33. Two loudspeakers, $A$ and $B$ (Fig. E16.33), are driven by the same amplifier and emit sinusoidal waves in phase. Speaker $B$ is 2.00 m to the right of speaker $A$. Consider point $Q$ along the extension of the line connecting the speakers, 1.00 m to the right of speaker $B$. Both speakers emit sound waves that travel directly from the speaker to point $Q$. (a) What is the lowest frequency for which constructive interference occurs at point $Q$? (b) What is the lowest frequency for which destructive interference occurs at point $Q$?

(a) For constructive interference, the path difference must be an integer number of wavelengths. The lowest frequency for this would be the longest wavelength, with the path difference equal to one wavelength.

$$\lambda = 2 \text{ m} \Rightarrow f = v/\lambda = (344 \text{ m/s})/2 \text{ m} = 172 \text{ Hz}.$$  

(b) For destructive interference, the path difference must be $n + 1/2$ wavelengths. The lowest frequency for this would be the longest wavelength, with the path difference equal to one-half wavelength.

$$\lambda = 4 \text{ m} \Rightarrow f = v/\lambda = (344 \text{ m/s})/4 \text{ m} = 86 \text{ Hz}.$$  

35. Two loudspeakers, $A$ and $B$, are driven by the same amplifier and emit sinusoidal waves in phase. Speaker $B$ is 12.0 m to the right of speaker $A$. The frequency of the waves emitted by each speaker is 688 Hz. You are standing between the speakers, along the line connecting them, and are at a point of constructive interference. How far must you walk toward speaker $B$ to move to a point of destructive interference?

The path difference must be $\lambda/2 = v/2f = (344 \text{ m/s})/(2 \cdot 688 \text{ Hz}) = 0.250 \text{ m}$. You achieve this path difference by moving half of this amount, or $0.125 \text{ m}$.  

39. Tuning a Violin. A violinist is tuning her instrument to concert A (440 Hz). She plays the note while listening to an electronically generated tone of exactly that frequency and hears a beat of frequency 3 Hz, which increases to 4 Hz when she tightens her violin string slightly. (a) What was the frequency of the note played by her violin when she heard the 3-Hz beat? (b) To get her violin perfectly tuned to concert A, should she tighten or loosen her string from what it was when she heard the 3-Hz beat?

(a) When she tightened the string, it increased the pitch and increased the error from 440. So she was 3 Hz above to start with, or $443 \text{ Hz}$. The answer in the back of the book is a misprint.  

(b) If tightening was the wrong way, loosen it.  

43. On the planet Arrakis a male ornithoid is flying toward his mate at 25.0 m/s while singing at a frequency of 1200 Hz. If the stationary female hears a tone of 1240 Hz, what is the speed of sound in the atmosphere of Arrakis?

Moving source equation $f' = f_0/(1 + v_s/v)$. Solve for $v$ (a few lines):

$$v = v_s f'/(f' - f_0) = (25 \text{ m/s})(1240 \text{ Hz})/(40 \text{ Hz}) = 775 \text{ m/s}.$$  

48. Moving Source vs. Moving Listener. (a) A sound source producing 1.00-kHz waves moves toward a stationary listener at one-half the speed of sound. What frequency will the listener hear? (b) Suppose instead that the source is stationary and the listener moves toward the source at
one-half the speed of sound. What frequency does the listener hear? How does your answer compare to that in part (a)? Explain on physical grounds why the two answers differ.

(a) \( f' = f_0/(1 - v_S/v) = (1 \text{ kHz})/(1 - 1/2) = 2.00 \text{ kHz} \).
(b) \( f' = f_0(1 + v_L/v) = (1 \text{ kHz})(1 + 1/2) = 1.50 \text{ kHz} \).

In the first case, the wavelengths are being compressed by a factor of 2. In the second case, the wavelength is unchanged, but the wave speed relative to the listener is boosted by a factor of 1.5.

65. An organ pipe has two successive harmonics with frequencies 1372 and 1764 Hz. (a) Is this an open or a stopped pipe? Explain. (b) What two harmonics are these? (c) What is the length of the pipe?

(a) The difference is obviously 392 Hz. If this is open-open, then the difference between successive harmonics is the fundamental, so that any harmonic is an integer multiple of the fundamental. For an open-closed tube, any harmonic is \((2n+1)\) times the fundamental. Since \(1372/392 = 3.5\), this is a stopped pipe.
(b) The fundamental is therefore \( (392 \text{ Hz})/2 = 196 \text{ Hz} \), so 1372 Hz is the 7th harmonic and 1764 Hz the 9th. Remember that the even harmonics don’t appear - only the odd ones.
(c) \( f_1 = v/4L \Rightarrow L = v/4F_1 = (344 \text{ m/s})/(4 \cdot 196 \text{ Hz}) = 0.439 \text{ m} \).

