Lectures: Physics 3306

Provides an introduction to a wide variety of topics in classical (pre-quantum) physics as a bridge to prepare students for subsequent upper-level courses in physics. The topics covered include thermodynamics, fluid mechanics, mechanical waves, optics, radiation, electromagnetic phenomena, atoms, and laboratory techniques. Prerequisites: C- or better in PHYS 1106; and in PHYS 1304 or PHYS 1308.

Saptaparna Bhattacharya

February 20th, 2026

Based on Simon Dalley's lectures taught in Spring 2025

Labs

Lectures

Schedule

No class

Month	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
January	19	20	21 ✅	22	23 ✅	24	25
	26 ❄️🌨️❄❄❄	27	28 ❄️🌨️❄❄❄	29	30 ✅	31	1
February	2 ✅	3	4 ✅	5	6 ✅	7	8
	9 ✅	10	11 HWB due	12	13 ✅	14	15
	16 ✅	17	18	19	20 HWC due ✅	21	22
	23 Hegi Center	24	25 HWD due	26	27	28	1
March	2	3	4	5	6	7	8
	9	10	11	12	13	14	15
	16	17	18	19	20	21	22
	23	24	25	26	27	28	29
April	30	31	1	2	3	4	5

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April	6	7	8	9	10	11	12
	13	14	15	16	17	18	19
	20	21	22	23	24	25	26
May	27	28	29	30	1	2	3
	4	5	6	7	8	9	10

Longitudinal Waves
Sound (Halliday 17.4-17.8)

Longitudinal waves: Key concepts

- A sound wave is defined as a longitudinal wave
- Key ideas:
  - Point S represents a tiny source, called a point source S
    - Emits sound in all directions
    - Wavefronts and rays indicate the direction of travel and the spread of sound waves
    - Wavefront: surface over which oscillation due to sound has the same value
      - Such surfaces are represented by whole or partial circles in a two-dimensional drawing for a point source

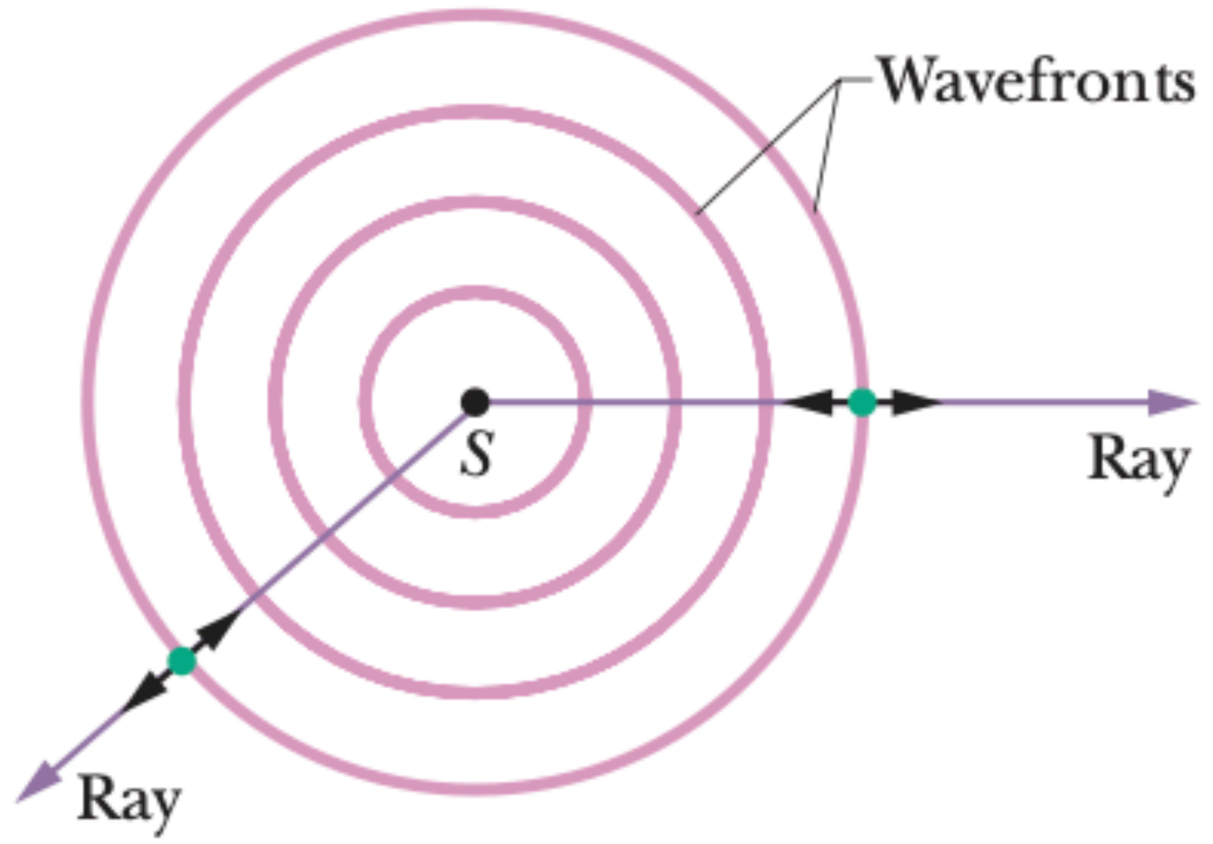
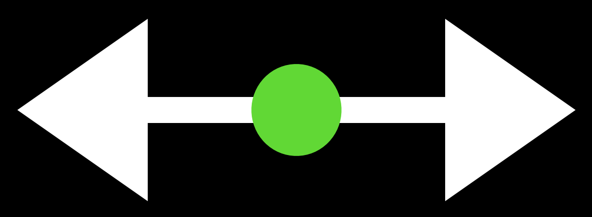


