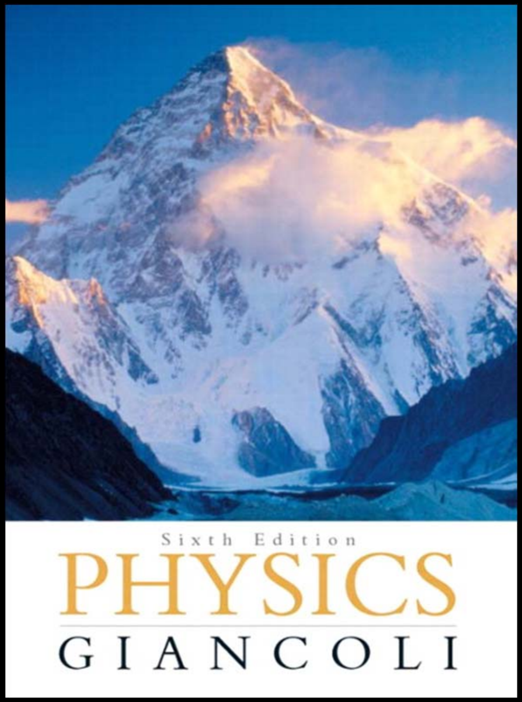


Lecture PowerPoints

Chapter 12

Physics: Principles with Applications, 6th edition

Giancoli

Chapter 12

Sound

Units of Chapter 12

- Characteristics of Sound
- Intensity of Sound: Decibels
- The Ear and Its Response; Loudness
- Sources of Sound: Vibrating Strings and Air Columns
- Quality of Sound, and Noise; Superposition
- Interference of Sound Waves; Beats
- Doppler Effect
- Shock Waves and the Sonic Boom
- Sonar, Ultrasound, and Medical Imaging

12-1 Characteristics of Sound

Sound can travel through any kind of matter, but not through a vacuum.

TABLE 12–1 Speed of Sound in Various Materials (20°C and 1 atm)

Material	Speed (m/s)
Air	343
Air (0°C)	331
Helium	1005
Hydrogen	1300
Water	1440
Sea water	1560
Iron and steel	≈5000
Glass	≈4500
Aluminum	≈5100
Hardwood	≈4000
Concrete	≈3000

The speed of sound is different in different materials; in general, it is slowest in gases, faster in liquids, and fastest in solids.

The speed depends somewhat on temperature, especially for gases.

12-1 Characteristics of Sound

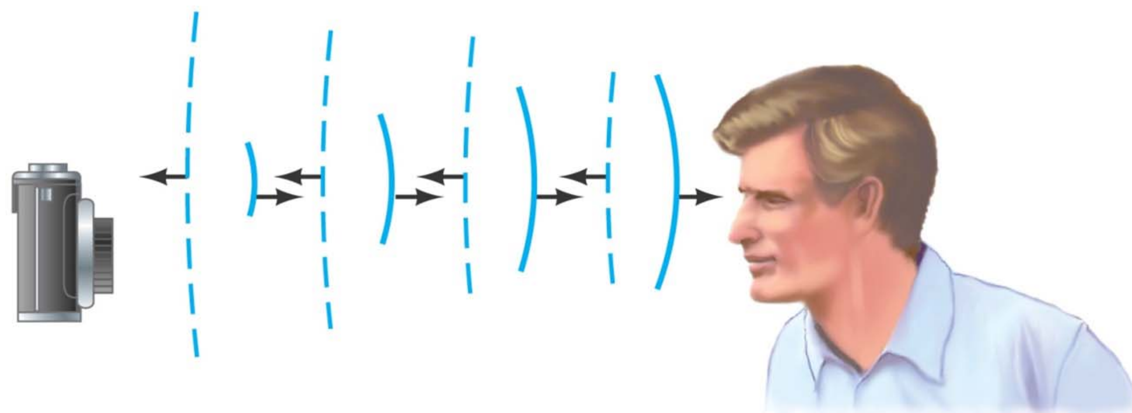
Loudness: related to **intensity** of the sound wave

Pitch: related to **frequency**.

Audible range: about **20** Hz to **20,000** Hz; upper limit decreases with age

Ultrasound: above **20,000** Hz; see ultrasonic camera focusing below

Infrasound: below **20** Hz



12-2 Intensity of Sound: Decibels

TABLE 12–2 Intensity of Various Sounds

Source of the Sound	Sound Level (dB)	Intensity (W/m^2)
Jet plane at 30 m	140	100
Threshold of pain	120	1
Loud rock concert	120	1
Siren at 30 m	100	1×10^{-2}
Auto interior, at 90 km/h	75	3×10^{-5}
Busy street traffic	70	1×10^{-5}
Talk, at 50 cm	65	3×10^{-6}
Quiet radio	40	1×10^{-8}
Whisper	20	1×10^{-10}
Rustle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

The **intensity** of a wave is the **energy** transported per unit **time** across a unit **area**.

The human ear can detect sounds with an intensity as low as **10^{-12} W/m^2** and as high as **1 W/m^2**.

Perceived **loudness**, however, is not proportional to the intensity.

12-2 Intensity of Sound: Decibels

The loudness of a sound is much more closely related to the logarithm of the intensity.

