Lecture 8

Sound Waves

Superposition and Standing Waves

Sound Waves

Speed of Sound Waves

Intensity of Periodic Sound Waves

The Doppler Effect

Sound Waves

- are the most common example of longitudinal waves.

- are divided into three categories that cover different frequency ranges:

(1) *Audible waves* lie within the range of sensitivity of the human ear.

(2) *Infrasonic waves* have frequencies below the audible range. (i.e. Elephant.)

(3) *Ultrasonic waves* have frequencies above the audible range. (i.e. medical imaging.)

Sound Waves

- They travel through any material medium with a speed that depends on the properties of the medium.

- The speed of sound waves depends on the compressibility (1\B) and density of the medium (ρ) . If the medium is a liquid or a gas and has a bulk modulus B and density ρ , the speed of sound waves in that medium is :

$$v = \sqrt{\frac{B}{\rho}}$$

  - The speed of sound also depends on the temperature of the medium.

Example

(A) Find the speed of sound in water, which has a bulk modulus of $2.1 \times 10^9\ \mathrm{N/m^2}$ at a temperature of $0°\mathrm{C}$ and a density of $1.00 \times 10^3\ \mathrm{kg/m^3}$.

Solution:

$$v_{water} = \sqrt{\frac{B}{\rho}} = \sqrt{\frac{2.1 \times 10^9 \text{ N/m}^2}{1.00 \times 10^3 \text{ kg/m}^3}} = \boxed{1.4 \text{ km/s}}$$

In general, sound waves travel more slowly in liquids than in solids because liquids are more compressible than solids. Note that the speed of sound in water is lower at 0°C than at 25°C

Intensity of Periodic Sound Waves

We define the intensity *of a wave (I) as the power* $\mathcal{P}$ *per unit area A , or the rate at* which the energy being transported $\mathcal{P}$ by the wave transfers through a unit area *A , perpendicular* to the direction of travel of the wave:

$$I = \frac{\mathcal{P}}{A}$$

Example

A point source emits sound waves with an average power output of 80.0 W.

(A) Find the intensity 3.00 m from the source.

(B) Find the distance at which the intensity of the sound is $1.00 \times 10^{-8}\ \mathrm{W/m^2}$.

A. ***Solution*** A point source emits energy in the form of spherical waves. Using Equation 17.7, we have

$$I = \frac{\mathcal{P}_{av}}{4\pi r^2} = \frac{80.0\ \text{W}}{4\pi(3.00\ \text{m})^2} = \boxed{0.707\ \text{W/m}^2}$$

an intensity that is close to the threshold of pain.

B. ***Solution*** Using this value for I in Equation 17.7 and solving for r, we obtain

$$r = \sqrt{\frac{\mathcal{P}_{av}}{4\pi I}} = \sqrt{\frac{80.0\ \text{W}}{4\pi(1.00 \times 10^{-8}\ \text{W/m}^2)}}$$

$$= \boxed{2.52 \times 10^4\ \text{m}}$$

which equals about 16 miles!

Sound Level in Decibels

Sound level β is defined by the equation:

$$\beta \equiv 10 \log\left(\frac{I}{I_0}\right)$$

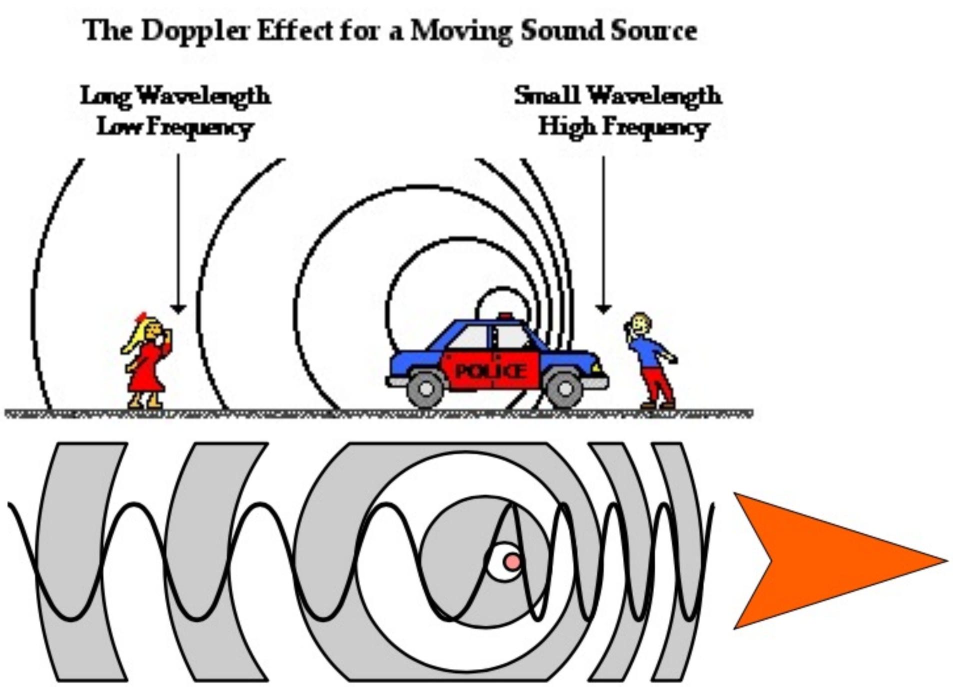
The constant I_0 is the reference intensity, taken to be at the threshold of hearing , $I_0 = 1.00 \times 10^{-12}\ \mathrm{W/m^2}$

