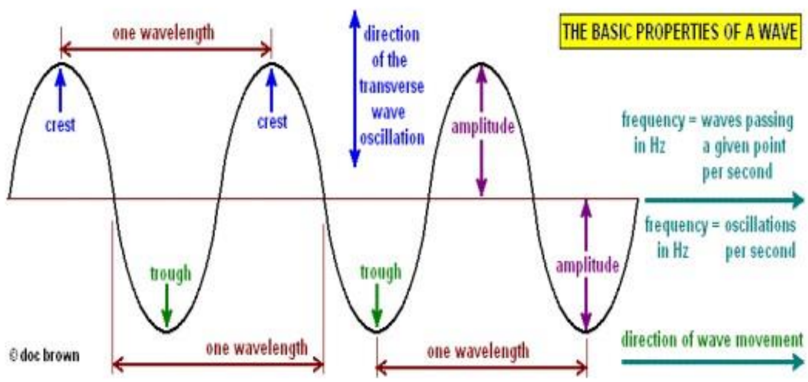
Wave and Oscillation

In physics, a wave is disturbance or oscillation (of a physical quantity), that travels through matter or space, accompanied by a transfer of energy.

Wave motion transfers energy from one point to another, often with no permanent displacement of the particles of the medium—that is, with little or no associated mass transport.

Waves are described by a wave equation which sets out how the disturbance proceeds over time.

The mathematical form of this equation varies depending on the type of wave.



Two main types of waves

Mechanical Waves

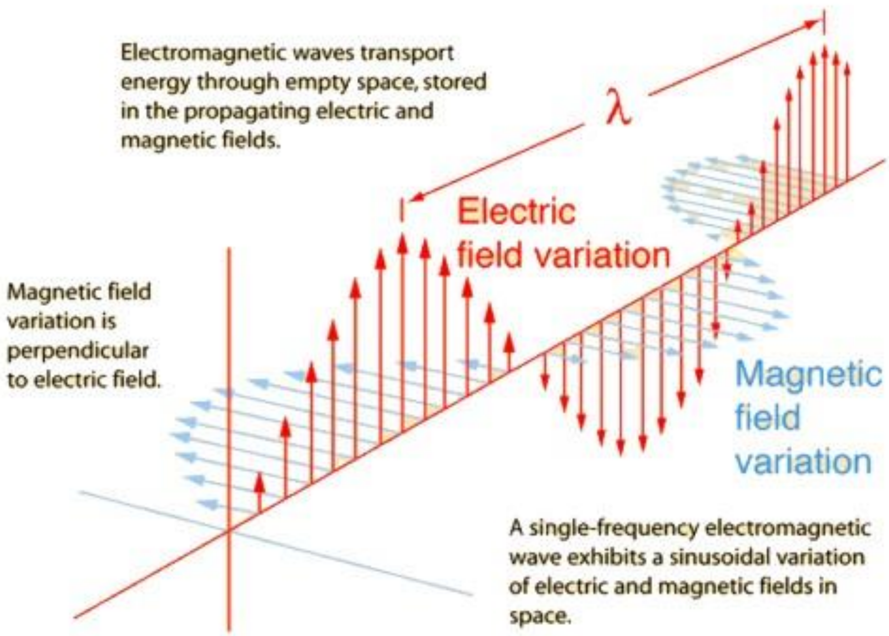
Mechanical waves propagate through a medium, and the substance of this medium is deformed.

For example, sound waves propagate via air molecules colliding with their neighbors. When air molecules collide, they also bounce away from each other (a restoring force). This keeps the molecules from continuing to travel in the direction of the wave.

Electromagnetic Waves

Electromagnetic waves do not require a medium. Instead, they consist of periodic oscillations of electrical and magnetic fields generated by charged particles, and can therefore travel through a vacuum.

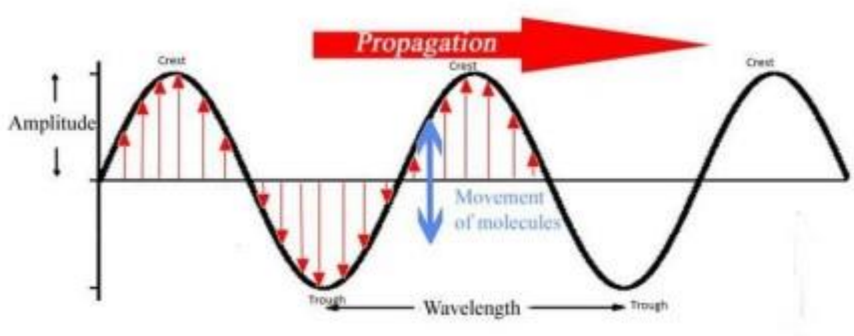
These types of waves vary in wavelength, and include radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.



Two Types of Mechanical Wave

Transverse Waves

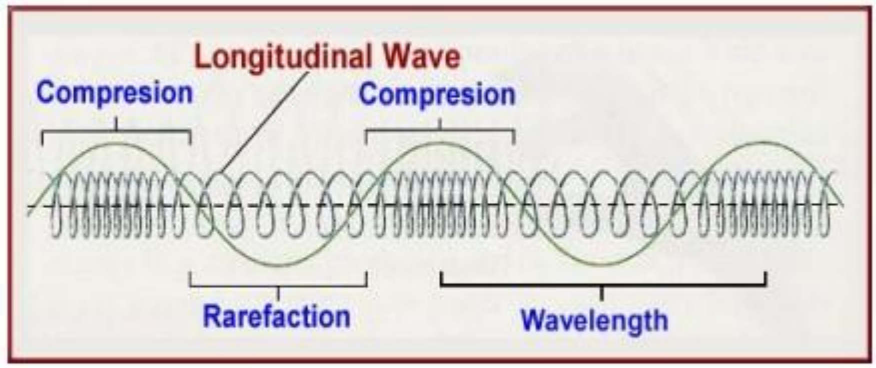
Transverse waves occur when a disturbance creates oscillations that are perpendicular (at right angles) to the propagation (the direction of energy transfer).



