Lecture 37: Wave motion II
Recap: properties of waves

- **Wavelength** $\lambda$ is the distance over which a wave repeats in space.

- **Period** $T$ is the time for a complete cycle of the wave at a fixed position:
  - Frequency $f = 1/T$

- **Amplitude** $A$ is the peak value of the wave disturbance.

- **Wave speed** is the rate at which the wave propagates:
  $$v = \frac{\lambda}{T} = \lambda f$$
Sound

- Sound waves are longitudinal mechanical waves that propagate through gases, liquids, and solids.
- Sound waves in air involve small changes in air pressure and density, associated with back-and-forth motion of the air as the wave passes.
- Sound intensity levels are measured in decibels, a logarithmic unit based on comparison with a reference intensity $I_0 = 10^{-12}$ W/m$^2$: $\beta = 10 \log \left( \frac{I}{I_0} \right)$.
- The human ear responds to a broad range of sound intensities and frequencies.
Wave interference

• Unlike particles, two waves can be in the same place at the same time.

• When they are, they interfere.
  • In most cases, the waves superpose, or simply add.
    • When wave crests coincide, the interference is constructive.
    • When crests coincide with troughs, the interference is destructive.
Interference phenomena

- When waves of slightly different frequencies interfere, they alternate between constructive and destructive interference.
  - This results in **beats** at the difference of their frequencies.

- Interference from two closely spaced sources results in patterns of high- and low-amplitude waves.
  - The photo shows such an interference pattern with water waves.
Wave reflection

- Waves reflect at an interface with a different medium.
  - The outgoing wave interferes with the incoming wave.
  - The reflected wave is inverted, depending on properties of the second medium.
  - The diagram shows waves on a string reflecting at clamped and free ends.

- More generally, a wave is partially reflected and partially transmitted at an interface between different media.
Standing waves

- Waves on a confined medium reflect at both ends.
  - The result is **standing waves** that oscillate but don’t propagate.
  - The length of the medium restricts the allowed wavelengths and frequencies to discrete values.

On a string clamped at both ends, the string length must be an integer multiple of a half-wavelength: \( L = m\lambda/2 \), with \( m \) an integer.

On a string clamped at one end, the string length must be an odd integer multiple of a half-wavelength: \( L = m\lambda/4 \), with \( m \) odd.
Standing waves in musical instruments

- Stringed instruments are analogous to the strings of the previous slide: The string length determines the allowed wavelengths and, together with the wave speed, the allowed frequencies.

- Wind instruments are analogous, with sound waves in their air columns.
  - Wind instruments are typically open at one end or both.
A string 1 m long is clamped down tightly at one end and is free to slide up and down at the other. Which one of the following values is a possible wavelength for this string?

A. 4/3 m
B. 3/2 m
C. 2 m
D. 3 m
The Doppler effect

- When a wave source moves through the wave medium, a stationary observer experiences a shift in wavelength and frequency.
  - The frequency increases for an approaching source.
  - The frequency decreases for a receding source.

- The shifted frequencies are given by $f' = f/(1 \pm u/v)$.
  - Here $u$ is the source speed and $v$ is the wave speed.
  - A similar effect occurs for a moving observer, but there’s no wavelength shift.
  - The Doppler effect for light is similar but slightly different because light has no medium. The formula above applies only for speeds much less than light.
Shock waves

- **Shock waves** occur when a wave source moves through the medium at greater than the wave speed.

- Examples include sonic booms from aircraft, wakes of boats, and astrophysical bodies moving through interplanetary and interstellar gas.

![Diagram](slide-37-11.png)

- Wave crests from all source locations pile up along this line, making a conical shock wave.
- This is the distance $vT$ that the wave crest moved in one period.
- Here’s where the source was two wave periods ago. The crest it emitted then has had more time to expand outward, so it’s larger.
- This is the Mach angle. Its sine is $vT/uT$, or $v/u$.
- Right now the source is here, about to emit a wave crest.
- Here’s where the source was one wave period ago, when it emitted the circular wave crest shown.
- This is the distance $uT$ that the source moved in one period.
Summary

- A wave is a traveling disturbance that carries energy but not matter.
  - Mechanical waves involve the disturbance of a material medium.
    - These include sound waves.
  - Electromagnetic waves, including light, have no medium.
  - Simple harmonic waves are sinusoidal in shape.

\[
y(x,t) = A \cos(kx - \omega t)
\]

- The speed of a wave follows from its frequency and wavelength or from its angular frequency and wavenumber: \( v = \lambda f = \omega / k \).
- Important wave phenomena include
  - Reflection and refraction
  - Interference
  - Standing waves
  - The Doppler effect
  - Shock waves