

Physics 2A

Chapter 15/16 HW Solutions

Chapter 15

Conceptual Question: 5, 7

Problems: 2, 13, 23, 45, 50

Chapter 16

Conceptual Question: 3, 6

Problems: 2, 7, 13, 30, 59

Q15.5. Reason: Equation 15.2, $v_{\text{string}} = \sqrt{T_s/\mu}$, gives the wave speed on a stretched string with tension T_s and linear mass density $\mu = m/L$. We will investigate how T_s and μ are changed in each case below and how that affects the wave speed. Use a subscript 1 for the original string, and a subscript 2 for the altered string.

We are given that $(v_{\text{string}})_1 = 200 \text{ cm/s}$.

(a) $(T_s)_2 = 2(T_s)_1 \quad \mu_2 = \mu_1$

$$\frac{(v_{\text{string}})_2}{(v_{\text{string}})_1} = \frac{\sqrt{(T_s)_2/\mu_2}}{\sqrt{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_2/\mu_2}{(T_s)_1/\mu_1}} = \sqrt{\frac{2(T_s)_1/\mu_1}{(T_s)_1/\mu_1}} = \sqrt{2}$$

$$(v_{\text{string}})_2 = \sqrt{2}(v_{\text{string}})_1 = \sqrt{2}(200 \text{ cm/s}) = 280 \text{ cm/s}$$

(b) $(T_s)_2 = (T_s)_1 \quad m_2 = 4m_1 \Rightarrow \mu_2 = 4\mu_1$

$$\frac{(v_{\text{string}})_2}{(v_{\text{string}})_1} = \frac{\sqrt{(T_s)_2/\mu_2}}{\sqrt{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_2/\mu_2}{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_1/4\mu_1}{(T_s)_1/\mu_1}} = \frac{1}{2}$$

$$(v_{\text{string}})_2 = \frac{1}{2}(v_{\text{string}})_1 = \frac{1}{2}(200 \text{ cm/s}) = 100 \text{ cm/s}$$

(c) $(T_s)_2 = (T_s)_1 \quad L_2 = 4L_1 \Rightarrow \mu_2 = \frac{1}{4}\mu_1$

$$\frac{(v_{\text{string}})_2}{(v_{\text{string}})_1} = \frac{\sqrt{(T_s)_2/\mu_2}}{\sqrt{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_2/\mu_2}{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_1/\frac{1}{4}\mu_1}{(T_s)_1/\mu_1}} = 2$$

$$(v_{\text{string}})_2 = 2(v_{\text{string}})_1 = 2(200 \text{ cm/s}) = 400 \text{ cm/s}$$

(d) $(T_s)_2 = (T_s)_1 \quad m_2 = 4m_1 \quad \text{and} \quad L_2 = 4L_1 \Rightarrow \mu_2 = \mu_1$

$$\frac{(v_{\text{string}})_2}{(v_{\text{string}})_1} = \frac{\sqrt{(T_s)_2/\mu_2}}{\sqrt{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_2/\mu_2}{(T_s)_1/\mu_1}} = \sqrt{\frac{(T_s)_1/\mu_1}{(T_s)_1/\mu_1}} = 1$$

$$(v_{\text{string}})_2 = (v_{\text{string}})_1 = 200 \text{ cm/s}$$

Assess: Notice as in part (d) that if both the mass and length of the string are increased by the same factor, then μ is not changed, so the speed is the same (with no change in tension).

Q15.7. Reason: The speed of sound in air depends on the temperature of the air. The distance across the stadium can be measured to give the path length of the sound. Then, you can take the path length and divide by the time between the

emission and detection of the pulse to get the speed of the sound. Finally, once the speed of sound is known, you can find the corresponding temperature either by consulting a chart like Table 15.1 or by using Equation 15.3.

Assess: The advantage of measuring temperature this way is that it gives you an idea of the average temperature for the whole stadium. It also determines the temperature quickly—the time of measurement is simply the time it takes for sound to travel across the stadium.

P15.2. Prepare: The wave is a traveling wave on a stretched string. We will use Equation 15.2 to find the tension that corresponds to a wave speed of 180 m/s. To be able to obtain the tension from 15.2, we will first obtain μ from the first part of the problem.