Figure 17-2 A sound wave travels from a point source S through a three-dimensional medium. The wavefronts form spheres centered on S; the rays are radial to S. The short, double-headed arrows indicate that elements of the medium oscillate parallel to the rays.

Longitudinal waves: Key concepts

- A sound wave is defined as a longitudinal wave
- Key ideas:
  - Ray: Directed lines perpendicular to the wavefront
    - The short double arrows superimposed on the rays indicate that the longitudinal oscillations of the air are parallel to the rays
    - 

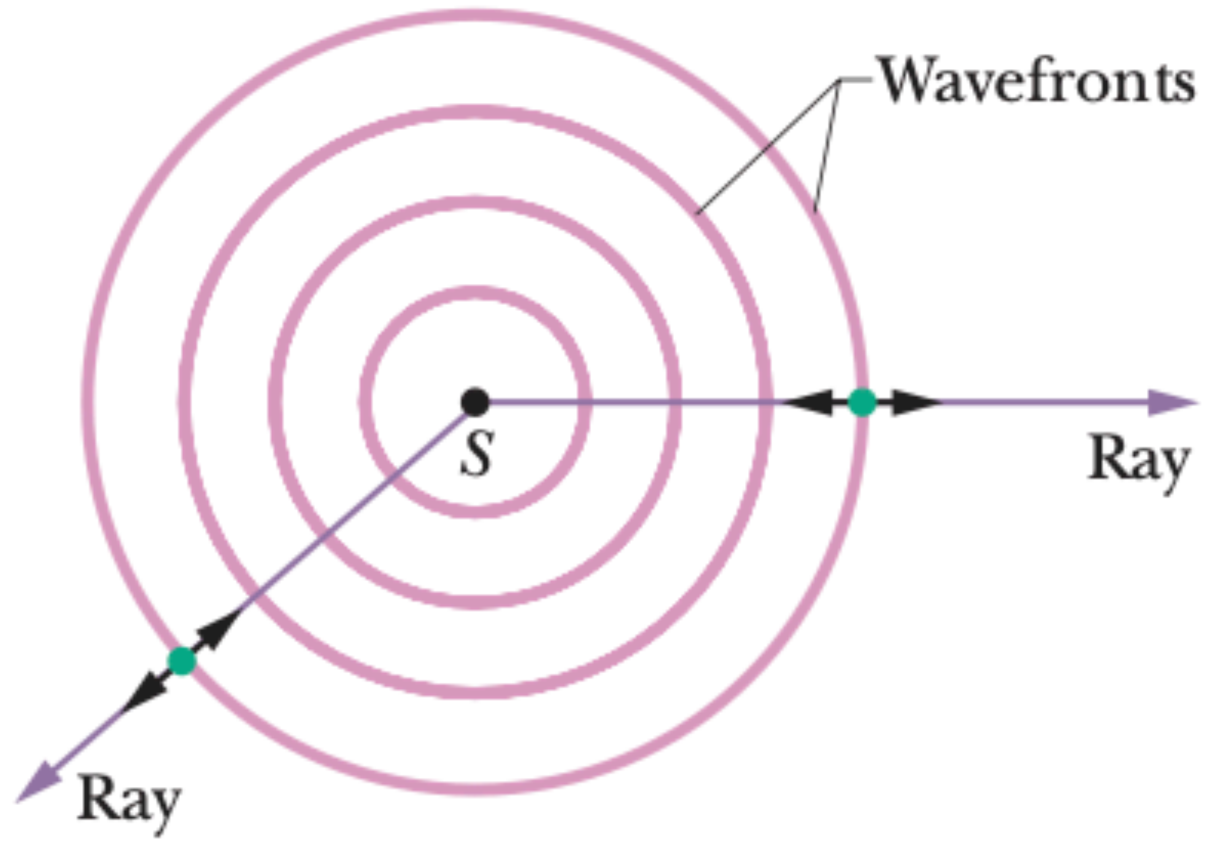


Figure 17-2 A sound wave travels from a point source S through a three-dimensional medium. The wavefronts form spheres centered on S; the rays are radial to S. The short, double-headed arrows indicate that elements of the medium oscillate parallel to the rays.

Key concepts

- If you have ever tried to sleep while someone played loud music nearby, you are well aware that there is more to sound than frequency, wavelength, and speed. There is also intensity.
- The intensity of a sound wave at a surface is the average rate per unit area at which energy is transferred by the wave through or onto the surface:
  - $I = \frac{P}{A}$ where P is the time rate of energy transfer (the power) of the sound wave
    - A is the area of the surface intercepting the sound
  - $I = \frac{1}{2}\rho v \omega^2 s_m^2$

