11. From Example 12-4, we see that a sound level decrease of 3 dB corresponds to a halving of intensity. Thus, if two engines are shut down, the intensity will be cut in half, and the sound level will be 117 dB. Then, if one more engine is shut down, the intensity will be cut in half again, and the sound level will drop by 3 more dB, to a final value of $\boxed{114\text{ dB}}$.

14. (*a*) The energy absorbed per second is the power of the wave, which is the intensity times the area.

$$50\text{ dB} = 10\log\frac{I}{I_0} \quad\rightarrow\quad I = 10^5\, I_0 = 10^5\left(1.0\times10^{-12}\text{ W/m}^2\right) = 1.0\times10^{-7}\text{ W/m}^2$$

$$P = IA = \left(1.0\times10^{-7}\text{ W/m}^2\right)\left(5.0\times10^{-5}\text{ m}^2\right) = \boxed{5.0\times10^{-12}\text{ W}}$$

(*b*) $$1\text{ J}\left(\frac{1\text{ s}}{5.0\times10^{-12}\text{ J}}\right)\left(\frac{1\text{ yr}}{3.16\times10^{7}\text{ s}}\right) = \boxed{6.3\times10^{3}\text{ yr}}$$

16. (*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.

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

$$P = IA = 4\pi r^2 I = 4\pi(2.8\text{ m})^2\left(10\text{ W/m}^2\right) = 985\text{ W} \approx \boxed{9.9\times10^2\text{ W}}$$

(*b*) Find the intensity from the 90 dB value, and then from the power output, find the distance corresponding to that intensity.

$$\beta = 90\text{ dB} = 10\log\frac{I}{I_0} \quad\rightarrow\quad I = 10^9\, I_0 = 10^9\left(1.0\times10^{-12}\text{ W/m}^2\right) = 1.0\times10^{-3}\text{ W/m}^2$$

$$P = 4\pi r^2 I \quad\rightarrow\quad r = \sqrt{\frac{P}{4\pi I}} = \sqrt{\frac{985\text{ W}}{4\pi\left(1.0\times10^{-3}\text{ W/m}^2\right)}} = \boxed{2.8\times10^2\text{ m}}$$

29. (*a*) We assume that the speed of waves on the guitar string does not change when the string is fretted. The fundamental frequency is given by $f = \dfrac{v}{2L},$ and so the frequency is inversely proportional to the length.

$$f \propto \frac{1}{L} \quad\rightarrow\quad fL = \text{constant}$$

$$f_E L_E = f_A L_A \quad\rightarrow\quad L_A = L_E\frac{f_E}{f_A} = (0.73\text{ m})\left(\frac{330\text{ Hz}}{440\text{ Hz}}\right) = 0.5475\text{ m}$$

The string should be fretted a distance $0.73\text{ m} - 0.5475\text{ m} = 0.1825\text{ m} \approx \boxed{0.18\text{ m}}$ from the nut of the guitar.

(*b*) The string is fixed at both ends and is vibrating in its fundamental mode. Thus the wavelength is twice the length of the string (see Fig. 12-7).

$$\lambda = 2L = 2(0.5475 \text{ m}) = 1.095 \text{ m} \approx \boxed{1.1 \text{ m}}$$

(*c*) The frequency of the sound will be the same as that of the string, $\boxed{440 \text{ Hz}}$. The wavelength is given by the following.

$$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{440 \text{ Hz}} = \boxed{0.78 \text{ m}}$$

33. (*a*) At $T = 20°\text{C}$, the speed of sound is 343 m/s. For an open pipe, the fundamental frequency is given by $f = \dfrac{v}{2L}.$

$$f = \frac{v}{2L} \rightarrow L = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(294 \text{ Hz})} = \boxed{0.583 \text{ m}}$$

(*b*) The speed of sound in helium is 1005 m/s, from Table 12-1. Use this and the pipe's length to find the pipe's fundamental frequency.

$$f = \frac{v}{2L} = \frac{1005 \text{ m/s}}{2(0.583 \text{ m})} = \boxed{862 \text{ Hz}}$$

51. (*a*) For the 15 m/s relative velocity:

$$f'_{\substack{\text{source}\\\text{moving}}} = f\frac{1}{\left(1 - \frac{v_{\text{src}}}{v_{\text{snd}}}\right)} = (2000 \text{ Hz})\frac{1}{\left(1 - \frac{15 \text{ m/s}}{343 \text{ m/s}}\right)} = \boxed{2091 \text{ Hz}}$$

$$f'_{\substack{\text{observer}\\\text{moving}}} = f\left(1 + \frac{v_{\text{src}}}{v_{\text{snd}}}\right) = (2000 \text{ Hz})\left(1 - \frac{15 \text{ m/s}}{343 \text{ m/s}}\right) = \boxed{2087 \text{ Hz}}$$

The frequency shifts are slightly different, with $f'_{\substack{\text{source}\\\text{moving}}} > f'_{\substack{\text{observer}\\\text{moving}}}$. The two frequencies are close, but they are not identical. To 3 significant figures they are the same.

