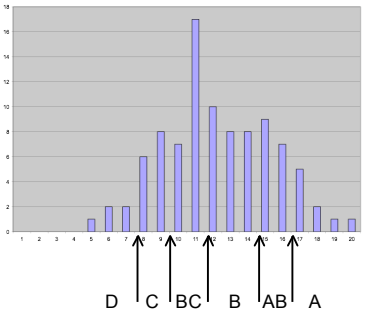
Exam Results

- Exam:
  - Exam scores posted on Learn@UW
- No homework due next week



Today: waves

- Have studied Newton's laws, motion of particles, momentum, energy, etc.
- Laws for describing things that move.
- **Waves** are a different type of object
  - They move (propagate), but in a different way
- Examples:
  - Waves on a rope
  - Sound waves
  - Water waves
  - Stadium wave!

Wave Motion

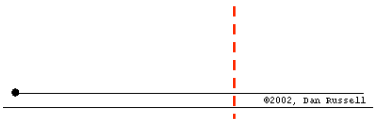
- A wave is a type of motion
  - But unlike motion of particles
- A propagating disturbance
  - The rope stays in one place
  - The *disturbance* moves down the rope

What is moving?

- Mechanical waves require:
  - Some source of disturbance
  - A medium that can be disturbed
  - Some physical connection between or mechanism though which adjacent portions of the medium influence each other
  - Waves move at a velocity determined by the medium
- The disturbance in the medium moves through the medium.
- **Energy** moves down the rope.

Motion of a piece of the rope

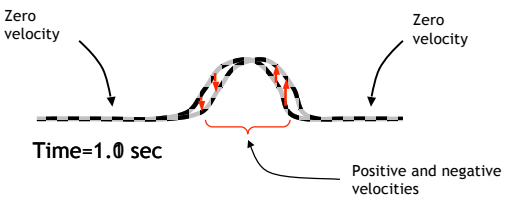
- As the wave passes through, a piece of the rope vibrates up and down.



As the pulse passes, there is kinetic energy of motion.

Energy transport

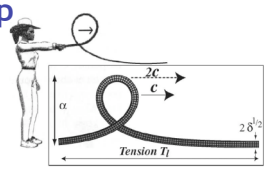
- If rope section is not moving, kinetic energy is zero.
- Determine motion by looking at rope position at two different times.



How does the wave travel

- Energy is transmitted down the rope
- Each little segment of rope at position *x* has some mass *m(x)*,
  and moves at a velocity *v(x)*,
  and has kinetic energy $\frac{1}{2}m(x)v(x)^2$

Waves on a whip



The forward crack

- The loop travels at velocity *c*, whereas a material point on top of the loop moves at velocity 2*c*.

Whip tapers from handle to tip, so that wave velocity increases.

'Crack' occurs as tip breaks sound barrier!

Wave speed

- The speed of sound is higher in solids than in gases
  - The molecules in a solid interact more strongly, elastic property larger
- The speed is slower in liquids than in solids
  - Liquids are softer, elastic property smaller

$$velocity = \sqrt{\frac{elastic\_property}{inertial\_property}}$$

- Speed of waves on a string

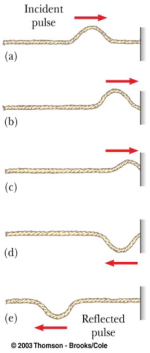
$$v = \sqrt{\frac{F}{\mu}}$$

F: Tension

μ: Mass per unit length

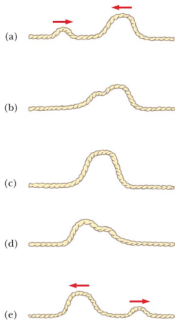
Waves can reflect

- Whenever a traveling wave reaches a boundary, some or all of the wave is reflected
- Like a particle, it bounces back. But…
- When it is reflected from a fixed end, the wave is inverted



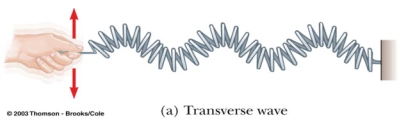
Superposition of waves

- Two pulses are traveling in opposite directions
- The net displacement when they overlap is the sum of the displacements of the pulses
- Note that the pulses are unchanged after the passing through each other



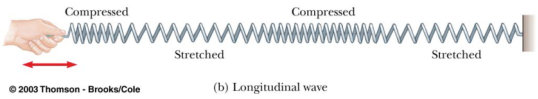
Types of waves

- Wave on a rope was a **transverse** wave
- Transverse wave: each piece of the medium moves perpendicular to the wave propagation direction



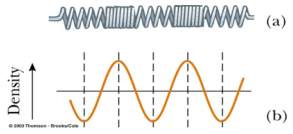
Longitudinal Waves

- In a longitudinal wave, the elements of the medium undergo displacements parallel to the motion of the wave
- A longitudinal wave is also called a compression wave



Graph of longitudinal wave

- A longitudinal wave can also be represented as a graph
- Compressions correspond to crests and stretches correspond to troughs

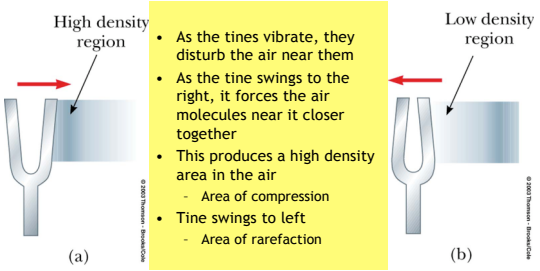


Sound waves

- The medium transporting the wave is the air
- The air is locally compressed, then compresses air next to it, etc.
- The sound velocity depends on
  - Mass density of the air (mass per unit volume)
  - and the 'compressibility' of the air

