Physics 1501

Fall 2008

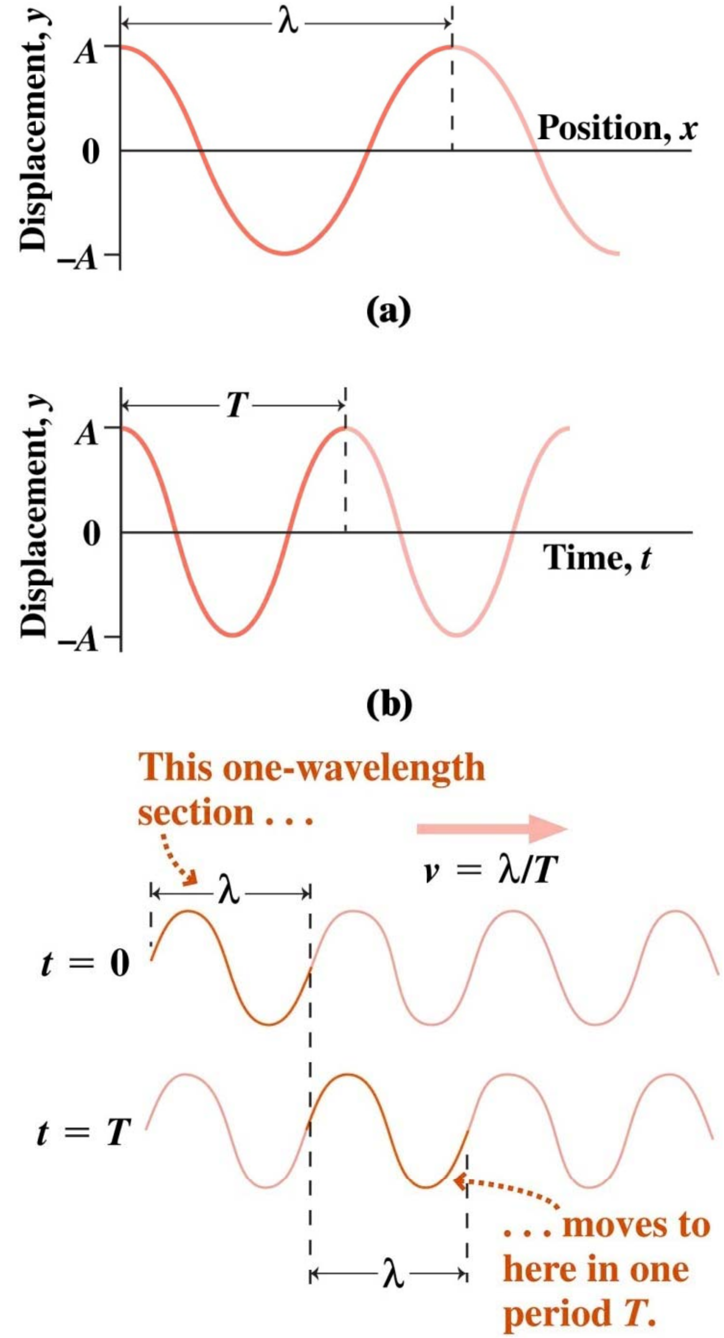
Mechanics, Thermodynamics, Waves, Fluids

Lecture 37: Wave motion II

Recap: properties of waves

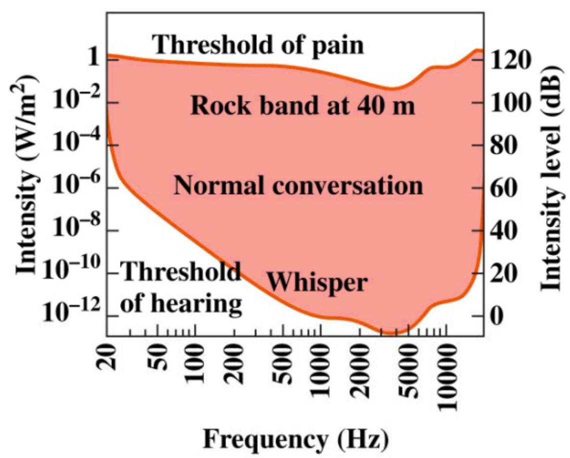
- **Wavelength** λ is the distance over which a wave repeats in space.
- **Period** T is the time for a complete cycle of the wave at a fixed position:
  - **Frequency** $f = 1/T$
- **Amplitude** A is the peak value of the wave disturbance.
- **Wave speed** is the rate at which the wave propagates:

