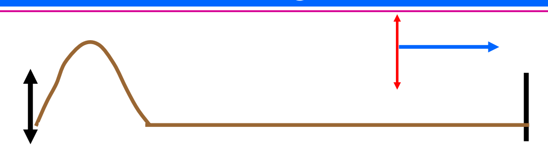
L 23 – Vibrations and Waves [3]

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

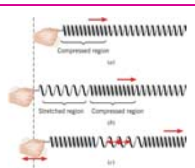
Review

- A mechanical wave is a disturbance that travels through a medium – solids, liquids or gases – *it is a vibration that propagates*
- 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 & longitudinal waves



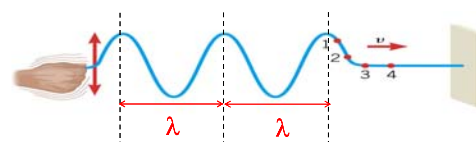
the string motion in vertical but the wave moves in the horizontal (perpendicular) direction➔ **transverse wave**



the coils of the slinky move along the same direction (horizontal) as the wave

➔ **longitudinal wave**

Harmonic waves

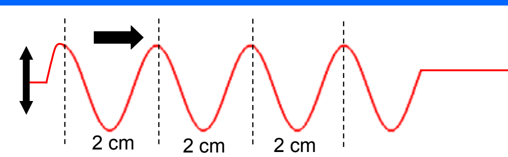


- each segment of the string undergoes simple harmonic motion as the wave passes by
- Look at a snapshot of the string at some time
- distance between successive peaks is called the **WAVELENGTH λ (lambda),** *it is measured in meters or cm*

The golden rule for waves

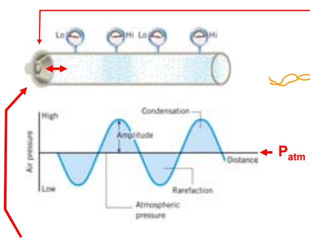
- The "golden rule" is the relationship between the speed (v) of the wave, the wavelength (λ) and the period (T) or frequency (f). ***(recall that*** $T = 1/f$, $f = 1/T$ ***)***
- it follows from → speed = distance / time
- the wave travels one wavelength in one period, so wave speed **$v = \lambda / T$,** but since $f = 1 / T$, we have
- $$v = \lambda f$$
- this is the *"Golden Rule"* for waves

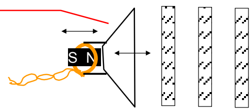
Example: wave on a string



- A wave moves on a string at a speed of 4 cm/s
- A snapshot of the motion shows that the wavelength, λ is 2 cm, what is the frequency, f ?
- $v = \lambda \times f$, so $f = v \div \lambda$ = (4 cm/s) / (2 cm) = 2 Hz
- $T = 1 / f$ = 1 / (2 Hz) = 0.5 s

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
- Sound waves cannot propagate in a vacuum → DEMO

Sound and Music

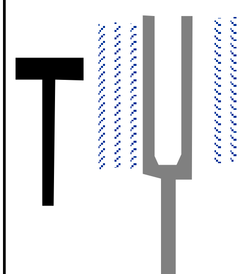
- Sound→ pressure waves in a solid, liquid or gas
- The speed of sound→ v_s
  - Air at 20 C: 343 m/s = 767 mph ≈ 1/5 mile/sec
  - Water at 20 C: 1500 m/s
  - copper: 5000 m/s
- Depends on density and temperature

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

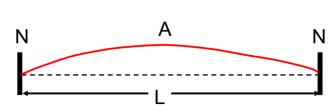


- The vibration of the fork causes the air near it to vibrate
- The length of the fork determines the frequency
  - longer fork → lower f
  - shorter fork → higher f
- It produces a pure pitch→ single frequency

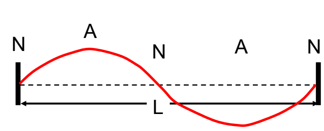
Stringed instruments

- 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

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

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)

