L 22 – Vibrations and Waves-3

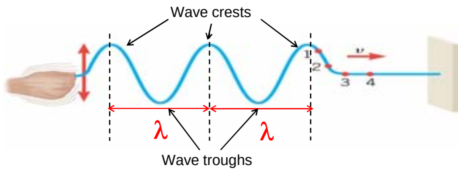
- resonance
- clocks – pendulum
- springs
- harmonic motion
- mechanical waves
- sound waves
- The periodic wave relation
- Wave interference
  - standing waves
  - beats
- musical instruments

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--- waves on strings
  - longitudinal wave --- sound

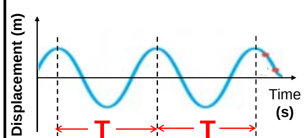
Wavelength: λ (lambda)

Snapshot of the string at some time – freezes the motion



- each segment of the string undergoes simple harmonic motion as the wave passes by
- distance between successive peaks (wave crests) is called the **WAVELENGTH λ (lambda),** *it is measured in meters or centimeters*

Period (T) *or* Frequency (*f*)



Period and frequency are inversely related

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

- An observer at a *fixed position* observes the wave moving by
- The time between successive crests passing by (or troughs) is the **PERIOD T**
- The number of crests passing by per unit time is the **FREQUENCY *f***

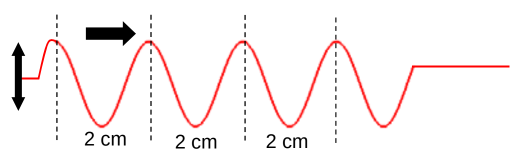
The periodic wave relation

- The wavelength, period (or frequency) and wave speed are related
- In one period the wave moves one wavelength, so the wave speed **v** = λ/T
- Since $f = 1/T$, this can be written as

$$\lambda f = v$$

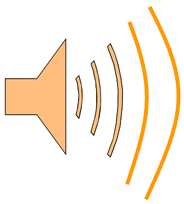
which is ***the periodic wave relation***.

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 = 2 cm, what is the frequency, f ?
- v = λ × f, so f = v / λ = (4 cm/s) / (2 cm) = 2 Hz
- T = 1 / f = 1 / (2 Hz) = 0.5 s

Making sound waves
→ longitudinal pressure disturbances



- When the diaphragm in the speaker moves out it compresses the layer of air in front of it.
- This compressed air layer then expands and pushes on another layer of air adjacent to it
- A propagating sound wave is produced

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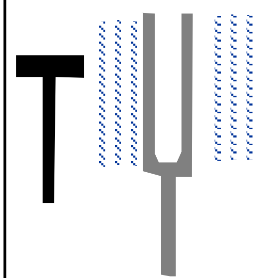
Tuning forks make sound waves



- 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

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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
- The **speed** of the wave on the string depends on:
  - The tension in the string which is adjustable (tuning)
  - The thickness of the string (instruments have some thin and some thicker strings)
- The periodic wave relation applies: $\lambda f = v$

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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 → includes a mixture of tones (richness)

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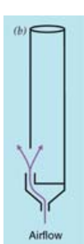
Wind instruments: organs, flutes…



- 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

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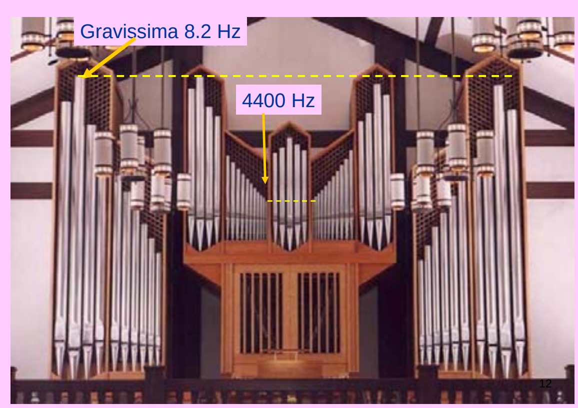
St. Vincent's Episcopal Church in Bedford, Texas



