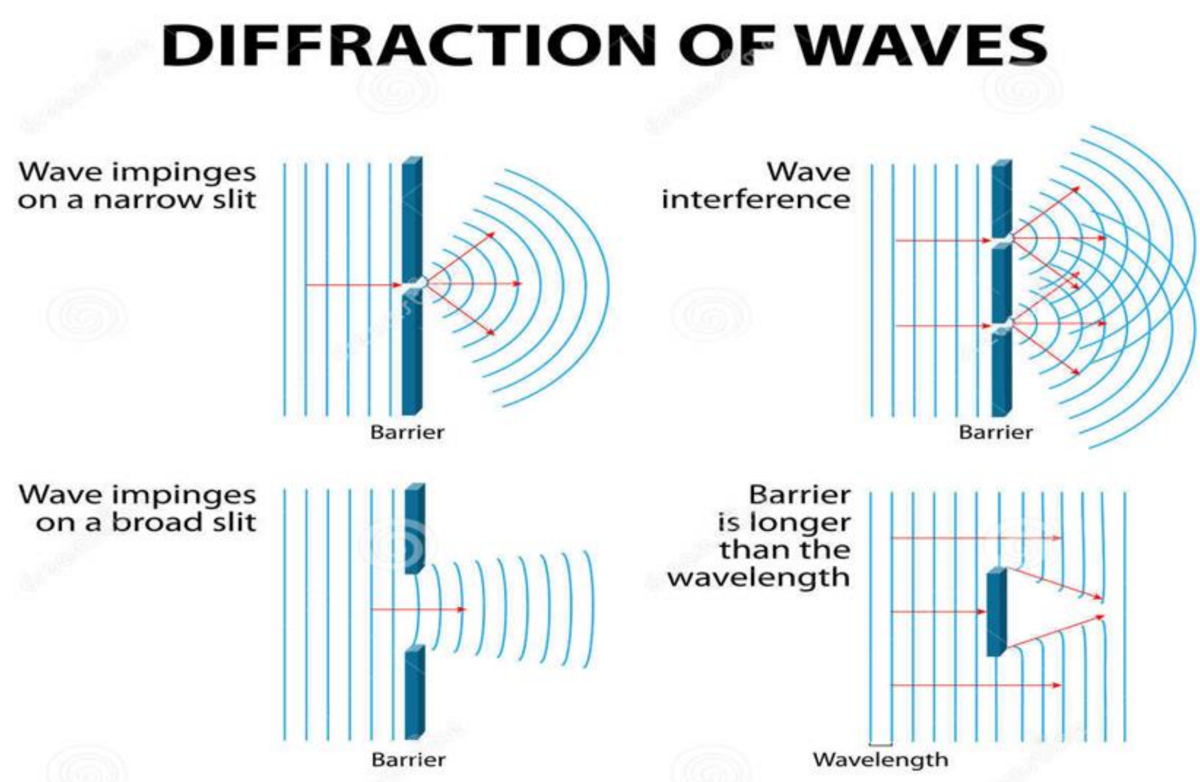
n_1 = refractive index of material 1 n_2 = refractive index of material 2

θ_1 = angle of incidence θ_2 = angle of refraction

Reflection. Some materials interact with light in such a way that incident waves are not necessarily propagated through. If the incident light is not bent, but bounced back at the same angle of incidence, it is said to have been reflected. This law of reflection (the angle of incidence equals the angle of reflection) is demonstrated when banking a basketball shot and in many billiard shots. As seen in the diagram below, the angles of incidence and reflection are next to the "normal" which is perpendicular to the reflective surface.



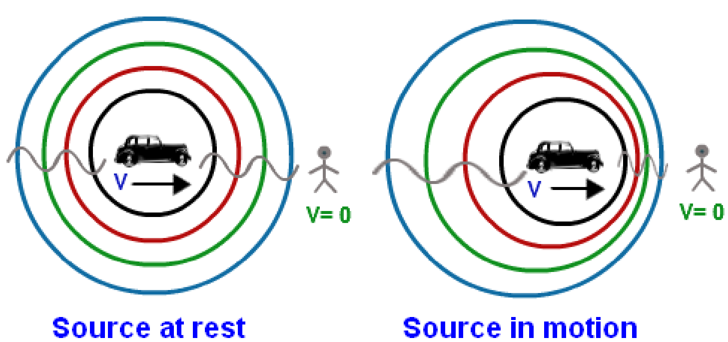
Diffraction. Diffraction is the slight bending of a wave as it passes around the edge of an object or through an opening in an object. The amount of bending depends on the relative size of the wavelength to the size of the opening.