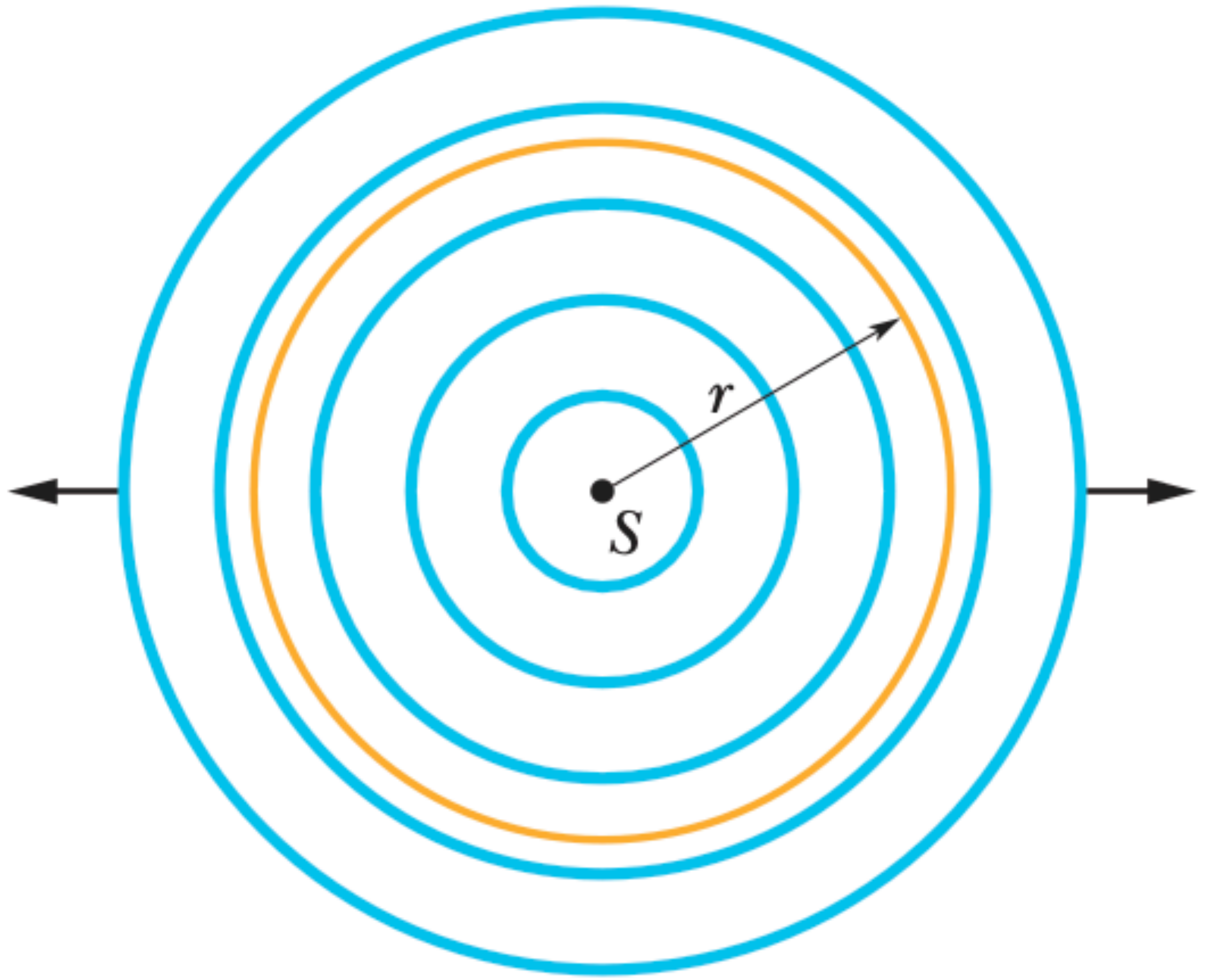


Figure 17-9 A point source S emits sound waves uniformly in all directions. The waves pass through an