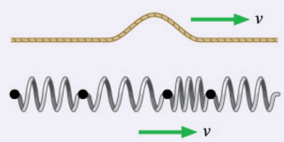
Physics 4A
Chapters 16 and 17: Traveling Waves and Superposition

GENERAL PRINCIPLES

The Wave Model

This model is based on the idea of a traveling wave, which is an organized disturbance traveling at a well-defined **wave speed** v.

- In transverse waves the displacement is perpendicular to the direction in which the wave travels.
- In longitudinal waves the particles of the medium are displaced parallel to the direction in which the wave travels.



A wave transfers **energy,** but no material or substance is transferred outward from the source.

Two basic classes of waves:

- Mechanical waves travel through a material medium such as water or air.
- Electromagnetic waves require no material medium and can travel through a vacuum.

For mechanical waves, such as sound waves and waves on strings, the speed of the wave is a property of the medium. Speed does not depend on the size or shape of the wave.

IMPORTANT CONCEPTS

The **displacement** D of a wave is a function of both position (where) and time (when).

- A snapshot graph shows the wave's displacement as a function of position at a single instant of time.

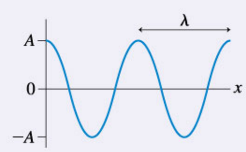
- A history graph shows the wave's displacement as a function of time at a single point in space.

For a transverse wave on a string, the snapshot graph is a picture of the wave. The displacement of a longitudinal wave is parallel to the motion; thus the snapshot graph of a longitudinal sound wave is *not* a picture of the wave.

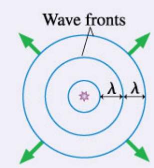
Sinusoidal waves are periodic in both time (period T) and space (wavelength λ):

$$D(x, t) = A\sin[2\pi(x/\lambda - t/T) + \phi_0]$$
$$= A\sin(kx - \omega t + \phi_0)$$

where A is the **amplitude,** $k = 2\pi/\lambda$ is the **wave number,** $\omega = 2\pi f = 2\pi/T$ is the **angular frequency,** and ϕ_0 is the **phase constant** that describes initial conditions.



One-dimensional waves



Two- and three-dimensional waves

The fundamental relationship for any sinusoidal wave is $v = \lambda f$.

APPLICATIONS

- **String** (transverse): $v = \sqrt{T_s/\mu}$
- **Sound** (longitudinal): $v = \sqrt{B/\rho} = 343$ m/s in 20°C air
- **Light** (transverse): $v = c/n$, where $c = 3.00 \times 10^8$ m/s is the speed of light in a vacuum and n is the material's **index of refraction**

The wave intensity is the power-to-area ratio: $I = P/a$

For a circular or spherical wave: $I = P_{source}/4\pi r^2$

The sound intensity level is

$$\beta = (10\text{ dB})\log_{10}(I/1.0 \times 10^{-12}\text{ W/m}^2)$$

The Doppler effect occurs when a wave source and detector are moving with respect to each other: the frequency detected differs from the frequency f_0 emitted.

Approaching source

$$f_+ = \frac{f_0}{1 - v_s/v}$$

Observer approaching a source

$$f_+ = (1 + v_o/v)f_0$$

Receding source

$$f_- = \frac{f_0}{1 + v_s/v}$$

Observer receding from a source

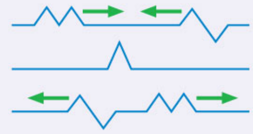
$$f_- = (1 - v_o/v)f_0$$

The Doppler effect for light uses a result derived from the theory of relativity.

GENERAL PRINCIPLES

Principle of Superposition

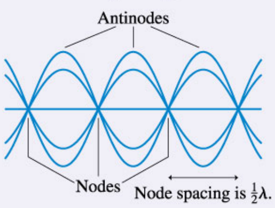
The displacement of a medium when more than one wave is present is the sum at each point of the displacements due to each individual wave.



IMPORTANT CONCEPTS

Standing Waves

Standing waves are due to the superposition of two traveling waves moving in opposite directions.

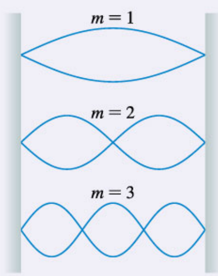


The amplitude at position x is

$$A(x) = 2a \sin kx$$

where a is the amplitude of each wave.

The boundary conditions determine which standing-wave frequencies and wavelengths are allowed. The allowed standing waves are **modes** of the system.



