# Waves
# Kinds of Waves
# Wave Properties

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# Last time

- oscillations
- simple harmonic motion
- springs and SHM
- energy and SHM

# Overview

- pendula and SHM
- waves
- wave quantities
- sine waves

# Pendula and SHM

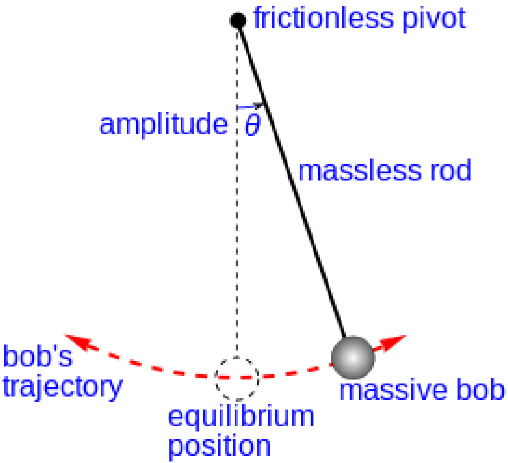
**pendulum**

a massive bob attached to the end rod or string that will oscillate along a circular arc under the influence of gravity

A pendulum bob that is displaced to one side by a small amount and released follows SHM to a good approximation.

Gravity and the tension in the string provide the *restoring force*.

# Pendula and SHM



# Pendula and SHM

Pendula also obey simple harmonic motion to a very good approximation, as long as the amplitude of the swing is small.

$$\theta = A\cos(\omega t + \phi)$$

Period of a pendulum:

$$\text{Period, } T = 2\pi\sqrt{\frac{L}{g}}$$

where $L$ is the length of the pendulum and $g$ is the acceleration due to gravity.

# Problem

An astronaut on the Moon attaches a small brass ball to a 1.00 m length of string and makes a simple pendulum. She times 15 complete swings in a time of 75 seconds. From this measurement she calculates the acceleration due to gravity on the Moon. What is her result?[1]

[1] Hewitt, "Conceptual Physics", problem 8, page 350.

# Problem

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$$T = 2\pi\sqrt{\frac{L}{g}}$$

1.58 m/s$^2$

[1] Hewitt, "Conceptual Physics", problem 8, page 350.

# Waves

Very often an oscillation or one-time disturbance can be detected far away.

Plucking one end of a stretched string will eventually result in the far end of the string vibrating.

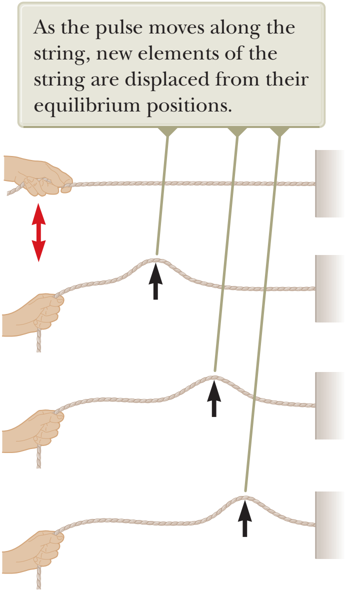
The string is a medium along which the vibration travels.

It carries energy from on part of the string to another.

**Wave**

a disturbance or oscillation that transfers energy through matter or space.

# Wave Pulses



As the pulse moves along the string, new elements of the string are displaced from their equilibrium positions.

# Wave Motion

**Wave**

a disturbance or oscillation that transfers energy through matter or space.

The waveform moves along the medium and energy is carried with it.

The particles in the medium *do not* move along with the wave.

The particles in the medium are briefly shifted from their equilibrium positions, and then return to them.

# Kinds of Waves

**medium**

a material substance that carries waves. The constituent particles are temporarily displaced as the wave passes, but they return to their original position.

Kinds of waves:

- mechanical waves – waves that travel on a medium, *eg.* sound waves, waves on string, water waves
- electromagnetic waves – light, in all its various wavelengths, *eg.* x-rays, uv, infrared, radio waves
- matter waves – may hear something about this in Phys2C

# Waves

Depending on the medium, waves can travel outward from a disturbance in

- 1 dimension, *eg.* a plucked guitar string
- 2 dimensions, *eg.* a ripple on the surface of water
- 3 dimensions, *eg.* typical (incoherent) point sources of light or sound

# Waves

If the source of the disturbance continues to oscillate, in can create regular waves that travel outward.

