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
- 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, $\lambda$ (lambda) measured in m or cm

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, $f = 1/T$
The golden rule for waves

- The speed of propagation of the wave ($v$), the wavelength ($\lambda$), and period ($T$) are related.
- Distance = speed x time $\Rightarrow \lambda = vT = v/f$
- The wavelength = wave speed / frequency
  or $\Rightarrow v = \lambda \times f$ (golden rule)
- Wave speed = wavelength x 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 ($\lambda$) is 2 cm, what is the frequency ($f$)?
  $\Rightarrow v = \lambda \times f$, so $f = v / \lambda = (4 \text{ cm/s}) / (2 \text{ cm}) = 2 \text{ Hz}$

Sound – a longitudinal wave

- A sound wave is a pressure “disturbance” that moves 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

- 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.

Why do I sound funny when I breathe 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 $\lambda$ is fixed and $v_s$ is higher in He, the frequencies of your sounds are 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 $\rightarrow$ lower $f$
  - smaller fork $\rightarrow$ higher $f$
- It produces a pure pitch $\rightarrow$ single frequency

Vibration modes of a string

- Fundamental mode
  - Wavelength = $2L$
  - Frequency = $f_0$
- First harmonic mode
  - Wavelength = $L$
  - Frequency = $2f_0$

$N = \text{nodes}$, $A = \text{antinodes}$

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, $f = \frac{v}{\lambda}$, where $v$ is the propagation speed of the string
- The propagation speed depends on the diameter and tension
- Modes
  - Fundamental: $f_0 = \frac{v}{2L}$
  - First harmonic: $f_1 = \frac{v}{L} = 2f_0$
- The effective length can be changed by the musician "fingering" the strings

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

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.

Constructive interference

Waves add to double amplitude.

Destructive interference

Waves add to give 0 amplitude.

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.

Combining 2 waves of the same frequency
Combining 2 waves of slightly different frequencies

Beats

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

Doppler effect → Radar guns

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.

Once you see the cop, he’s got you!

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