Solutions to HW29, Chapter 16

NOTE! The problems in masteringphysics.com had their numbers altered slightly for each individual student. The solutions below use the same numbers as those used in the book for that problem!

Section 16.1 An Introduction to Waves

16.21. Model: Microwaves are electromagnetic waves that travel with a speed of 3×10^8 m/s.

Solve: (a) The frequency of the microwave is

$$f_{\text{microwaves}} = \frac{c}{\lambda} = \frac{3.0\times10^8 \text{ m/s}}{3.0\times10^{-2} \text{ m}} = 1.0\times10^{10} \text{ Hz} = 10 \text{ GHz}$$

(b) The refractive index of air is 1.0003, so the speed of microwaves in air is $v_{\text{air}} = c/1.00 \approx \text{c}$. The time for the microwave signal to travel is

$$t = \frac{50 \text{ km}}{v_{\text{air}}} = \frac{50\times10^3 \text{ m}}{(3.0\times10^8 \text{ m/1.00})} = 0.167 \text{ ms} \approx 0.17 \text{ ms}$$

Assess: A small time of 0.17 ms for the microwaves to cover a distance of 50 km shows that the electromagnetic waves travel very fast.

16.22. Solve: Two pulses of sound are detected because one pulse travels through the metal to the microphone while the other travels through the air to the microphone. The time interval for the sound pulse traveling through the air is

$$\Delta t_{\text{air}} = \frac{\Delta x}{v_{\text{air}}} = \frac{4.00 \text{ m}}{343 \text{ m/s}} = 0.01166 \text{ s} = 11.66 \text{ ms}$$

Sound travels *faster* through solids than gases, so the pulse traveling through the metal will reach the microphone *before* the pulse traveling through the air. Because the pulses are separated in time by 9.00 ms, the pulse traveling through the metal takes $\Delta t_{\text{metal}} = 2.66 \text{ ms}$ to travel the 4.00 m to the microphone. Thus, the speed of sound in the metal is

$$v_{\text{metal}} = \frac{\Delta x}{\Delta t_{\text{metal}}} = \frac{4.00 \text{ m}}{0.00266 \text{ s}} = 1504 \text{ m/s} \approx 1500 \text{ m/s}$$

16.25. Solve: (a) The speed of light in a material is given by Equation 16.37:

$$n = \frac{c}{v_{\text{mat}}} \Rightarrow v_{\text{mat}} = \frac{c}{n}$$

The refractive index is

$$n = \frac{\lambda_{\text{vac}}}{\lambda_{\text{mat}}} \Rightarrow v_{\text{solid}} = c\frac{\lambda_{\text{solid}}}{\lambda_{\text{vac}}} = (3.0\times10^8 \text{ m/s})\frac{420 \text{ nm}}{670 \text{ nm}} = 1.88\times10^8 \text{ m/s}$$

(b) The frequency is

$$f = \frac{v_{\text{solid}}}{\lambda_{\text{solid}}} = \frac{1.88\times10^8 \text{ m/s}}{420 \text{ nm}} = 4.48\times10^{14} \text{ Hz}$$

16.26. Model: $v = \lambda f$ applies.

Solve: (a) The frequency must remain the same since the harmonic oscillators in one medium excite the oscillators in the second medium. So $f_{\text{water}} = 440$ Hz.

(b) The table in the chapter gives $v_{\text{water}} = 1480$ m/s.

$$\lambda = \frac{v}{f} = \frac{1480 \text{ m/s}}{440 \text{ Hz}} = 3.4 \text{ m}$$

Assess: This is a reasonable wavelength for a sound wave.

Section 16.7 Waves in Two and Three Dimensions

16.29. Solve: According to Equation 16.56, the phase difference between two points on a wave is

$$\Delta\phi = \phi_2 - \phi_1 = 2\pi\frac{\Delta r}{\lambda} = \frac{2\pi}{\lambda}(r_2 - r_1) \Rightarrow (3\pi \text{ rad} - 0 \text{ rad}) = \frac{2\pi}{\lambda}(80 \text{ cm} - 20 \text{ cm}) \Rightarrow \lambda = 40 \text{ cm}$$

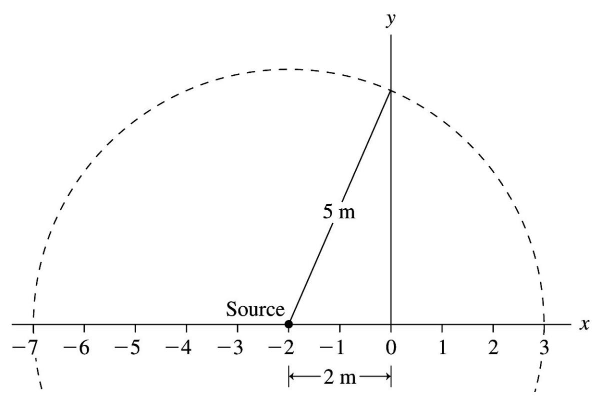
16.31. Visualize: A phase difference of 2π rad corresponds to a distance of λ. Set up a ratio.