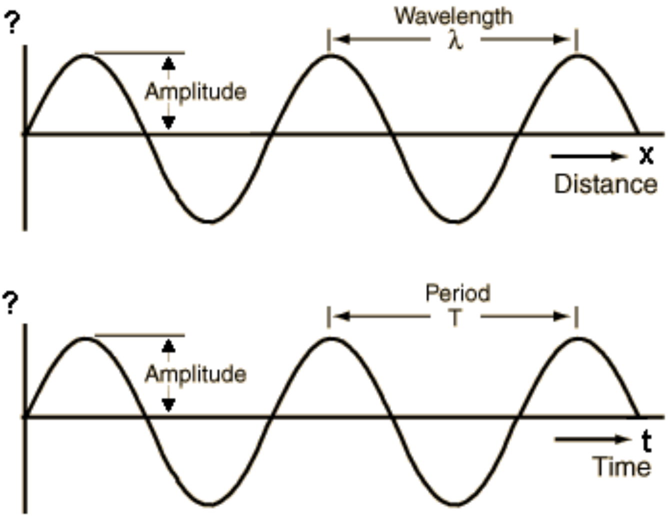
The cycles not only have a frequency, but also take up some amount of physical space.

The distance from the start of one cycle to the start of the next is the *wavelength*.

**wavelength**

the length of a single complete wave cycle

# Wave Quantities



# Wave speed

How fast does a wave travel?

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

It travels the distance of one complete cycle in the time for one complete cycle.

$$v = \frac{\lambda}{T}$$

But since frequency is the inverse of the time period, we can relate speed to frequency and wavelength:

$$v = f\lambda$$

# (Angular) Wave number

Recall, the definition of frequency, from period $T$:

$$f = \frac{1}{T}$$

and

$$\omega = \frac{2\pi}{T} = 2\pi f$$

We also define a new quantity.

**(Angular) Wave number, $k$**

$$k = \frac{2\pi}{\lambda}$$

units: $\mathrm{m}^{-1}$

# Another expression for wave speed

$$v = f\lambda$$

Since $\omega = 2\pi f$ and $k = \frac{2\pi}{\lambda}$:

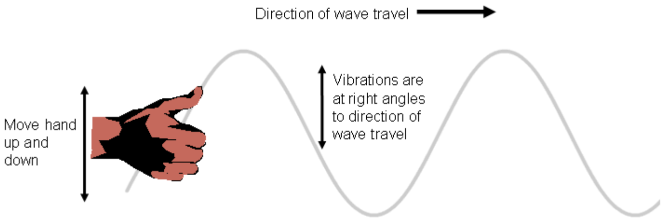
$$v = \left(\frac{\omega}{\cancel{2\pi}}\right)\left(\frac{\cancel{2\pi}}{k}\right)$$

$$v = \frac{\omega}{k}$$

# Transverse Waves

**Transverse wave**

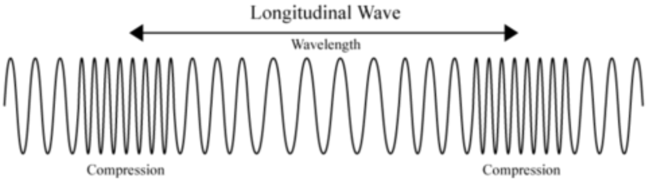
a wave with the oscillation in a direction **perpendicular** to the direction of propagation



# Longitudinal Waves

**Longitudinal wave**

a wave with the oscillation in a direction **parallel** to the direction of propagation



# Transverse vs. Longitudinal

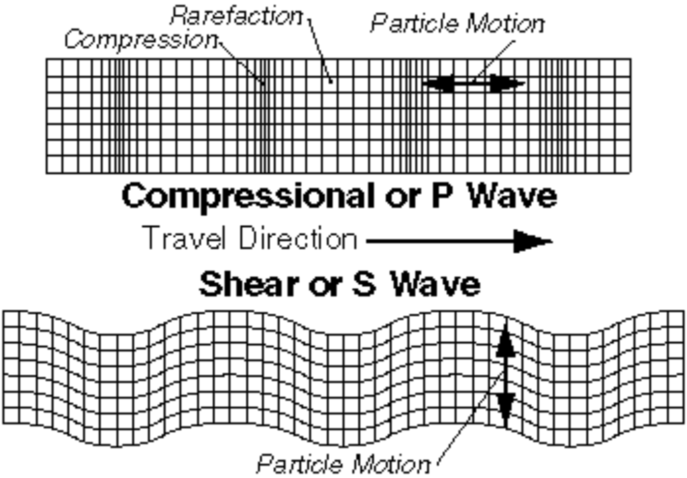
Examples of transverse waves:

- vibrations on a guitar string
- ripples in water
- light
- S-waves in an earthquake (more destructive)

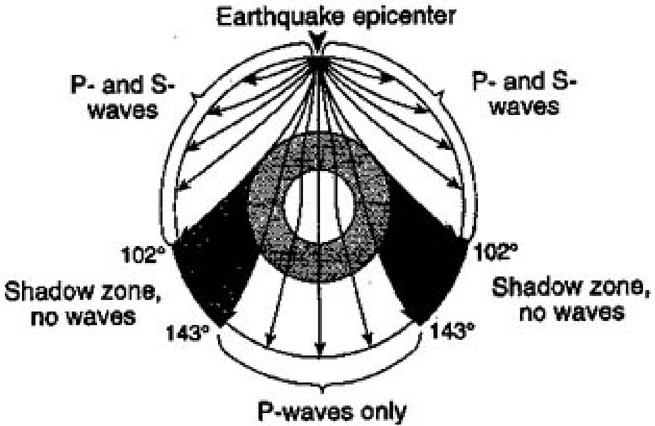
Examples of longitudinal waves:

