SLE123

Week 7

Sound

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Sound

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Looking Ahead

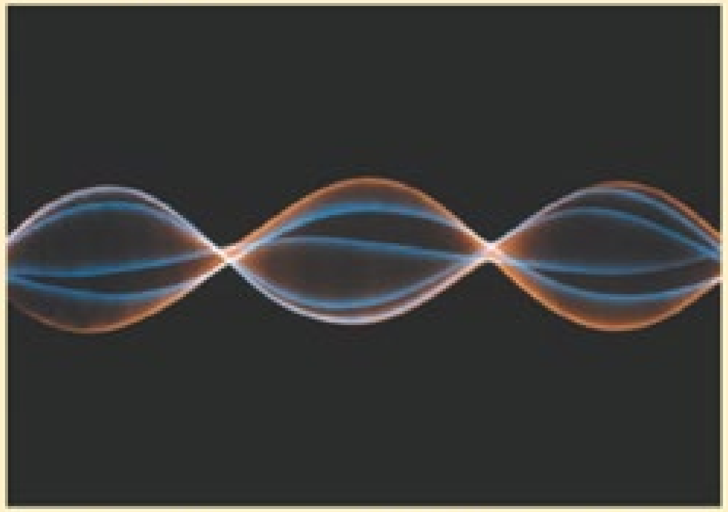
Energy and Intensity

All waves carry energy. The lens focuses sunlight into a small area, where the concentrated energy sets the wood on fire.

You'll learn to calculate **intensity,** a measure of how spread out a wave's energy is.

Standing Waves

The superposition of waves on a string can lead to a wave that oscillates in place—a **standing wave.**



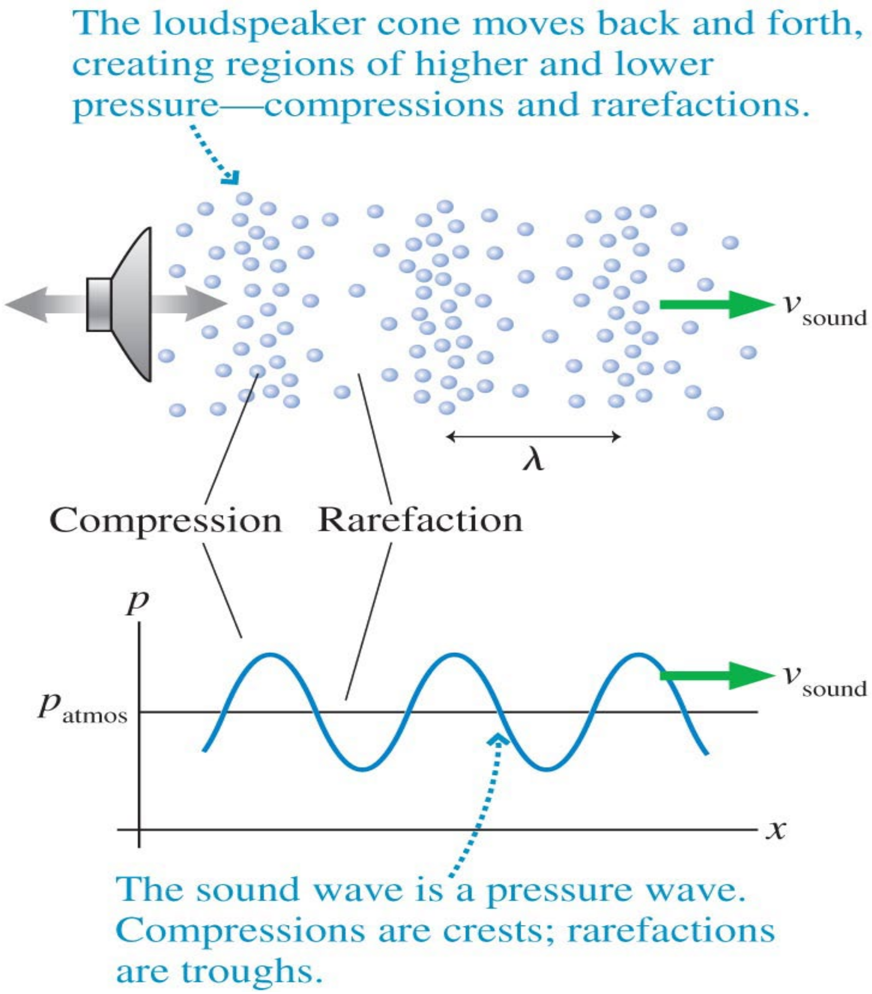
You'll learn the patterns of standing waves on strings and standing sound waves in tubes.