Standing waves on a string

Solving Interference Problems

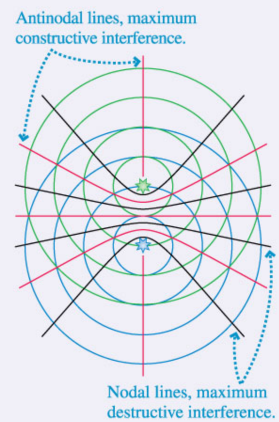
Maximum constructive interference occurs where crests are aligned with crests and troughs with troughs. The waves are in phase.

Maximum destructive interference occurs where crests are aligned with troughs. The waves are out of phase.

MODEL Model the wave as linear, circular, or spherical.

VISUALIZE Find distances to the sources.

SOLVE Interference depends on the **phase difference** $\Delta\phi$ between the waves:



$$\text{Constructive: } \Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = m \cdot 2\pi$$

$$\text{Destructive: } \Delta\phi = 2\pi\frac{\Delta r}{\lambda} + \Delta\phi_0 = \left(m + \tfrac{1}{2}\right) \cdot 2\pi$$

Δr is the path-length difference of the two waves, and $\Delta\phi_0$ is any phase difference between the sources. For identical (in-phase) sources:

$$\text{Constructive: } \Delta r = m\lambda \qquad \text{Destructive: } \Delta r = \left(m + \tfrac{1}{2}\right)\lambda$$

ASSESS Is the result reasonable?

APPLICATIONS

Boundary conditions

Strings, electromagnetic waves, and sound waves in closed-closed tubes must have nodes at both ends:

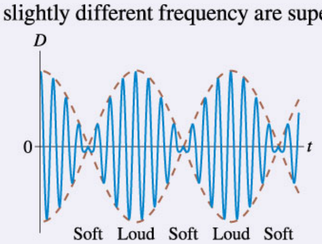
$$\lambda_m = \frac{2L}{m} \qquad f_m = m\frac{v}{2L} = mf_1 \qquad m = 1, 2, 3, \ldots$$

The frequencies and wavelengths are the same for a sound wave in an open-open tube, which has antinodes at both ends.

A sound wave in an open-closed tube must have a node at the closed end but an antinode at the open end. This leads to

$$\lambda_m = \frac{4L}{m} \qquad f_m = m\frac{v}{4L} = mf_1 \qquad m = 1, 3, 5, 7, \ldots$$

Beats (loud-soft-loud-soft modulations of intensity) occur when two waves of slightly different frequency are superimposed.

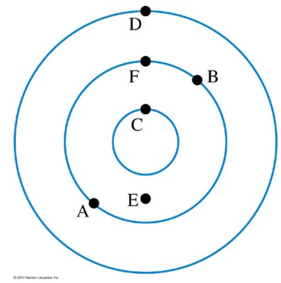


The beat frequency between waves of frequencies f_1 and f_2 is

$$f_{beat} = |f_1 - f_2|$$

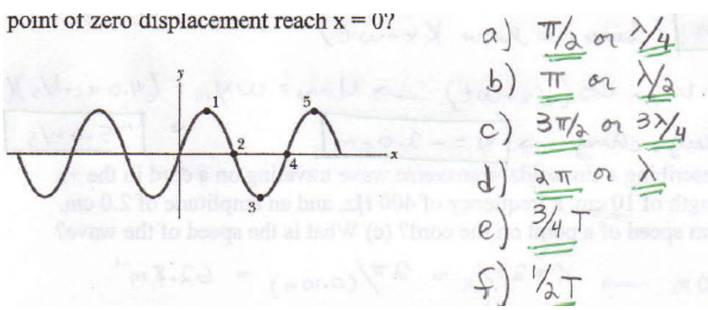
Questions and Example Problems from Chapter 16 and 17

Conceptual Question 16.9
The figure shows the wave fronts of a circular wave. What is the phase difference between **(a)** points A and B, **(b)** points C and D, and **(c)** points E and F?