Solve: The wave speed on a stretched string with linear density μ is

$$v_{\text{string}} = \sqrt{\frac{T_s}{\mu}} \Rightarrow 150 \text{ m/s} = \sqrt{\frac{75.0 \text{ N}}{\mu}} \Rightarrow \mu = 3.333 \times 10^{-3} \text{ kg/m}$$

For a wave speed of 180 m/s, the required tension will be

$$T_s = \mu v_{\text{string}}^2 = (3.333 \times 10^{-3} \text{ kg/m})(180 \text{ m/s})^2 = 110 \text{ N}$$

Assess: Increased wave speed must lead to increased tension, as is previously obtained.

P15.13. Prepare: Since the lab temperature is 20°C, we know the speed of sound is 343 m/s, as given in Table 15.1.

Solve: (a) $f = 40 \text{ kHz}$

$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{40 \times 10^3 \text{ Hz}} = 8.6 \text{ mm}$$

(b) For the round trip the distance is 5.0 m.

$$\Delta t = \frac{\Delta x}{v_x} = \frac{5.0 \text{ m}}{343 \text{ m/s}} = 0.015 \text{ s} = 15 \text{ ms}$$

Assess: 15 ms is quick by human reaction time standards, but it is easy to have electronics in the detector record time intervals such as this.

P15.23. Prepare: From Table 15.1, the speed of sound in room temperature air is 343 m/s and in water is 1480 m/s. On the other hand, the speed of an electromagnetic wave is c . We will use Equation 15.10 for the wave speed.

Solve: (a) The frequency is

$$f = \frac{v_{\text{air}}}{\lambda} = \frac{343 \text{ m/s}}{0.20 \text{ m}} = 1700 \text{ Hz}$$

to two significant figures.

(b) The frequency is

$$f = \frac{c}{\lambda} = \frac{3.0 \times 10^8 \text{ m/s}}{0.20 \text{ m}} = 1.5 \times 10^9 \text{ Hz} = 1.5 \text{ GHz}$$

(c) The speed of a sound wave in water is $v_{\text{water}} = 1480 \text{ m/s}$. The wavelength of the sound wave would be

$$\lambda = \frac{v_{\text{water}}}{f} = \frac{1480 \text{ m/s}}{1.5 \times 10^9 \text{ Hz}} = 9.9 \times 10^{-7} \text{ m} = 990 \text{ nm}$$

Assess: Because speed = frequency \times wavelength, we expected a much higher frequency for the electromagnetic wave.

P15.45. Prepare: First compute $f_0 = 3.0/10 \text{ s} = 0.30 \text{ Hz}$.

When the detector (you in the boat) is moving, the measured frequency is $f_- = 2.0/10 \text{ s} = 0.20 \text{ Hz}$.

The problem gives $v_o = 1.5 \text{ m/s}$.

Use Equation 15.17, $f_- = (1 - v_o/v)f_0$, and solve for v , the speed of the waves.

Solve:

$$\begin{aligned}\frac{f_-}{f_0} &= 1 - \frac{v_o}{v} \\ \frac{v_o}{v} &= 1 - \frac{f_-}{f_0} \\ v &= v_o \left(\frac{1}{1 - \frac{f_-}{f_0}} \right) \\ v &= v_o \left(\frac{f_0}{f_0 - f_-} \right) \\ v &= (1.5 \text{ m/s}) \left(\frac{0.30 \text{ Hz}}{0.30 \text{ Hz} - 0.20 \text{ Hz}} \right) = 4.5 \text{ m/s}\end{aligned}$$

Assess: These are pretty fast water waves, but within reason. The speed of surface water waves depends on the depth of the water, but is typically in the range of 2–3 m/s. However, tsunamis can travel much faster than this. Carefully note the subscripts: The o stands for observer while the 0 stands for the initial or original (frequency). They look similar but are different.

P15.50. Prepare: The wave pulse is a traveling wave on a stretched string. We will use Equations 15.2 and 15.1 to find the string mass.

Solve: The wave speed on a stretched string with linear density μ is

$$v_{\text{string}} = \sqrt{\frac{T_s}{\mu}} = \sqrt{\frac{T_s}{m/L}} = \sqrt{\frac{LT_s}{m}} \Rightarrow \frac{2.0 \text{ m}}{50 \times 10^{-3} \text{ s}} = \sqrt{\frac{(2.0 \text{ m})(20 \text{ N})}{m}} \Rightarrow m = 0.025 \text{ kg} = 25 \text{ g}$$

Assess: A mass of 25 g for the 2.0 m long string is realistic.

Q16.3. Reason: See Figure 16.10 in the text.

