chapter 17 Sound

Intensity of sound (Section 17.2)

1. Number of speakers
2. Point source

Standing waves (Section 17.3)

3. Standing waves in air columns

Doppler effect (Section 17.4)

4. Doppler shift—I
5. Doppler shift—II
6. Ambulance siren and nearby car

One loudspeaker gives a sound level of $\beta_1 = 100$ dB. How many identical speakers will generate $\beta_2 = 124$ dB?

	A	B	C
Number of Speakers	10–50	50–200	More than 200

Hint: $\beta = 10 \log_{10}(I/I_0)$, $\log_{10} 2 \approx 0.30$.

Explanation:

$\beta_2 - \beta_1 = 124 - 100 = 24 = 10 \log_{10}(I_2/I_1)$.

$I_2/I_1 = 10^{2.4} = 251$. We need 251 speakers. Answer = C.

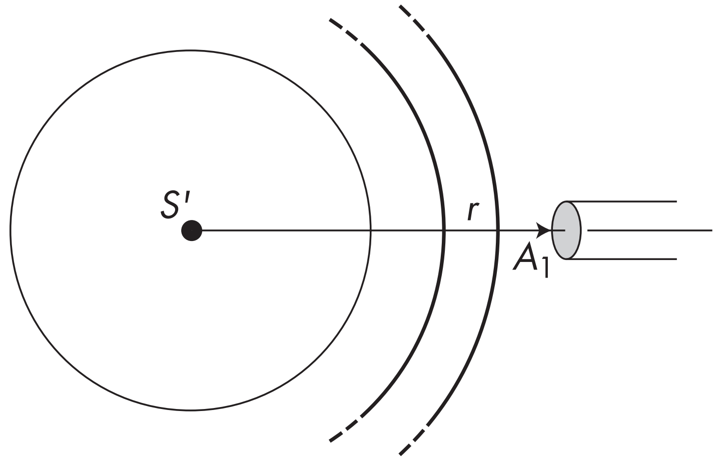
An alternative method: Use $\log_{10} 2 \approx 0.30$.

$24 = 10 \log_{10} 2^x \approx 10x \times 0.3 = 3x$.

Solving for x leads to $x \approx 24/3 = 8$, or $I_2/I_1 \approx 2^8 = 256$.

(This is an example of a "back-of-the-envelope" calculation for which we do not need to use a calculator.)

1. Number of Speakers



A point sound source S, generates sound waves isotropically that is the intensity of sound at a fixed distance from S is the same in all directions. The pattern of the wave fronts near the detector is shown in the figure. It generates waves with a power of $P = 3$ watts. A detector is placed facing the source at a distance $r = 0.5$ m away. The cross section of the detector is $A_1 = 0.1$ m^2. Determine the intensity detected:

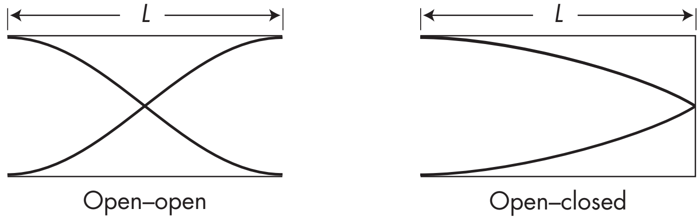
	A	B	C
Intensity: I	P/A_1	$P/(\pi r^2)$	$P/(4\pi r^2)$

Hint: I = Energy/(Area × Time) = Power/Area.

Extra: Show that the sound level detected is approximately 120 dB.

Explanation: The point source generates sound waves isotropically.
So $I = P/(4\pi r^2)$. Answer = C. Notice that the intensity is independent of A_1.

Explanation—extra: $I = P/(4\pi r^2) = 3/[4\pi \times 0.5^2] \approx 1$ W/m^2.
Thus, $\beta = 10 \log_{10}(1/10^{-12}) = 120$ db.



The wave patterns of the fundamental modes for the open–open and open–closed organ pipes are shown here. The wavelengths of the fundamental modes are as follows:

	A	B	C	D
Open–Open	L	L	$2L$	$2L$
Open–Closed	$2L$	$4L$	$2L$	$4L$

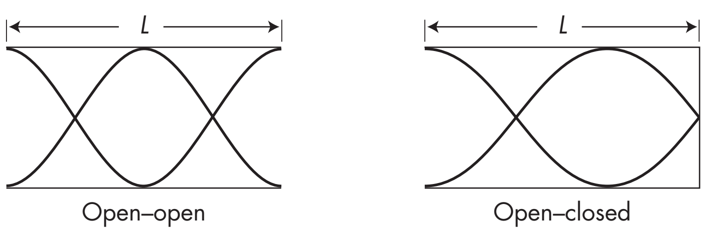
Hint: First sketch the patterns for a full wavelength.

Extra: Show that for the next (second) harmonic

- The wavelength is L for the open–open case.
- The wavelength is $4L/3$ for the open–closed case.