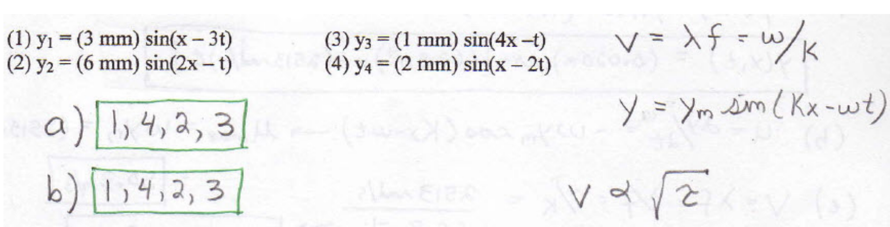


16.9. **(a)** 0; they are on the same wave front. **(b)** 4π rad; because they are two wave crests apart. **(c)** π rad; because F is on a crest and E on an adjacent trough.

Conceptual Question 16.A
In the figure below, five points are indicated on a snapshot of a sinusoidal wave. What is the phase difference between point 1 and **(a)** point 2, **(b)** point 3, **(c)** point 4, and **(d)** point 5? Answer in radians and in terms of the wavelength of the wave. The snapshot shows a point of zero displacement at x = 0. In terms of the period T of the wave, when will **(e)** a peak and **(f)** the next point of zero displacement reach x = 0?



Conceptual Question 16.B
The following four waves are sent along strings with the same linear densities (*x* is in meters and *t* is in seconds). Rank the waves according to **(a)** their wave speed and **(b)** the tensions in the strings along which they travel, greatest first:



Conceptual Question 17.9
The figure shows the circular waves emitted by two in-phase sources. Are a, b, and c points of maximum constructive interference, maximum destructive interference, or in between?

17.9. At point a, two crests are arriving at the same place at the same time from in-phase sources, so it is a point of constructive interference. At point b, a crest from source 2 is arriving at the same time as a trough is arriving from source 1, so it is a point of destructive interference. At point c, two troughs are arriving at the same place at the same time from in-phase sources, so it is a point of constructive interference.

Problem 16.2

A 25 g string is under 20 N of tension. A pulse travels the length of the string in 50 ms. How long is the string?

16.2. Solve:

$$L = v\Delta t = \sqrt{\frac{T_S}{\mu}}\,\Delta t = \sqrt{\frac{T_S}{m/L}}\,\Delta t = \sqrt{\frac{T_S L}{m}}\,\Delta t \Rightarrow \sqrt{L} = \sqrt{\frac{T_S}{m}}\,\Delta t \Rightarrow$$

$$L = \frac{T_S}{m}(\Delta t)^2 = \frac{20\ \text{N}}{0.025\ \text{kg}}(50\ \text{ms})^2 = 2.0\ \text{m}$$

Assess: 2.0 m seems like a reasonable length for a string.

Problem 16.12

The displacement of a wave traveling in the positive x-direction is $D(x,t) = (3.5cm)\sin(2.7x - 124t)$, where x is in m and t is in s. What are the **(a)** frequency, **(b)** wavelength, and **(c)** speed of this wave?

16.12. Model: The wave is a traveling wave.
Solve: **(a)** A comparison of the wave equation with Equation 16.14 yields: $A = 5.2$ cm, $k = 5.5$ rad/m, $\omega =$ 72 rad/s, and $\phi_0 = 0$ rad. The frequency is

$$f = \frac{\omega}{2\pi} = \frac{72\ \text{rad/s}}{2\pi} = 11.5\ \text{Hz} \approx 11\ \text{Hz}$$

(b) The wavelength is

$$\lambda = \frac{2\pi}{k} = \frac{2\pi}{5.5\ \text{rad/m}} = 1.14\ \text{m} \approx 1.1\ \text{m}$$

(c) The wave speed $v = \lambda f = 13$ m/s.

Problem 16.41

A friend of yours is loudly singing a single note at 400 Hz while racing toward you at 25.0 m/s on a day when the speed of sound is 340 m/s. **(a)** What frequency do you hear? **(b)** What frequency does your friend hear if you suddenly start singing at 400 Hz?

16.41. Model: Your friend's frequency is altered by the Doppler effect. The frequency of your friend's note increases as he races toward you (moving source and a stationary observer). The frequency of your note for your approaching friend is also higher (stationary source and a moving observer).
Solve: **(a)** The frequency of your friend's note as heard by you is

$$f_+ = \frac{f_0}{1 - \frac{v_S}{v}} = \frac{400\ \text{Hz}}{1 - \frac{25.0\ \text{m/s}}{340\ \text{m/s}}} = 432\ \text{Hz}$$

(b) The frequency heard by your friend of your note is

$$f_+ = f_0\left(1 + \frac{v_0}{v}\right) = (400\ \text{Hz})\left(1 + \frac{25.0\ \text{m/s}}{340\ \text{m/s}}\right) = 429\ \text{Hz}$$

Problem 16.44

A mother hawk screeches as she dives at you. You recall from biology that female hawks screech at 800 Hz, but you hear the screech at 900 Hz. How fast is the hawk approaching?