Sound

- Sound is a form of energy that arises from waves propagated in a material medium (solid, liquid or gas).
- Sound cannot travel in a vacuum.
- An Astronaut will not hear the clanging of a dropped spanner coming into contact the Space shuttle while repairing outside the craft.

Sound

1. Sound has a source – a vibrating object.
2. The energy is transferred from the source as longitudinal sound waves.
3. The sound is detected by the ear or some other instrument.



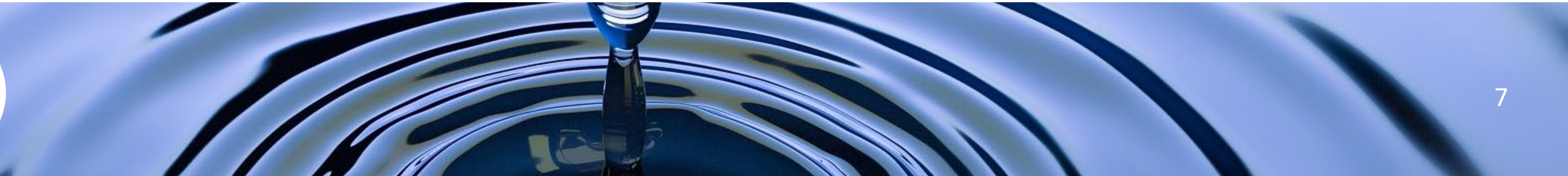
Speed of Sound in Air

The speed of sound in air depends on the nature of air.

Factors influencing the speed of sound include:

temperature, wind and humidity

- Speed in dry air @ 0°C is 331 m/s.
- Water vapour increases it slightly.
- Speed in warm air is faster than cold.



The Speed of Sound

In air

$$v \approx (331 + 0.6\,T)\ \text{m/s}$$

Table 14.1 Speeds of Sound in Various Media

Medium	v (m/s)
Gases	
Air (0°C)	331
Air (100°C)	386
Hydrogen (0°C)	1 286
Oxygen (0°C)	317
Helium (0°C)	972
Liquids at 25°C	
Water	1 493
Methyl alcohol	1 143
Sea water	1 533
Solids[a]	
Aluminum	6 420
Copper (rolled)	5 010
Steel	5 950
Lead (rolled)	1 960
Synthetic rubber	1 600

[a]Values given are for propagation of longitudinal waves in bulk media. Speeds for longitudinal waves in thin rods are smaller, and speeds of transverse waves in

$$v = (331\ \text{m/s})\sqrt{\frac{T}{273\ \text{K}}}$$

for $T = 293$ K (room temperature)

$$v = (331\ \text{m/s})\sqrt{\frac{293\ \text{K}}{273\ \text{K}}} = 343\ \text{m/s}$$

Sound Waves

- Most sounds are waves produced by the vibrating of material object.
- Voice results from the vibration of vocal cords in the throat.
- Vibrating vocal cords disturb the surrounding air to give a sound wave with a frequency the same as the vibrating cord.

Media that transmit Sound

- The sound we hear is transmitted through air.
- Any elastic substance, in any state a solid, liquid or gas can transmit sound.
- Where an elastic substance is considered to be a material that can change shape in response to an applied and return to its original shape after the force is removed

Pitch

- The term commonly used to describe frequency is "pitch"
- A high pitched sound is like a whistle.
- A low pitched sound is like a fog horn
- A human ear can hear frequencies between
- Infrasonic< 20-20,000 Hz <Ultrasonic

Musical Sound

- Sound comes from vibrating objects:
- A drum has a vibrating membrane.
- Xylophones have vibrating bars.
- Bells, symbols, gongs are vibrating metal.
- Vibrating strings: violin, guitar, piano.
- Vibrating columns of air: flute, trumpet, pipe organ.

Music : The Chromatic Scale

The pitch of a sound is determined by its frequency.

Note	Frequency (Hz)
C	262
$C^\#$ or $D^\flat$	277
D	294
$D^\#$ or $E^\flat$	311
E	330
F	349
$F^\#$ or $G^\flat$	370
G	392
$G^\#$ or $A^\flat$	415
A	440
$A^\#$ or $B^\flat$	466
B	494
C'	524

Ultra Sound Waves

- <u>Ultrasound waves</u> (also called ultrasonic waves) have frequencies above the threshold of hearing although they can be heard by some animals especially cats, dolphins and bats.

