Physics 123 - 2013 - Solutions to Prob Set 5

1.
15-38

(a) The speed of the wave in a stretched cord is given by Eq. 15-2, $v=\sqrt{F_T/\mu}$. The tensions must be the same in both parts of the cord. If they were not the same, then the net longitudinal force on the joint between the two parts would not be zero, and the joint would have to accelerate along the length of the cord.

$$v=\sqrt{F_T/\mu} \;\rightarrow\; \frac{v_{II}}{v_I}=\frac{\sqrt{F_T/\mu_{II}}}{\sqrt{F_T/\mu_I}}=\boxed{\sqrt{\frac{\mu_I}{\mu_{II}}}}$$

(b) The frequency must be the same in both sections. If it were not, then the joint between the two sections would not be able to keep the two sections together. The ends could not stay in phase with each other if the frequencies were different.

$$f=\frac{v}{\lambda} \;\rightarrow\; \frac{v_{II}}{\lambda_{II}}=\frac{v_I}{\lambda_I} \;\rightarrow\; \frac{\lambda_{II}}{\lambda_I}=\frac{v_{II}}{v_I}=\boxed{\sqrt{\frac{\mu_I}{\mu_{II}}}}$$

(c) The ratio under the square root sign is less than 1, and so the lighter cord has the greater wavelength.

2.
15-86

The addition of the support will force the bridge to have its lowest mode of oscillation to have a node at the center of the span, which would be the first overtone of the fundamental frequency. If the wave speed in the bridge material remains constant, then the resonant frequency will double, to $\boxed{6.0\ \text{Hz}}$. Since earthquakes don't do significant shaking at that frequency, the modifications would be effective at keeping the bridge from having large oscillations during an earthquake.

3.
16-18

Compare the two power output ratings using the definition of decibels.

$$\beta = 10\log\frac{P_{150}}{P_{100}} = 10\log\frac{150\ \text{W}}{100\ \text{W}} = \boxed{1.8\ \text{dB}}$$

This would barely be perceptible.

4.
16-20

$$95 = 10 \log \frac{2 I_F}{I_0} = \underbrace{10 \log 2}_{3} + 10 \log \frac{I_F}{I_0}$$

I_f is intensity of single firecracker

$$95 = 3 + \underbrace{10 \log I_F / I_0}_{\beta \text{ for single firecracker}}$$

$$\beta_{single} = 95 - 3 \text{ dB} = 92 \text{ dB}$$

5.
16-26

(*a*) Find the intensity from the 130 dB value, and then find the power output corresponding to that intensity at that distance from the speaker.

$$\beta = 130\ \text{dB} = 10\log\frac{I_{2.8\text{m}}}{I_0} \rightarrow I_{2.8\text{m}} = 10^{13} I_0 = 10^{13}\left(1.0\times10^{-12}\ \text{W/m}^2\right) = 10\ \text{W/m}^2$$

$$P = IA = 4\pi r^2 I = 4\pi\left(2.2\,\text{m}\right)^2\left(10\ \text{W/m}^2\right) = 608\ \text{W} \approx \boxed{610\ \text{W}}$$

(*b*) Find the intensity from the 85 dB value, and then from the power output, find the distance corresponding to that intensity.

$$\beta = 85\,\text{dB} = 10\log\frac{I}{I_0} \rightarrow I = 10^{8.5} I_0 = 10^{8.5}\left(1.0\times10^{-12}\ \text{W/m}^2\right) = 3.16\times10^{-4}\ \text{W/m}^2$$

$$P = 4\pi r^2 I \rightarrow r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{608\ \text{W}}{4\pi\left(3.16\times10^{-4}\ \text{W/m}^2\right)}} = \boxed{390\,\text{m}}$$

6.
16-31

(*a*) We find the intensity of the sound from the decibel value, and then calculate the displacement amplitude from Eq. 15-7.

$$\beta = 10\log\frac{I}{I_0} \rightarrow I = 10^{\beta/10} I_0 = 10^{12}\left(10^{-12}\,\mathrm{W/m^2}\right) = 1.0\,\mathrm{W/m^2}$$

$$I = 2\pi^2 v\rho f^2 A^2 \rightarrow$$

$$A = \frac{1}{\pi f}\sqrt{\frac{I}{2\rho v}} = \frac{1}{\pi(330\,\mathrm{Hz})}\sqrt{\frac{1.0\,\mathrm{W/m^2}}{2(1.29\,\mathrm{kg/m^3})(343\,\mathrm{m/s})}} = \boxed{3.2\times10^{-5}\,\mathrm{m}}$$

(*b*) The pressure amplitude can be found from Eq. 16-7.