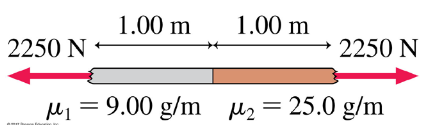
16.44. Model: The mother hawk's frequency is altered by the Doppler effect.
Solve: The frequency is f_+ as the hawk approaches you is

$$f_+ = \frac{f_0}{1 - v_S/v} \Rightarrow 900\ \text{Hz} = \frac{800\ \text{Hz}}{1 - \dfrac{v_S}{343\ \text{m/s}}} \Rightarrow v_S = 38.1\ \text{m/s}$$

Assess: The mother hawk's speed of $38.1\ \text{m/s} \approx 80\ \text{mph}$ is reasonable.

Problem 16.59

A wire is made by welding together two metals having different densities. The figure shows a 2.00-m-long section of wire centered on the junction, but the wire extends much farther in both directions. The wire is placed under 2250 N tension, then a 1500 Hz wave with an amplitude of 3.00 mm is sent down the wire. How many wavelengths (complete cycles) of the wave are in this 2.00-m-long section of the wire?



16.59. Solve: The wave speeds along the two metal wires are

$$v_1 = \sqrt{\frac{T}{\mu_1}} = \sqrt{\frac{2250\ \text{N}}{0.009\ \text{kg/m}}} = 500\ \text{m/s} \qquad v_2 = \sqrt{\frac{T}{\mu_2}} = \sqrt{\frac{2250\ \text{N}}{0.025\ \text{kg/m}}} = 300\ \text{m/s}$$

The wavelengths along the two wires are

$$\lambda_1 = \frac{v_1}{f} = \frac{500\ \text{m/s}}{1500\ \text{Hz}} = \frac{1}{3}\ \text{m} \qquad \lambda_2 = \frac{v_2}{f} = \frac{300\ \text{m/s}}{1500\ \text{Hz}} = \frac{1}{5}\ \text{m}$$

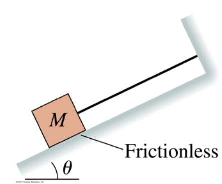
Thus, the number of wavelengths over two sections of the wire are

$$\frac{1.0\ \text{m}}{\lambda_1} = \frac{1.0\ \text{m}}{\left(\frac{1}{3}\ \text{m}\right)} = 3 \qquad \frac{1.0\ \text{m}}{\lambda_2} = \frac{1.0\ \text{m}}{\left(\frac{1}{5}\ \text{m}\right)} = 5$$

The number of complete cycles of the wave in the 2.00-m-long wire is 8.

Problem 16.60

The string in the figure has linear density μ. Find an expression in terms of M, μ, and θ for the speed of waves on the string.



16.60. Model: The object is in static equilibrium. μ is the linear density of the string, *not* a coefficient of friction.
Visualize: Use tilted axes with the x-direction along the string. The tension in the string is T_S.
Solve: From a free-body diagram we see that

$$\Sigma F_x = T_S - Mg\sin\theta = 0 \Rightarrow T_S = Mg\sin\theta$$

$$v = \sqrt{\frac{T_S}{\mu}} = \sqrt{\frac{Mg\sin\theta}{\mu}}$$

Problem 16.A

The equation of a transverse wave traveling along a very long string is y = 6.0 *sin*(0.020πx + 4.0πt), where x and y are expressed in centimeters and t is in seconds. Determine **(a)** the amplitude, **(b)** the wavelength, **(c)** the frequency, **(d)** the speed, **(e)** the direction of propagation of the wave, and **(f)** the maximum transverse speed of a particle in the string. **(g)** What is the transverse displacement at x = 3.5 cm when t = 0.26 s?