- Ultrasound was probably first used by bats who emit them in short bursts (sometimes called pulses) and listen with their large ears for their reflection from prey and other objects.

Ultra Sound Waves

Ultrasound was used in WWII SONAR systems (SOund Navigation And Ranging)

which used a submerged ultrasonic emitter and very sensitive microphones to detect the reflected waves.

- (The term SONAR was also applied to other types of detection methods such as using sensitive microphones to detect enemy ships engines).

- Liquid immersion ultrasonic cleaning systems using high energy waves were developed after WWII using the new technology.

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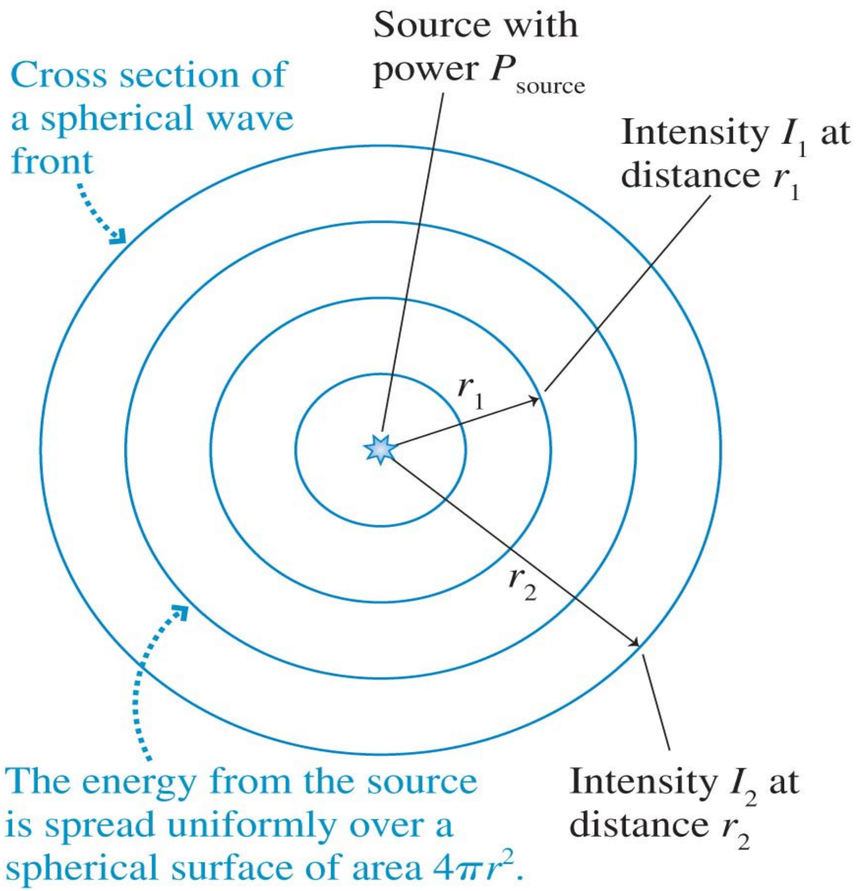
Ultra Sound

- Ultrasound has been used
  - in the production of emulsions
  - to treat bursitis (a joint inflammation)
  - to treat rheumatoid arthritis
  - in ultrasonic “scalpels”.
- In medicine ultrasound has become indispensable as a diagnostic tool (foetal development, safe imaging of tumours etc – poor resolution but rapidly improving).
- Recent developments use the Doppler effect to measure heart beat functions in developing embryos.

Loudness, Energy and Intensity



- As waves spread out, so does the energy of the wave.
- The intensity decreases.
- Intensity is the energy transported by the wave per unit time across some unit area.
- Intensity is proportional to the square of the wave's amplitude.
- Intensity is in W/m^2

$$I = \frac{P_{source}}{4\pi r^2}$$

Intensity of a uniform spherical wave at distance r from source of power P_{source}

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Sound Loudness

- The intensity of sound depends on the amplitude of the pressure variations within the sound wave, which is directly proportional to the square of the wave amplitude.
- The intensity is measured in watts/metre^2
- Human ear from

  10^{-12} W/m^2 (Threshold of Hearing)

