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: \( \lambda \) (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 \( \lambda \) (lambda), it is measured in meters or centimeters

Period (T) or Frequency (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 \( v = \lambda / T \)
• 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, \( \lambda = 2 \text{ cm} \), what is the frequency, \( f \) ?
• \( v = \lambda \times f \), so \( f = v / \lambda = (4 \text{ cm/s} ) / (2 \text{ cm}) = 2 \text{ Hz} \)
• \( T = 1 / f = 1 / (2 \text{ Hz}) = 0.5 \text{ s} \)
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

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
- 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: \( \lambda f = v \)

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)

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

St. Vincent’s Episcopal Church in Bedford, Texas
Gravissima 8.2 Hz
4400 Hz
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

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.

Modes of vibration

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

<table>
<thead>
<tr>
<th>Mode</th>
<th>Wavelength</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental</td>
<td>2L</td>
<td>( f_0 )</td>
</tr>
<tr>
<td>First harmonic</td>
<td>L</td>
<td>2( f_0 )</td>
</tr>
<tr>
<td>Second harmonic</td>
<td>2/3L</td>
<td>3( f_0 )</td>
</tr>
</tbody>
</table>

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., 2L, L, 2/3L, ½L, etc.
- The frequency is determined by the velocity and mode number (wavelength).
**Mode vibration frequencies**

- In general, \( f = \frac{v}{\lambda}, \) where \( v \) is the propagation speed of the string.
- The propagation speed depends on the diameter and tension of the string.
- Modes:
  - Fundamental: \( f_0 = \frac{v}{2L} \)
  - First harmonic: \( f_1 = \frac{v}{L} = 2f_0 \)
  - Second harmonic: \( f_2 = \frac{v}{(2/3)L} = 3f_0 \)
- The effective length can be changed by the musician “fingering” the strings.

**Beats – sound wave interference**

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

**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**

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