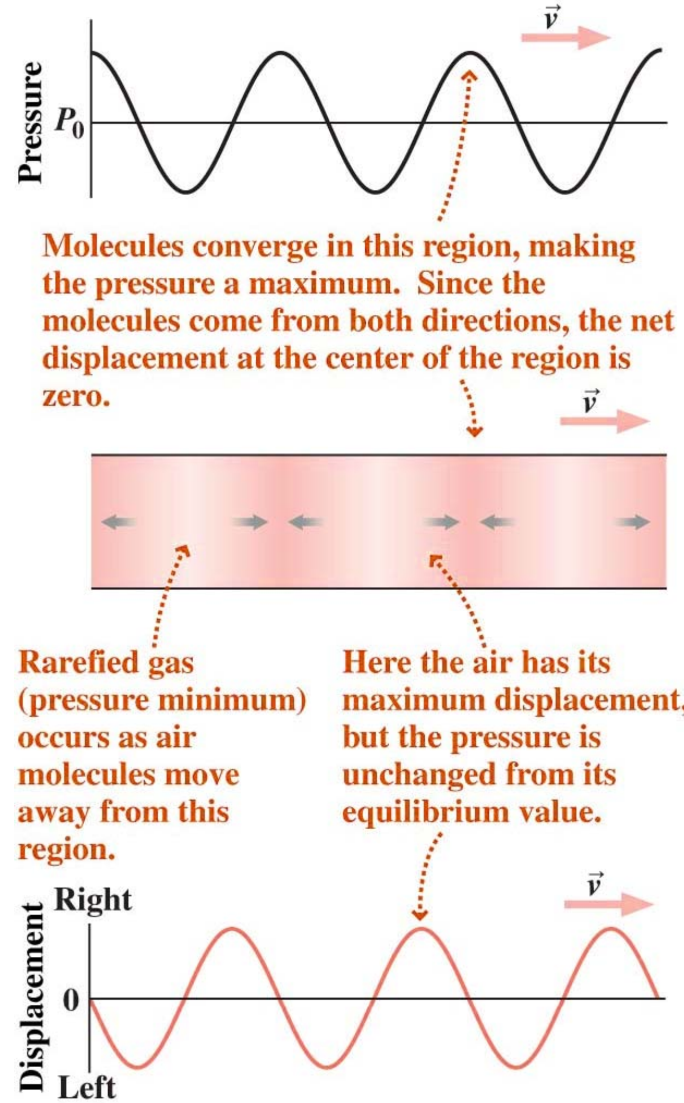
$$v = \lambda/T = \lambda f$$



Sound

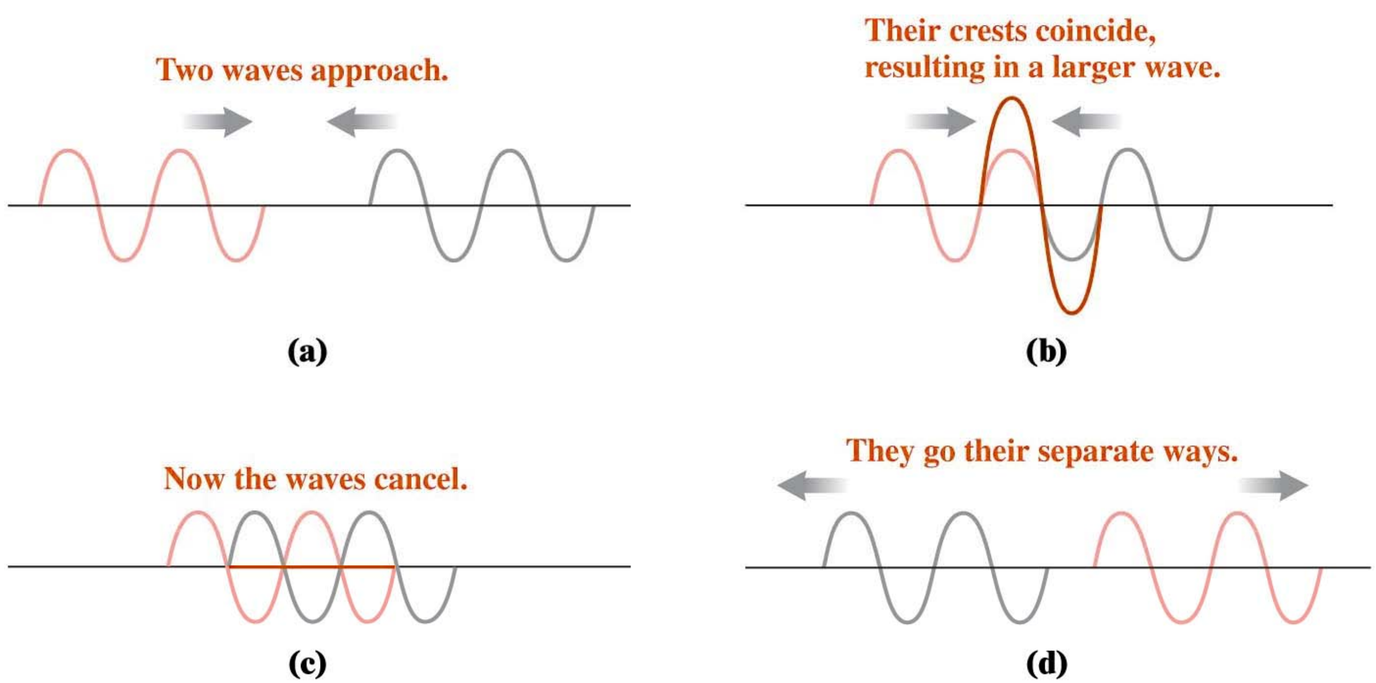
- Sound waves are longitudinal mechanical waves that propagate through gases, liquids, and solids.
  - Sound waves in air involve small changes in air pressure and density, associated with back-and-forth motion of the air as the wave passes.
  - Sound intensity levels are measured in decibels, a logarithmic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





