Questions and Example Problems from Chapters 15 and 16

Question 1

Two cars, one behind the other, are traveling in the same direction at the same speed. Does either driver hear the other's horn at a frequency that is different from that heard when both cars are at rest?

No, both cars hear the same frequency as when the cars are at rest. The formula for the Doppler effect is $f = \left(\frac{1 \pm V_o/V}{1 \mp V_s/V}\right) f_o$. Assuming the cars are moving like:

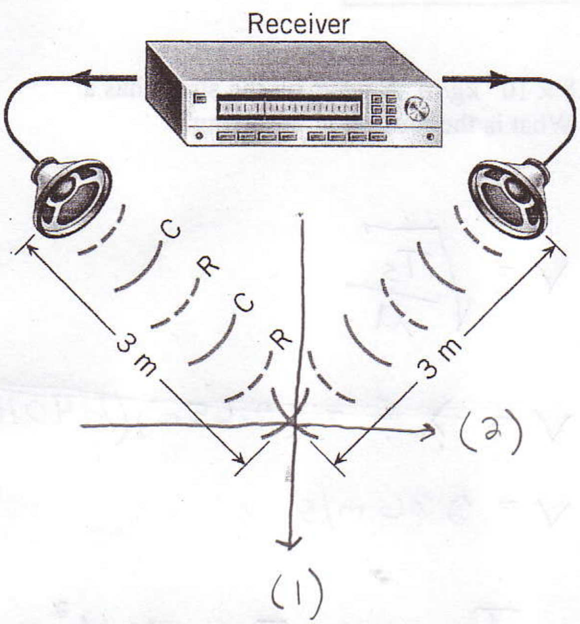
[A] → [B] →
source observer

This equation gives $f = \left(\frac{1 - V_o/V}{1 - V_s/V}\right) f_o$.

If $V_o = V_s$, then $f = f_o$.

Question 2

Refer to the figure below. As you walk along a line that is perpendicular to the line between the speakers and passes through the overlap point, you do not observe the loudness to change from loud to faint to loud. However, as you walk along a line through the overlap point and parallel to the line between the speakers, you do observe the loudness to alternate between faint and loud. Explain why your observations are different in the two cases.



constructive interference:

$\Delta d = m\lambda \quad m = 0, 1, 2, \ldots$

destructive interference:

$\Delta d = (m + \frac{1}{2})\lambda \quad m = 0, 1, 2, \ldots$

In case (1), you are always the same distance from each speaker so $\Delta d = 0$ and there is always constructive interference.

In case (2), Δd changes so you alternate between constructive + destructive interference as you walk.

Problem 1
A person lying on an air mattress in the ocean rises and falls through one complete cycle every five seconds. The crests of the wave causing the motion are 20.0 m apart. Determine (a) the frequency and (b) the speed of the wave.

⇒ the period of the wave is the same as the period of the person so $T = 5.00s$

(a) $f = 1/T = 1/5.00s \longrightarrow \boxed{f = 0.200 Hz}$

(b) $f = 0.200 Hz$

$\lambda = 20.0 m$

$v = ?$

$v = \lambda f$

$= (20.0 m)(0.200 Hz)$

$\boxed{v = 40.0 m/s}$

Problem 2
The linear density of the A string on a violin is 7.8×10^{-4} kg/m. A wave on the string has a frequency of 440 Hz and a wavelength of 65 cm. What is the tension in the string?

$m/L = 7.8 \times 10^{-4} Kg/m$

$f = 440 Hz$

$\lambda = 65 cm = 0.65 m$

$T_s = ?$

$v = \sqrt{\frac{T_s}{\mu}}$

$v = \lambda f = (0.65 m)(440 Hz)$

$v = 286 m/s$

$v = \sqrt{\frac{T_s}{\mu}} \longrightarrow v^2 = \frac{T_s}{\mu} \longrightarrow T_s = \mu v^2$

$T_s = (7.8 \times 10^{-4} Kg/m)(286 m/s)^2$

$\boxed{T_s = 63.8 N}$

Problem 3

The middle C string on a piano is under a tension of 944 N. The period and wavelength of a wave on this string are 3.82 ms and 1.26 m, respectively. Find the linear density of the string.

