L 23 – Vibrations and Waves [3]

- resonance
- clocks – pendulum
- springs
- harmonic motion
- mechanical waves
- sound waves
- **golden rule for waves**
- musical instruments
- The Doppler effect
  - Doppler radar
  - radar guns

updated 10/23/07

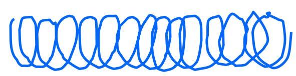
Review

- A mechanical wave is a disturbance that travels through a medium – solids, liquids or gases
- The disturbance moves because of the elastic nature of the material
- As the disturbance moves, the parts of the material (segment of string, air molecules) execute harmonic motion (move up and down or back and forth)
  - transverse wave
  - longitudinal wave

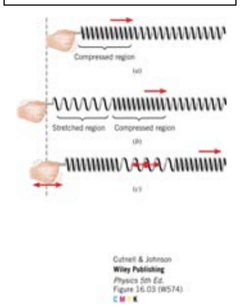
transverse wave on a string

- jiggle the end of the string to create a disturbance
- the disturbance moves down the string
- as it passes, the string moves up and then down
- the string motion in vertical but the wave moves in the horizontal (perpendicular) direction➔ transverse wave
- this is a single pulse wave (non-repetitive)
- the "wave" in the football stadium is a **transverse wave**

Slinky waves

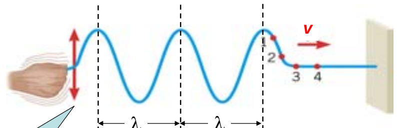


- you can create a **longitudinal** wave on a slinky
- instead of jiggling the slinky up and down, you jiggle it in and out
- the coils of the slinky move along the same direction (horizontal) as the wave



Harmonic waves

- continually jiggle the end of the string up and down
- each segment of the string undergoes simple harmonic motion and the disturbance (wave) moves with speed *v*
- the distance between successive peaks is called the WAVELENGTH, λ (lambda) measured in m or cm

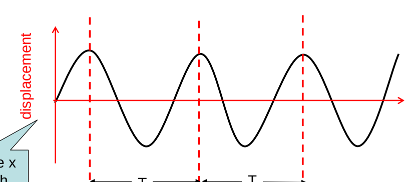


snapshot of the string at some time

Cutnell & Johnson
Wiley Publishing
Physics 5th Ed.
Figure 16.08 (W579)

watching the waves go by

- suppose we keep watching one segment of the string as the wave goes by and then make a plot of its motion
- the time between the appearance of a new wave crest is the PERIOD of the wave, T
- the number of wave crests that pass by every second is the wave frequency, f = 1/T

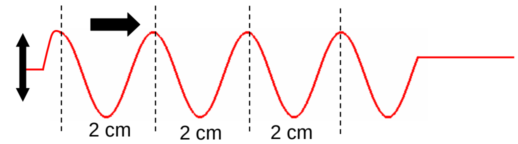


sit at some x and watch

The golden rule for waves

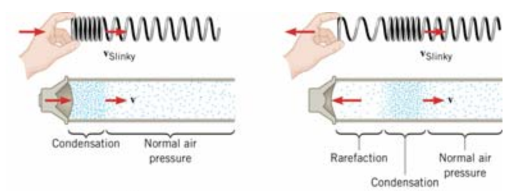
- the speed of propagation of the wave (v), the wavelength (λ), and period (T) are related
- distance = speed x time → $\lambda = v\,T = v / f$
- The wavelength = wave speed / frequency
  or → $v = \lambda \times f$ ← (golden rule)
- **Wave speed = wavelength × frequency**
- This applies to all waves → water waves, waves on strings, sound, radio, light . .
- This rule is important for understanding how musical instruments work

Example: wave on a string



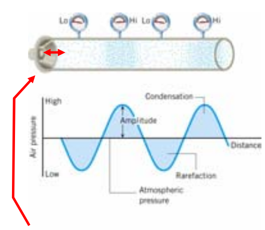
- A wave moves on a string at a speed of 4 cm/s
- A snapshot of the motion reveals that the wavelength(λ) is 2 cm, what is the frequency (f)?
- $v = \lambda \times f$, so $f = v / \lambda$ = (4 cm/s) / (2 cm) = 2 Hz

Sound – a longitudinal wave



- a sound wave is a pressure "disturbance" that moves the through air (or other gas or liquid)
- the "disturbance" is a *change* in the air pressure (increase or decrease) compared to its normal value (atmospheric pressure)
- it is a longitudinal wave