Explanation: Notice that the standing wave pattern for a full wavelength contains two loops. For the open–open case, the pipe has the length of one loop, so $L = \lambda/2$, or $\lambda = 2L$. For the open–closed case, $L = \lambda/4$, or $\lambda = 4L$. Answer = D.

Explanation—extra: The next harmonic patterns are as follows:



By inspection, for the open–open case, $\lambda = L$. For the open–closed case, $L = 3\lambda/4$, or $\lambda = 4L/3$.

Consider the case in which both the emitter and the detector are moving along the positive x direction. (See the sketch.) The frequency emitted by the emitter is f_0. The speeds of the detector and the emitter are respectively $v_d = 0.4v_s$ and $v_e = 0.2v_s$, where v_s refers to the speed of sound in air. Determine v_{det}, the speed at which wave fronts of sound waves cross the detector, and λ_{det}, the wavelength of sound waves as detected by the detector.

	v_{det}	λ_{det}
A	$v_s + v_d$	$(v_s + v_e)/f_0$
B	$v_s + v_d$	$(v_s - v_e)/f_0$
C	$v_s - v_d$	$(v_s + v_e)/f_0$
D	$v_s - v_d$	$(v_s - v_e)/f_0$

Hint: $v_{detected} = v_s \pm v_d$. $\lambda_{det} = \lambda_0 \pm v_e T = (v_s \pm v_e)/f_0$. In the last step, $\lambda_0 = v_s T$ and $f_0 = 1/T$ are used.

Extra: Show that the detected frequency $f' = v_{det}/\lambda_{det} \sim 1.2f_0$.

Explanation: The detector is moving toward the sound waves. So the sound waves cross the detector with greater speed—that is, $v_{det} = v_s + v_d$. The emitter is moving away from the detector. So the detected wavelength is stretched: $\lambda_{det} = \lambda_0 + v_e T = (v_s + v_e)/f_0$. This leads to Answer = A.

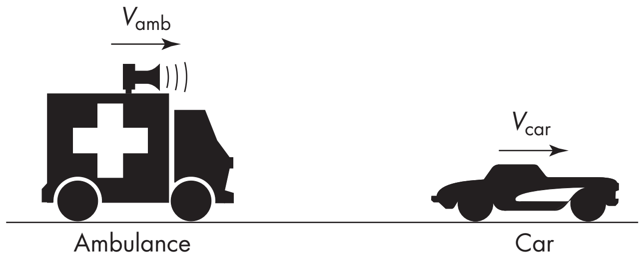
Explanation—extra: The detected frequency $f' = v_{det}/\lambda_{det} = [(v_s + v_d)/(v_s + v_e)]f_0 = (1.4/1.2)f_0 \sim 1.2f_0$.

Consider the setup shown. Both the emitter and the detector are moving in the same direction, and the emitter is behind the detector. Assume the detector is accelerating while the emitter is kept at a constant speed. What will happen to the detected frequency?

	Detected Frequency
A	Increases
B	Stays the same
C	Decreases

Hint: $v_{det} = v_s \pm v_d$. $\lambda_{det} = \lambda_0 \pm v_e T = (v_s \pm v_e)/f_0$, where in the last step, $\lambda_0 = v_s T = v_s/f_0$ is used.

Explanation: The detector is moving away from the sound waves: $v_{det} = v_s - v_d$. The emitter is moving toward the detector. The detected wavelength is shortened: $\lambda_{det} = \lambda_0 - v_e T = (v_s - v_e)/f_0$. So the detected frequency $f' = v_{det}/\lambda_{det} = [(v_s - v_d)/(v_s - v_e)]f_0$. As the detector increases its speed, f' decreases. Answer = C.



Let us begin with the situation where both the ambulance and the car are *stationary*. Here the sound waves emitted by the ambulance siren have a wavelength $\lambda = v_s/f$, where v_s is the speed of the sound in the air and f is the frequency of the sound emitted by the siren. When both the car and the ambulance are stationary, the wave fronts of sound waves are detected by the car at a speed $v_{det} = v_s$.

Now consider the case shown, where both vehicles are moving to the right. Denote the wavelength of the detected sound waves resulting from the moving ambulance siren by λ'. Also denote the speed of the wave fronts relative to the detector (to be more precise, the driver in the car) by v_{det}'. Choose the correct relation:

A	B	C	D
$\lambda' > \lambda$, $v'_{det} > v_{det}$	$\lambda' > \lambda$, $v'_{det} < v_{det}$	$\lambda' < \lambda$, $v'_{det} > v_{det}$	$\lambda' < \lambda$, $v'_{det} < v_{det}$

Explanation: Because the siren is moving along the direction in which the waves travel, the motion of the siren compresses the waves, so $\lambda' < \lambda$. The detector is also moving along the same direction as the waves, so relative to the detector the waves travel more slowly. Answer = D.