Sound level is measured in decibels (dB) and is defined:

$$\beta \text{ (in dB)} = 10 \log \frac{I}{I_0} \qquad \textbf{(12-1)}$$

I_0 **is taken to be the threshold of hearing:**

$$I_0 = 1.0 \times 10^{-12}\ \mathrm{W/m^2}$$

12-2 Intensity of Sound: Decibels

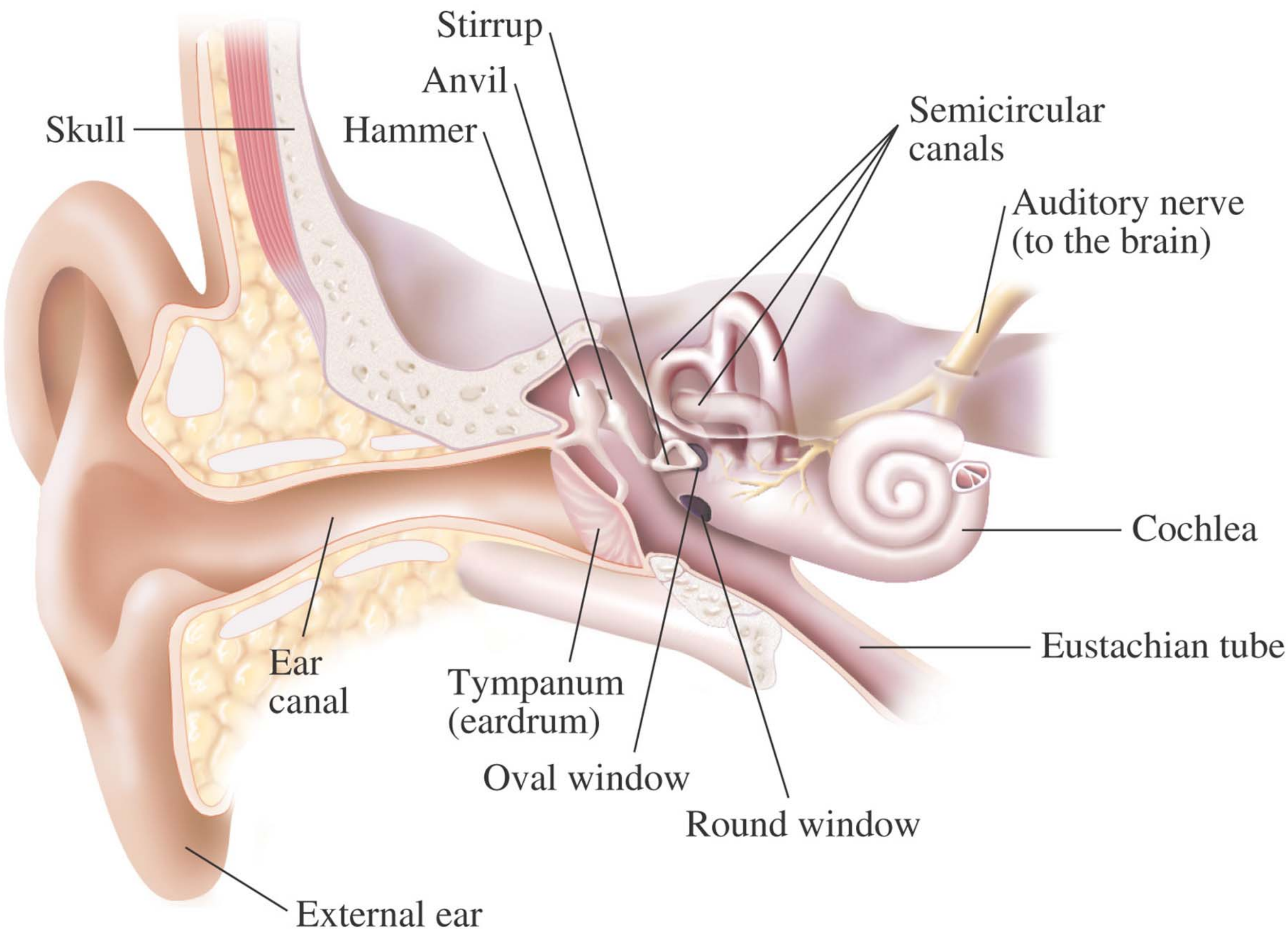
An increase in sound level of 3 dB, which is a **doubling** in intensity, is a very small change in loudness.

In open areas, the **intensity** of sound diminishes with distance:

$$I \propto \frac{1}{r^2}$$

However, in **enclosed** spaces this is complicated by **reflections**, and if sound travels through air the higher frequencies get preferentially **absorbed**.

12-3 The Ear and Its Response; Loudness



12-3 The Ear and Its Response; Loudness

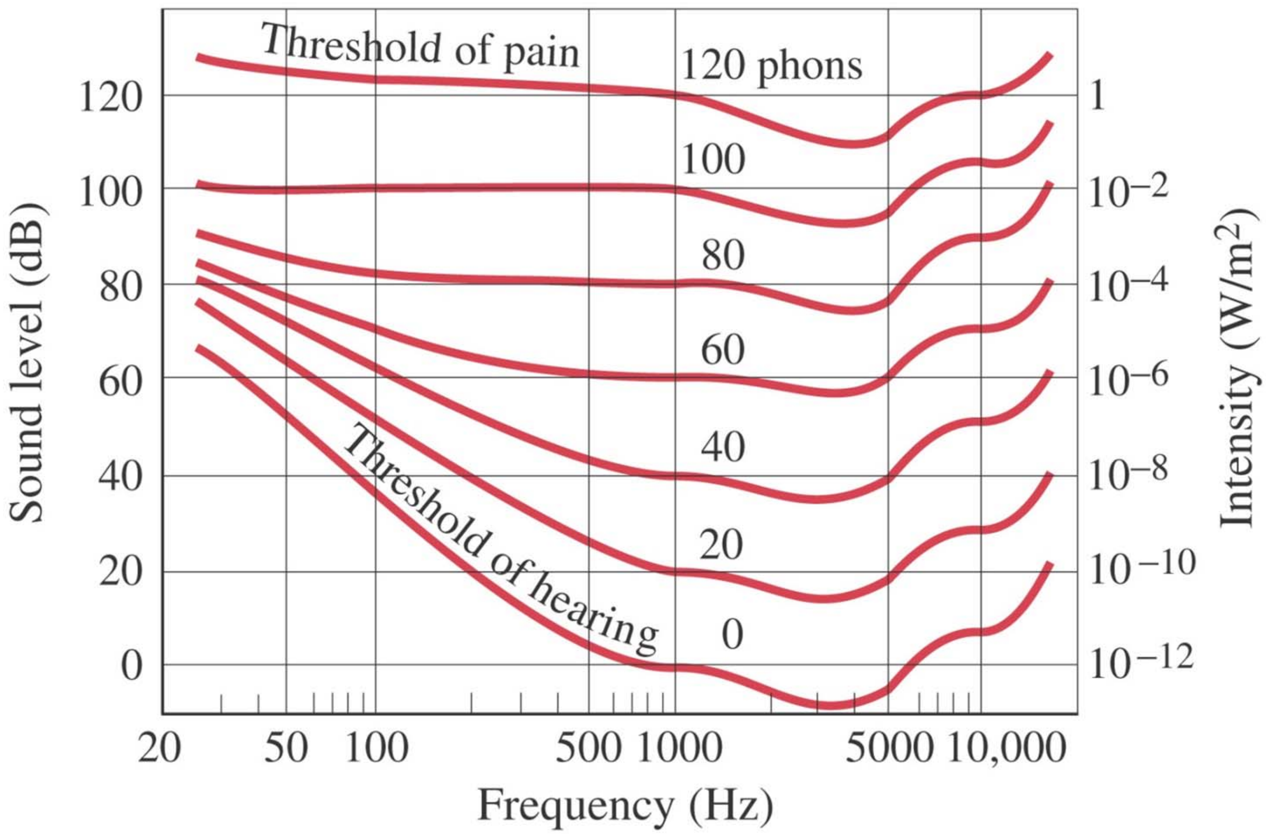
Outer ear: sound waves travel down the **ear canal** to the **eardrum**, which vibrates in response