imaginary sphere of radius r that is centered on S.

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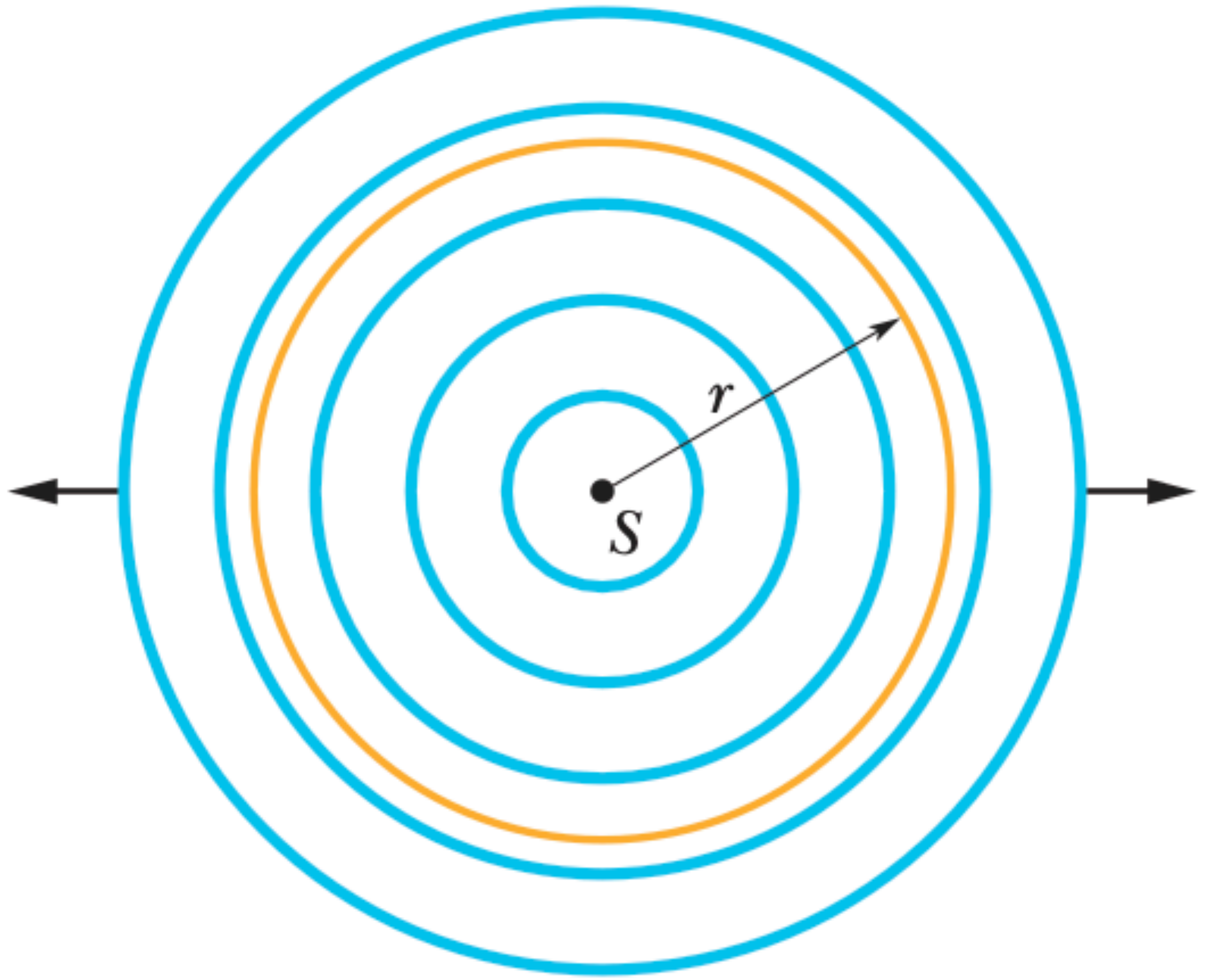