(a) In Chapter 15 we saw that the speed of a wave on a stretched string is $v = \sqrt{T_s/\mu}$. Since the left side of the string has a lower speed, the linear density must be greater there.

(b) You would start a pulse from the left side, in the part with the greater linear density, in order to have the reflection not inverted.

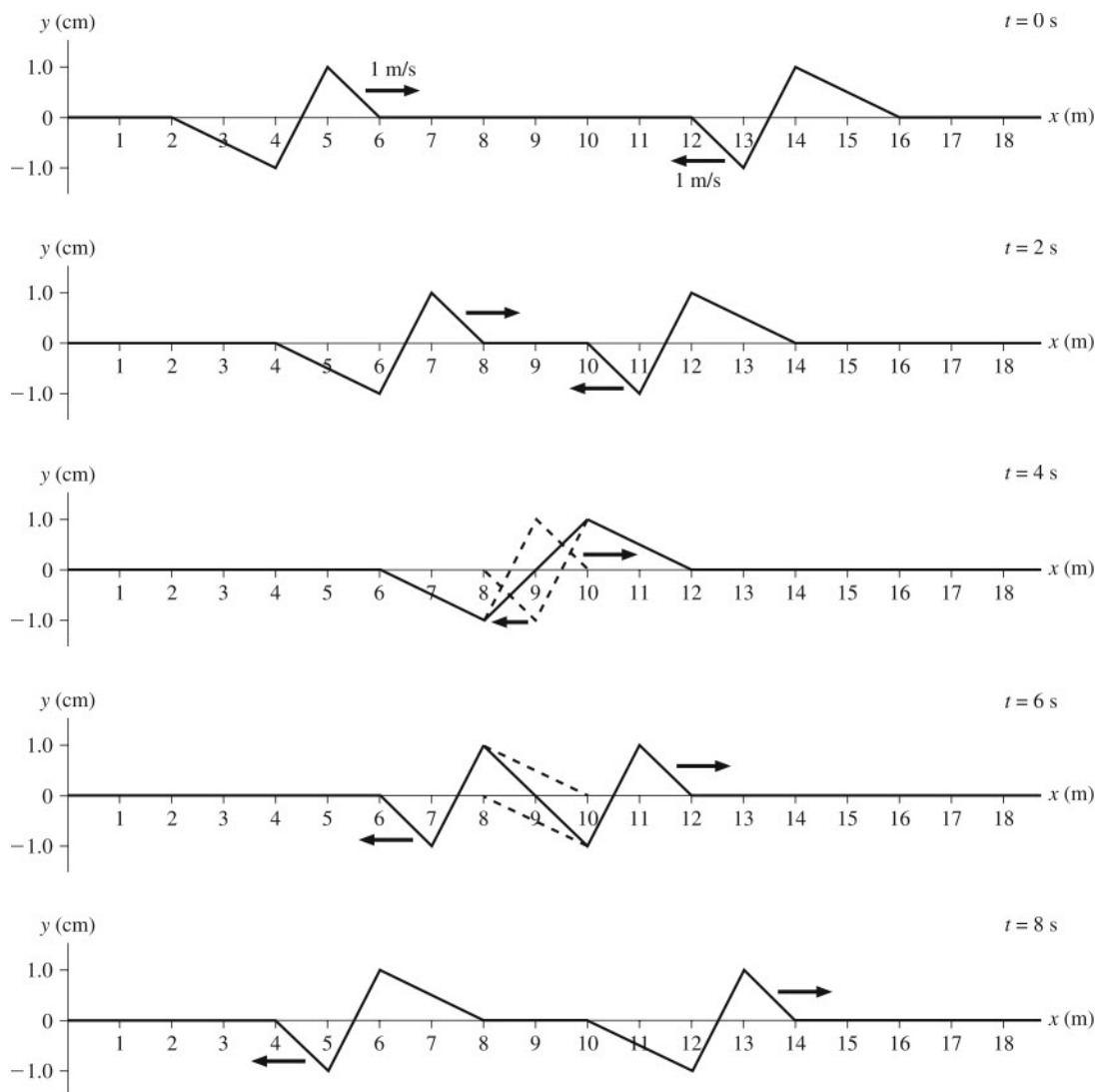
Assess: This would be a fairly easy experiment to set up at home with two different strings tied together.

Q16.6. Reason: When the frequency is doubled the wavelength is halved. This halving of the wavelength will increase the number of antinodes to six.