Middle ear: **hammer**, **anvil**, and **stirrup** transfer vibrations to inner ear

Inner ear: **cochlea** separates vibrations spatially by wavelength and sends signals to the brain through the auditory nerve

12-3 The Ear and its Response; Loudness

The ear's sensitivity varies with frequency. These curves translate the intensity into sound level at different frequencies.

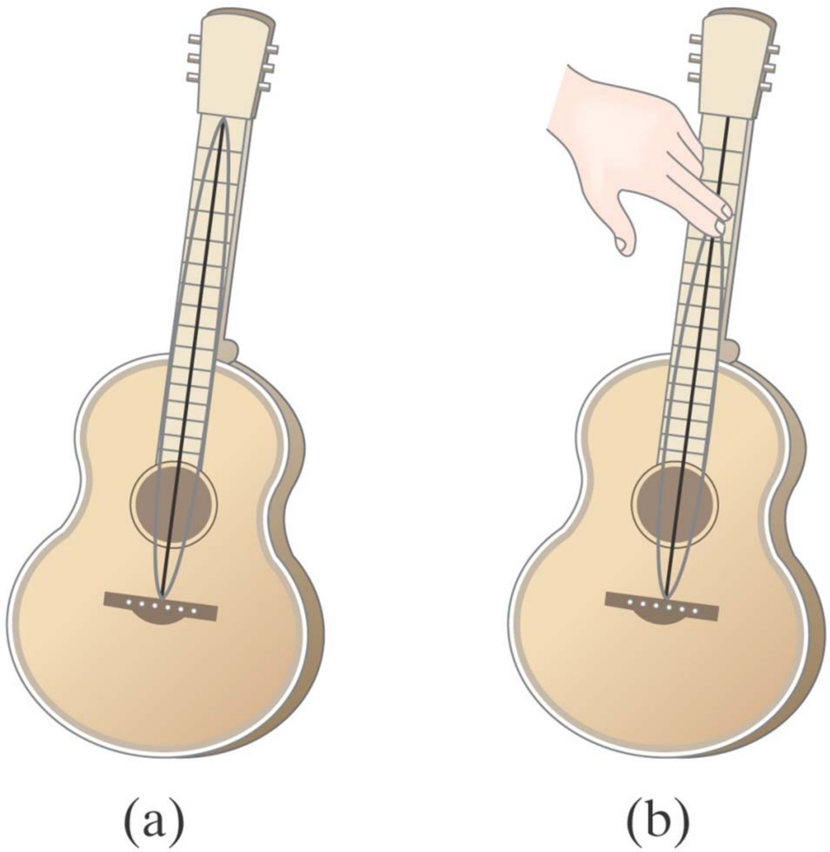


12-4 Sources of Sound: Vibrating Strings and Air Columns

Musical instruments produce sounds in various ways – vibrating strings, vibrating membranes, vibrating metal or wood shapes, vibrating air columns.

The vibration may be started by plucking, striking, bowing, or blowing. The vibrations are transmitted to the air and then to our ears.

12-4 Sources of Sound: Vibrating Strings and Air Columns



The strings on a guitar can be effectively **shortened** by fingering, raising the fundamental pitch.

The **pitch** of a string of a given length can also be altered by using a string of different **density**.