and I is the intensity in watts per square meter, where β is measured in decibels (dB).

Note that we use a logarithmic scale due to the range of intensities the human ear can detect is so wide !!

The Doppler Effect

Perhaps you have noticed how the sound of a vehicle's horn changes as the vehicle moves past you. The frequency of the sound you hear as the vehicle approaches you is higher than the frequency you hear as it moves away from you. This is one example of the Doppler effect.



Change of wavelength caused by motion of the source

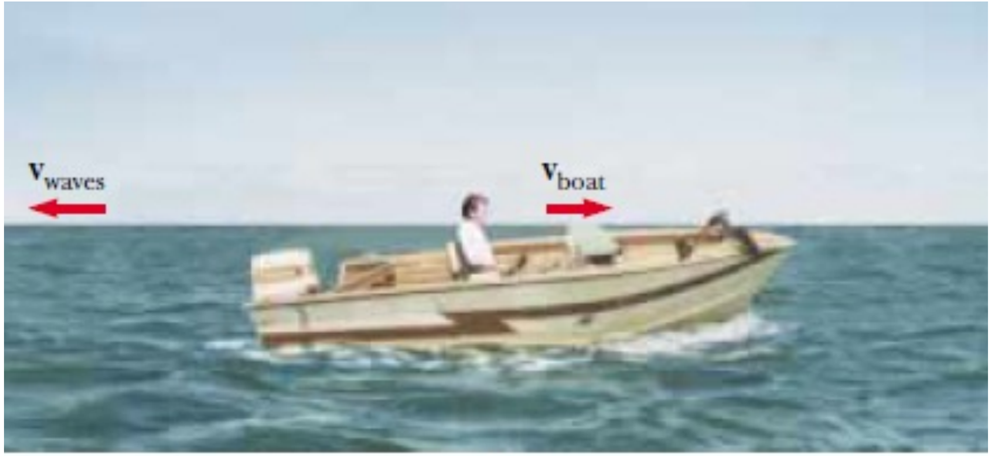
The Doppler Effect … more explanation

- To see what causes this apparent frequency change, imagine you are in a boat that is lying at anchor on a gentle sea where the waves have a period of T # 3.0 s. This means that every 3.0 s a crest hits your boat. Figure **a** shows this situation, with the water waves moving toward the left.
- If you set your watch to t = 0 just as one crest hits, the watch reads 3.0 s when the next crest hits, 6.0 s when the third crest hits, and so on. From these observations you conclude that the wave frequency is f= 1/T =1/(3.0 s) = 0.33 Hz.

(a)

The Doppler Effect … more explanation

- Now suppose you start your motor and head directly into the oncoming waves, as in Figure **b**. Again you set your watch to t= 0 as a crest hits the front of your boat. Now, however, because you are moving toward the next wave crest as it moves toward you, it hits you less than 3.0 s after the first hit. In other words, the period you observe is shorter than the 3.0-s period you observed when you were stationary. Because f = 1/T, you observe a higher wave frequency than when you were at rest.



(b)

The Doppler Effect … more explanation

- If you turn around and move in the same direction as the waves (see Fig. **c**), you observe the opposite effect. You set your watch to t # 0 as a crest hits the back of the boat. Because you are now moving away from the next crest, more than 3.0 s has elapsed on your watch by the time that crest catches you. Thus, you observe a lower frequency than when you were at rest.

