Vibrations, oscillations, and repetitive motion

There are many examples of systems that have oscillatory motion.

The maximum displacement from the equilibrium position during oscillatory motion is called the amplitude. The oscillation is described by the period, the time it takes to complete one full cycle. It is related to the frequency which is the number of oscillation cycles in a given amount of time. Frequency is often measured in units of cycles per second which defines the unit called the Hertz (Hz).

\[ \text{frequency} = \frac{1}{\text{period}}; f = \frac{1}{T} \]

During the "spin cycle" of my washing machine, the drum makes 1,200 rotations per minute. What is the frequency of these rotations in Hz and the period in units of seconds?

Natural Frequency

All physical systems that can vibrate will have a natural or resonance frequency.

Typically the resonant frequency is higher for smaller objects. For a pendulum of length \( L \), this frequency is

\[ f = \frac{1}{2\pi} \sqrt{\frac{g}{L}} \]

What happens to the frequency and period of a pendulum as its length \( L \) gets longer?

Resonance

Large amplitudes can result when a periodic force is applied to a system at its natural frequency. A child on a swing, a wine glass, musical instruments, tuning forks, radio receivers, and atoms can all have large amplitude oscillations when driven at their resonance or natural frequency.

Two tuning forks that have the same natural frequency are said to be in resonance. The oscillations of one tuning fork will set the other tuning fork into vibration if their natural frequencies are identical.

Waves

A wave is a vibration or oscillation that travels through space.

A periodic wave is characterized by its the repetition distance or wavelength.

The wave speed is the distance the wave moves per unit time.

\[ \text{wave speed} = \frac{\text{wavelength}}{\text{period}} = \text{wavelength} \times \text{frequency} \]

\[ v = \frac{\lambda}{T} = \lambda f \]

If the breakers at the beach are separated by 6 m and hit the shore with a frequency of 0.2 Hz, what is the speed of the waves? What is their period?

Shorter wavelengths (and higher frequencies) are produced when the end of the rope is shaken more rapidly.

How does the speed of sound in air change with increasing frequency?

Transverse and Longitudinal Waves

The wave on a string is transverse because the wave is moving to the right but the string is moving up and down.

A sound wave is an example of a longitudinal wave since the air molecules move parallel to the direction that the wave is moving.

Ultrasonic imaging is a common diagnostic tool in medicine. The high frequency sound waves are reflected from the interface between regions of different density to form an image.
Electromagnetic waves

The vibrations of the electrons in atoms and molecules produces a wave of the electric and magnetic force fields.

The velocity of these waves in empty space is \( c = 3 \times 10^8 \text{ m/s} \), the velocity of light. As the frequency (and wavelength) of these waves change, the waves take on different names.

Many microwave ovens use microwaves with a frequency of \( 2.45 \times 10^9 \text{ Hz} \). What is the wavelength of this radiation and how does it compare with the size of a typical oven?

Standing waves

Standing waves can occur when a wave is confined to a particular region. They have alternating node and antinode regions. At the positions of the nodes, the string is stationary. The standing wave in the diagram has exactly one-half of a wavelength that exactly fits on a string of length \( L \).

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What is the fundamental frequency for the waves on a 3-m rope that is tied on both ends if the wave speed is 24 m/s?