12-4 Sources of Sound: Vibrating Strings and Air Columns

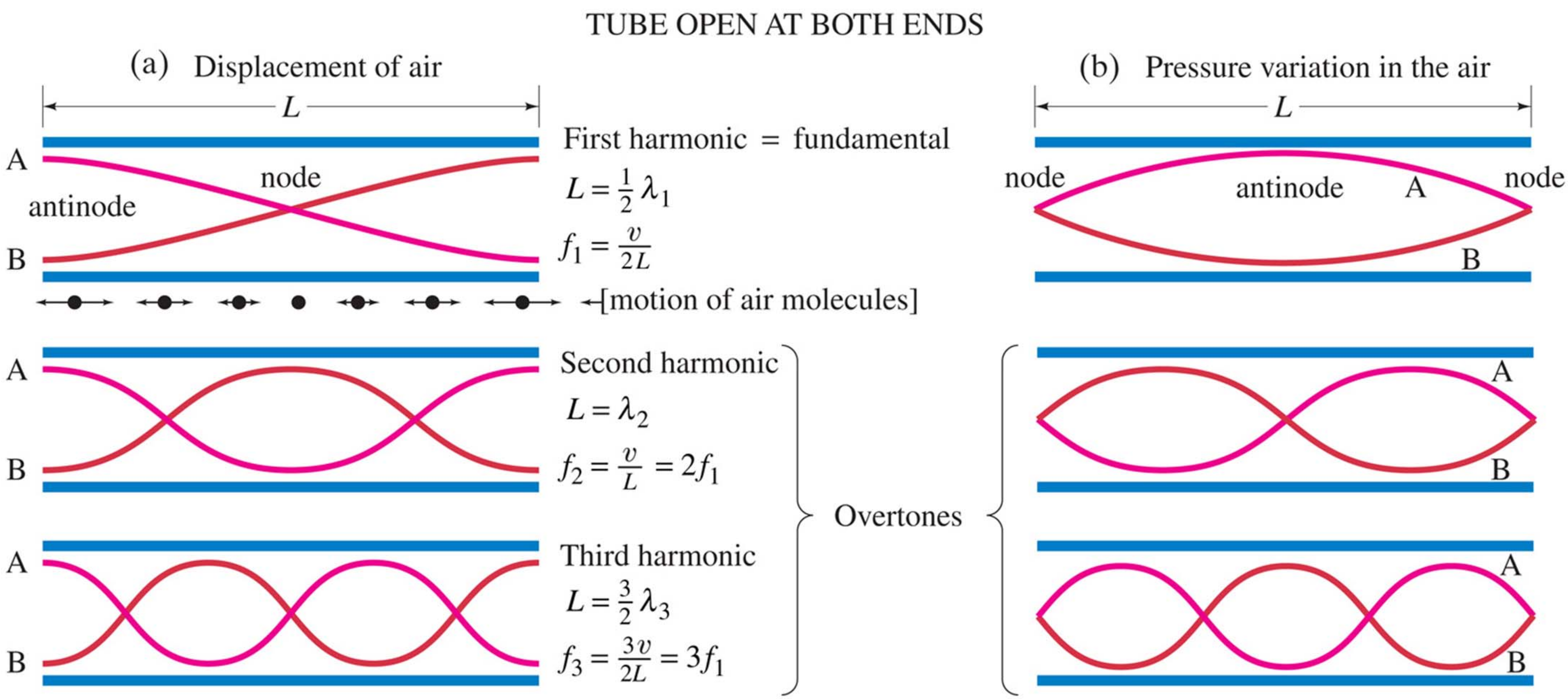
A piano uses both methods to cover its more than seven-octave range – the lower strings (at bottom) are both much **longer** and much **thicker** than the higher ones.

12-4 Sources of Sound: Vibrating Strings and Air Columns

Wind instruments create sound through standing waves in a column of air.

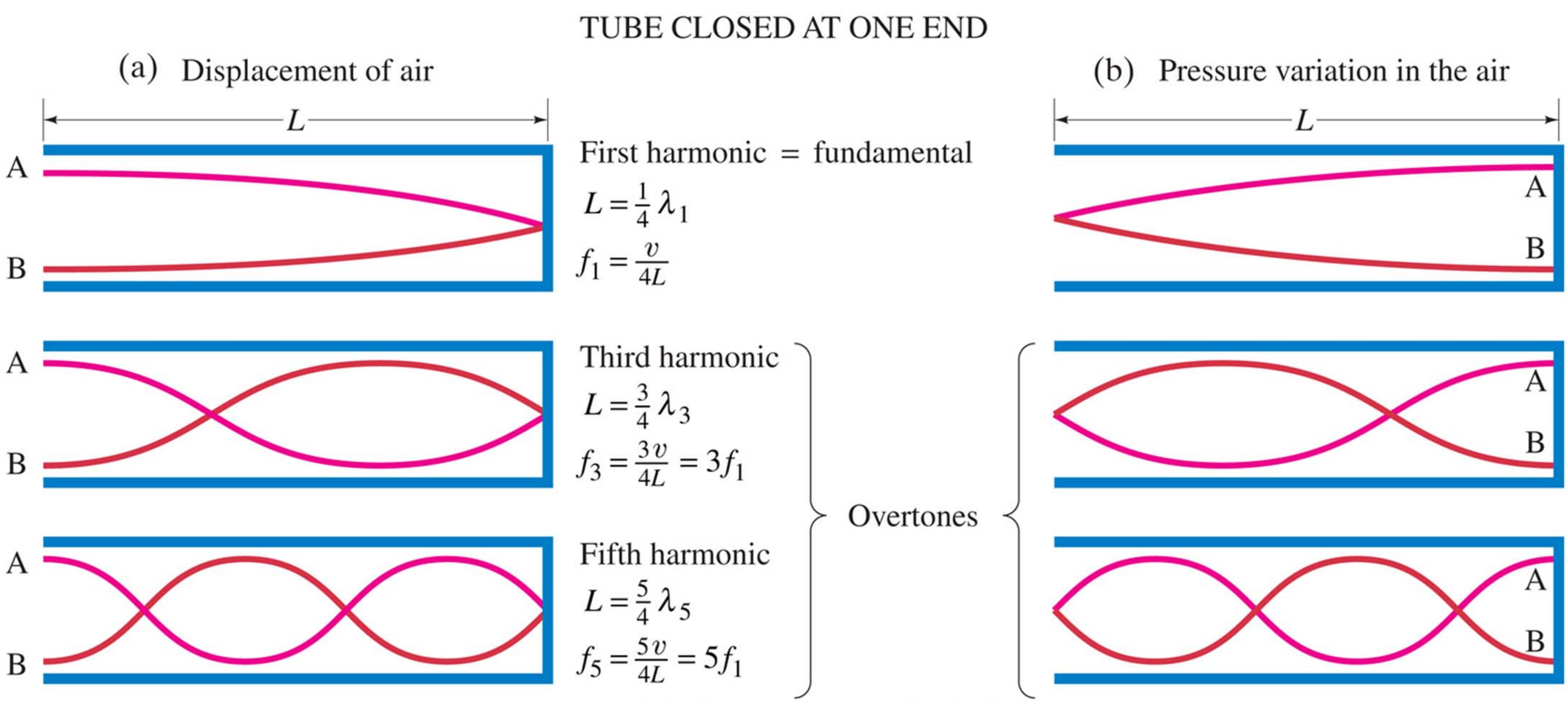
12-4 Sources of Sound: Vibrating Strings and Air Columns

A tube **open** at both ends (most wind instruments) has pressure **nodes**, and therefore displacement **antinodes**, at the ends.