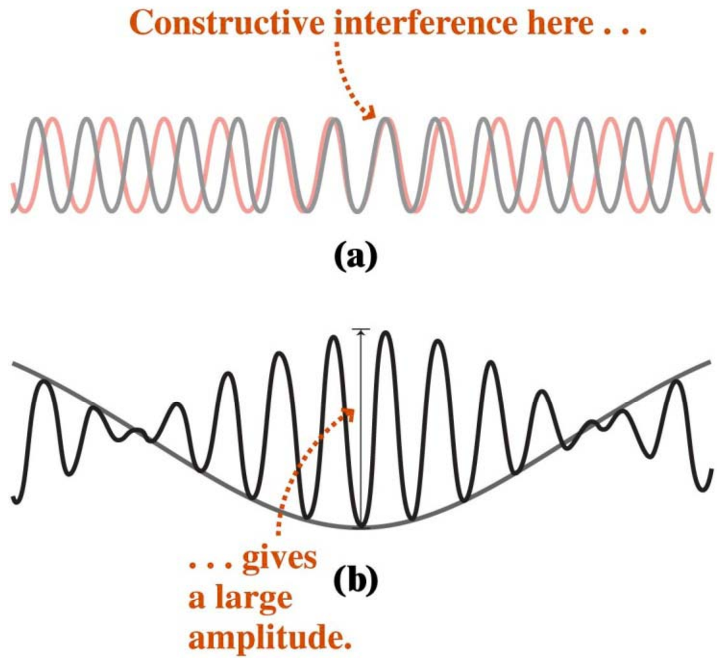
Wave interference

- 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.**

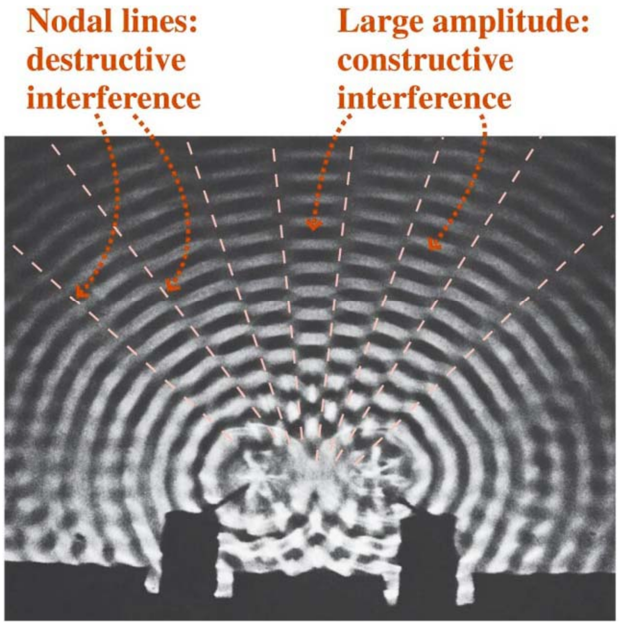


Interference phenomena

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

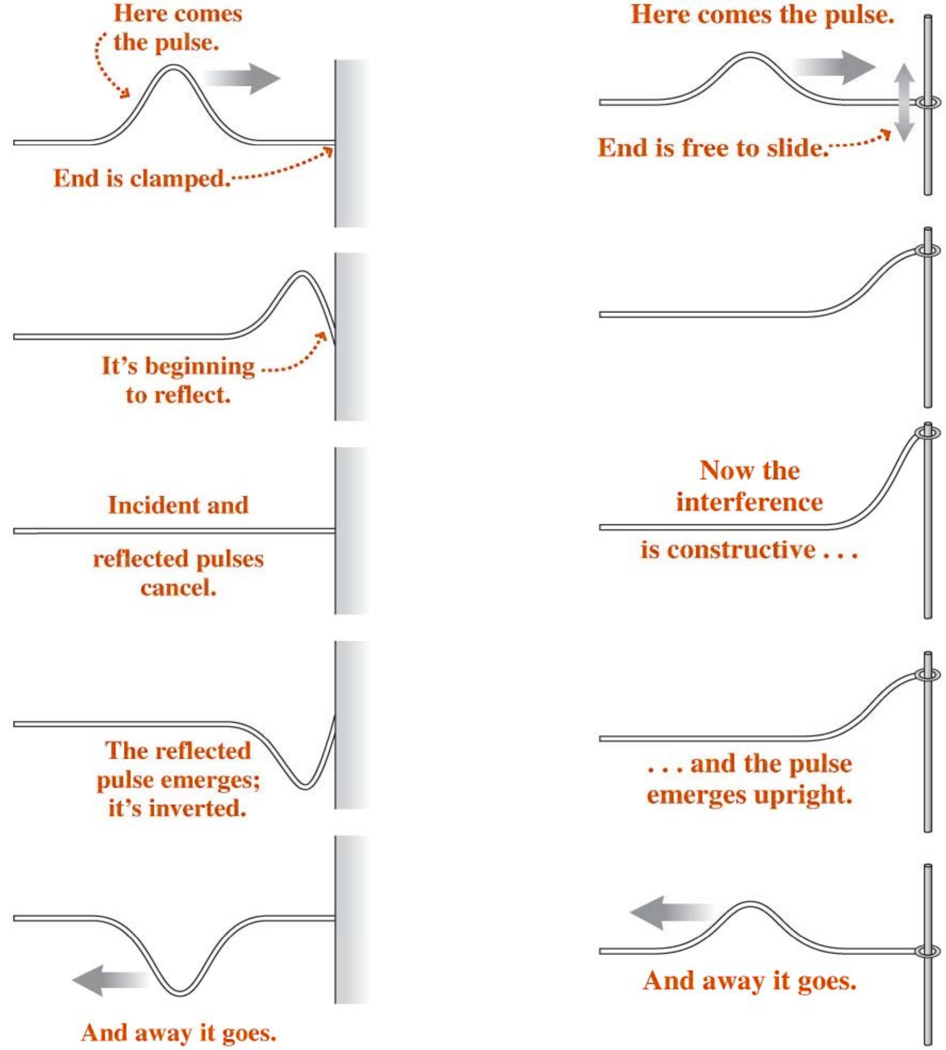


- Interference from two closely spaced sources results in patterns of high- and low-amplitude waves.
  - The photo shows such an interference pattern with water waves.