$T_s = 944N$

$T = 3.82 \times 10^{-3} s$

$\lambda = 1.26 m$

$\mu = ?$

$$v = \lambda f = \lambda / T = \frac{1.26m}{3.82 \times 10^{-3} s}$$

$$\underline{v = 330 m/s}$$

$$v = \sqrt{\frac{T_s}{\mu}} \rightarrow v^2 = \frac{T_s}{\mu} \rightarrow \mu = T_s / v^2$$

$$\mu = \frac{944N}{(330 m/s)^2} \rightarrow \boxed{\mu = 8.67 \times 10^{-3}\ Kg/m}$$

Problem 4

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. (a) What is the frequency detected by sub B? (b) Part of the sonar wave is reflected from B and returns to A. What frequency does A detect for this reflected wave?

(a) $f_o = 1550 Hz$ $\quad \xrightarrow{A} \ \xleftarrow{B}$

$V_s = 12 m/s$

$V_o = 8 m/s$

$V = 1522 m/s$

$f = ?$

$$f = \left(\frac{1 \pm V_o/V}{1 \mp V_s/V} \right) f_o \rightarrow f = \left(\frac{1 + V_o/V}{1 - V_s/V} \right) f_o$$

$$f = \left[\frac{1 + \frac{(8 m/s)}{1522 m/s}}{1 - \frac{(12 m/s)}{1522 m/s}} \right] (1550 Hz) = \boxed{1571 Hz}$$

(b) $f_o = 1571 Hz$

$V_s = 8 m/s$

$V_o = 12 m/s$

$V = 1522 m/s$

$f = ?$

$$f = \left(\frac{1 + V_o/V}{1 - V_s/V} \right) f_o$$

$$f = \left[\frac{1 + \frac{12 m/s}{1522 m/s}}{1 - \frac{8 m/s}{1522 m/s}} \right] (1571 Hz)$$

$$\boxed{f = 1592 Hz}$$

Problem 5

The security alarm on a parked car goes off and produces a frequency of 960 Hz. The speed of sound is 343 m/s. As you drive toward this parked car, pass it, and drive away, you observe the frequency to change by 95 Hz. At what speed are you driving?

$f_o = 960\,Hz$ observer moving toward source $f = (1 + V_o/V)f_o$

$V = 343\,m/s$ observer moving away from source $f = (1 - V_o/V)f_o$

$\Delta f = 95\,Hz$

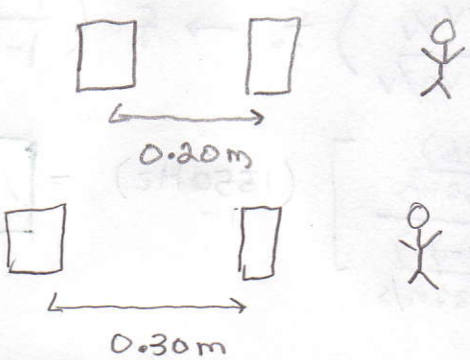
$V_o = ?$ $\Delta f = f_{toward} - f_{away} = (1 + V_o/V)f_o - (1 - V_o/V)f_o$

$$\Delta f = 2f_o(V_o/V)$$

$$V_o = \frac{(\Delta f)V}{2f_o} \longrightarrow V_o = \frac{(95\,Hz)(343\,m/s)}{2(960\,Hz)} \longrightarrow \boxed{V_o = 17\,m/s}$$

Problem 6

Two loudspeakers 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 30 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?



$\Delta d = 0.20\,m$ max intensity → constructive interference

$\Delta d = m\lambda \longrightarrow \lambda = \frac{\Delta d}{m} = \frac{0.20\,m}{m}$ $m = 1, 2, 3, \ldots$

$\lambda = 0.20\,m, 0.10\,m, 0.067\,m, \ldots$

$\Delta d = 0.30\,m$ destructive interference

$\Delta d = (m + \tfrac{1}{2})\lambda \longrightarrow \lambda = \frac{\Delta d}{m + \frac{1}{2}}$ $m = 0, 1, 2, \ldots$

$\lambda = 0.60\,m, 0.20\,m, 0.12\,m, \ldots$

(a) $\lambda = 0.20\,m$ (this is the wavelength in common to both).

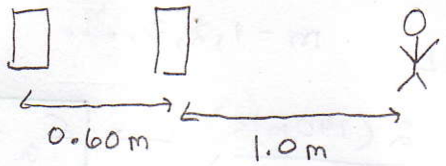
(b) sound intensity is a maximum for $\Delta d = m\lambda$ $m = 0, 1, 2, \ldots$

$\Delta d = m(0.20\,m) \longrightarrow \Delta d = 0, 0.20\,m, 0.40\,m, \ldots$

$$\boxed{\Delta d = 0.40\,m}$$

Problem 7

A pair of in-phase stereo speakers are placed next to each other, 0.60 m apart. You stand directly in front of one of the speakers, 1.0 m from the speaker. What is the lowest frequency that will produce constructive interference at your location?