12-4 Sources of Sound: Vibrating Strings and Air Columns

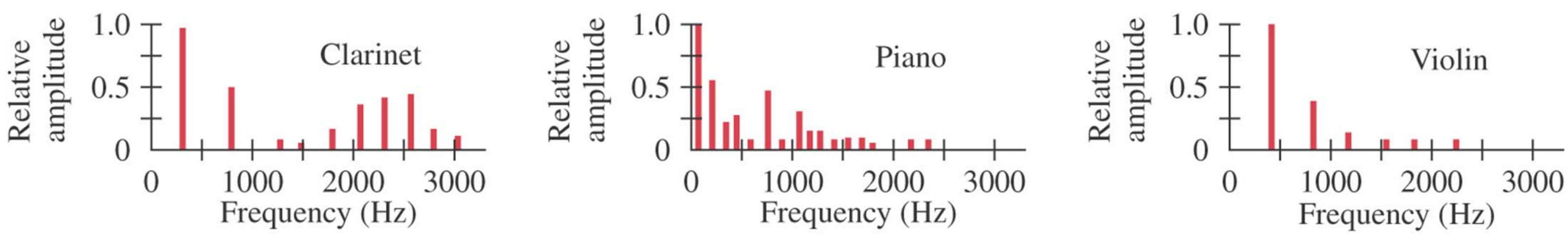
A tube **closed** at one end (some organ pipes) has a displacement **node** (and pressure **antinode**) at the closed end.



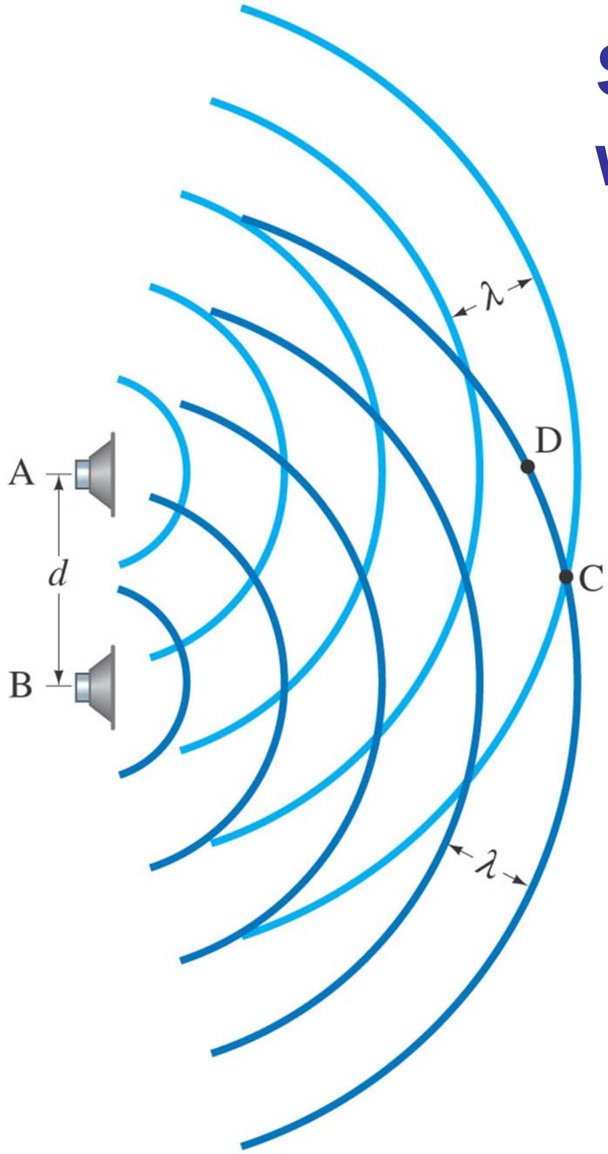
12-5 Quality of Sound, and Noise; Superposition

So why does a trumpet sound different from a flute? The answer lies in overtones – which ones are present, and how strong they are, makes a big difference.

The plot below shows frequency spectra for a clarinet, a piano, and a violin. The differences in overtone strength are apparent.