Absorption. Light waves incident upon a material will impart energy to the atoms composing the material. Each type of atom or molecule possesses a resonant vibrational energy, and if the incoming light matches the particular resonant energy, the light will be absorbed. If not absorbed, the light is either reemitted and passed between the atoms through the material (translucent/transparent materials) or reemitted and reflected back from the material (opaque materials. Visible light is literally composed of a rainbow of light, each color with a different wavelength. An opaque blue object has within it atoms that absorb all the colors of visible light, except for blue light. The blue light is reflected from the object and thus the eye interprets the object as blue. A green object absorbs all the colors except green, which is again reflected. Black objects absorb all the colors of the visible light equally. An object appears white when it reflects all the visible frequencies in equal proportions (total reflection).

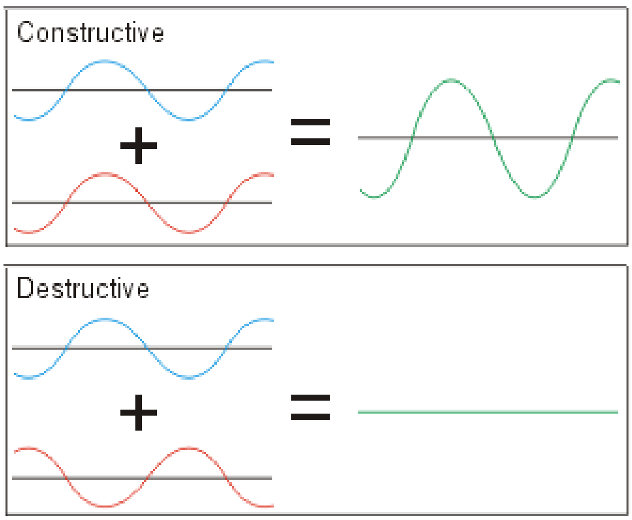
Seeing color: The Eye. The retina contains a layer of photoreceptor cells, called rods and cones. Rods are the most sensitive to light, detecting light and dark, and are most active in dimly lit environments. Three types of cones exist within the retina and act as energy detectors, roughly corresponding to either a blue, red, or green wavelength. The cones sense the light within their respective sensory range, send messages via the optic nerve, and the brain is able to determine the color of an object. When a particular wavelength(s) of light is reflected from an object or substance, as described above, the light waves enter the eye through the pupil, is incident upon the retina, and is interpreted as color via the rods and cones.

Doppler Effect. The Doppler Effect is described as the effect produced by a moving source in which there is an apparent increase in frequency for the observer when the source are approaching the observer and an apparent decrease in frequency when the observer and the source is moving away from each other.

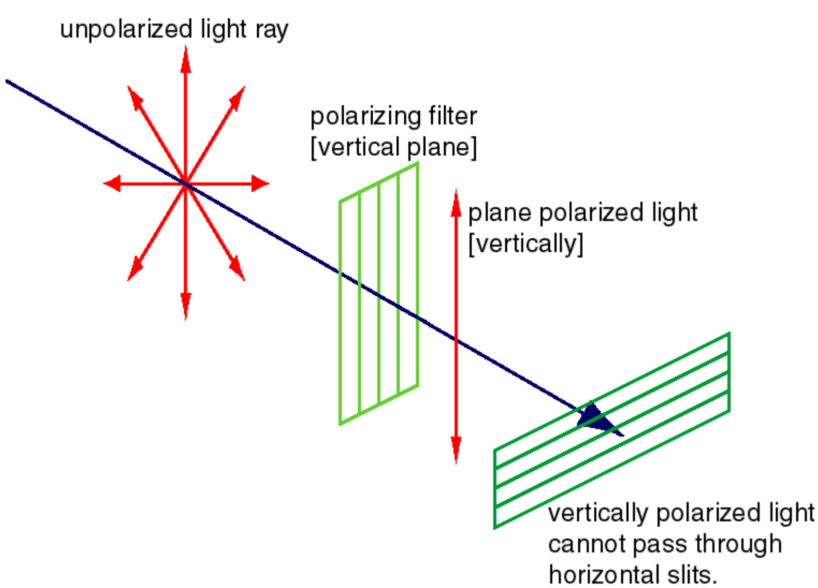


Resonance. All objects vibrate at a natural frequency usually based on the object's composition and shape. When an object is forced to vibrate (like plucking a guitar string, blowing air over or through an opening or striking an object), the vibrations travel through various media (the actual material, air or water). If these forced vibrations cause another object to vibrate at its natural frequency, this is called resonance.