$$I = \frac{(\Delta P_M)^2}{2v\rho} \rightarrow$$

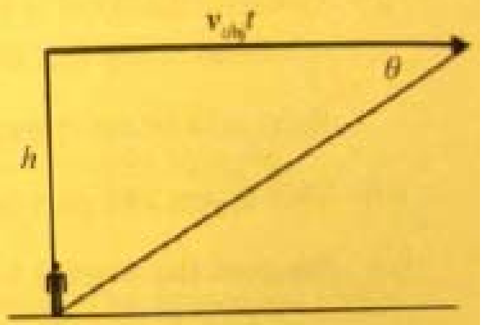
$$\Delta P_M = \sqrt{2v\rho I} = \sqrt{2(343\,\mathrm{m/s})(1.29\,\mathrm{kg/m^3})(1.0\,\mathrm{W/m^2})} = \boxed{30\,\mathrm{Pa}\,(2\text{ sig. fig.})}$$

7.
16-72

(*a*) The angle of the shock wave front relative to the direction of motion is given by Eq. 16-12.

$$\sin\theta = \frac{v_{snd}}{v_{obj}} = \frac{v_{snd}}{2.0v_{snd}} = \frac{1}{2.0} \rightarrow \theta = \sin^{-1}\frac{1}{2.0} = \boxed{30^\circ} \text{ (2 sig. fig.)}$$

(*b*) The displacement of the plane $(v_{obj}t)$ from the time it passes overhead to the time the shock wave reaches the observer is shown, along with the shock wave front. From the displacement and height of the plane, the time is found.



$$\tan\theta = \frac{h}{v_{obj}t} \rightarrow t = \frac{h}{v_{obj}\tan\theta}$$

$$= \frac{6500\text{ m}}{(2.0)(310\text{ m/s})\tan 30^\circ} = \boxed{18\text{ s}}$$

8.
16-74

From Eq. 16-12, $\sin\theta = \dfrac{v_{snd}}{v_{obj}}$.

(*a*) $\theta = \sin^{-1}\dfrac{v_{snd}}{v_{obj}} = \sin^{-1}\dfrac{343\,\text{m/s}}{8800\,\text{m/s}} = \boxed{2.2^\circ}$

(*b*) $\theta = \sin^{-1}\dfrac{v_{snd}}{v_{obj}} = \sin^{-1}\dfrac{1560\,\text{m/s}}{8800\,\text{m/s}} = \boxed{10^\circ}$ (2 sig. fig.)

9.
16-90

The apparatus is a closed tube. The water level is the closed end, and so is a node of air displacement. As the water level lowers, the distance from one resonance level to the next corresponds to the distance between adjacent nodes, which is one-half wavelength.

$$\Delta\ell = \tfrac{1}{2}\lambda \;\rightarrow\; \lambda = 2\Delta\ell = 2(0.395\,\text{m} - 0.125\,\text{m}) = 0.540\ \text{m}$$

$$f = \frac{v}{\lambda} = \frac{343\,\text{m/s}}{0.540\ \text{m}} = \boxed{635\ \text{Hz}}$$

10.
16-104

There will be two Doppler shifts in this problem – first for a stationary source with a moving "observer" (the blood cells), and then for a moving source (the blood cells) and a stationary "observer" (the receiver). Note that the velocity component of the blood parallel to the sound transmission is $v_{blood}\cos 45^\circ = \frac{1}{\sqrt{2}} v_{blood}$. It is that component that causes the Doppler shift.

$$f'_{blood} = f_{original}\left(1 - \frac{\frac{1}{\sqrt{2}} v_{blood}}{v_{snd}}\right)$$

$$f''_{detector} = \frac{f'_{blood}}{\left(1 + \frac{\frac{1}{\sqrt{2}} v_{blood}}{v_{snd}}\right)} = f_{original}\frac{\left(1 - \frac{\frac{1}{\sqrt{2}} v_{blood}}{v_{snd}}\right)}{\left(1 + \frac{\frac{1}{\sqrt{2}} v_{blood}}{v_{snd}}\right)} = f_{original}\frac{\left(v_{snd} - \frac{1}{\sqrt{2}} v_{blood}\right)}{\left(v_{snd} + \frac{1}{\sqrt{2}} v_{blood}\right)} \rightarrow$$

$$v_{blood} = \sqrt{2}\frac{\left(f_{original} - f''_{detector}\right)}{\left(f''_{detector} + f_{original}\right)} v_{snd}$$

Since the cells are moving away from the transmitter / receiver combination, the final frequency received is less than the original frequency, by 780 Hz. Thus $f''_{detector} = f_{original} - 780\,\text{Hz}$.

$$v_{blood} = \sqrt{2}\frac{\left(f_{original} - f''_{detector}\right)}{\left(f''_{detector} + f_{original}\right)} v_{snd} = \sqrt{2}\frac{(780\,\text{Hz})}{\left(2f_{original} - 780\,\text{Hz}\right)} v_{snd}$$

$$= \sqrt{2}\frac{(780\,\text{Hz})}{\left[2\left(5.0\times 10^6\,\text{Hz}\right) - 780\,\text{Hz}\right]}(1540\,\text{m/s}) = \boxed{0.17\,\text{m/s}}$$