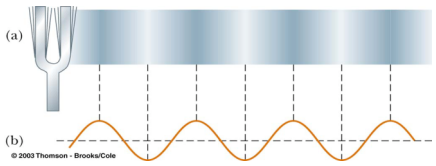
Producing a Sound Wave

- Sound waves are longitudinal waves traveling through a medium
- A tuning fork can be used as an example of producing a sound wave



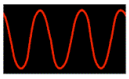
- As the tines vibrate, they disturb the air near them
- As the tine swings to the right, it forces the air molecules near it closer together
- This produces a high density area in the air
  - Area of compression
- Tine swings to left
  - Area of rarefaction

Sound from a Tuning Fork



- As the tuning fork continues to vibrate, a succession of compressions and rarefactions spread out from the fork
- A sinusoidal curve can be used to represent the longitudinal wave
  - Crests correspond to compressions and troughs to rarefactions

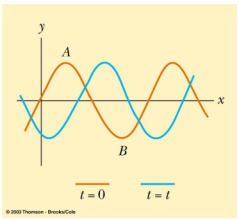
Continuous wave



- Can generate a wave that occupies all of the rope by continuing to shake the end up and down.
- This wave is present throughout the length of the rope, but also continually moves.
- Can think of a wave **source** continually emitting waves along the string.
- This is sort of like a string of pulses

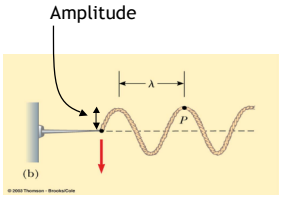
Waveform – A Picture of a Wave

- Just like the pulse, a continuous wave moves.
- The red curve is a "snapshot" of the wave at some instant in time
- The blue curve is later in time
- A is a *crest* of the wave
- B is a *trough* of the wave



Description of a Wave

- Amplitude is the maximum displacement of string above the equilibrium position
- Wavelength, λ, is the distance between two successive points that behave identically



- For instance, the distance between two crests

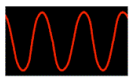
Period, frequency and velocity of a wave

- Period: **time** required to complete one cycle
  - Unit = seconds
- Frequency = 1/Period
  = rate at which cycles are completed
  - Units are cycles/sec = Hertz
- Period wavelength and velocity are related
  - If the wave travels one wavelength in the time of one period then
- velocity = wavelength/period

Equation form

- Velocity = Wavelength / Period
- $v = \lambda / T$, or $v = \lambda f$
- f = Frequency = 1 / Period = $1/T$

Periodic waves



- Shake one end of a string up and down with period T (frequency f=1/T). The height (up or down) is the amplitude.
- Peaks move at speed v so are separated by distance (wavelength) λ=vT = v/f.
- The wave can shake a fixed object with that frequency.

Examples

- The speed of sound in air is 340 m/s.
- A source period of 1 Hz=1/s produces a wavelength of λ=v/f= 340 m
- A string vibrating at frequency f= 340 Hz produces a wavelength λ=v/f = 1 m

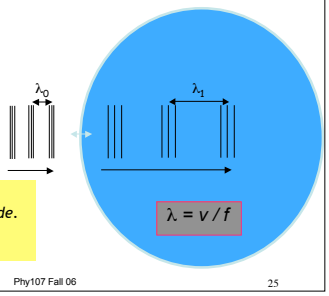
Question

- A sound wave is traveling through air when in encounters a large helium-filled balloon. The sound velocity inside the balloon is greater than in the air. Compare the wavelength of the sound wave inside and outside the balloon.

A. $\lambda_{inside} = \lambda_{outside}$

B. $\lambda_{inside} > \lambda_{outside}$

C. $\lambda_{inside} < \lambda_{outside}$



The frequency inside the balloon is the same as outside. Use $\lambda = v / f$ to find that the wavelength is less

Wave quantities summary

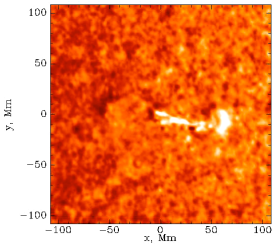
- Time of one COMPLETE up and down motion
  - one period T = 1/f
  - one wavelength in one period
- Velocity of disturbance (wave or phase) velocity
- Particles don't move with v (only up-and-down) or (back and forth)

$v = \lambda f$

- v depends only on properties of "medium"

Water waves?

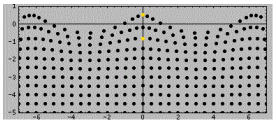
- Water waves occur on the surface. They are a kind of transverse wave.

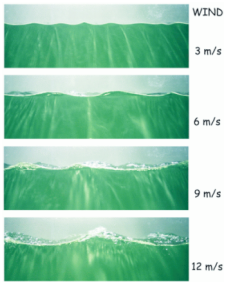


On Earth

On the sun

Surface water waves

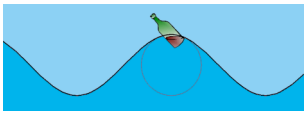


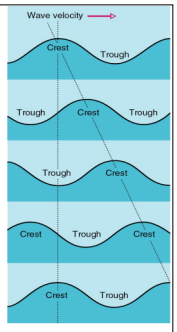


- Surface water waves produced by wind.
- The wave travels with some speed, but the water does not!

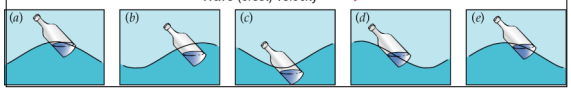
Water's Motion I

The wave travels while the water circles!





Wave (crest) velocity



Water's Motion

- Circling strongest at surface
- Weak ~ 1/2 wavelength deep