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Wave interference

- If there are 2 waves on a string, they can combine together to make another type of wave called a *standing wave*
- Standing waves are produced by an effect called *wave interference,* and there are two types of interference:
  - *Constructive interference* – the combination wave is bigger than the 2 waves
  - *Destructive interference-* the combination wave is smaller than the 2 waves

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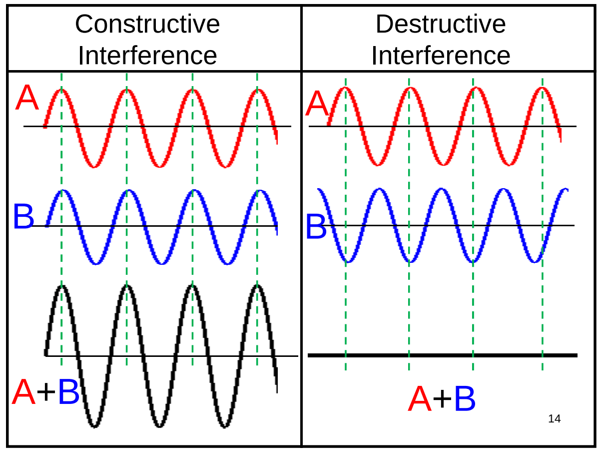

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Wave interference effects

- Waves can interfere with each other in space or in time
- Wave interference in space gives rise to standing waves
- Wave interference in time gives rise to beats

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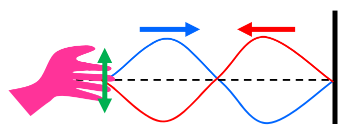
Standing waves

- 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 primary and reflected waves *interfere* with each other to produce a *standing wave*
- In some places along the string, the waves interfere constructively and at other places destructively

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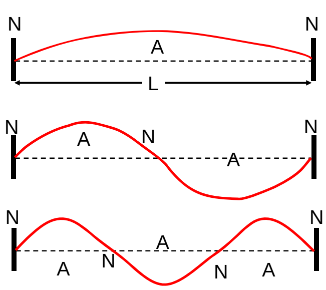
Modes of vibration

- Nodes N → the string does not move
- Antinodes A→ string has maximum amplitude



Fundamental mode
Wavelength = 2 L
Frequency = f_o

First harmonic mode
Wavelength = L
Frequency = 2 f_o

Second harmonic mode
Wavelength = 2/3 L
Frequency = 3 f_o

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Standing waves

- At the NODES, the string does not move
- At the ANTINODES the string moves up and down harmonically
- Since the ends are fixed, only an integer number of half wavelengths can fit
- e. g., 2 L, L, 2/3 L, ½ L, *etc*.
- The frequency is determined by the velocity and mode number (wavelength)

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Mode 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 of the string
- Modes
  - Fundamental: $f_o = v / 2L$
  - First harmonic: $f_1 = v / L = 2 f_o$
  - Second harmonic: $f_2 = v / (2/3)L = 3 f_o$
- The effective length can be changed by the musician "fingering" the strings

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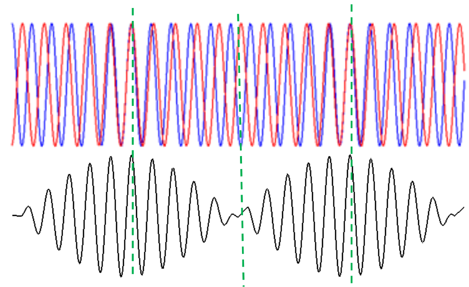
Beats – sound wave interference

Beats occur when 2 waves of slightly different frequencies are combined.



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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

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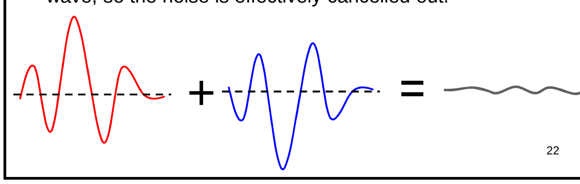
Wave interference can be used to eliminate noise – anti-noise technology

Noise elimination headphones

The noise wave is inverted and added to the original wave, so the noise is effectively cancelled out.



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