Interference. Interference occurs when two waves arrive at the same location in a medium and their energies interact. The net effect of their energies could either reinforce each other creating a new wave in which the energies added together (constructive interference) or the energies could diminish the energy of each other creating a wave that has an overall reduced amplitude (destructive interference). When this occurs with sound waves, beats can be heard. The closer the two original frequencies are to each other, the fewer beats are heard.



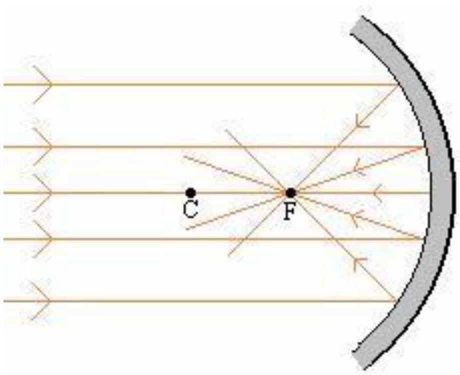
Polarization. Polarization occurs when light is selectively filtered as it moves through a filter or encounters a surface. Light is said to be polarized when it only moves in one plane (vertical or horizontal).

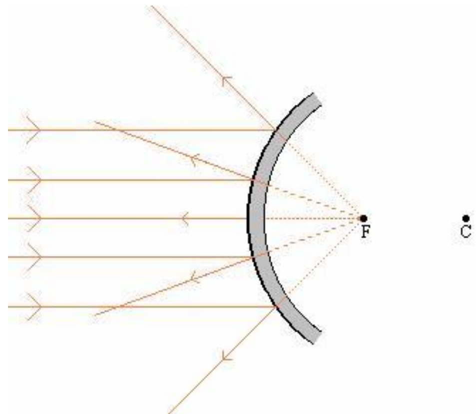


What are optics?

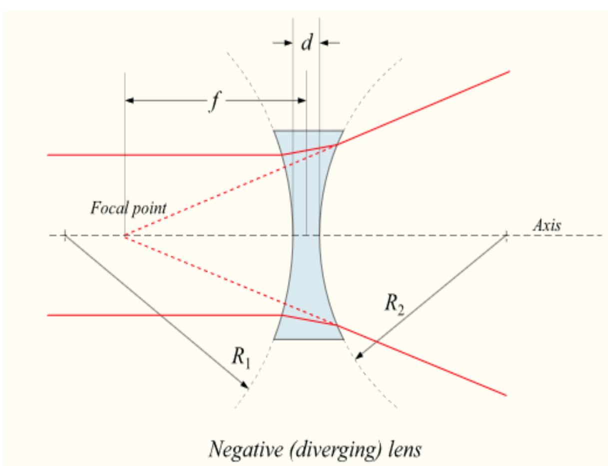
Although sound can be refracted and reflected, it is usually easiest describe behaviors of waves using light. Optics is the study of how light interacts as it travels through and/or encounters various media. Optics is a very broad field of study so specific attention will only be given to lenses and mirrors.

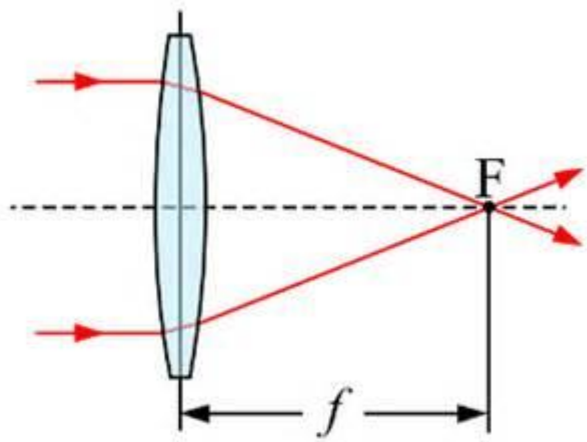
Mirrors and lenses have several common features. A focal point is the point at which light rays meet parallel to the principal axis after reflection or refraction or the point from which diverging rays appear to originate.





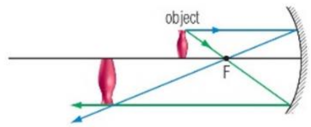
The focal length is the distance from the center of the lens or mirror to the focal point.