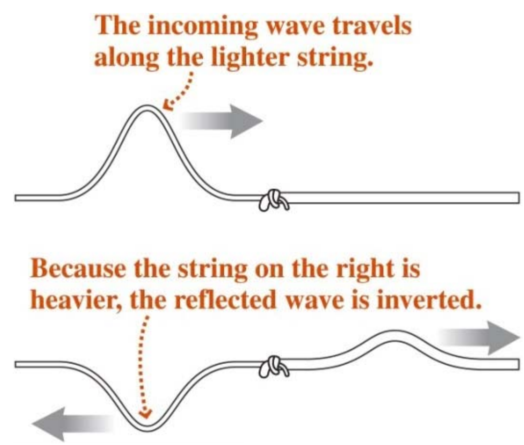


Wave reflection

- 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.



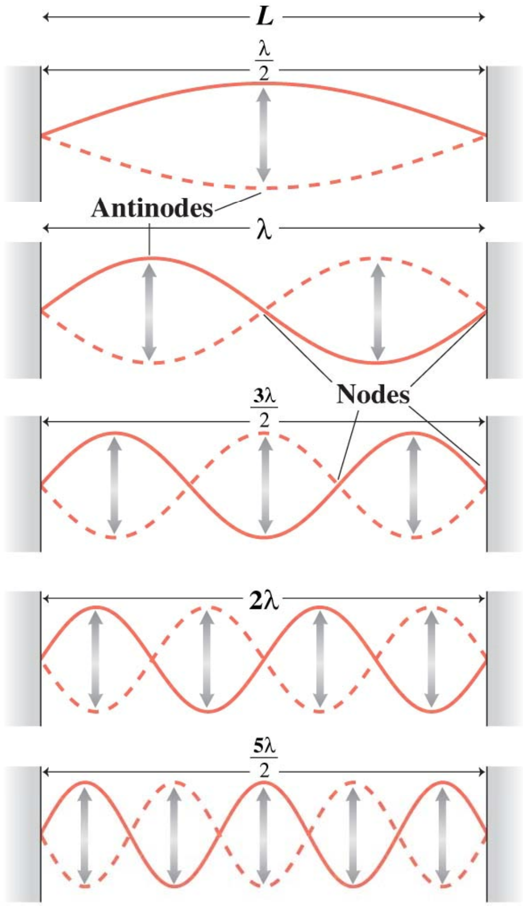
  - More generally, a wave is partially reflected and partially transmitted at an interface between different media.



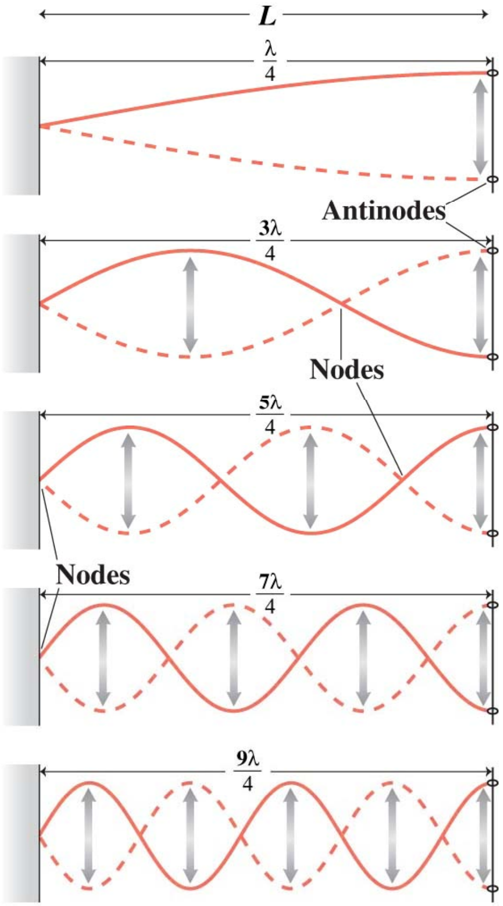
Standing waves

- 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.