$$y = (6.0\text{ cm}) \sin\left[(0.020\pi\text{ cm}^{-1})x + (4.0\pi\text{ rad/s})t\right]$$

a) amplitude $\boxed{y_m = 6.0\text{ cm}}$

b) $K = 2\pi/\lambda \rightarrow \lambda = 2\pi/K = 2\pi/(0.020\pi\text{ cm}^{-1}) \rightarrow \boxed{\lambda = 100\text{ cm}}$

c) $f = \omega/2\pi = \dfrac{(4.0\pi\text{ rad/s})}{2\pi} \rightarrow \boxed{f = 2.0\text{ Hz}}$

d) $v = \lambda f = (100\text{ cm})(2.0\text{ Hz}) \rightarrow \boxed{v = 200\text{ cm/s}}$

e) $\boxed{-x\text{ direction}}$ (since we have $Kx + \omega t$)

f) $u = \partial y/\partial t = \omega y_m \cos(Kx + \omega t) \rightarrow u_{max} = \omega y_m = (4.0\pi\text{ rad/s})(6.0\text{ cm})$ $= \boxed{75.0\text{ m/s}}$

Problem 2 g) plug + chug $\rightarrow \boxed{y = -2.0\text{ cm}}$

Problem 16.B
The equation of a transverse wave on a string is

$$y = (2.0\text{ mm}) \sin\left[(20\text{ m}^{-1})x - (600\text{ s}^{-1})t\right]$$

The tension in the string is 15 N. **(a)** What is the wave speed? **(b)** Find the linear density of the string in grams per meter.

wave equation $y(x,t) = y_m \sin(Kx - \omega t)$

$y_m = 2.0\text{ mm}$

$K = 20\text{ m}^{-1}$

$\omega = 600\text{ rad/s}$

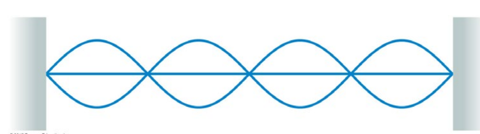
(a) $v = \omega/K = \dfrac{600\text{ rad/s}}{20\text{ m}^{-1}} \rightarrow \boxed{v = 30\text{ m/s}}$

(b) $v = \sqrt{\dfrac{\tau}{\mu}} \rightarrow v^2 = \tau/\mu \rightarrow \mu = \tau/v^2$

$\mu = \dfrac{15\text{ N}}{(30\text{ m/s})^2} \rightarrow \mu = 1.67\times10^{-2}\text{ Kg/m}$

$\boxed{\mu = 16.7\text{ g/m}}$

Problem 17.6
The figure shows the standing wave on a 2.0-m-long string that has been fixed at both ends and tightened until the wave speed is 40 m/s. What is the frequency?

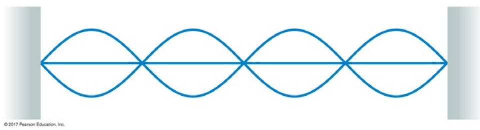


17.6. Model: Reflections at both ends of the string cause the formation of a standing wave.
Solve: The figure indicates two full wavelengths on the string. Thus, the wavelength of the standing wave is $\lambda = \frac{1}{2}(2.0\text{ m}) = 1.0\text{ m}$. The frequency of the standing wave is

$$f = \frac{v}{\lambda} = \frac{40\text{ m/s}}{1.0\text{ m}} = 40\text{ Hz}$$

Problem 17.7

The figure shows a standing wave on a string that is oscillating at 100 Hz. **(a)** How many antinodes will there be if the frequency is increase to 200 Hz? **(b)** If the tension is increased by a factor of 4, at what frequency will the string continue to oscillate as a standing wave that looks like the one in the figure?



17.7. Model: Reflections at the string boundaries cause a standing wave on the string.

Solve: (a) When the frequency is doubled to 200 Hz the wavelength is halved $(\lambda' = \frac{1}{2}\lambda_0)$. This halving of the wavelength will increase the number of antinodes from 4 to 8.

(b) Increasing the tension by a factor of 4 means

$$v = \sqrt{\frac{T}{\mu}} \quad \Rightarrow \quad v' = \sqrt{\frac{T'}{\mu}} = \sqrt{\frac{4T}{\mu}} = 2v$$

For the string to continue to oscillate as a standing wave with four antinodes means $\lambda' = \lambda_0$. Hence,

$$v' = 2v \quad \Rightarrow \quad f'\lambda' = 2f_0\lambda_0 \quad \Rightarrow \quad f'\lambda_0 = 2f_0\lambda_0 \quad \Rightarrow \quad f' = 2f_0 = 200 \text{ Hz}$$

That is, the new frequency is 200 Hz, twice the original frequency.