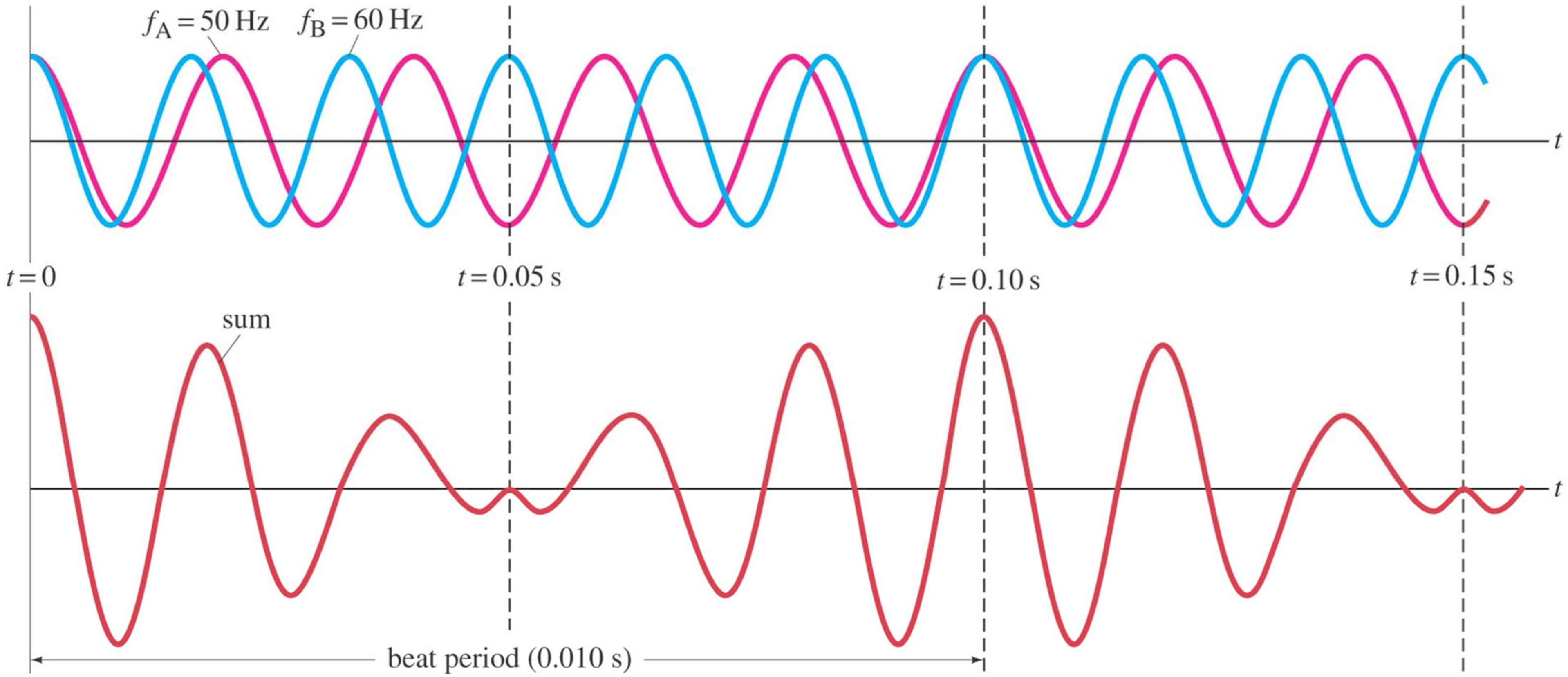
12-6 Interference of Sound Waves; Beats



Sound waves interfere in the same way that other waves do in space.

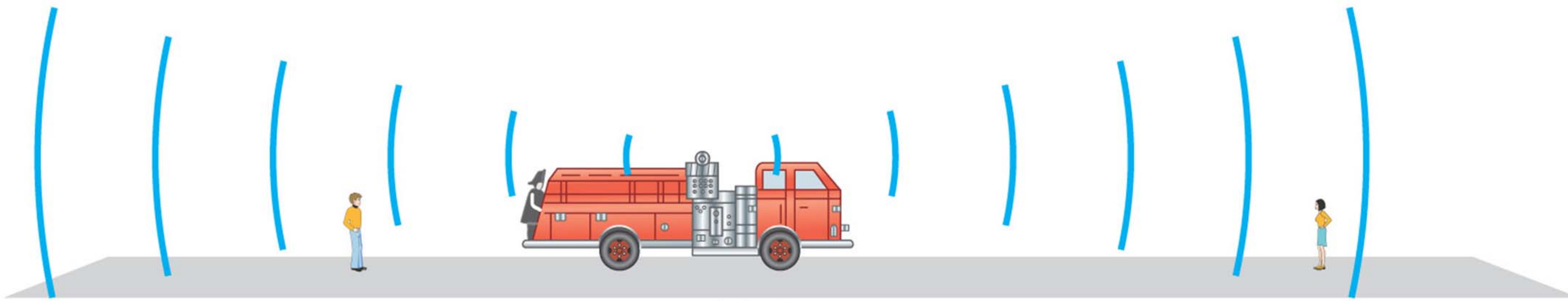
12-6 Interference of Sound Waves; Beats

Waves can also interfere in time, causing a phenomenon called beats. Beats are the slow "envelope" around two waves that are relatively close in frequency.

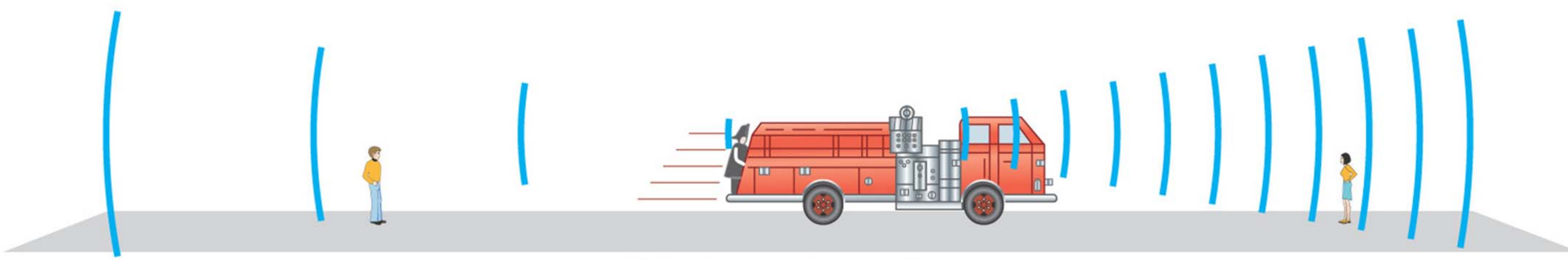


12-7 Doppler Effect

The Doppler effect occurs when a source of sound is moving with respect to an observer.