  1 W/m^2 (Threshold of Pain)

Sound Level

- Because the range is so large the intensities are scaled by factor of ten (log scale).
-
- 10^{-12} W/m^2 is barely audible – set at 0 bel (B)
- A sound 10 times this intensity of this is

  1 bel (10^{-11}) or 10 decibels (dB)

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Common Sounds

Source of Sound	Intensity	Sound Level(dB)
Jet (30m) away	10^2	140
Air raid Siren	1	120
Pop Music,amplified	10^{-1}	115 (85)
Busy Street traffic	10^{-5}	70
Conversation	10^{-6}	60
Whisper	10^{-10}	20
Rustling leaves	10^{-11}	10

- Damage depends on exposure time and pitch

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Loudness, Intensity and Intensity Level

- Loudness of a sound is what we perceive.

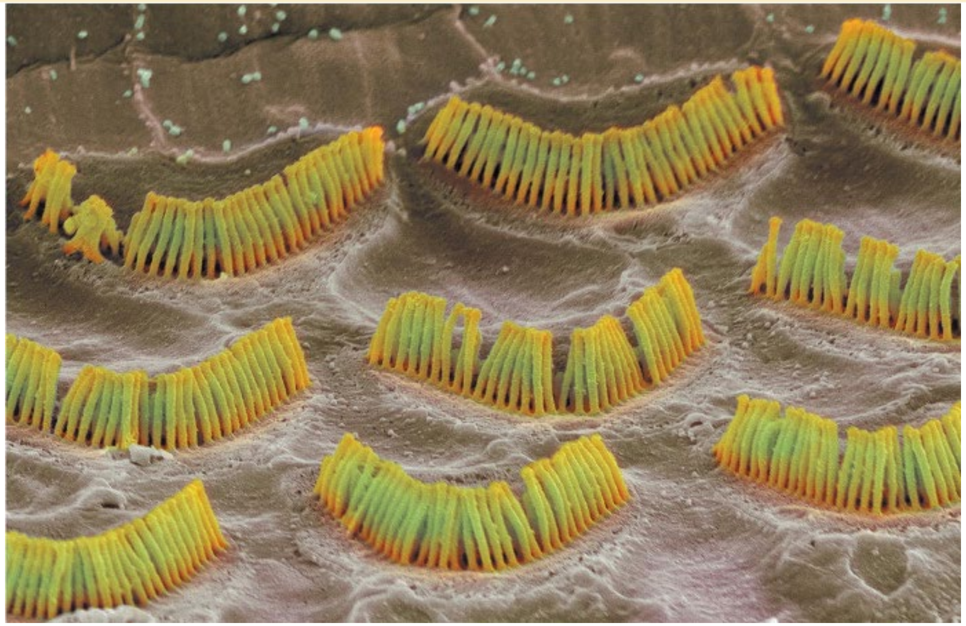
- Loudness differs from *intensity* because the ear does not respond linearly to sound but logarithmically. This means that if the sound intensity doubles, we perceive this as a just perceptible increase in loudness.

Loudness, the Decibel Scale

Sound intensity level is measured in decibels.

$$\beta = (10\text{ dB})\log_{10}\left(\frac{I}{I_0}\right)$$

Sound intensity level in decibels for a sound of intensity I



Hearing hairs (Knight, Jones, Field, p. 494).

Sound	β (dB)	I (W/m^2)
Threshold of hearing	0	1.0×10^{-12}
Person breathing, at 3 m	10	1.0×10^{-11}
A whisper, at 1 m	20	1.0×10^{-10}
Classroom during test, no talking	30	1.0×10^{-9}
Residential street, no traffic	40	1.0×10^{-8}
Quiet restaurant	50	1.0×10^{-7}
Normal conversation, at 1 m	60	1.0×10^{-6}
Busy traffic	70	1.0×10^{-5}
Vacuum cleaner, for user	80	1.0×10^{-4}
Niagara Falls, at viewpoint	90	1.0×10^{-3}
Pneumatic hammer, at 2 m	100	0.010
Home stereo at max volume	110	0.10
Rock concert	120	1.0
Threshold of pain	130	10

Problem

The sound intensity 0.250 m from a roaring lion is 0.250 W/m^2.

What is the sound intensity level in decibels? (Use the usual reference level of $I_0 = 1.00 \times 10^{-12}$ W/m^2.)

Strategy

We are given the intensity in W/m^2 and asked for the intensity level in dB.