Problem 17.22

Two loud speakers emit sound waves along the x-axis. The sound has maximum intensity when the speakers are 20 cm apart. The sound intensity decreases as the distance between the speakers is increased, reaching zero at a separation of 60 cm. **(a)** What is the wavelength of the sound? **(b)** If the distance between the speakers continues to increase, at what separation will the sound intensity again be a maximum?

17.22. Model: Interference occurs according to the difference between the phases $(\Delta\phi)$ of the two waves.

Solve: (a) A separation of 20 cm between the speakers leads to maximum intensity on the x-axis, but a separation of 60 cm leads to zero intensity. That is, the waves are in phase when $(\Delta x)_1 = 20$ cm but out of phase when $(\Delta x)_2 = 60$ cm. Thus,

$$(\Delta x)_2 - (\Delta x)_1 = \frac{\lambda}{2} \quad \Rightarrow \quad \lambda = 2(60 \text{ cm} - 20 \text{ cm}) = 80 \text{ cm}$$

(b) If the distance between the speakers continues to increase, the intensity will again be a maximum when the separation between the speakers that produced a maximum has increased by one wavelength. That is, when the separation between the speakers is $20 \text{ cm} + 80 \text{ cm} = 100 \text{ cm}$.

Problem 17.41

A violinist places her finger so that the vibrating section of a 1.0 g/m string has a length of 30 cm, then she draws her bow across it. A listener nearby in a 20° C room hears a note with a wavelength of 40 cm. What is the tension in the string?

17.41. Model: The wave on a stretched string with both ends fixed is a standing wave.

Solve: We must distinguish between the sound wave in the air and the wave on the string. The listener hears a sound wave of wavelength $\lambda_{\text{sound}} = 40 \text{ cm} = 0.40 \text{ m}$. Thus, the frequency is

$$f = \frac{v_{sound}}{\lambda_{sound}} = \frac{343 \text{ m/s}}{0.40 \text{ m}} = 857.5 \text{ Hz}$$

The violin string oscillates at the same frequency, because each oscillation of the string causes one oscillation of the air. But the *wavelength* of the standing wave on the string is very different because the wave speed on the string is not the same as the wave speed in air. Bowing a string produces sound at the string's fundamental frequency, so the wavelength of the string is

$$\lambda_{string} = \lambda_1 = 2L = 0.60 \text{ m} \quad \Rightarrow \quad v_{string} = \lambda_{string} f = (0.60 \text{ m})(857.5 \text{ Hz}) = 514.5 \text{ m/s}$$

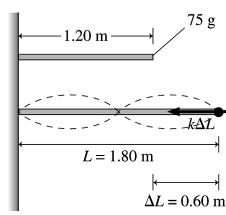
The tension is the string is found as follows:

$$v_{string} = \sqrt{\frac{T_S}{\mu}} \quad \Rightarrow \quad T_S = \mu(v_{string})^2 = (0.001 \text{ kg/m})(514.5 \text{ m/s})^2 = 260 \text{ N}$$

Problem 17.44

A 75 g bungee cord has an equilibrium length of 1.20 m. The cord is stretched to a length of 1.80 m, then vibrated at 20 Hz. This produces a standing wave with two antinodes. What is the spring constant of the bungee cord?

17.44. Model: The stretched bungee cord that forms a standing wave with two antinodes is vibrating at the second harmonic frequency.
Visualize:



Solve: Because the vibrating cord has two antinodes, $\lambda_2 = L = 1.80$ m. The wave speed on the cord is

$$v_{cord} = f\lambda = (20 \text{ Hz})(1.80 \text{ m}) = 36 \text{ m/s}$$

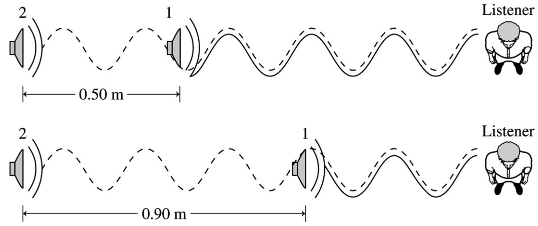
The linear density of the cord is $v_{cord} = \sqrt{T_s/\mu}$. The tension T_S in the cord is equal to $k\Delta L$, where k is the bungee's spring constant and ΔL is the 0.60 m the bungee has been stretched. The linear density has to be calculated at the stretched length of 1.8 m where it is now vibrating. Thus,

$$v_{cord} = \sqrt{\frac{T_s}{\mu}} = \sqrt{\frac{k\Delta L}{m/L}} \Rightarrow k = \frac{mv_{cord}^2}{L\Delta L} = \frac{(0.075 \text{ kg})(36 \text{ m/s})^2}{(1.80 \text{ m})(0.60 \text{ m})} = 90 \text{ N/m}$$