(*b*) For the 150 m/s relative velocity:

$$f'_{\substack{\text{source}\\\text{moving}}} = f\frac{1}{\left(1 - \frac{v_{\text{src}}}{v_{\text{snd}}}\right)} = (2000 \text{ Hz})\frac{1}{\left(1 - \frac{150 \text{ m/s}}{343 \text{ m/s}}\right)} = \boxed{3.55 \times 10^3 \text{ Hz}}$$

$$f'_{\substack{\text{observer}\\\text{moving}}} = f\left(1 + \frac{v_{\text{src}}}{v_{\text{snd}}}\right) = (2000 \text{ Hz})\left(1 + \frac{150 \text{ m/s}}{343 \text{ m/s}}\right) = \boxed{2.87 \times 10^3 \text{ Hz}}$$

The difference in the frequency shifts is much larger this time, still with $f'_{\substack{\text{source}\\\text{moving}}} > f'_{\substack{\text{observer}\\\text{moving}}}$.

(*c*) For the 300 m/s relative velocity:

$$f'_{\substack{\text{source}\\\text{moving}}} = f\frac{1}{\left(1-\dfrac{v_{\text{src}}}{v_{\text{snd}}}\right)} = (2000\text{ Hz})\frac{1}{\left(1-\dfrac{300\text{ m/s}}{343\text{ m/s}}\right)} = \boxed{16.0\times10^{3}\text{ Hz}}$$

$$f'_{\substack{\text{observer}\\\text{moving}}} = f\left(1+\frac{v_{\text{src}}}{v_{\text{snd}}}\right) = (2000\text{ Hz})\left(1+\frac{300\text{ m/s}}{343\text{ m/s}}\right) = \boxed{3.75\times10^{3}\text{ Hz}}$$

The difference in the frequency shifts is quite large, still with $f'_{\substack{\text{source}\\\text{moving}}} > f'_{\substack{\text{observer}\\\text{moving}}}$.

The Doppler formulas are asymmetric, with a larger shift for the moving source than for the moving observer, when the two are getting closer to each other. As the source moves toward the observer with speeds approaching the speed of sound, the observed frequency tends towards infinity. As the observer moves toward the source with speeds approaching the speed of sound, the observed frequency tends towards twice the emitted frequency.

52. The frequency received by the stationary car is higher than the frequency emitted by the stationary car, by $\Delta f = 5.5\text{ Hz}$.

$$f_{\text{obs}} = f_{\text{source}} + \Delta f = \frac{f_{\text{source}}}{\left(1-\dfrac{v_{\text{source}}}{v_{\text{snd}}}\right)} \quad\rightarrow$$

$$f_{\text{source}} = \Delta f\left(\frac{v_{\text{snd}}}{v_{\text{source}}}-1\right) = (5.5\text{ Hz})\left(\frac{343\text{ m/s}}{15\text{ m/s}}-1\right) = \boxed{120\text{ Hz}}$$

54. The wall can be treated as a stationary "observer" for calculating the frequency it receives. The bat is flying toward the wall.

$$f'_{\text{wall}} = f_{\text{bat}}\frac{1}{\left(1-\dfrac{v_{\text{bat}}}{v_{\text{snd}}}\right)}$$

Then the wall can be treated as a stationary source emitting the frequency f'_{wall}, and the bat as a moving observer, flying toward the wall.

$$f''_{\text{bat}} = f'_{\text{wall}}\left(1+\frac{v_{\text{bat}}}{v_{\text{snd}}}\right) = f_{\text{bat}}\frac{1}{\left(1-\dfrac{v_{\text{bat}}}{v_{\text{snd}}}\right)}\left(1+\frac{v_{\text{bat}}}{v_{\text{snd}}}\right) = f_{\text{bat}}\frac{(v_{\text{snd}}+v_{\text{bat}})}{(v_{\text{snd}}-v_{\text{bat}})}$$

$$= (3.00\times10^{4}\text{ Hz})\frac{343\text{ m/s}+5.0\text{ m/s}}{343\text{ m/s}-5.0\text{ m/s}} = \boxed{3.09\times10^{4}\text{ Hz}}$$