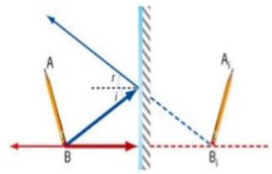


Mirrors and lens produce images. Images can also be real image or virtual. A real image is produced when the reflected light rays cross paths (converge) and go through the point where the image is formed. Real images can be projected onto a screen for viewing that will be on the same side of the mirror as the object. Virtual images are formed from light rays that do not cross paths (diverge) and cannot be projected onto a screen. Images can be smaller or larger than the object. Images can be inverted or upright.

- **Real** - image appears in front of the mirror (could be projected onto a screen)



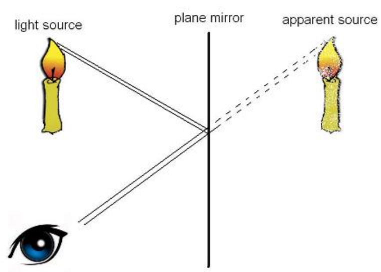
- **Virtual** - image appears behind the mirror



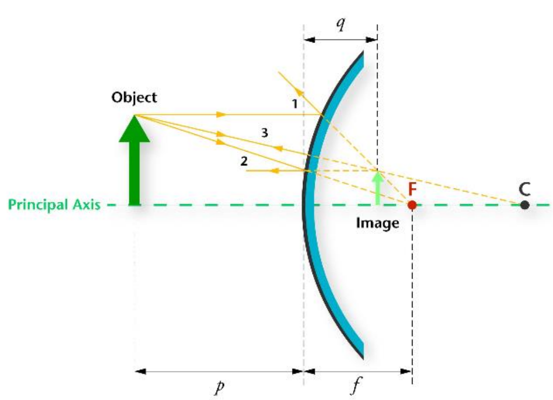
How does mirrors influence light?

Mirrors are reflective surfaces that are either flat or curved. Mirrors obey the Law of Reflection in that the angle of incidence is equal to the angle of reflection. Mirrors produce images.

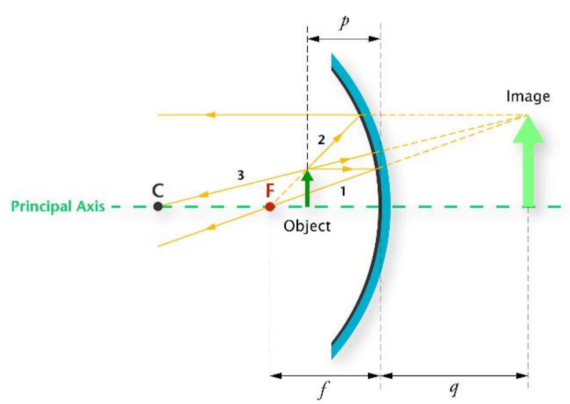
Flat mirrors. The image produced by a flat mirror is upright, virtual.

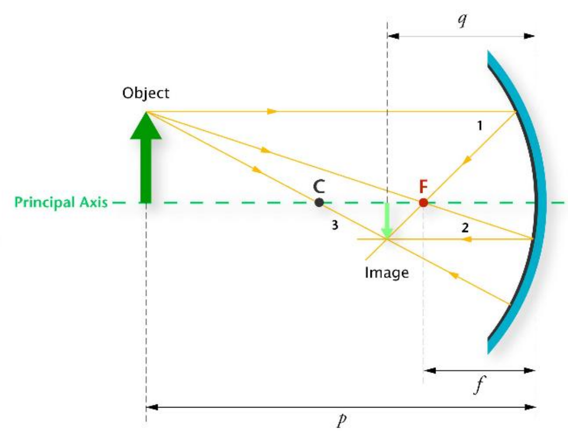


Curved mirrors. Mirrors that curve toward the observer are convex mirrors. They are also referred to as diverging mirrors because incoming parallel light rays will diverge upon contact with the surface. This type of mirror always produces an image the is upright, reduced in size compared to the object and virtual. These mirrors are commonly used in stores and on side-view mirrors of cars to enable a wide viewing area for the observer.