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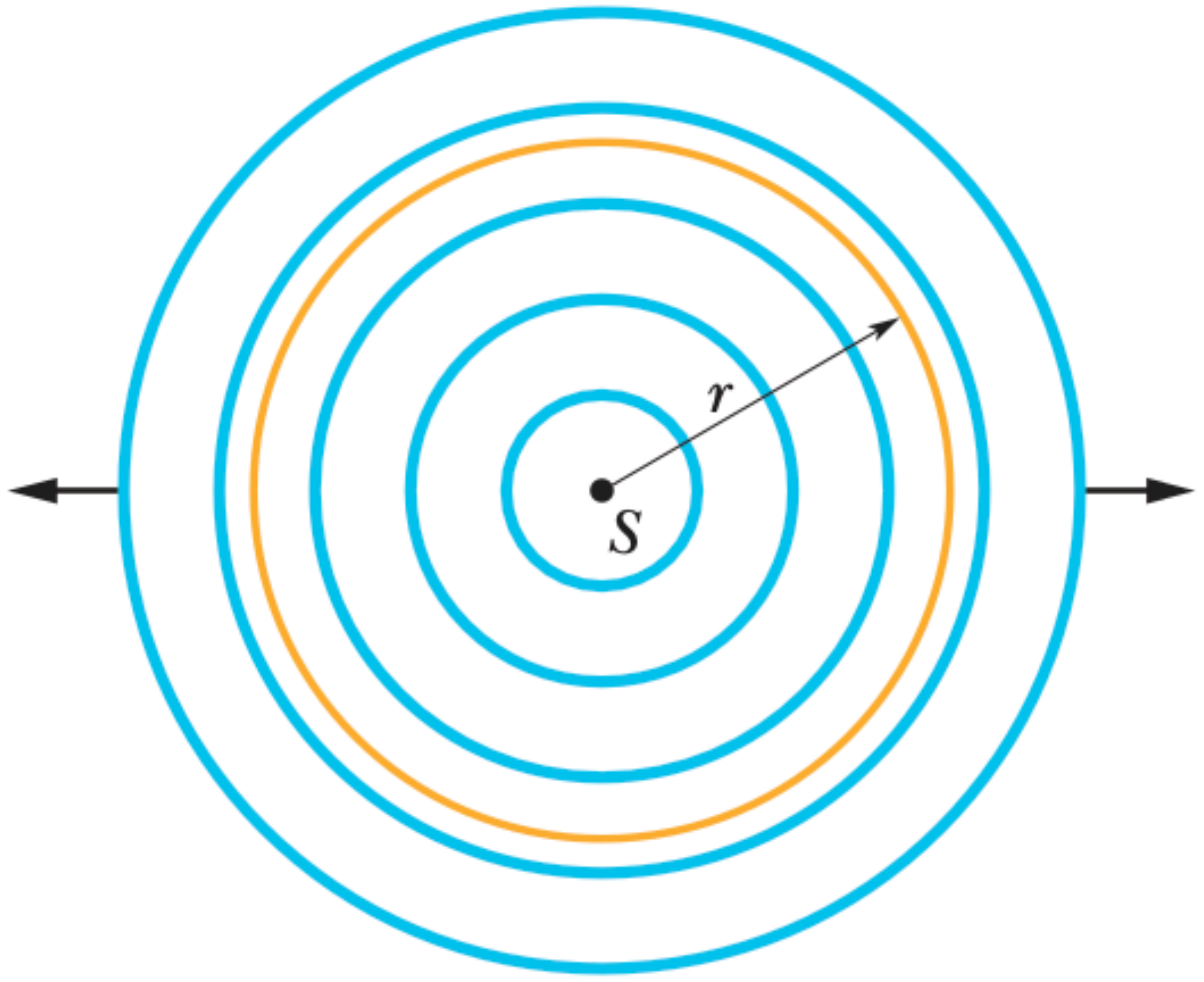
- Variation of intensity with distance:
  - Assuming sound source is a point source and emits sound isotropically (does not always hold: directionality or reflected waves (echoes))
    - $I = \frac{P_S}{4\pi r^2}$, what is $4\pi r^2$?