(c)

The Doppler Effect … more explanation

- These effects occur because the relative speed between your boat and the waves depends on the direction of travel and on the speed of your boat. When you are moving toward the right in Figure **b**, this relative speed is higher than that of the wave speed, which leads to the observation of an increased frequency. When you turn around and move to the left, the relative speed is lower, as is the observed frequency of the water waves.

(b)

(c)

Case 1: The Observer Is Moving Relative to a Stationary Source

$$f' = \left(\frac{v + v_O}{v}\right)f$$ (observer moving toward source)

$$f' = \left(\frac{v - v_O}{v}\right)f$$ (observer moving away from source)

Case 2: The Source Is Moving Relative to a Stationary Observer

$$f' = \left(\frac{v}{v - v_S}\right)f$$ (source moving toward observer)

$$f' = \left(\frac{v}{v + v_S}\right)f$$ (source moving away from observer)

General Case:

$$f' = \left(\frac{v + v_O}{v - v_S}\right) f$$

A positive value is used for motion of the observer or the source toward the other, and a negative sign for motion of one away from the other.

The word *toward* is associated with an *increase* in observed frequency. The words *away from* are associated with a *decrease* in observed frequency.

Example

A submarine (sub A) travels through water at a speed of 8.00 m/s, emitting a sonar wave at a frequency of 1400 Hz. The speed of sound in the water is 1533 m/s. A second submarine (sub B) is located such that both submarines are traveling directly toward one another. The second submarine is moving at 9.00 m/s.

(A) What frequency is detected by an observer riding on sub B as the subs approach each other?

(B) The subs barely miss each other and pass. What frequency is detected by an observer riding on sub B as the subs recede from each other?

Solution

(A) We use Equation 17.13 to find the Doppler-shifted frequency. As the two submarines approach each other, the observer in sub B hears the frequency

$$f' = \left(\frac{v + v_O}{v - v_S}\right) f$$

$$= \left(\frac{1\,533\text{ m/s} + (+9.00\text{ m/s})}{1\,533\text{ m/s} - (+8.00\text{ m/s})}\right)(1\,400\text{ Hz}) = \boxed{1\,416\text{ Hz}}$$

(B) As the two submarines recede from each other, the observer in sub B hears the frequency

$$f' = \left(\frac{v + v_O}{v - v_S}\right) f$$

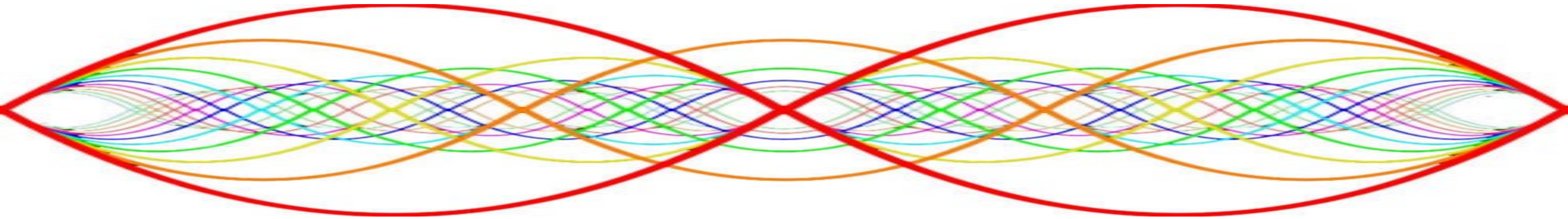
$$= \left(\frac{1\,533\text{ m/s} + (-9.00\text{ m/s})}{1\,533\text{ m/s} - (-8.00\text{ m/s})}\right)(1\,400\text{ Hz}) = \boxed{1\,385\text{ Hz}}$$