Solve:

$$\frac{x}{\lambda} = \frac{5.5 \text{ rad}}{2\pi \text{ rad}} \Rightarrow x = \left(\frac{5.5 \text{ rad}}{2\pi \text{ rad}}\right)\lambda = \left(\frac{5.5 \text{ rad}}{2\pi \text{ rad}}\right)\frac{v}{f} = \left(\frac{5.5 \text{ rad}}{2\pi \text{ rad}}\right)\frac{340 \text{ m/s}}{120 \text{ Hz}} = 2.5 \text{ m}$$

Assess: 2.5 m seems like a reasonable distance.

16.32. Visualize:



Solve: **(a)** Because the same wavefront simultaneously reaches listeners at $x = -7.0$ m and $x = +3.0$ m,

$$\Delta\phi = 0 \text{ rad} = \frac{2\pi}{\lambda}(r_2 - r_1) \Rightarrow r_2 = r_1$$

Thus, the source is at $x = -2.0$ m, so that it is equidistant from the two listeners.

(b) The third person is also 5.0 m away from the source. Her y-coordinate is thus $y = \sqrt{(5 \text{ m})^2 - (2 \text{ m})^2} = 4.6$ m.

Section 16.9 The Doppler Effect

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

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

16.42. Model: The frequency of the opera singer's note is altered by the Doppler effect.

Solve: **(a)** Using $90 \text{ km/h} = 25 \text{ m/s}$, the frequency as her convertible approaches the stationary person is

$$f_+ = \frac{f_0}{1 - v_S/v} = \frac{600 \text{ Hz}}{1 - \frac{25 \text{ m/s}}{343 \text{ m/s}}} = 650 \text{ Hz}$$

(b) The frequency as her convertible recedes from the stationary person is

$$f_- = \frac{f_0}{1 + v_S/v} = \frac{600 \text{ Hz}}{1 + \frac{25 \text{ m/s}}{343 \text{ m/s}}} = 560 \text{ Hz}$$

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.

16.50. Model: The laser beam is an electromagnetic wave that travels with the speed of light.
Solve: The speed of light in the liquid is

$$v_{\text{liquid}} = \frac{30 \times 10^{-2}\ \text{m}}{1.38 \times 10^{-9}\ \text{s}} = 2.174 \times 10^8\ \text{m/s}$$

The liquid's index of refraction is

$$n = \frac{c}{v_{\text{liquid}}} = \frac{3.0 \times 10^8}{2.174 \times 10^8} = 1.38$$

Thus the wavelength of the laser beam in the liquid is

$$\lambda_{\text{liquid}} = \frac{\lambda_{\text{vac}}}{n} = \frac{633\ \text{nm}}{1.38} = 459\ \text{nm}$$

16.74. Model: The sound generator's frequency is altered by the Doppler effect. The frequency increases as the generator approaches the student, and it decreases as the generator recedes from the student.
Solve: The generator's speed is

$$v_S = r\omega = r(2\pi f) = (1.0\ \text{m})2\pi\left(\frac{100}{60}\ \text{rev/s}\right) = 10.47\ \text{m/s}$$

The frequency of the approaching generator is

$$f_+ = \frac{f_0}{1 - v_S/v} = \frac{600\ \text{Hz}}{1 - \dfrac{10.47\ \text{m/s}}{343\ \text{m/s}}} = 619\ \text{Hz} \approx 620\ \text{Hz}$$

Doppler effect for the receding generator, on the other hand, is

$$f_- = \frac{f_0}{1 + v_S/v} = \frac{600\ \text{Hz}}{1 + \dfrac{10.47\ \text{m/s}}{343\ \text{m/s}}} = 582\ \text{Hz} \approx 580\ \text{Hz}$$

Thus, the highest and the lowest frequencies heard by the student are 620 Hz and 580 Hz.

16.80. Model: The Doppler effect for light of an approaching source leads to a decreased wavelength.
Solve: The red wavelength $(\lambda_0 = 650\ \text{nm})$ is Doppler shifted to green $(\lambda = 540\ \text{nm})$ due to the approaching light source. In relativity theory, the distinction between the motion of the source and the motion of the observer disappears. What matters is the relative approaching or receding motion between the source and the observer. Thus, we can use Equation 16.66 as follows:

$$\lambda = \lambda_0\sqrt{\frac{1 - v_s/c}{1 + v_s/c}} \Rightarrow 540\ \text{nm} = (650\ \text{nm})\sqrt{\frac{1 - v_s/c}{1 + v_s/c}}$$

$$\Rightarrow v_s = 5.5 \times 10^4\ \text{km/s} = 2.0 \times 10^8\ \text{km/h}$$

The fine will be

$$(2.0 \times 10^8\ \text{km/h} - 50\ \text{km/h})\left(\frac{1\ \$}{1\ \text{km/h}}\right) = \$200\ \text{million}$$

Assess: The police officer knew his physics.