SOUND WAVES



the diaphragm of the speaker moves in and out

- longitudinal pressure disturbances in a gas
- the air molecules jiggle back and forth in the same direction as the wave
- with no air molecules to juggle, there is no sound , e.g. in vacuum

The speed of sound

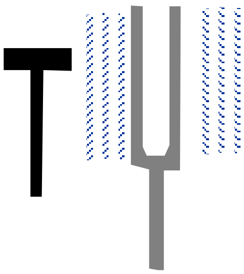
- Sound→ pressure waves in a gas, liquid or solid
- The speed of sound→ v_s
  - Air at 20 C: 343 m/s = 767 mph ≈ 1/5 mile/sec
  - Water at 20 C: 1500 m/s
  - copper: 5000 m/s
- Depends on density and temperature

5 second rule
for thunder and lightening

Why do I sound funny when I breath helium?

- Sound travels twice as fast in helium, because Helium is lighter than air
- Remember the golden rule $v_s = \lambda \times f$
- The wavelength of the sound waves you make with your voice is fixed by the size of your mouth and throat cavity.
- Since λ is fixed and v_s is higher in He, the frequencies of your sounds is twice as high in helium!

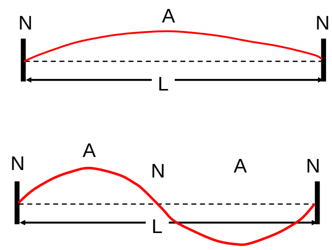
Tuning forks make sound waves



- The vibration of the fork causes the air near it to vibrate
- The size of the fork determines the frequency
  - bigger fork → lower f
  - smaller fork → higher f
- It produces a pure pitch→ single frequency

13

Vibration modes of a string



Fundamental mode
Wavelength = 2 L
Frequency = f_o

First harmonic mode
Wavelength = L
Frequency = 2 f_o

N = nodes,   A = antinodes

14

Standing waves

- At the NODE positions, the string does not move
- At the ANTINODES the string moves up and down harmonically
- Only certain wavelengths can fit into the distance L
- The frequency is determined by the velocity and mode number (wavelength)

15

Vibration frequencies

- In general, $f = v / \lambda$, where v is the propagation speed of the string
- The propagation speed depends on the diameter and tension
- Modes
  - Fundamental: $f_o = v / 2L$
  - First harmonic: $f_1 = v / L = 2 f_o$
- The effective length can be changed by the musician "fingering" the strings

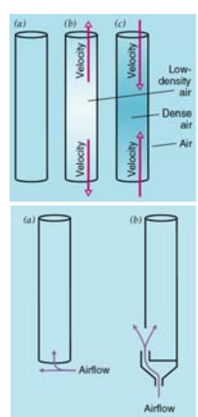
16

Stringed instruments

- Three types
  - **Plucked**: guitar, bass, harp, harpsichord
  - **Bowed**: violin, viola, cello, bass
  - **Struck**: piano
- All use strings that are *fixed at both ends*
  - Use different diameter strings (mass per unit length is different)
  - The *string tension is adjustable* - tuning

17

Organ pipes



- The air pressure inside the pipe can vibrate, in some places it is high and in other places low
- Depending on the length of the pipe, various resonant modes are excited, just like blowing across a pop bottle
- The long pipes make the low notes, the short pipes make the high notes

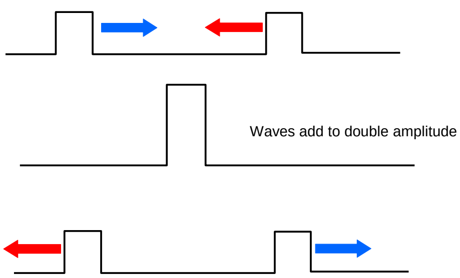
18

Beats – wave interference

- Waves show a special property called interference
- When two waves are combined together, the waves can add or subtract
- We call this constructive and destructive interference
- When a wave is launched on a string it can reflect back from the far end. The reflected wave can combine with the original wave to make a standing wave