First we find the ratio of the given intensity to the reference level. Then we take the logarithm of the result (to get the level in bels) and multiply by 10 (to convert from bels to dB).

Solution

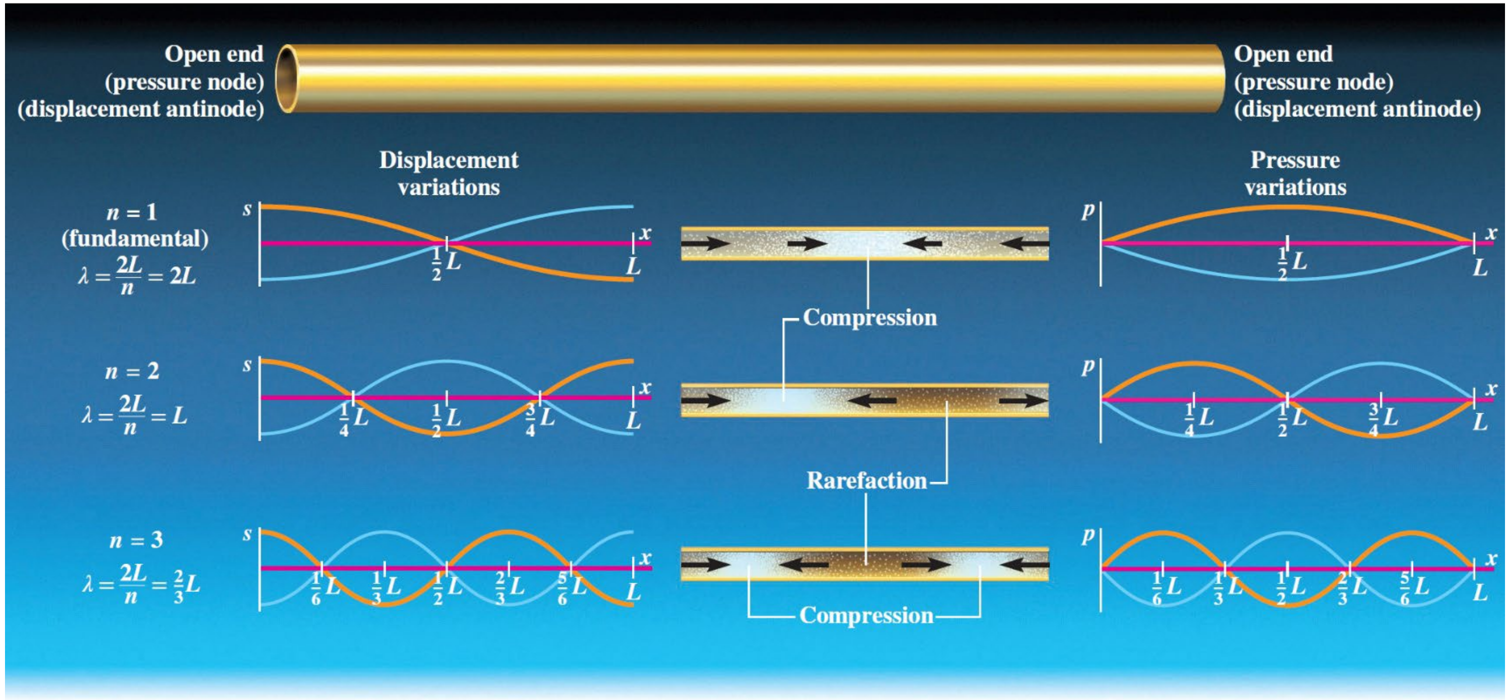
$$\frac{I}{I_0} = \frac{0.250\ \mathrm{W/m^2}}{1.00 \times 10^{-12}\ \mathrm{W/m^2}} = 2.50 \times 10^{11}$$