- compression waves on a slinky
- sound
- P-waves in an earthquake (initial shockwave, faster moving)

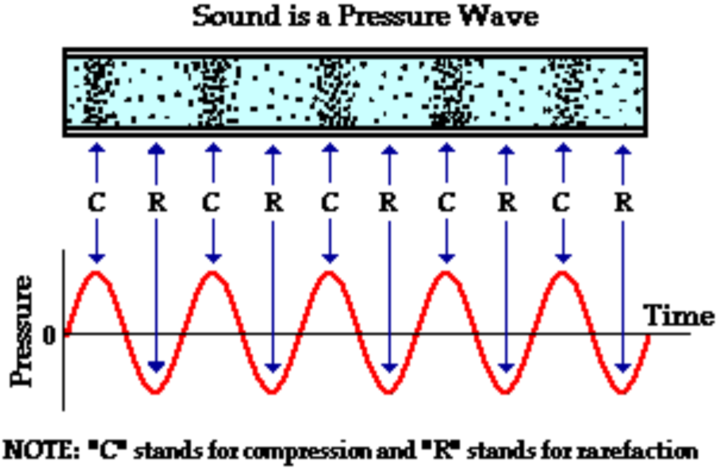
# Earthquakes



# Earthquakes



# Sound waves



Sound is a Pressure Wave
C
R
C
R
C
R
C
R
C
R
Pressure
0
Time
NOTE: "C" stands for compression and "R" stands for rarefaction

# Equation for Waves?

Analyzing a particle in the medium and using $\mathbf{F}_{\text{net}} = m\mathbf{a}$

OR

Analyzing Maxwell's equations for electromagnetism (light)

$\searrow$ $\swarrow$

Arrive at the Wave Equation

$$\left( \frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2} \frac{\partial^2 y}{\partial t^2} \right)$$

[Don't need to know it.]

Solutions have the form:

$$y(x, t) = f(x \pm vt)$$

# Solutions to the Wave Equation

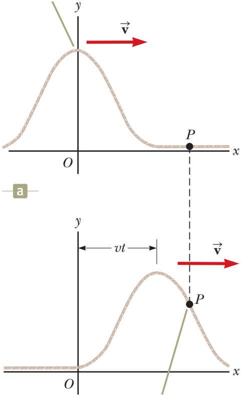
Wave solutions:

$$y(x, t) = f(x \pm vt)$$

should describe waves moving with speed $v$.

Example:

$$y(x, t) = f(x - vt)$$

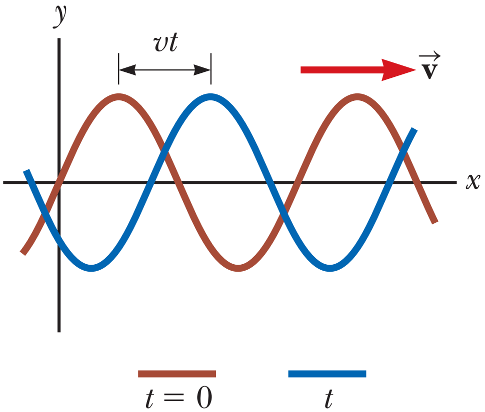


# Sine Waves

Suppose a point on the medium is driven in simple harmonic motion.

What kind of waves would result?

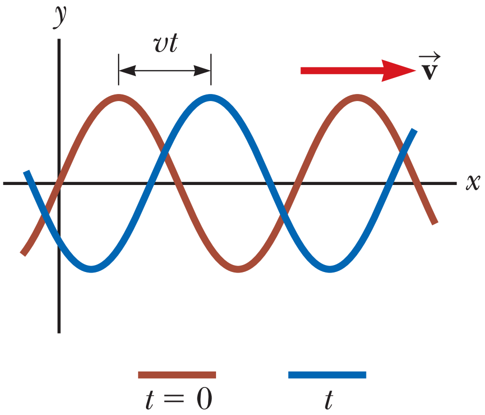
# Sine Waves




$$y(x, t) = A \sin\left(\frac{2\pi}{\lambda}(x - vt) + \phi\right)$$

This is usually written in a slightly different form...

# Sine Waves




$$y(x, t) = A \sin(kx - \omega t + \phi)$$

where $\phi$ is a phase constant.

# Summary

- waves
- wave quantities
- sine waves
- refraction
- diffraction

**Final Exam** Tuesday Dec 11, 9:15–11:15am, S16.

**Watch for an email** from me later today.

## Homework

- Ch 16 Probs: 3, 9