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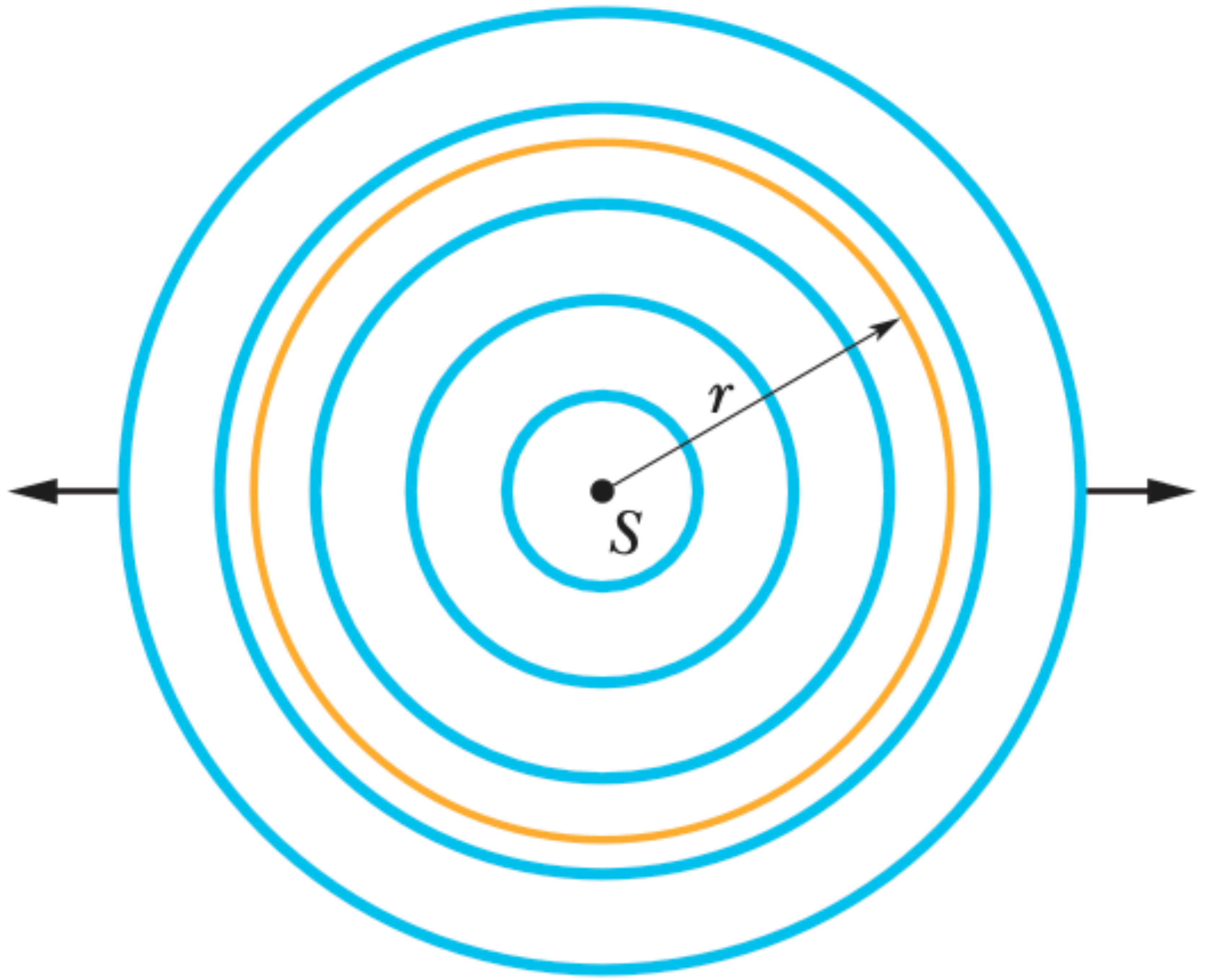


Figure 17-9 A point source S emits sound waves uniformly in all directions. The waves pass through an imaginary sphere of radius r that is centered on S.