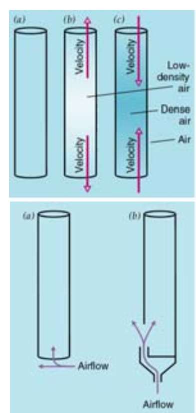
Vibration frequencies

- 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

Bowed instruments

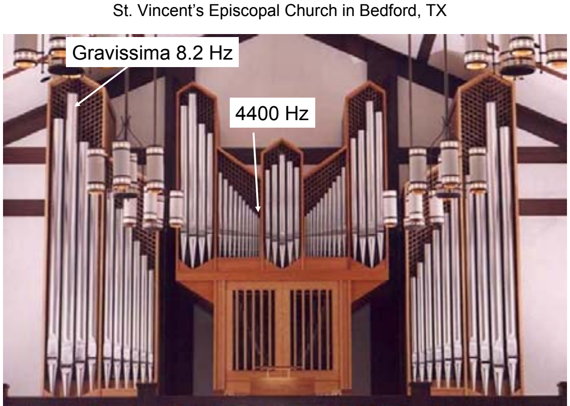
- In violins, violas, cellos and basses, a bow made of horse hair is used to excite the strings into vibration
- Each of these instruments are successively bigger (longer and heavier strings).
- The shorter strings make the high frequencies and the long strings make the low frequencies
- Bowing excites many vibration modes simultaneously→ mixture of tones (richness)

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

St. Vincent's Episcopal Church in Bedford, TX

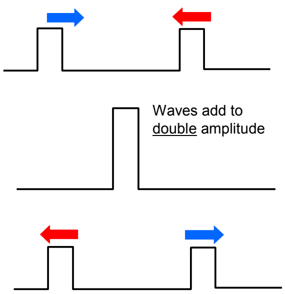


Beats – wave interference

- 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

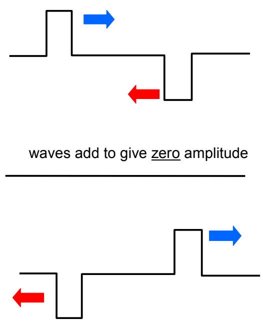
Constructive interference

Launch 2 up-going pulses on string

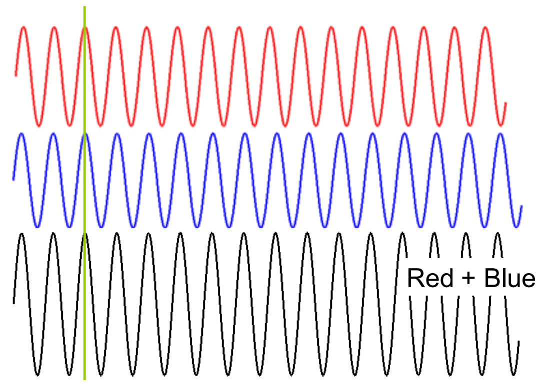


Destructive interference

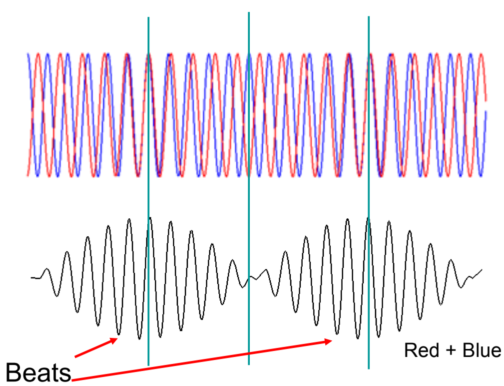
Launch 1 up-going and 1 down-going pulses on string



Combining 2 waves of the same frequency



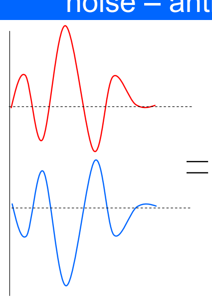
Combining 2 waves of slightly different frequencies



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

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

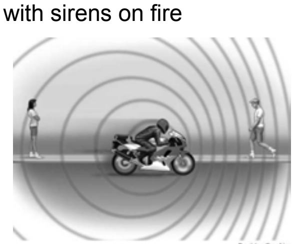


Take one wave, turn it upside down (invert its phase) then add it to the original wave

Noise elimination headphones

The Doppler Effect

- If a source of sound is moving toward you, you hear a higher frequency than when it is at rest
- If a source of sound is moving away from you, you hear a lower frequency than when it is at rest
- You can hear this effect with sirens on fire engines of train whistles
- A similar effect occurs with light waves and radar waves



Doppler effect → Radar guns

• The Doppler effect works for all kinds of waves, including light waves and radar

• 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.