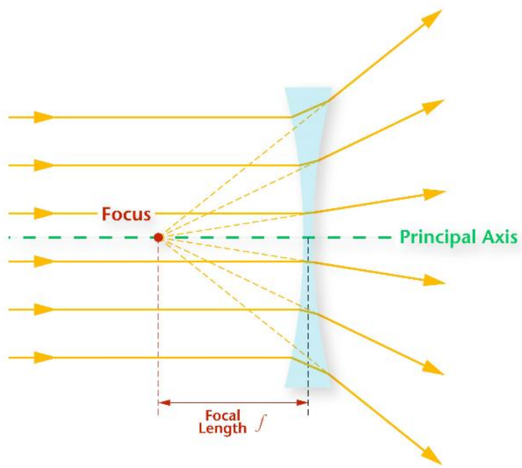
Mirrors that curve inward so that the observer is looking into the "scoop" of the mirror are called concave (or converging) mirrors. For this mirror, the location of the object determines the attributes of the image. When the object is within one focal length of the mirror, the image produced is upright, enlarged and virtual. An example of this type of mirror is a makeup mirror. When the object is beyond one focal length, the image is inverted, reduced in size and real (see diagrams). Concave mirrors are used in some types of telescopes.

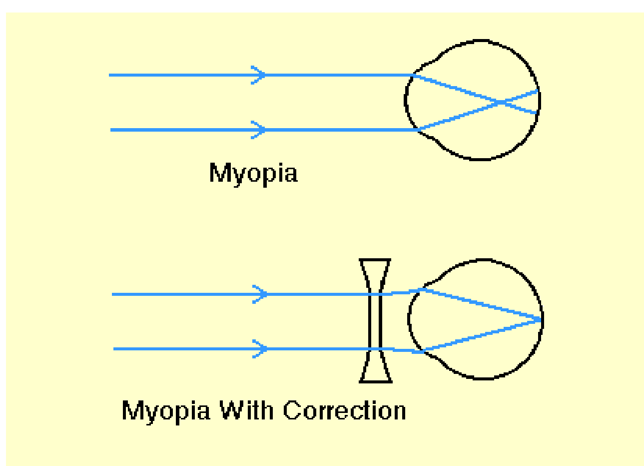




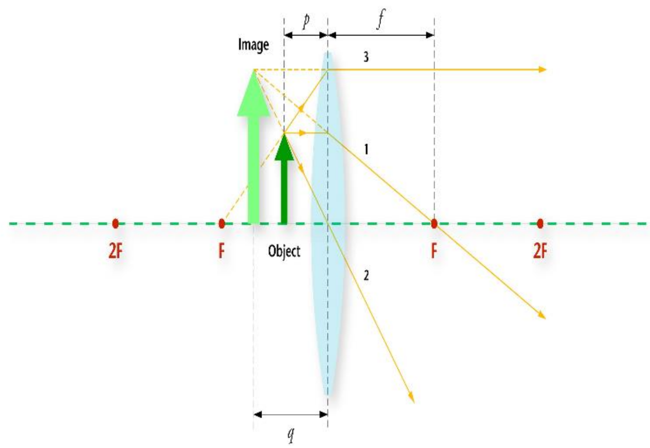
Lenses. Unlike mirrors which reflect light rays, lens are made of materials that will refract incoming light rays. As stated before, refraction occurs when a wave moves from one medium into another medium at some angle. As the ray enters the refractive material (medium), its speed will decrease and its path will change. The light is said to bend.

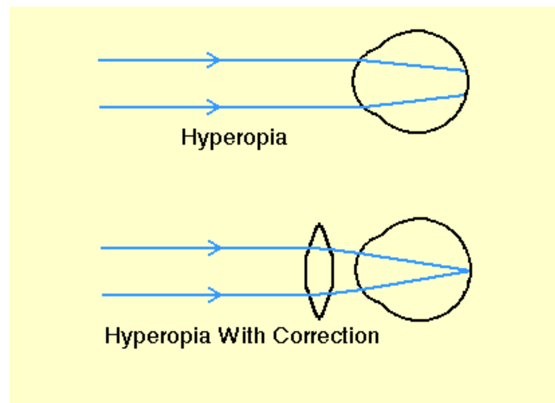
Lenses that are thicker at the edges than in the center are called concave (diverging) lenses. These lenses will cause parallel light rays to diverge. The image produced is always upright, smaller than the object and virtual. This type of lens is used to correct nearsightedness. It diverges/spreads the light rays prior to entering the cornea and lens of the eye which will in turn focus the light rays on the retina in the back of the eye.