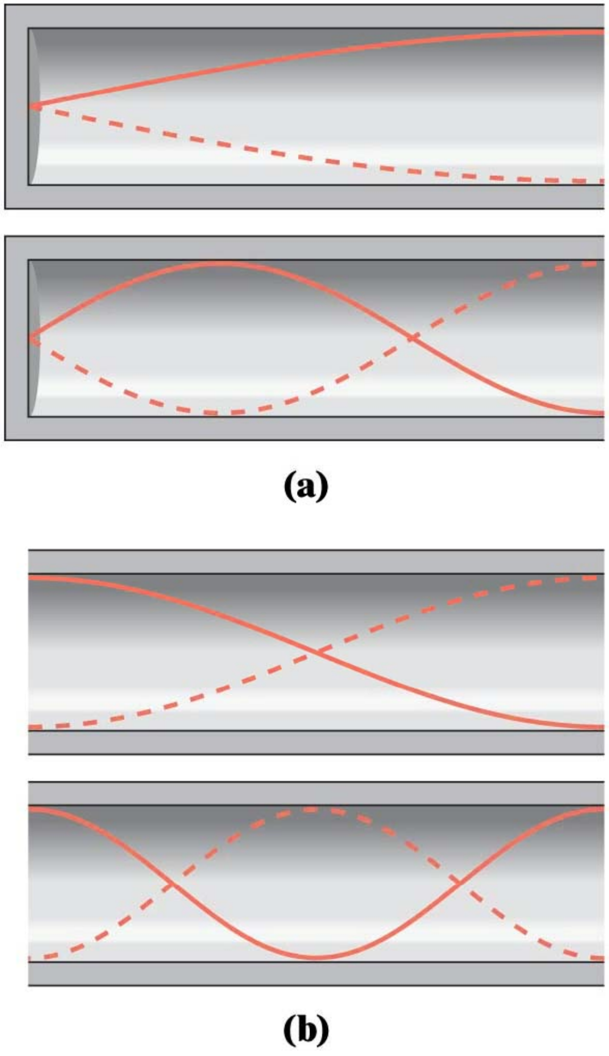


On a string clamped at one end, the string length must be an odd integer multiple of a half-wavelength: $L = m\lambda/4$, with m odd.



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.