$$\log_{10} \frac{I}{I_0} = \log_{10} 2.50 \times 10^{11} = 11.4\ \text{bels}$$

$$\beta = 11.4\ \text{bels} \times (10\ \mathrm{dB/bel}) = 114\ \mathrm{dB}$$

Standing Sound Waves

Pipe Open at Both Ends



Pipe open at both ends

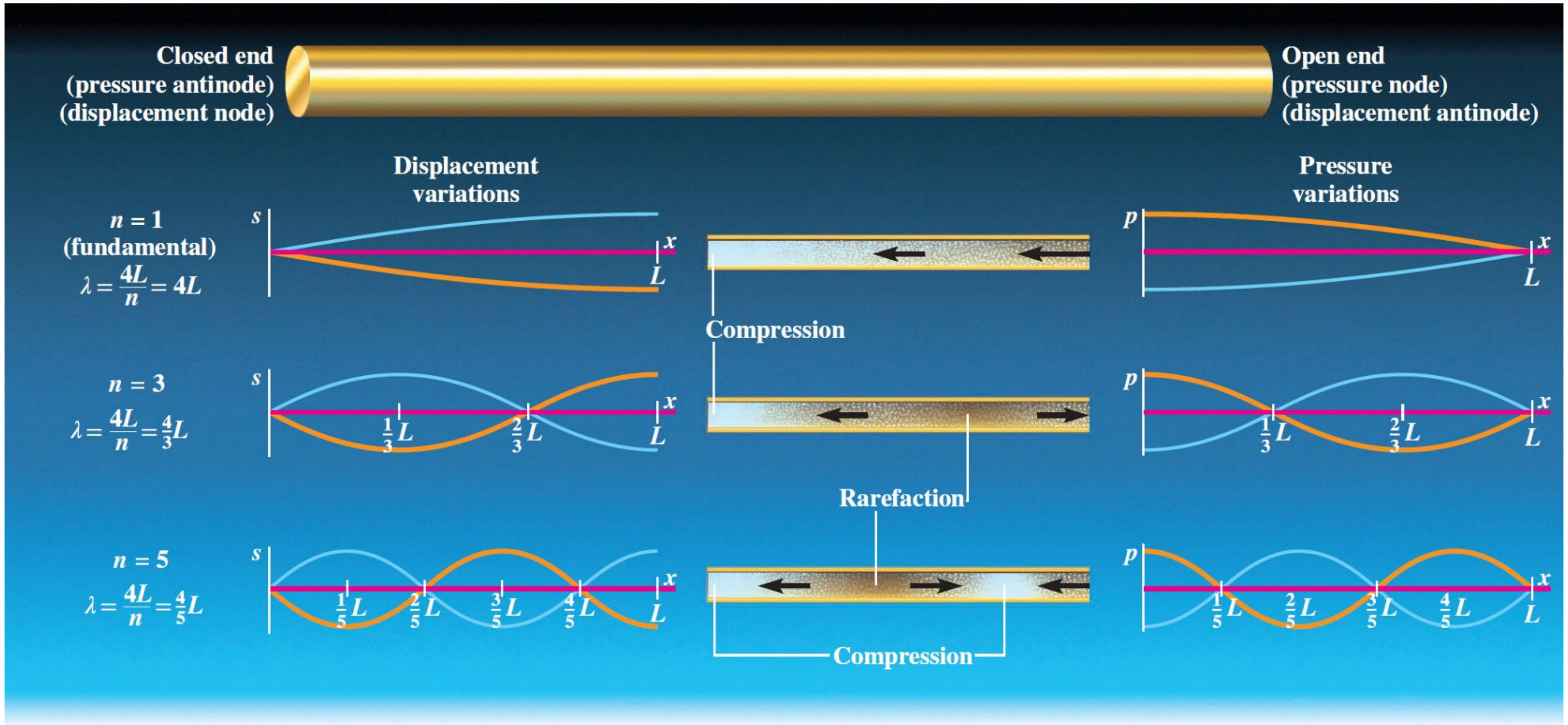
Standing sound waves (thin pipe open at both ends):

$$\lambda_n = \frac{2L}{n}$$

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{2L} = nf_1$$

where n = 1, 2, 3, . . .

Pipe closed at one end



Pipe closed at one end

Standing sound waves (thin pipe closed at one end):

$$\lambda_n = \frac{4L}{n}$$

$$f_n = \frac{v}{\lambda_n} = n\frac{v}{4L} = nf_1$$

where n = 1, 3, 5, 7, . . .