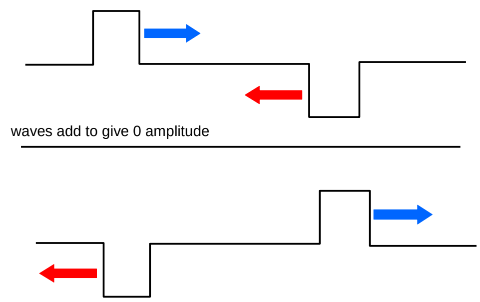
20

Constructive interference



21

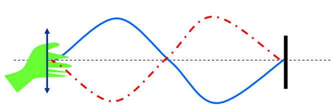
Destructive interference



22

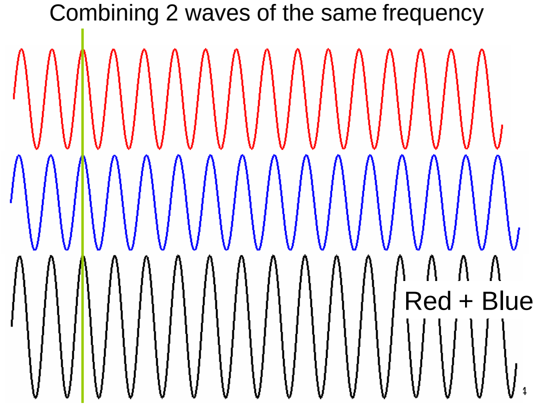
Standing waves

- standing waves are produced by wave interference
- when a transverse wave is launched on a string a reflected wave is produced at the other end
- the incident and reflected waves interfere with each other to produce a standing wave

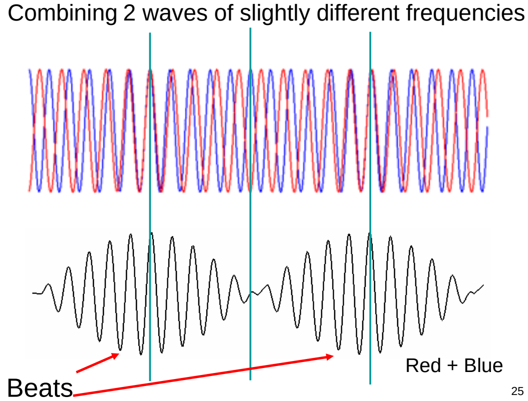


23

Combining 2 waves of the same frequency



Combining 2 waves of slightly different frequencies



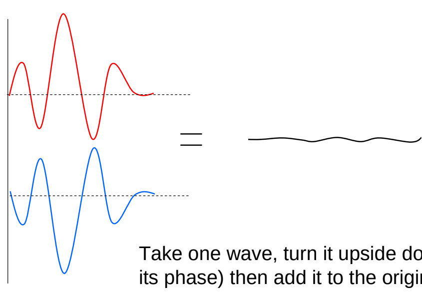
25

Room Acoustics

- Destructive interference accounts for bad room acoustics
- Sound that bounces off a wall can interfere destructively (cancel out) sound from the speakers resulting in dead spots

26

Wave interference can be used to eliminate noise –anti-noise technology



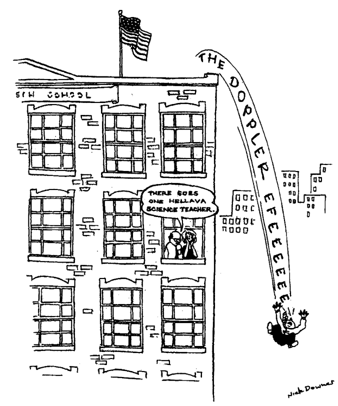
Take one wave, turn it upside down (invert its phase) then add it to the original wave

27

A science teacher demonstrating the Doppler effect

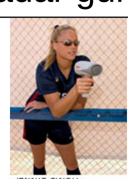
→If the source of sound moves toward you, you hear a higher frequency (pitch) sound.

→ If the source of sound moves away from you, you hear a lower frequency sound.



28

Doppler effect → Radar guns



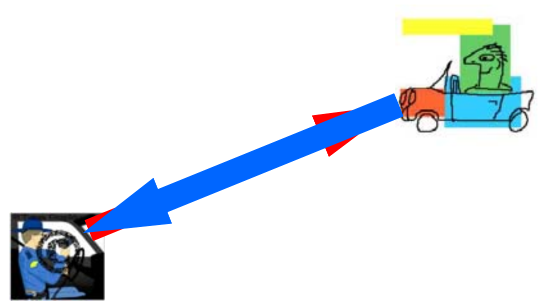
JENNIE FINCH - USA SOFTBALL

When radar waves bounce off a moving object (echo)the frequency of the reflected radar changes by an amount that depends on how fast the object is moving. The detector senses the frequency shift and translates this into a speed.

http://auto.howstuffworks.com/radar-detector1.htm

29

Once you see the cop, he's got you!



30