Chapter 16 Sound Waves

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June 6, 2019

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1 Sound Waves

- The simplest sound waves are sinusoidal waves, which have definite frequency, amplitude, and wavelength.
- If the wave is sinusoidal going in the +x direction, we can express it by using:

$$y(x,t) = A\cos(kx - \omega t) \tag{1}$$

1.1 Perception of sound Waves

- For a given frequency, the greater the pressure amplitude of a sinusoidal sound wave, the greater the perceived loudness
- The frequency of a sound wave is the primary factor in determining the pitch of a sound
- Unlike the tones made by musical instruments, noise is a combination of all frequencies, not just frequencies that are integer multiples of a fundamental frequency

2 Speed of Sound Waves

- Earlier we found that the speed v of a transverse wave on a string depends on the string tension F and the linear mass density μ: $v = \sqrt{\frac{F}{\mu}}$, we may want to ask, on what properties of the medium does the speed depend?
- For mechanical waves, the speed of the wave is of the form:

$$v = \sqrt{\frac{\text{Restoring force returning the system equilibrium}}{\text{Inertia resisting the return to equilibrium}}} \tag{2}$$

- According to Newton's second law, inertia is related to mass. We can describe this with the mass per unit volume ρ, so speed of sound waves should be of the form $v = \sqrt{\frac{B}{\rho}}$

3 Sound Intensity

- Consider a sound wave propagating in the $+x$ direction, so we can use the expression found for $y(x,t)$ in Section 16.1
- Note that power per unit area in this sound wave equals the product of $p(x,t)$, and the particle velocity, $v_y(x,t)$, which is the velocity at time t of that portion of the wave medium. We find that

$$v_y(x,t) = \frac{\partial y(x,t)}{\partial t} = \omega A \sin(kx - \omega t) \tag{3}$$

And that leads to

$$p(x,t)v_y(x,t) = [BkA\sin(kx - \omega t)][\omega A \sin(kx - \omega t)] = B\omega k A^2 \sin^2(kx - \omega t) \tag{4}$$

- The intensity is the time average value of the power unit area $p(x,t)v_y(x,t)$. For any value x, the average value of $\sin^2(kx - \omega t)$ over one period $T = \frac{2\pi}{\omega}$ is $\frac{1}{2}$ so

$$I = \frac{1}{2} B\omega k A^2 \tag{5}$$

Where here ρ is the density of the fluid, B is the bulk modulus of the fluid, and $\omega = 2\pi f$

3.1 The decibel scale

- Because the ear is sensitive over a broad range of intensities, a logarithmic measure of intensity called sound intensity level is often used

$$\beta = (10dB)\log\frac{I}{I_0} \tag{6}$$

Where $I_0 = 10^{-12} W/m^2$ is the reference intensity

- Using the decibel scale, $\beta = 0$ corresponds to $I = I_0$ and a $I = 1W/\ m^2$ corresponds to $\beta = 120$ corresponds
- This scale deemphasizes the low and very high frequencies, where the ear is less sensitive

4 The Doppler Effect

- When a car approaches you with its horn sounding, the pitch seems to drop as the car passes; the phenomena is known as the Doppler Effect
- Let v_s and v_L be the direction from the listener L to the source S. The speed of sound relative to the medium, v is always considered positive

4.1 Moving Listener And Stationary Source

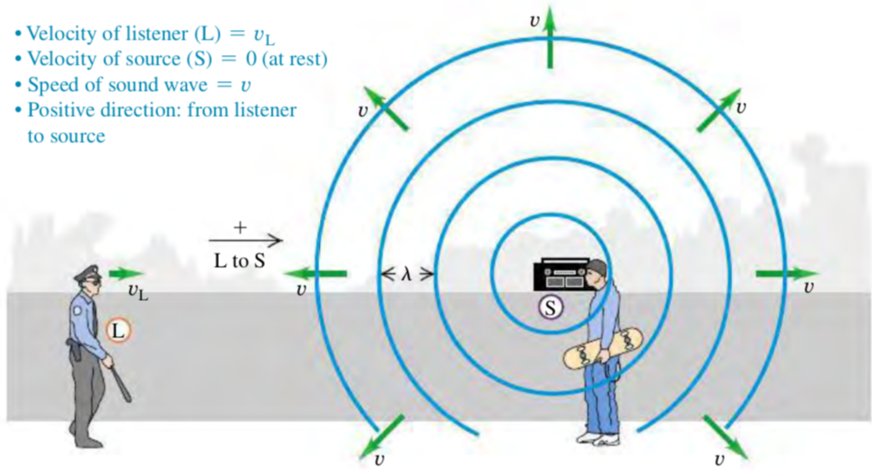
- Think about a Listener L moving with velocity v_L toward a stationary source S. The source emits a sound wave with frequency f_S and a wavelength $\lambda = \frac{v}{f_S}$
- The Wave crests approaching the moving listener have a speed of propagation *relative* to the *listener* of $(v + v_L)$. So the frequency f_L with which the crests arrive at the listener's position is

$$f_L = \frac{v + v_L}{\lambda} = \frac{v + v_L}{v/f_S} \tag{7}$$

This can then be written as

$$f_L = \left(\frac{v + v_L}{v}\right) f_S = \left(1 + \frac{v_L}{v}\right) f_S \tag{8}$$

16.27 A listener moving toward a stationary source hears a frequency that is higher than the source frequency. This is because the relative speed of listener and wave is greater than the wave speed v.



4.2 Moving source and Moving Listener

- Now suppose the source is moving as well, with a velocity v_S, The wave speed is still v, but the wavelength is no longer v/f_S.
- To find the frequency heard by the listener behind the source, we substitute the equation

$$\lambda_{behind} = \frac{v + v_S}{f_S} \tag{9}$$

into the equation

$$f_L = \frac{v + v_L}{\lambda_{behind}} = \frac{v + v_L}{v + v_S} f_S \tag{10}$$