A point source of sound emits power P_o isotropically (uniformly in all directions). A detector of area a_d is located a distance R away from the source.

What is the power ***received*** by the detector?

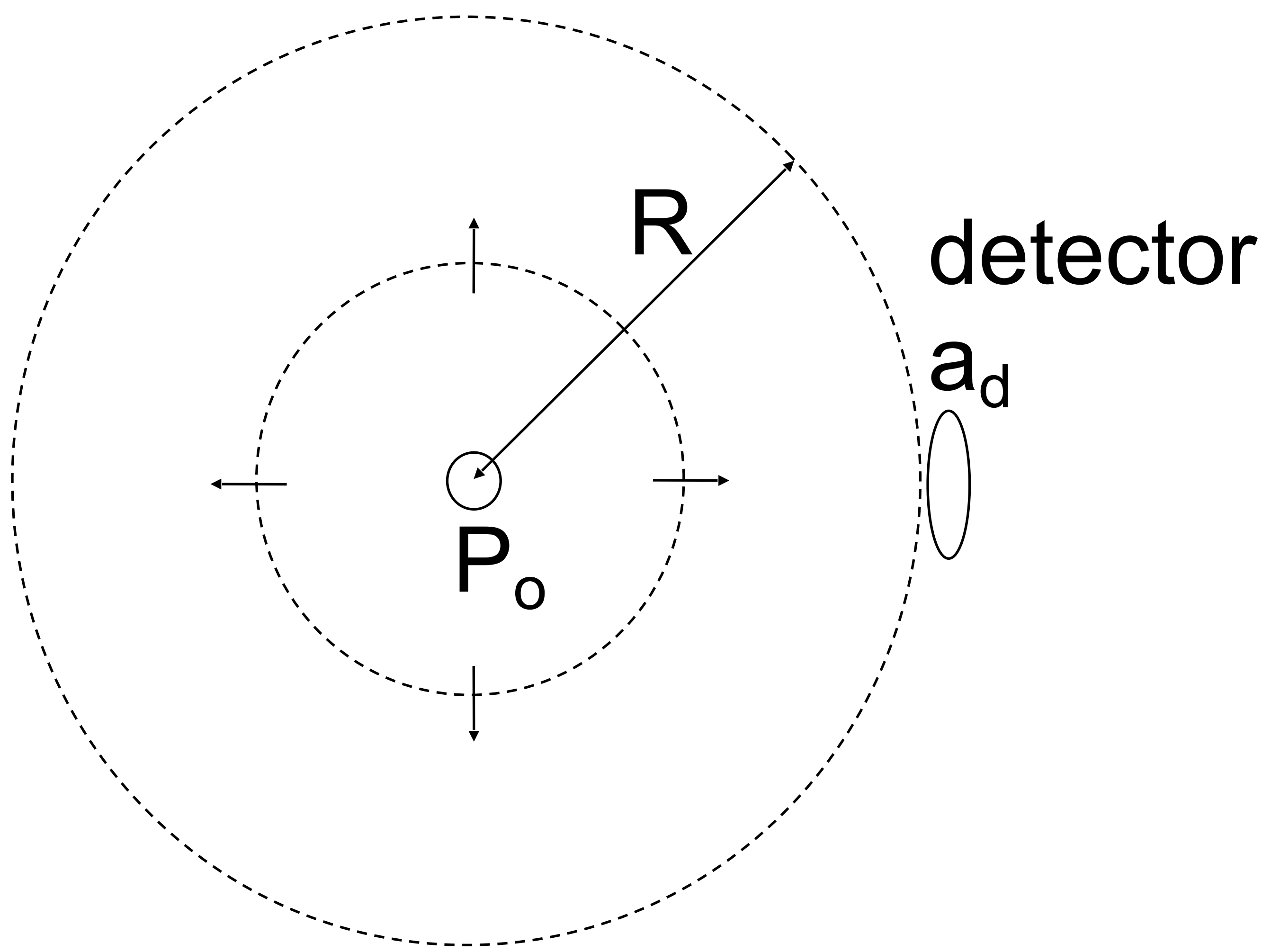