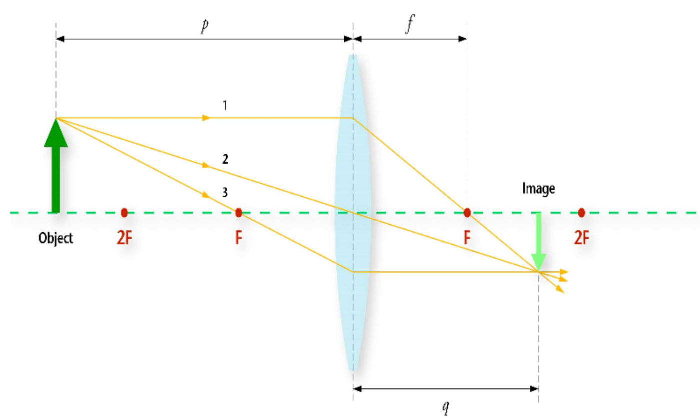


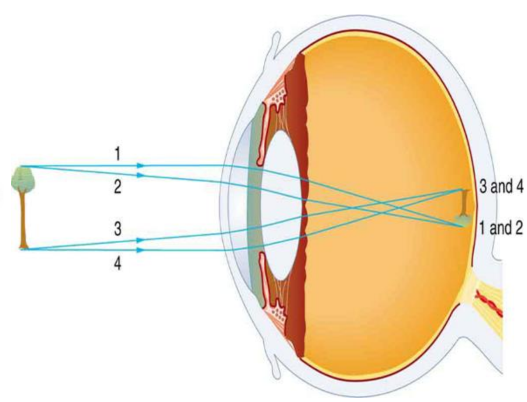
Lenses that are thicker in the center are called convex (converging) lenses. When the object is within one focal length of the lens, the image produced is upright, enlarged and virtual. A common example of this behavior is the use of a convex lens as a magnifying glass. This application can be used to correct farsightedness.





When the object is beyond one focal length, the convex lens produces an image that is inverted, reduced in size and real. These types of lenses are used in projectors and the lens in the human eye is convex in shape.



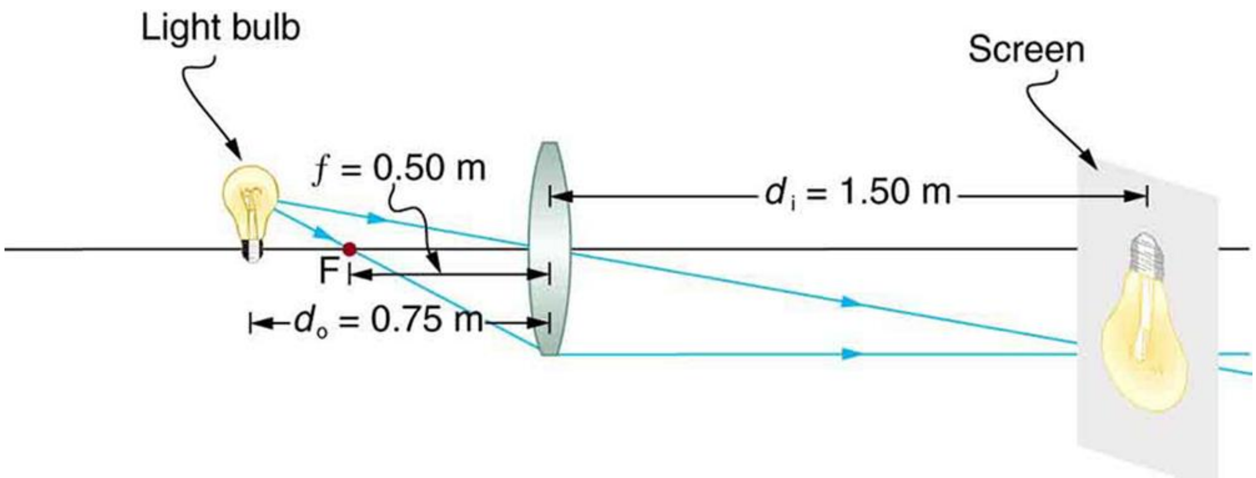


Calculations with mirrors and lenses. Quantities such as focal length, the distance of the object from the optical device and attributes regarding the image (distance, orientation, and/or magnification) can be calculated using the thin lens equation. Although this equation is called the "thin lens equation," it can be used with spherical mirrors (like concave and convex mirrors).

$$\boxed{\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}}$$

d_0 = distance of object from lens
d_i = distance of image from lens
f = focal length of the lens

An example using this equation is seen below.



In the above example, students can use the magnification equation to determine the orientation (inverted or upright) and the size of the image (magnified or reduced).

Magnification Equation

$$M = \frac{h_i}{h_0} = -\frac{d_i}{d_0}$$