Superposition and Standing Waves

Superposition and Interference

Standing Waves

Beats: Interference in Time

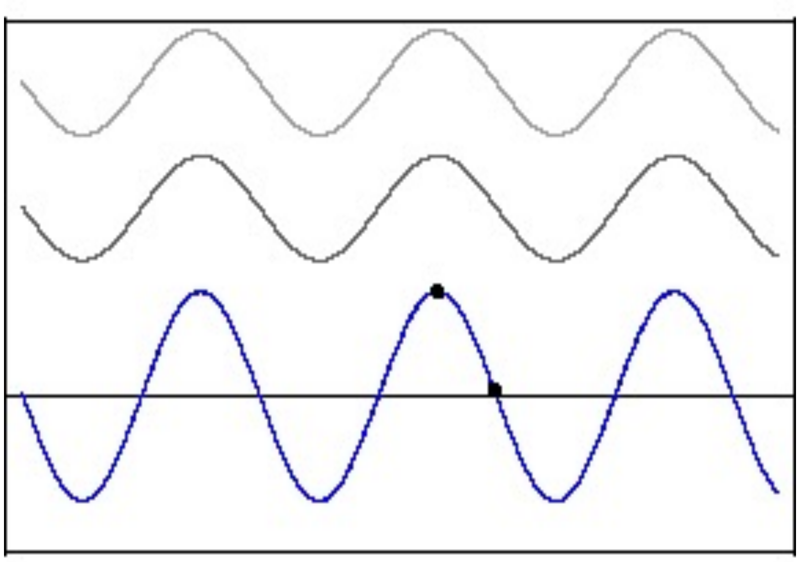


Superposition principle

If two or more traveling waves are moving through a medium, the resultant value of the wave function at any point is the algebraic sum of the values of the wave functions of the individual waves.

One consequence of that :

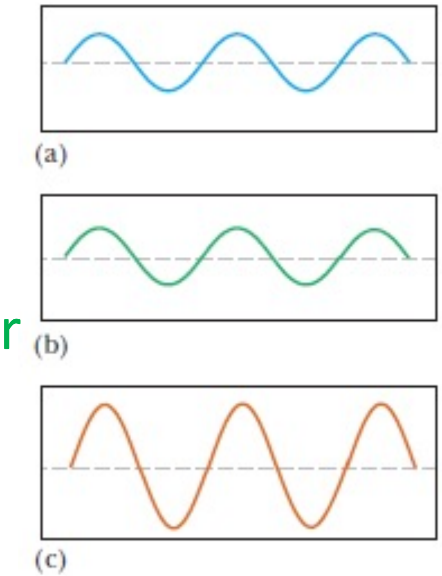
Two traveling waves can pass through each other without being destroyed or even altered. That's called interference of wave



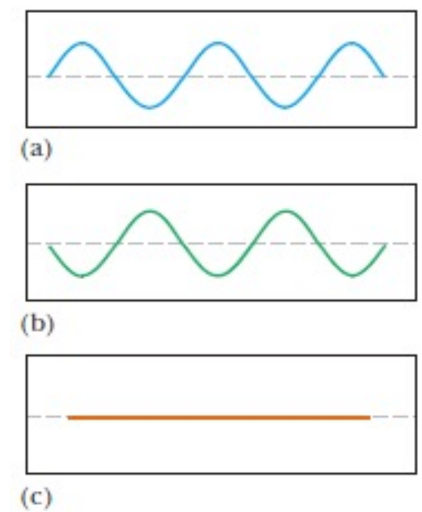
INTERFERENCE OF WAVES

The combination of separate waves in the same region of space to produce
a resultant wave is called interference.

If at some instant of time there is two waves of the same amplitude and frequency were traveling through the same region of space, the resultant wave has the same frequency as the individual waves, but twice their amplitude. Waves coming together like this are said to be in phase and to exhibit constructive interference.



If one wave is inverted relative to the other. The result would be no motion. In such a situation, the two waves are said to be 180° out of phase and to exhibit destructive interference.



STANDING WAVES

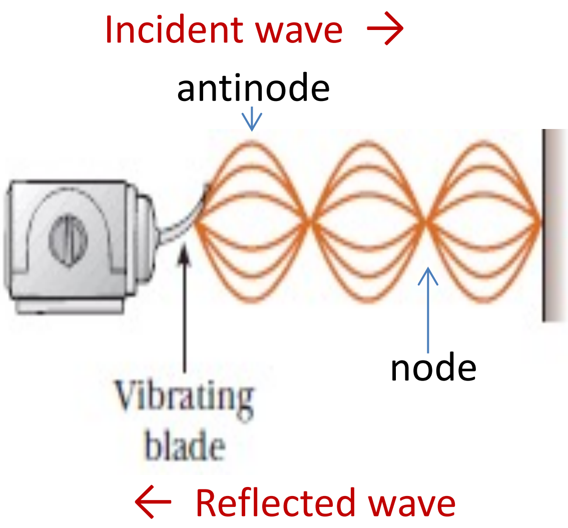
A standing wave, is an oscillation pattern *with a stationary outline* that results from the superposition of two identical waves traveling in opposite directions.

One wave is called the incident wave & the other is called the reflected wave. They combine according to the superposition principle.

The waves occurs in strings and pipes are common examples of Standing waves.

STANDING WAVES' components

Standing waves can be set up in a stretched string by connecting one end of the string to a stationary clamp and connecting the other end to a vibrating object.