Longitudinal Waves

Longitudinal waves occur when the oscillations are parallel to the direction of propagation.

While mechanical waves can be both transverse and longitudinal, all electromagnetic waves are transverse in free space



Simple Harmonic Motion

Simple harmonic motion, in physics, repetitive movement back and forth through an equilibrium, or central, position, so that the maximum displacement on one side of this position is equal to the maximum displacement on the other side.

The time interval of each complete vibration is the same, and the force responsible for the motion is always directed toward the equilibrium position and is directly proportional to the distance from it.

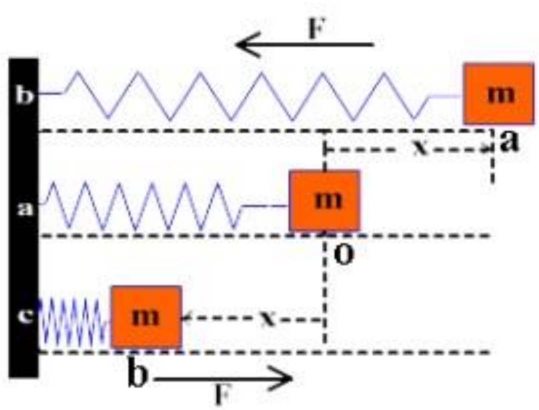


Fig: Spring moving back and forth under the action of external force

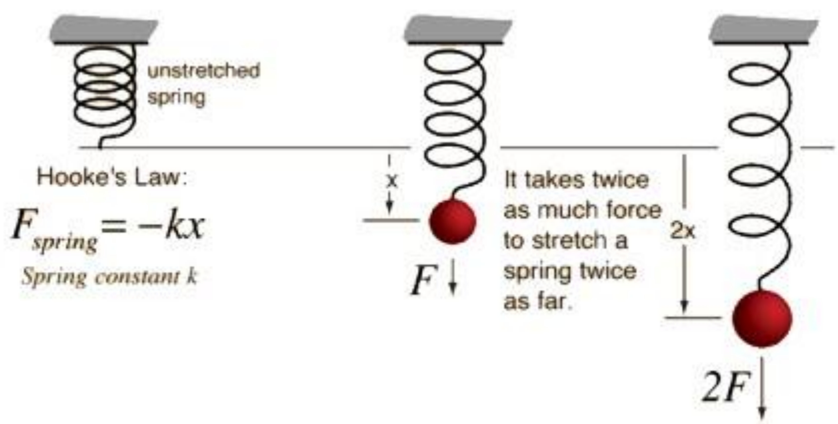
Many physical systems exhibit simple harmonic motion (assuming no energy loss): an oscillating pendulum, the electrons in a wire carrying alternating current, the vibrating particles of the medium in a sound wave, and other assemblages involving relatively small oscillations about a position of stable equilibrium.

Hooke's Law

Hooke's law, law of elasticity discovered by the English scientist Robert Hooke in 1660

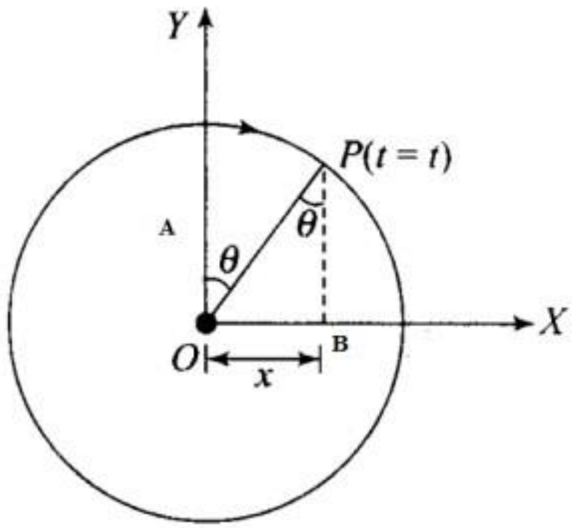
This law states that, for relatively small deformations of an object, the displacement or size of the deformation is directly proportional to the deforming force or load. Under these conditions the object returns to its original shape and size upon removal of the load.

Mathematically, Hooke's law states that the restoring force of the spring (F) is directly proportional to the displacement or change in length x, or $F = -kx$. The value of k depends not only on the kind of elastic material under consideration but also on its dimensions and shape.



Elastic behavior of solids according to Hooke's law can be explained by the fact that small displacements of their constituent molecules, atoms, or ions from normal positions is also proportional to the force that causes the displacement.

Differential Equation of Simple Harmonic Motion



Let a particle of mass be executing simple harmonic oscillations. The acceleration of the particle at displacement from a fixed point will be $\frac{dx}{dt}$. For the particle

Restoring force $\propto -$ displacement

$F \propto - x$

$ma = -k\,x$ [Using $F = ma$]

$m\,\frac{d^2x}{dt^2} = -k\,x$ [Acceleration, $a = \frac{d^2x}{dt^2}$]

$$\frac{d^2x}{dt^2} = -\frac{k}{m}x$$

$$\frac{d^2x}{dt^2} = -\omega^2 x \qquad \left[\text{ Angular velocity, } \omega = \sqrt{\frac{k}{m}}\ \right]$$

$$\frac{d^2x}{dt^2} + \omega^2 x = 0$$

This is the differential equation of a particle executing simple harmonic motion.