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Doppler Effect

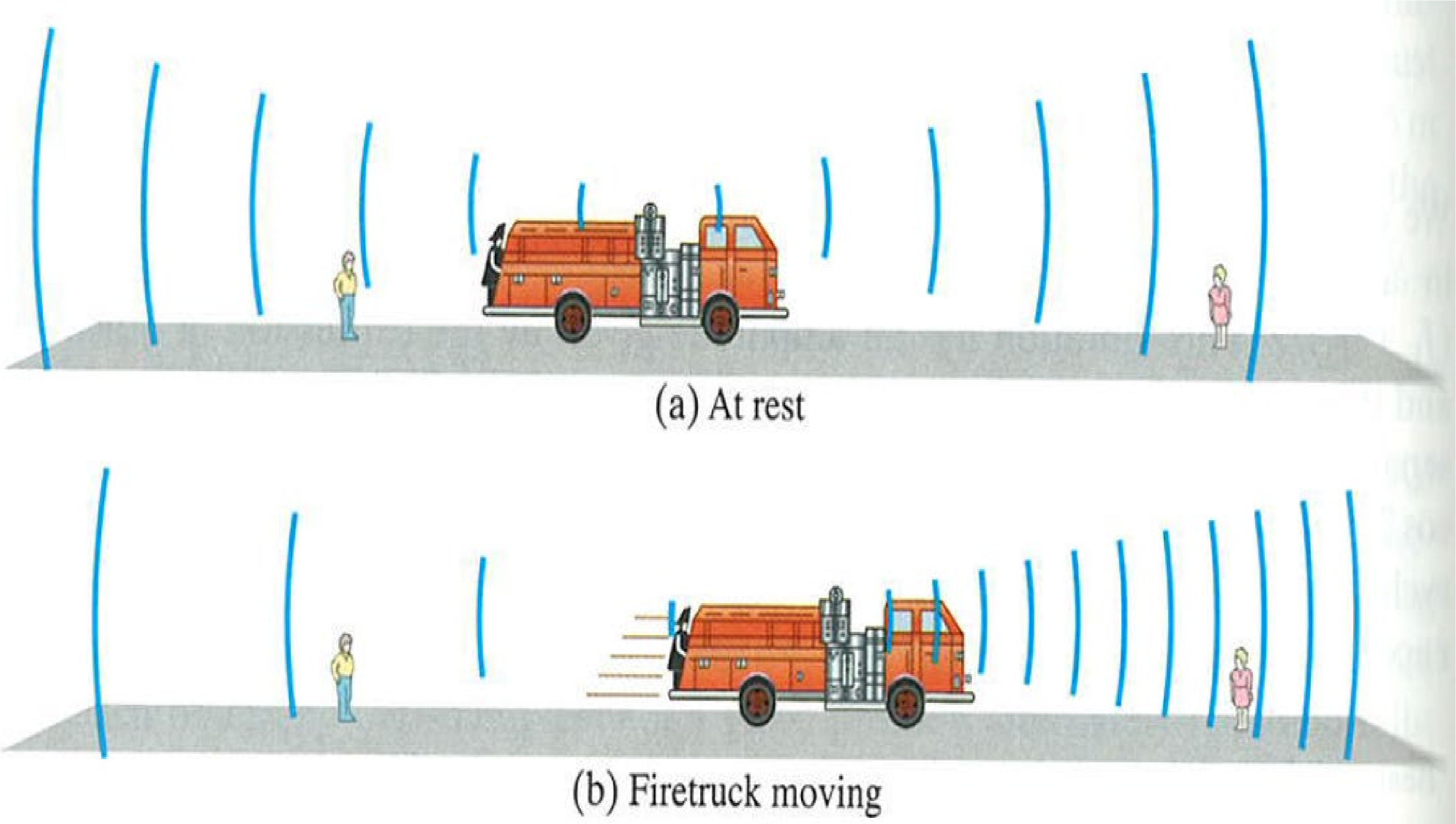

FIGURE 16–19 (a) Both observers on the sidewalk hear the same frequency from the firetruck at rest.

(b) Doppler effect: observer toward whom the firetruck moves hears a higher-frequency sound, and observer behind the firetruck hears a lower frequency.

Moving Source, Fixed Observer

Approaching source

Frequency of the source (Hz) → f_s

Speed of the *waves* (m/s) → v

$$f_+ = \frac{f_s}{1 - v_s/v}$$

Speed of the *source* of the waves (m/s) → v_s

The observed frequency is *increased.*

Receding source

$$f_- = \frac{f_s}{1 + v_s/v}$$

The observed frequency is *decreased.*

Fixed Source, moving observer

Approaching observer

Speed of the *observer* (m/s)

Frequency of the source (Hz)

$$f_+ = \left(1 + \frac{v_0}{v}\right) f_s$$

The observed frequency is *increased*.

Speed of the *waves* (m/s)

Receding observer

$$f_- = \left(1 - \frac{v_0}{v}\right) f_s$$

The observed frequency is *decreased*.