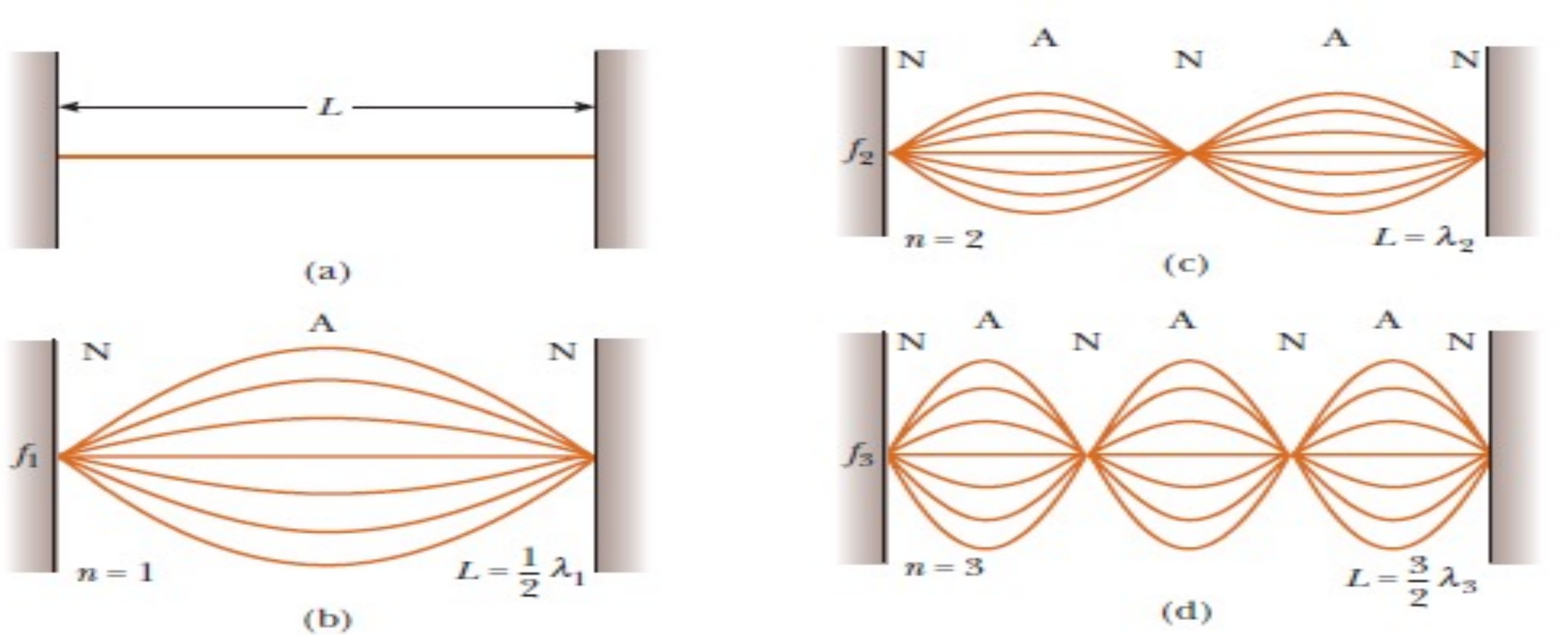
The incident and reflected waves combine according to the superposition principle.

A node occurs where the two traveling waves always have the same magnitude of displacement but the opposite sign, so the net displacement is zero at that point.

An Antinode occurs when the string vibrates with the largest amplitude.

STANDING WAVES, cont.

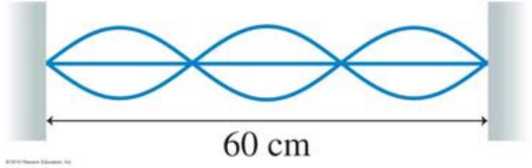
The distance between adjacent nodes or antinode:
is one-half the wavelength of the wave: $d_{\mathrm{NN}} = \frac{1}{2}\lambda$



All points on the string oscillate together vertically with the same frequency, but different points have different amplitudes of motion.

Homework

- The figure shows a standing wave oscillating at 100 Hz on a string. What is the wave speed?



- Two submarines are underwater and approaching each other head-on. Sub A has a speed of 12 m/s and sub B has a speed of 8 m/s. Sub A sends out a 1550 Hz sonar wave that travels at a speed of 1522 m/s. What is the frequency detected by sub B?
- When two coherent waves combine **destructively** to create a minimum, what is the smallest phase difference possible in Degrees and Radians?