From Last Time...

Wave Properties

- **Amplitude** is the maximum displacement of string above the equilibrium position.
- **Wavelength**, $\lambda$, is the distance between two successive points that behave identically.
- **Period**: required to complete one cycle.
- **Frequency** = $1/\text{Period}$ = rate at which cycles are completed.

- **Velocity** = Wavelength/Period, $v = \lambda / T$, or $v = \lambda f$. 

Hour Exam #1 Scores

65% = high BC

Mean = 65%
Min = 27%
Max = 93%
Quality of Sound - Tuning Fork

- Tuning fork produces only the fundamental frequency
Quality of Sound - Flute

- The same note played on a flute sounds differently.
- The second harmonic is very strong.
- The fourth harmonic is close in strength to the first.
Quality of Sound - Clarinet

- The fifth harmonic is very strong
- The first and fourth harmonics are very similar, with the third being close to them
Timbre

• In music, the characteristic sound of any instrument is referred to as the quality of sound, or the *timbre* of the sound
• The quality depends on the mixture of harmonics in the sound
Pitch

- Pitch is related mainly, although not completely, to the frequency of the sound.
- Pitch is not a physical property of the sound.
- Frequency is the stimulus and pitch is the response.
  - It is a psychological reaction that allows humans to place the sound on a scale.
Frequency Response Curves

- Bottom curve is the threshold of hearing
  - Threshold of hearing is strongly dependent on frequency
  - Easiest frequency to hear is about 3000 Hz

- When the sound is loud (top curve, threshold of pain) all frequencies can be heard equally well
Combining waves

- Two traveling waves can meet and pass through each other without being destroyed or even altered

- Waves obey the *Superposition Principle*
  - If two or more traveling waves are moving through a medium, the resulting wave is found by adding together the displacements of the individual waves point by point
  - **Constructive interference:** waves reinforce
  - **Destructive interference:** waves tend to cancel
Constructive Interference in a String

- Two pulses are traveling in opposite directions
- The net displacement when they overlap is the sum of the displacements of the pulses
- Note that the pulses are unchanged after the interference
Constructive Interference

- Two waves, a and b, have the same frequency, amplitude, and start point
  - Are in phase
- The combined wave, c, has the same frequency and a greater amplitude

Combined wave
Destructive Interference in a String

- Two pulses are traveling in opposite directions
- The net displacement when they overlap the displacements of the pulses subtract
- Note that the pulses are unchanged after the interference
Destructive Interference

- Two waves, a and b, have the same amplitude and frequency
- They are 1/2 wavelength out of phase
- When they combine, the waveforms cancel

\[ \text{(a)} + \text{(b)} = \text{(c)} \]
Interference of sound waves

- Interference arises when waves change their ‘phase relationship’.
- Can vary phase relationship of two waves by changing physical location of speaker.

- *Constructive*
- ‘in-phase’
- ‘1/2 λ phase diff’

- *Destructive*
Example

- Speed of sound \(~ 340 \text{ m/s}\)
- So \(f=340 \text{ Hz}\) gives \(\lambda=v/f = 1 \text{ meter}\)
- Change of 1/2 wavelength is 1/2 meter.
Spherical Waves

- A spherical wave propagates radially outward from the oscillating sphere.
- The energy propagates equally in all directions.
Representations of Waves

- **Wave fronts** are the concentric arcs
  - The distance between successive wave fronts is the wavelength
- **Rays** are the radial lines pointing out from the source and perpendicular to the wave fronts
Shock Waves and Sonic Booms

• A shock wave results when the source velocity exceeds the speed of the wave itself.

• The circles represent the wave fronts emitted by the source.
Sonic Boom

- What happens if the source of sound approaching the listener is equal to or faster than the speed of sound
  - Each successive wave is superimposed on the previous one
  - If the speed is exceeded
    - No sound received till after the source passes the listener - then a sonic boom
    - followed by normal sound from the source
  - Conical bow wake
  - Much like triangular bow wake behind a duck swimming in a pond
Superposition of Unequal Frequency Waves

- Consider two harmonic waves $A$ and $B$ meeting at $x=0$.
  - Same amplitudes, but $\omega_2 = 1.15 \omega_1$.
- The displacement versus time for each is shown below:

$A(\omega_1 t)$

$B(\omega_2 t)$

What does $C(t) = A(t) + B(t)$ look like??
Superposition & Interference

• Consider two harmonic waves $A$ and $B$ meeting at $x = 0$.
  - Same amplitudes, but $\omega_2 = 1.15 \times \omega_1$.
• The displacement versus time for each is shown below:

\[ C(t) = A(t) + B(t) \]
Beats

- The ‘beat’ frequency is exactly half the difference of the two source frequencies.
- The ‘pitch’ is the average (half the sum) of the two source frequencies.

\[ A \cos(\omega_1 t) + A \cos(\omega_2 t) = 2A \cos(\omega_L t) \cos(\omega_H t) \]

where \( \omega_L = \frac{1}{2}(\omega_1 - \omega_2) \) and \( \omega_H = \frac{1}{2}(\omega_1 + \omega_2) \)
Doppler Effect

• A Doppler effect is experienced whenever there is relative motion between a source of waves and an observer.
  - When the source and the observer are moving toward each other, the observer hears a higher frequency
  - When the source and the observer are moving away from each other, the observer hears a lower frequency

• Although the Doppler Effect is commonly experienced with sound waves, it is a phenomena common to all waves
Doppler Effect, Case 1

- An observer is moving toward a stationary source
- Due to his movement, the observer detects an additional number of wave fronts
- The frequency heard is increased

Fig 14.8, p. 435

Slide 12
Doppler Effect, Case 2

- An observer is moving away from a stationary source
- The observer detects fewer wave fronts per second
- The frequency appears lower
Doppler Effect, Source in Motion

- As the source moves toward the observer (A), the wavelength appears shorter and the frequency increases.
- As the source moves away from the observer (B), the wavelength appears longer and the frequency appears to be lower.