2. The density of oxygen gas is

$$\rho = \frac{0.0320\,\mathrm{kg}}{0.0224\,\mathrm{m}^3} = 1.43\,\mathrm{kg/m}^3.$$

From $v = \sqrt{B/\rho}$ we find

$$B = v^2\rho = (317\,\mathrm{m/s})^2\left(1.43\,\mathrm{kg/m}^3\right) = 1.44\times10^5\ \mathrm{Pa}.$$

6. Let ℓ be the length of the rod. Then the time of travel for sound in air (speed v_s) will be $t_s = \ell / v_s$. And the time of travel for compression waves in the rod (speed v_r) will be $t_r = \ell / v_r$. In these terms, the problem tells us that

$$t_s - t_r = 0.12\,\text{s} = \ell\left(\frac{1}{v_s} - \frac{1}{v_r}\right).$$

Thus, with $v_s = 343$ m/s and $v_r = 15v_s = 5145$ m/s, we find $\ell = 44\,\text{m}$.

12. (a) The amplitude of a sinusoidal wave is the numerical coefficient of the sine (or cosine) function: $p_m = 1.50$ Pa.

(b) We identify $k = 0.9\pi$ and $\omega = 315\pi$ (in SI units), which leads to $f = \omega/2\pi = 158$ Hz.

(c) We also obtain $\lambda = 2\pi/k = 2.22$ m.

(d) The speed of the wave is $v = \omega/k = 350$ m/s.

20. (a) The problem indicates that we should ignore the decrease in sound amplitude, which means that all waves passing through point P have equal amplitude. Their superposition at P if $d = \lambda/4$ results in a net effect of zero there since there are four sources (so the first and third are $\lambda/2$ apart and thus interfere destructively; similarly for the second and fourth sources).

(b) Their superposition at P if $d = \lambda/2$ also results in a net effect of zero there since there are an even number of sources (so the first and second being $\lambda/2$ apart will interfere destructively; similarly for the waves from the third and fourth sources).

(c) If $d = \lambda$ then the waves from the first and second sources will arrive at P in phase; similar observations apply to the second and third, and to the third and fourth sources. Thus, four waves interfere constructively there with net amplitude equal to $4s_m$.

21. **THINK** The sound waves from the two speakers undergo interference. Whether the interference is constructive or destructive depends on the path length difference, or the phase difference.

EXPRESS From the figure, we see that the distance from the closer speaker to the listener is $L = d_2$, and the distance from the other speaker to the listener is $L' = \sqrt{d_1^2 + d_2^2}$, where d_1 is the distance between the speakers. The phase difference at the location of the listener is $\phi = 2\pi(L' - L)/\lambda$, where λ is the wavelength. For a minimum in intensity at the listener, $\phi = (2n + 1)\pi$, where n is an integer. Thus,

$$\phi = \frac{2\pi(L' - L)}{\lambda_{\text{min}}} = (2n+1)\pi \quad \Rightarrow \quad \lambda_{\text{min}} = \frac{2(L' - L)}{2n+1},$$

and the frequency is

$$f_{\text{min}} = \frac{v}{\lambda_{\text{min}}} = \frac{(2n+1)v}{2\left(\sqrt{d_1^2 + d_2^2} - d_2\right)} = \frac{(2n+1)(343\,\text{m/s})}{2\left(\sqrt{(2.00\,\text{m})^2 + (3.75\,\text{m})^2} - 3.75\,\text{m}\right)} = (2n+1)(343\,\text{Hz}).$$

Now 20,000/343 = 58.3, so $2n + 1$ must range from 0 to 57 for the frequency to be in the audible range (20 Hz to 20 kHz). This means n ranges from 0 to 28.

On the other hand, for a maximum in intensity at the listener, $\phi = 2n\pi$, where n is any positive integer. Thus $\lambda_{\text{max}} = (1/n)\left(\sqrt{d_1^2 + d_2^2} - d_2\right)$ and

$$f_{\text{max}} = \frac{v}{\lambda_{\text{max}}} = \frac{nv}{\sqrt{d_1^2 + d_2^2} - d_2} = \frac{n(343\,\text{m/s})}{\sqrt{(2.00\,\text{m})^2 + (3.75\,\text{m})^2} - 3.75\,\text{m}} = n(686\,\text{Hz}).$$

Since 20,000/686 = 29.2, n must be in the range from 1 to 29 for the frequency to be audible.

ANALYZE (a) The lowest frequency that gives minimum signal is (n = 0) $f_{\min,1} = 343 \text{ Hz}$.

(b) The second lowest frequency is (n = 1) $f_{\min,2} = [2(1)+1](343 \text{ Hz}) = 1029 \text{ Hz} = 3 f_{\min,1}$. Thus, the factor is 3.

(c) The third lowest frequency is (n = 2) $f_{\min,3} = [2(2)+1](343 \text{ Hz}) = 1715 \text{ Hz} = 5 f_{\min,1}$. Thus, the factor is 5.

(d) The lowest frequency that gives maximum signal is (n =1) $f_{\max,1} = 686 \text{ Hz}$.

(e) The second lowest frequency is (n = 2) $f_{\max,2} = 2(686 \text{ Hz}) = 1372 \text{ Hz} = 2 f_{\max,1}$. Thus, the factor is 2.

(f) The third lowest frequency is (n = 3) $f_{\max,3} = 3(686 \text{ Hz}) = 2058 \text{ Hz} = 3 f_{\max,1}$. Thus, the factor is 3.

LEARN We see that the interference of the two sound waves depends on their phase difference $\phi = 2\pi(L' - L)/\lambda$. The interference is fully constructive when ϕ is a multiple of 2π, but fully destructive when ϕ is an odd multiple of π.