Physics 23
Assignment 2 Solutions

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E19-6
a) In miles per second, the speed of sound is 02.06 mi/s. In five seconds, the sound of the
lightning travels approximately 1.03 miles, which is about 3 percent too large.
b) Simply count in seconds and divide by 3.

E19-20
Let one person speak with an intensity \(I_1\). N people would have an intensity \(I_2 = NI_1\). The sound levels and intensities are related by
\[
SL_1 - SL_2 = 10 \log \left( \frac{I_1}{I_2} \right) = 10 \log \left( \frac{1}{N} \right).
\]
(1)
Using \(SL_1 = 65dB\) and \(SL_2 = 80dB\), we obtain \(N \approx 32\).

E19-24
a) The path length difference (the extra distance that a wave from the upper speaker has
to travel compared to the lower one in order to reach the listener) between the waves from
the speakers is
\[
\Delta L = [(2.12m)^2 + (3.75m)^2]^{1/2} - 3.75m \approx 0.56m.
\]
(2)
In order to have a minimum when reaching the listener, upon traveling the path length
difference a wave from the upper speaker must be completely out of phase with the wave
from the lower speaker. (we assume that the speakers emit waves at the same time with
the same wavelength and frequency) Therefore \(\Delta L\) must be a half integer number of the
wavelengths so that
\[
\Delta L = \left( n - \frac{1}{2} \right) \lambda \approx 0.56m,
\]
(3)
where \( n \) is an integer. Since
\[
f = \frac{c_s}{\lambda},
\]
where \( c_s \) is the speed of sound in air, the listener will hear a minimum at the frequencies
\[
f \approx \left( n - \frac{1}{2} \right) 615 \text{ Hz}.
\]

b) Now \( \Delta L \) must be an integer number of the wavelengths so that the waves arrive at the listener in phase. We therefore have
\[
\Delta L = n\lambda \cong 0.56 \text{ m}.
\]
The frequencies for which the listener hears a maximum are thus
\[
f \cong n(615 \text{ Hz}).
\]

E19-32

Since the tunnel is open on both ends, the air pressure perturbation at the ends must be zero, therefore the resonance condition for sound waves inside the tunnel is exactly the same as for that of standing waves on a string,
\[
f = \frac{nc_s}{2L}.
\]
Here \( n \) is an integer, \( L \) is the length of the tunnel and \( c_s \) is the speed of sound in air. Assuming that 135Hz and 138Hz are two consecutive resonances (or overtones) of the tunnel, the conditions on the shortest possible \( L \) are
\[
L = \frac{nc_s}{2f_n},
\]
and
\[
L = \frac{(n + 1)c_s}{2f_{n+1}},
\]
where \( f_n = 135 \text{ Hz} \) and \( f_{n+1} = 138 \text{ Hz} \). Solving the two equations, we obtain \( L \cong 57.2 \text{ m} \).

P19-6

a) To obtain a minima at D, the wave traveling through SBD must destructively interfere with that through SAD. Conversely, position D will see a maxima only if waves from the
two paths interfere constructively. Therefore changing the length of the SBD has to add half
a wavelength to the path length difference between SBD and SAD. Since the same length
is added on both sides of the tube, we see that \(2(1.65\text{cm}) \approx \lambda/2\) and thus \(\lambda \approx 6.6\text{cm}\),
corresponding to approximately 5200Hz.
b) Let the amplitude of the wave from SAD and SBD be \(S_1\) and \(S_2\), respectively. When D
hears a minima, the waves destructively interfere and so their amplitudes subtract in order
to give the detected intensity:

\[
I_{\text{min}} \propto (s_1 - s_2)^2.
\]  

(11)

On the other hand, the amplitudes add when we have complete constructive interference,
so that

\[
I_{\text{max}} \propto (s_1 + s_2)^2.
\]  

(12)

Solving for the ratio \(s_1/s_2\), we obtain

\[
\frac{s_1}{s_2} = \frac{I^{1/2}_{\text{max}} + I^{1/2}_{\text{min}}}{I^{1/2}_{\text{max}} - I^{1/2}_{\text{min}}} \approx 2.
\]  

(13)

P19-12

a) The sound wave in the tube is in the fundamental \((n=1)\) mode with frequency

\[
f_1 = \frac{nc_s}{4L_t} = \frac{c_s}{4L_t} \approx 72.7\text{Hz},
\]  

(14)

where \(L_t\) is the length of the tube. Note that we have a factor 4 instead of 2 in the
denominator of Eqn.(14) since one end of the tube is closed.
b) Since the string also vibrate at \(f_1\), the tension is

\[
T = \mu v^2 = \mu(\lambda f_1)^2 = \mu(L_s f_1)^2 \approx 67.1\text{N}.
\]  

(15)

Here \(\lambda = 2L_s\), where \(L_s\) is the string length, since we have an \(n=1\) mode.

P19-16

a) The observer is stationary while both sources are moving. The Doppler shifted frequencies are

\[
f_\pm = f \frac{c_s}{c_s \pm v_s},
\]  

(16)
where $v_s$ is the speed of the source, $f$ is the original frequency and $f_+$ is the up shifted frequency due to the source moving closer, corresponding to the minus sign in the formula. $f_-$ gives the reverse. The observer hears the beat frequency of the up and down shifted waves:

$$\Delta f = f_+ - f_- \approx 81 \text{Hz}. \quad (17)$$

b) Now the sources are stationary while the observer moves, resulting in Doppler shifted frequencies of

$$f_{\pm} = f \frac{c_s \pm v_o}{c_s}. \quad (18)$$

Here $v_o$ is the speed of the observer. The plus sign in the equation gives the up shifted frequency $f_+$ with the observer moving towards the source. The minus sign indicates the opposite. The observer hears a beat frequency of approximately 81Hz.

**P19-20**

The submarine moves at 75.2km/h wrt to the ocean floor but only $75.2 \text{km/h} - 30.5 \text{km/h} \approx 12.4 \text{m/s}$ wrt to the medium, namely the ocean current. Since the Doppler shift equations are derived in the reference frame of the medium, we effectively have a stationary observer listening to a moving source, since the observing ship is stationary wrt to the current. The resulting shifted frequency is therefore

$$f' = f \frac{c_s}{c_s - v_s} \approx 997 \text{Hz}. \quad (19)$$

Note that the speed of sound in water is approximately 1482m/s, much greater than in air.