79. Supernova! The gas cloud known as the Crab Nebula can be seen with even a small telescope. It is the remnant of a supernova, a cataclysmic explosion of a star. The explosion was seen on the earth on July 4, 1054 C.E. The streamers glow with the characteristic red color of heated hydrogen gas. In a laboratory on the earth, heated hydrogen produces red light with frequency \( 4.568 \times 10^{14} \text{ Hz} \); the red light received from streamers in the Crab Nebula pointed toward the earth has frequency \( 4.586 \times 10^{14} \text{ Hz} \). (a) Estimate the speed with which the outer edges of the Crab Nebula are expanding. Assume that the speed of the center of the nebula relative to the earth is negligible. (You may use the formulas derived in Problem 16.78. The speed of light is \( 3.00 \times 10^8 \text{ m/s} \)) (b) Assuming that the expansion speed has been constant since the supernova explosion, estimate the diameter of the Crab Nebula. Give your answer in meters and in light-years. (c) The angular diameter of the Crab Nebula as seen from earth is about 5 arc minutes (1 arc-minute = 1/60 degree. Estimate the distance (in light-years) to the Crab Nebula, and estimate the year in which the supernova explosion actually took place.

(a) Take the formula in problem 78: \( F_R = f_S(1 - v/c) \). Note that \( c \) is the speed of the wave (light) and \( v \) is the speed of the source. Solve for \( v \) and plug:
\[
v = c(1 - f_R/f_S) = (3.00 \times 10^8 \text{ m/s})(1 - 4.586/4.568) = 1.18 \times 10^6 \text{ m/s}.
\]
If you look closely at the accuracy of the factor in parentheses, we are only justified in two sigdigs, but I’ll keep one extra.
(b) I will assume an observation date of Jul 4, 2014, so the elapsed time is 960.00 years, or
\[
\Delta t = (960 \text{ yr})(3.16 \times 10^7 \text{ sec/yr} = 3.03 \times 10^{10} \text{ s}.
\]
The distance traveled is the radius, so the diameter \( d \) is twice that:
\[
d = 2 \cdot (1.2 \times 10^6 \text{ m/s})(3.03 \times 10^{10} \text{ s}) = 7.14 \times 10^{16} \text{ m}.
\]
\[
d = (3.57 \times 10^{16} \text{ m})(1 \text{ LY})/(9.46 \times 10^{15} \text{ m}) = 7.76 \text{ LY}.
\]
(c) Astronomers reasonably assume that the cloud is roughly spherical, so that the physical diameter we obtained from the Doppler shift, which is along our line of sight, is equal to the physical diameter across the line of sight \( d' \). Since the angular diameter is small, we can use the
small angle approximation that $d' = R\theta$, where $R$ is the range to the Crab and $\theta$ is measured in radians. 

$\theta = (5/60)^\circ = 0.083^\circ = 1.45 \times 10^{-3}$ rad. 
$R = d'/\theta = (7.76 \text{ LY})/(1.45 \times 10^{-3} \text{ rad}) = 5350 \text{ LY}$.

This means the light took 5350 years to reach Earth, so the explosion actually took place around 4100 BCE, reaching Earth in 1054 CE. 
The accepted distance is 6523 LY, so we’re off about 20% on this crude technique.

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**Opt. 81.** A woman stands at rest in front of a large, smooth wall. She holds a vibrating tuning fork of frequency $f_0$ directly in front of her (between her and the wall). (a) The woman now runs toward the wall with speed $v_W$. She detects beats due to the interference between the sound waves reaching her directly from the fork and those reaching her after being reflected from the wall. How many beats per second will she detect? (Note: If the beat frequency is too large, the woman may have to use some instrumentation other than her ears to detect and count the beats.) (b) If the woman instead runs away from the wall, holding the tuning fork at her back so it is between her and the wall, how many beats per second will she detect?

(a) First: she hears the fork in her hand at $f_0$, since both are moving in the same direction at the same speed. A person standing near the wall hears frequency $f_1$, where 

$$f_1 = f_0 v/(v - v_W).$$

The reflected wave is heard by the standing person at $f_1$. However, the runner hears it shifted to $f_2$ based on the moving listener equation:

$$f_2 = f_1 (v + v_W)/v.$$  Substitute for $f_1$:

$$f_2 = f_0 [(v + v_W)/v][v/(v - vW)] = f_0 (v + v_W)/(v - v_W).$$

The problem asks for the beat frequency, which is the absolute value of the difference between $f_0$ and $f_2$:

$$f_{\text{beat}} = f_0 [(v + v_W)/(v - v_W) - 1] = 2f_0 v_W/(v - v_W) \text{ Answer. (a bit of algebra).}$$

(b) Substitute $-v_W$ for $v_W$ in part (a); then take the absolute value, since it’s a beat frequency.

**Answer:**  $2f_0 v_W/(v + v_W)$. 