L 23 – Vibrations and Waves [3]

- resonance ✓
- clocks – pendulum ✓
- springs ✓
- harmonic motion ✓
- mechanical waves ✓
- sound waves ✓
- golden rule for waves
- 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
  - longitudinal wave

The golden rule for waves

- The “golden rule” is the relationship between the speed \( v \) of the wave, the wavelength \( \lambda \) and the period \( T \) or frequency \( f \)
- recall that \( T = 1 / f, f = 1 / T \)
- it follows from \( \rightarrow \) 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, \( \lambda \) is 2 cm, what is the frequency, \( f \)?
- \[ v = \lambda \times f, \text{ so } f = \frac{v}{\lambda} = \frac{(4 \text{ cm/s})}{(2 \text{ cm})} = 2 \text{ Hz} \]
- \( T = \frac{1}{f} = \frac{1}{(2 \text{ Hz})} = 0.5 \text{ s} \)
SOUND WAVES

- Longitudinal pressure disturbances in a gas
- The air molecules jiggle back and forth in the same direction as the wave
- Sound speed in air is 343 m/s

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

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

Constructive interference

- Launch 2 up-going pulses on string
- Waves add to double amplitude

Destructive interference

- Launch 1 up-going and 1 down-going pulses on string
- Waves add to give zero amplitude

Standing waves

- At the NODE positions, the string does not move
- At the ANTIODES 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 modes of a string

Fundamental mode
Wavelength = 2L
Frequency = \( f_0 \)

First harmonic mode
Wavelength = L
Frequency = 2\( f_0 \)

N = nodes, A = antinodes

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: \( f_0 = v / 2L \)
  - First harmonic: \( f_1 = v / L = 2 f_0 \)
- 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 \( \rightarrow \) 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

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

St. Vincent’s Episcopal Church in Bedford, Texas

Gravissima 8.2 Hz

4400 Hz
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