(a) At rest

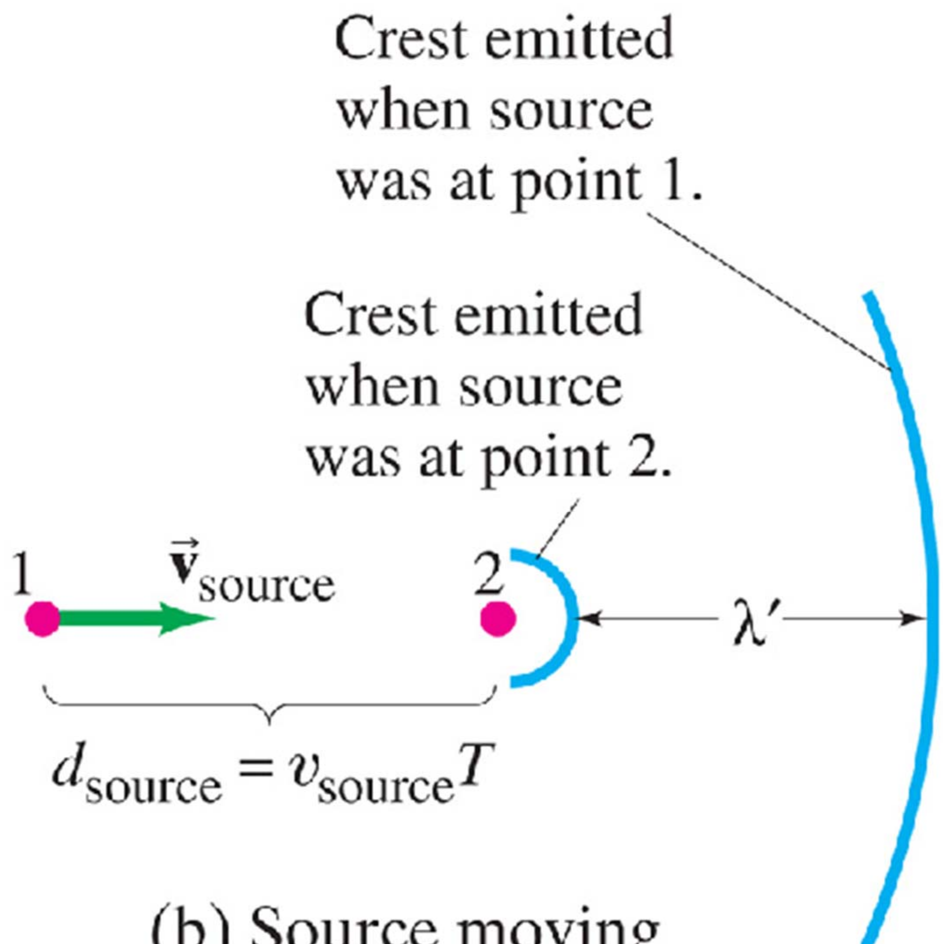


(b) Firetruck moving

12-7 Doppler Effect

As can be seen in the previous image, a source moving **toward** an observer has a **higher** frequency and **shorter** wavelength; the opposite is true when a source is moving **away** from an observer.

12-7 Doppler Effect

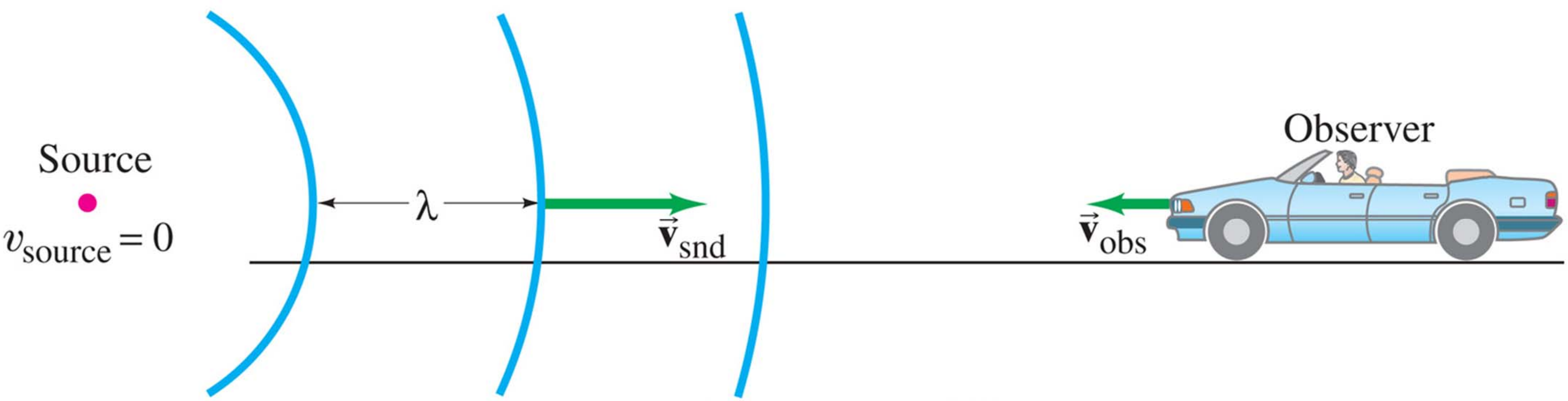


(b) Source moving

If we can figure out what the change in the wavelength is, we also know the change in the frequency.

12-7 Doppler Effect

If the **observer** is moving with respect to the source, things are a bit different. The **wavelength** remains the same, but the wave **speed** is different for the observer.