Problem 17.62

Two loudspeakers emit sound waves along the x-axis. A listener in front of both speakers hears a maximum sound intensity when speaker 2 is at the origin and speaker 1 is at x = 0.50 m. If speaker 1 is slowly moved forward, the sound intensity decreases and then increases, reaching a maximum when speaker 1 is at x = 0.90 m. **(a)** What is the frequency of the sound? Assume v_{sound} = 340 m/s. **(b)** What is the phase difference between the speakers?

17.62. Model: Interference occurs according to the difference between the phases of the two waves.
Visualize:



Solve: **(a)** The phase difference between the sound waves from the two speakers is

$$\Delta\phi = 2\pi\frac{\Delta x}{\lambda} + \Delta\phi_0$$

We have a maximum intensity when $\Delta x = 0.50$ m and $\Delta x = 0.90$ m. This means

$$2\pi\frac{(0.50\text{ m})}{\lambda} + \Delta\phi_0 = 2m\pi\text{ rad} \qquad 2\pi\left(\frac{0.90\text{ m}}{\lambda}\right) + \Delta\phi_0 = 2(m+1)\pi\text{ rad}$$

Taking the difference of these two equations gives

$$2\pi\left(\frac{0.40\text{ m}}{\lambda}\right) = 2\pi \;\Rightarrow\; \lambda = 0.40\text{ m} \;\Rightarrow\; f = \frac{v_{\text{sound}}}{\lambda} = \frac{340\text{ m/s}}{0.40\text{ m}} = 850\text{ Hz}$$

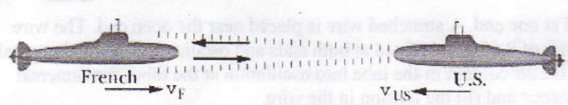
(b) Using again the equations that correspond to constructive interference, we find

$$2\pi\left(\frac{0.50\text{ m}}{0.40\text{ m}}\right) + \Delta\phi_0 = 2m\pi\text{ rad} \;\Rightarrow\; \Delta\phi_0 = \phi_{20} - \phi_{10} = -\frac{\pi}{2}\text{rad}$$

We have taken $m = 1$ in the last equation. This is because we always specify phase constants in the range $-\pi$ rad to π rad (or 0 rad to 2π rad). $m = 1$ gives $-\frac{1}{2}\pi$ rad (or equivalently, $m = 2$ will give $\frac{3}{2}\pi$ rad).

Problem 17.A

In the figure below, a French submarine and a U.S. submarine move toward each other during maneuvers in motionless water in the North Atlantic. The French sub moves at speed $v_F = 50.00$ km/h, and the U.S. sub at $v_{US} = 70.00$ km/h. The French sub sends out a sonar signal (sound wave in water) at 1.00×10^3 Hz. Sonar waves travel at 5470 km/h. (a) What is the signal's frequency as detected by the U.S. sub? (b) What frequency is detected by the French sub in the signal reflected back to it by the U.S. sub?



$$f' = f\left(\frac{V \pm V_D}{V \mp V_S}\right)$$

(a) $f = 1.00\times10^3$ Hz
$V_S = 50.00$ Km/hr
$V_D = 70.00$ Km/hr
$V = 5470$ Km/hr

$$f' = f\left(\frac{V + V_D}{V - V_S}\right)$$

$$f' = (1.00\times10^3\text{ Hz})\left[\frac{5470\text{ Km/hr} + 70.00\text{ Km/hr}}{5470\text{ Km/hr} - 50.00\text{ Km/hr}}\right]$$

$f' = 1022$ Hz

(b) $f = 1022$ Hz
$V_S = 70.00$ Km/hr
$V_D = 50.00$ Km/hr
$V = 5470$ Km/hr

$$f' = f\left(\frac{V + V_D}{V - V_S}\right)$$

$$f' = (1022\text{ Hz})\left[\frac{5470\text{ Km/hr} + 50.00\text{ Km/hr}}{5470\text{ Km/hr} - 70.00\text{ Km/hr}}\right]$$

$f' = 1045$ Hz