question

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

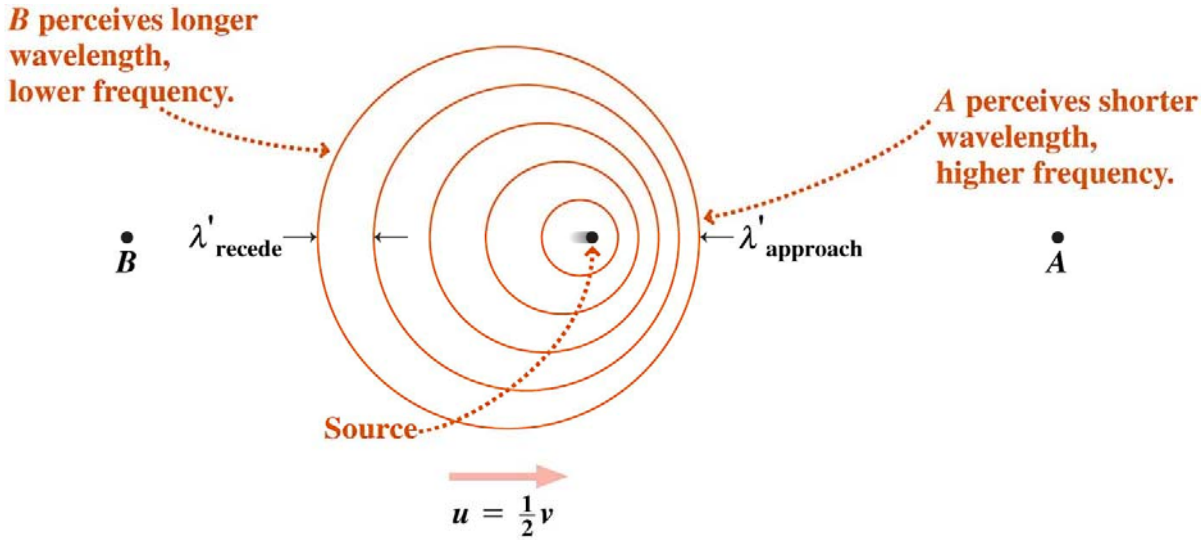
B. 3/2 m

C. 2 m

D. 3 m

The Doppler effect

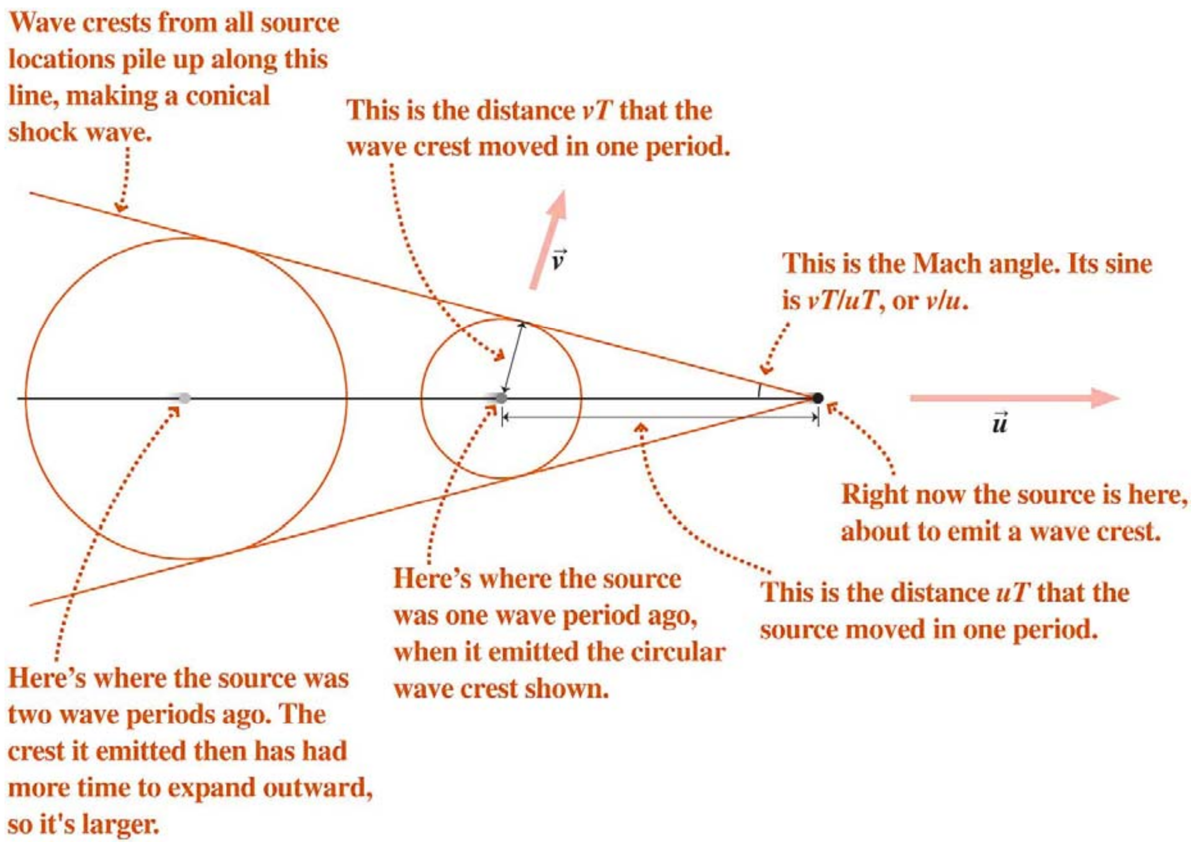
- When a wave source moves through the wave medium, a stationary observer experiences a shift in wavelength and frequency.
  - The frequency increases for an approaching source.
  - The frequency decreases for a receding source.



  - 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

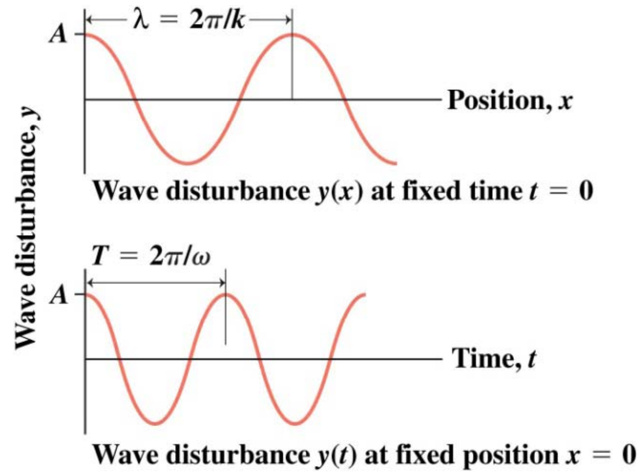
- **Shock waves** occur when a wave source moves through the medium at greater than the wave speed.
  - Examples include sonic booms from aircraft, wakes of boats, and astrophysical bodies moving through interplanetary and interstellar gas.



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