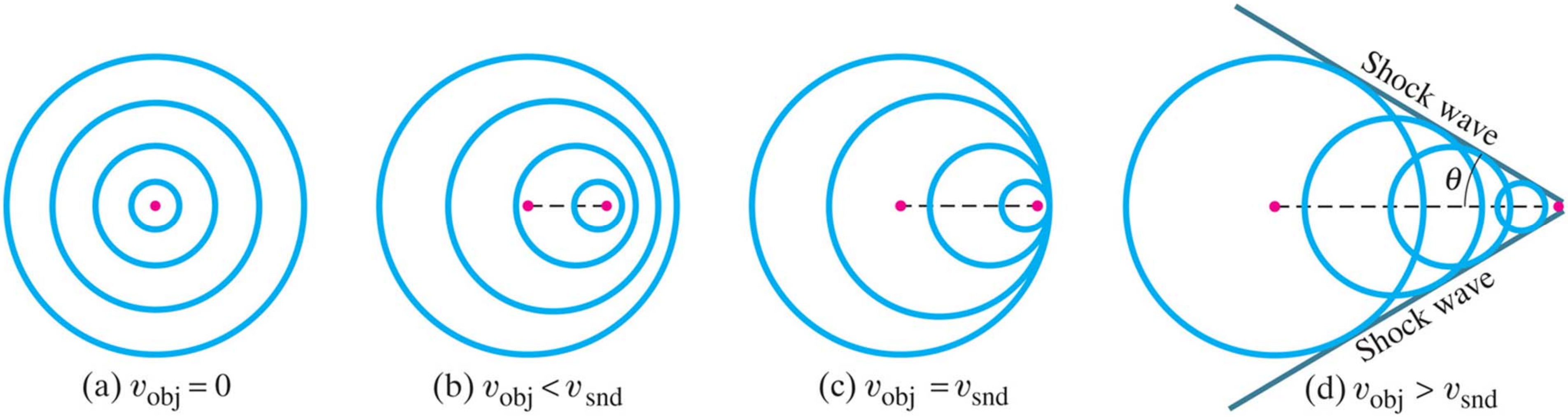
12-7 Doppler Effect

$$f' = f\left(\frac{v \pm v_O}{v \mp v_S}\right)$$

12-8 Shock Waves and the Sonic Boom

If a source is moving **faster** than the **wave speed** in a medium, waves cannot keep up and a **shock wave** is formed.

The angle of the cone is: $$\sin\theta = \frac{v_{\text{snd}}}{v_{\text{obj}}} \qquad \textbf{(12-5)}$$



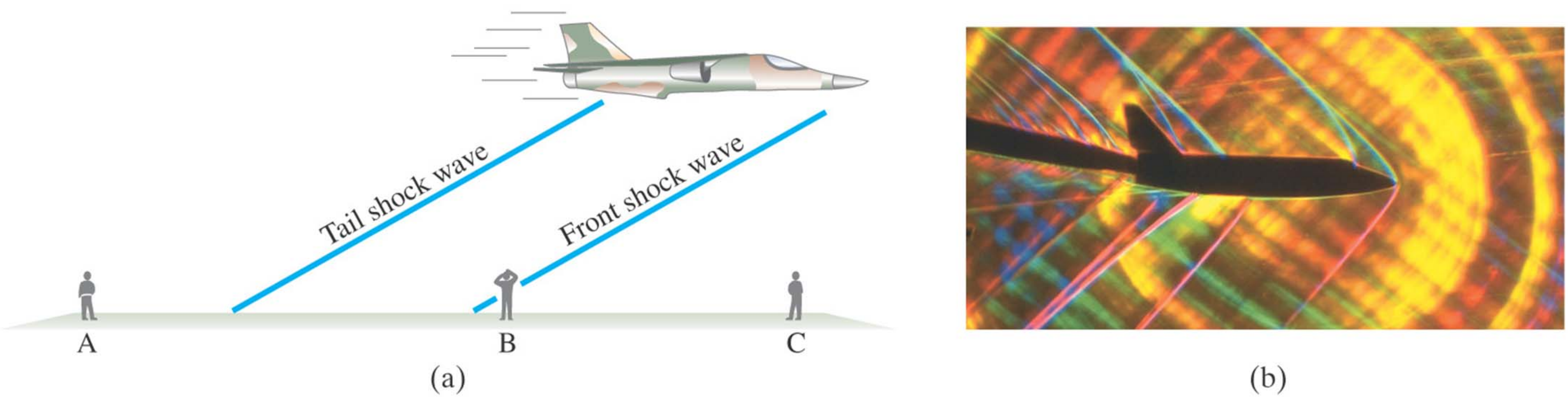
(a) $v_{\text{obj}} = 0$ (b) $v_{\text{obj}} < v_{\text{snd}}$ (c) $v_{\text{obj}} = v_{\text{snd}}$ (d) $v_{\text{obj}} > v_{\text{snd}}$

12-8 Shock Waves and the Sonic Boom

Shock waves are analogous to the **bow waves** produced by a boat going faster than the wave speed in water.

12-8 Shock Waves and the Sonic Boom

Aircraft exceeding the speed of sound in air will produce two sonic booms, one from the front and one from the tail.



12-9 Applications: Sonar, Ultrasound, and Medical Imaging

Sonar is used to locate objects underwater by measuring the **time** it takes a sound **pulse** to reflect back to the receiver.

Similar techniques can be used to learn about the **internal structure** of the Earth.

Sonar usually uses **ultrasound** waves, as the shorter wavelengths are less likely to be **diffracted** by obstacles.

Summary of Chapter 12

- Sound is a longitudinal wave in a medium.
- The pitch of the sound depends on the frequency.
- The loudness of the sound depends on the intensity and also on the sensitivity of the ear.
- The strings on stringed instruments produce a fundamental tone whose wavelength is twice the length of the string; there are also various harmonics present.

Summary of Chapter 12

- Wind instruments have a vibrating column of air when played. If the tube is open, the fundamental is twice its length; if it is closed the fundamental is four times the tube length.

- Sound waves exhibit interference; if two sounds are at slightly different frequencies they produce beats.

- The Doppler effect is the shift in frequency of a sound due to motion of the source or the observer.