Section Summary

17.1 Sound

- Sound is a disturbance of matter that is transmitted from its source outward.
- Sound is one type of wave.
- Hearing is the perception of sound.

17.2 Speed of Sound, Frequency, and Wavelength

The relationship of the speed of sound v_w, its frequency f, and its wavelength λ is given by

$v_{\mathrm{w}} = f\lambda$,

which is the same relationship given for all waves.

In air, the speed of sound is related to air temperature T by

$v_{\mathrm{w}} = (331\ \mathrm{m/s})\sqrt{\frac{T}{273\ \mathrm{K}}}$.

v_{w} is the same for all frequencies and wavelengths.

17.3 Sound Intensity and Sound Level

- Intensity is the same for a sound wave as was defined for all waves; it is
- $I = \frac{P}{A}$,
- where P is the power crossing area A. The SI unit for I is watts per meter squared. The intensity of a sound wave is also related to the pressure amplitude Δp
- $I = \frac{(\Delta p)^2}{2\ \mathrm{v}_w}$,
- where ρ is the density of the medium in which the sound wave travels and v_w is the speed of sound in the medium.
- Sound intensity level in units of decibels (dB) is
- $\beta\ \mathrm{(dB)} = 10\ \log_{10}\left(\frac{I}{I_0}\right)$,
- where $I_0 = 10^{-12}\ W/\mathrm{m}^2$ is the threshold intensity of hearing.

17.4 Doppler Effect and Sonic Booms

- The Doppler effect is an alteration in the observed frequency of a sound due to motion of either the source or the observer.
- The actual change in frequency is called the Doppler shift.
- A sonic boom is constructive interference of sound created by an object moving faster than sound.

- A sonic boom is a type of bow wake created when any wave source moves faster than the wave propagation speed.
- For a stationary observer and a moving source, the observed frequency f_{obs} is:
- $f_{\text{obs}} = f_s \left(\frac{v_w}{v_w \pm v_s} \right)$,

  where f_s is the frequency of the source, v_s is the speed of the source, and v_w is the speed of sound. The minus sign is used for motion toward the observer and the plus sign for motion away.

- For a stationary source and moving observer, the observed frequency is:
- $f_{\text{obs}} = f_s \left(\frac{v_w \pm v_{\text{obs}}}{v_w} \right)$,

  where v_{obs} is the speed of the observer.

17.5 Sound Interference and Resonance: Standing Waves in Air Columns

- Sound interference and resonance have the same properties as defined for all waves.
- In air columns, the lowest-frequency resonance is called the fundamental, whereas all higher resonant frequencies are called overtones. Collectively, they are called harmonics.
- The resonant frequencies of a tube closed at one end are:
- $f_n = n\frac{v_w}{4L}$, $n = 1,\ 3,\ 5...$,

  f_1 is the fundamental and L is the length of the tube.

- The resonant frequencies of a tube open at both ends are:
- $f_n = n\frac{v_w}{2L}$, $n = 1,\ 2,\ 3...$

17.6 Hearing

- The range of audible frequencies is 20 to 20,000 Hz.
- Those sounds above 20,000 Hz are ultrasound, whereas those below 20 Hz are infrasound.
- The perception of frequency is pitch.
- The perception of intensity is loudness.
- Loudness has units of phons.

17.7 Ultrasound

- The acoustic impedance is defined as:
- $Z = \rho v$,

  ρ is the density of a medium through which the sound travels and v is the speed of sound through that medium.

- The intensity reflection coefficient a, a measure of the ratio of the intensity of the wave reflected off a boundary between two media relative to the intensity of the incident wave, is given by
- $a = \frac{(Z_2 - Z_1)^2}{(Z_1 + Z_2)^2}$.
- The intensity reflection coefficient is a unitless quantity.