$\Delta d = d_2 - d_1 = 1.60\text{m} - 1.0\text{m}$

$\Delta d = 0.60\text{m}$

$V = 343\text{m/s}$

constructive interference: $\Delta d = m\lambda \quad m = 0, 1, 2, \ldots \longrightarrow \lambda = \frac{\Delta d}{m}$

$\lambda f = v \longrightarrow f = v/\lambda = v/(\Delta d/m) \longrightarrow f = \frac{mv}{\Delta d} \quad m = 0, 1, 2, \ldots$

lowest (non-zero) frequency $\longrightarrow m = 1$

$f = \frac{(1)(343\text{m/s})}{0.60\text{m}} \longrightarrow \boxed{f = 572\text{ Hz}}$

Problem 8

Two out-of-tune flutes play the same note. One produces a tone that has a frequency of 262 Hz, while the other produces 266 Hz. When a tuning fork is sounded together with the 262-Hz tone, a beat frequency of 1 Hz is produced. When the same tuning fork is sounded together with the 266 Hz tone, a beat frequency of 3 Hz is produced. What is the frequency of the tuning fork?

$f_{beat} = |f_2 - f_1| \longrightarrow f_2 = f_1 \pm f_{beat}$

$\Rightarrow$ 1 Hz beat frequency when sounded with 262 Hz tone implies frequency of tuning fork is $\underline{\underline{f = 261\text{ Hz}}}$ or $\underline{\underline{f = 263\text{ Hz}}}$

$\Rightarrow$ 3 Hz beat frequency when sounded with 266 Hz tone implies frequency of tuning fork is $\underline{\underline{f = 263\text{ Hz}}}$ or $\underline{\underline{f = 269\text{ Hz}}}$

$$\boxed{f_{\text{tuning fork}} = 263\text{ Hz}}$$

Problem 9
A string of length 0.28 m is fixed at both ends. The string is plucked and a standing wave is set up that is vibrating at its second harmonic. The traveling waves that make up the standing waves have a speed of 140 m/s. What is the frequency of vibration?

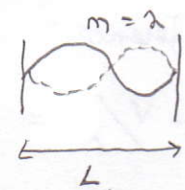
$L = 0.28\,m$ $\quad f_m = m\,V/2L \quad m = 1, 2, 3, \ldots$

$m = 2$

$V = 140\,m/s$ $\quad f_2 = \frac{2V}{2L} = \frac{2(140\,m/s)}{2(0.28\,m)} \longrightarrow \boxed{f_2 = 500\,Hz}$

$f_2 = ?$

alternate method $\longrightarrow$



$\lambda = L = 0.28\,m$

$\lambda f = V$

$f = V/\lambda = \frac{140\,m/s}{0.28\,m} \longrightarrow \boxed{f = 500\,Hz}$

Problem 10
On a cello, the string with the largest linear density (1.56×10^{-2} kg/m) is the C string. The string produces a fundamental frequency of 65.4 Hz and has a length of 0.800 m between the two fixed ends. Find the tension in the string.

$\mu = 1.56 \times 10^{-2}\,kg/m$ $\quad f_m = m\left(\frac{V}{2L}\right) = m f_1 \quad f_1 = V/2L$

$f_1 = 65.4\,Hz$

$L = 0.800\,m$

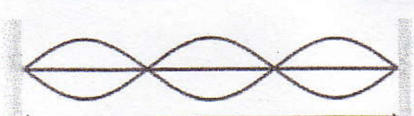
$\left.\begin{aligned} V &= 2Lf_1 \\ V &= \sqrt{\frac{T_s}{\mu}} \end{aligned}\right\} \; 2Lf_1 = \sqrt{\frac{T_s}{\mu}}$

$T_s = ?$

$4L^2 f_1^2 = T_s/\mu \longrightarrow T_s = 4L^2 f_1^2 \mu$

$T_s = 4(0.800\,m)^2(65.4\,Hz)^2(1.56 \times 10^{-2}\,kg/m) = \boxed{171\,N}$

Problem 11
The figure shows a standing wave oscillating at 100 Hz on a string. What is the wave speed?



60 cm

$f = 100\,Hz$

$\lambda = 0.40\,m$

$\lambda = 40\,cm = 0.40\,m$

$v = \lambda f$

$v = (0.40\,m)(100\,Hz) = \boxed{40\,m/s}$