Assess: Calculating the number of antinodes in this situation is easier than calculating the number of nodes because there are nodes on each end of the string, so the number is not doubled: It goes from four to seven.

P16.2. Prepare: The principle of superposition comes into play whenever the waves overlap. The waves are approaching each other at a speed of 1 m/s, that is, each part of each wave is moving 1 m every second.

Solve: The graph at $t = 2$ s differs from the graph at $t = 0$ s in that the left wave has moved to the right by 2 m and the right wave has moved to the left by 2 m. This is because the distance covered by the wave pulse in 2 s is 2 m. The snapshot graphs at $t = 4$ s and $t = 6$ s are a superposition of the left- and the right-moving waves. The overlapping parts of the two are shown by the dotted lines.



Assess: This is an excellent problem because it allows you to see the progress of each wave and the superposition (addition) of the waves. As time progresses, you know exactly what has happened to each wave and to the superposition of these waves.

P16.7. Prepare: Reflections at both ends of the string cause the formation of a standing wave. Figure P16.7 indicates that there are three full wavelengths on the 2.0-m-long string and that the wave speed is 40 m/s. We will use Equation 15.10 to find the frequency of the standing wave.

Solve: The wavelength of the standing wave is $\lambda = \frac{1}{3}(2.0 \text{ m}) = 0.667 \text{ m}$. The frequency of the standing wave is thus

$$f = \frac{v}{\lambda} = \frac{40 \text{ m/s}}{0.667 \text{ m}} = 60 \text{ Hz}$$

Assess: The units are correct and this is a reasonable frequency for a vibrating string.

P16.13. Prepare: A string fixed at both ends forms standing waves. Three antinodes means the string are vibrating as the $m = 3$ standing wave. The wavelengths of standing wave modes of a string of length L are given by Equation 16.1.

Solve: (a) The frequency is $f_3 = 3f_1$, so the fundamental frequency is $f_1 = \frac{1}{3}(420 \text{ Hz}) = 140 \text{ Hz}$. The fifth harmonic will have the frequency $f_5 = 5f_1 = 700 \text{ Hz}$.

(b) The wavelength of the fundamental mode is $\lambda_1 = 2L = 1.20 \text{ m}$. The wave speed on the string is $v = \lambda_1 f_1 = (1.20 \text{ m})(140 \text{ Hz}) = 168 \text{ m/s}$. Alternatively, the wavelength of the $n = 3$ mode is $\lambda_3 = \frac{1}{3}(2L) = 0.40 \text{ m}$, from which $v = \lambda_3 f_3 = (0.40 \text{ m})(420 \text{ Hz}) = 168 \text{ m/s}$. The wave speed on the string, given by Equation 15.2, is

$$v = \sqrt{\frac{T_s}{\mu}} \Rightarrow T_s = \mu v^2 = (0.0020 \text{ kg/m})(168 \text{ m/s})^2 = 56 \text{ N}$$

Assess: You must remember to use the linear density in SI units of kg/m. Also, the speed is the same for all modes, but you must use a matching λ and f to calculate the speed.

P16.30. Prepare: We assume that the speakers are identical and that they are emitting in phase. Since you don't hear anything, the separation between the two speakers corresponds to the condition of destructive interference.

Solve: Equation 16.9 for destructive interference is

$$\Delta d = \left(m + \frac{1}{2}\right)\lambda \Rightarrow \Delta d = \frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}$$

Since the wavelength is

$$\lambda = \frac{v}{f} = \frac{340 \text{ m/s}}{170 \text{ Hz}} = 2.0 \text{ m}$$

three possible values for d are 1.0 m, 3.0 m, and 5.0 m.

Assess: The units worked out and these are reasonable distances.

P16.59. Prepare: The waves constructively interfere when speaker 2 is located at 0.75 m and 1.00 m, but not in between. Assume the two speakers are in phase (helpful for visualization, but the result will be generally true as long as the two frequencies are the same). For constructive interference the path length difference must be an integer number of wavelengths, $0.75 \text{ m} = n\lambda$, and $1.00 \text{ m} = (n+1)\lambda$. Subtracting the two equations gives $\lambda = 0.25 \text{ m}$.

Solve:

$$f = \frac{v}{\lambda} = \frac{340 \text{ m/s}}{0.25 \text{ m}} = 1360 \text{ Hz} \approx 1400 \text{ Hz}$$

Assess: 1400 Hz is near the "middle" of the range of human hearing, so it is probably right.