A) $\dfrac{P_o}{4\pi R^2} a_d$

B) $P_o \dfrac{a_d^2}{R^2}$

C) $P_o \dfrac{a_d}{R}$

D) $\dfrac{P_o}{\pi R^2} a_d$

E) None of these



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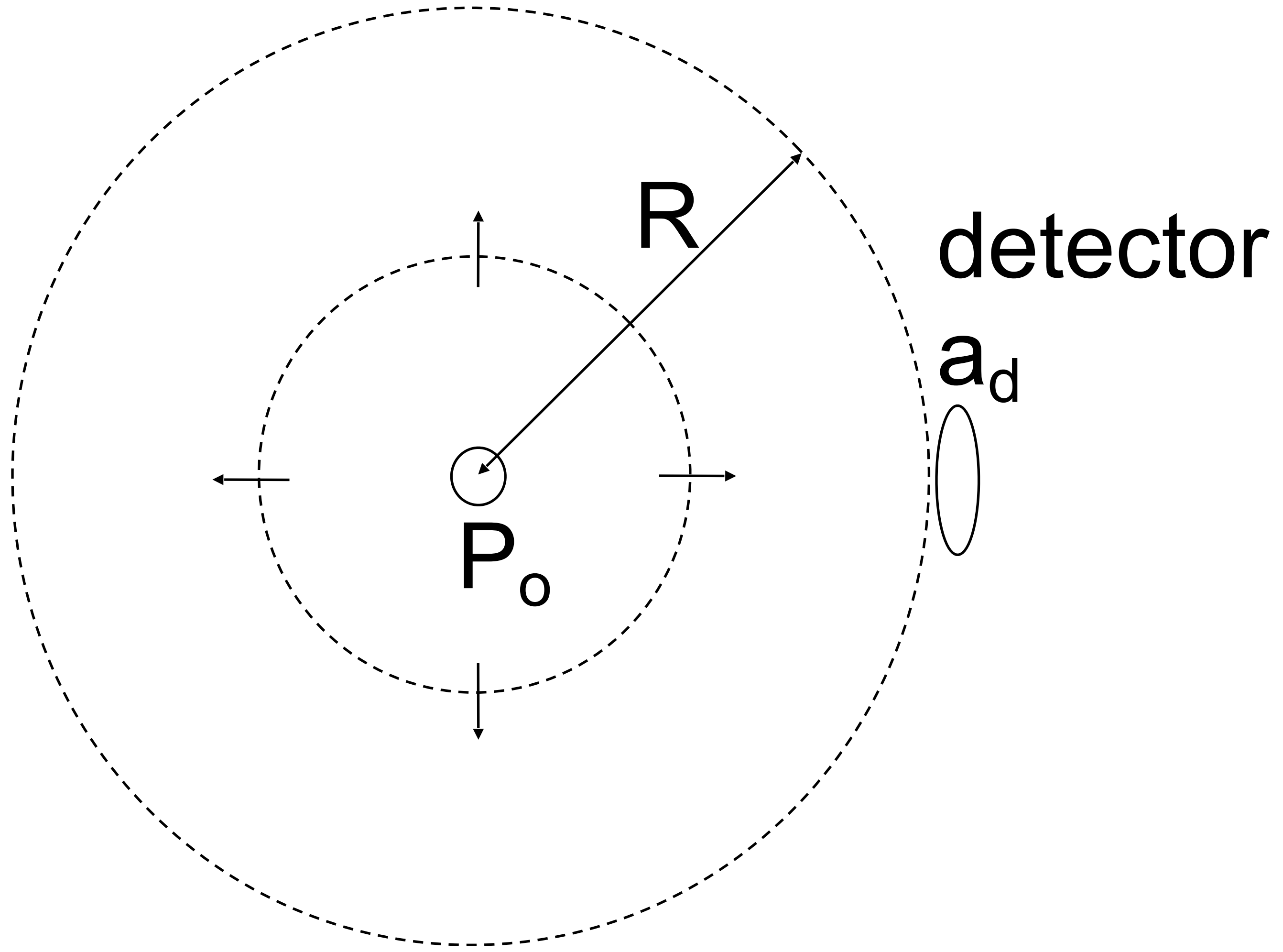


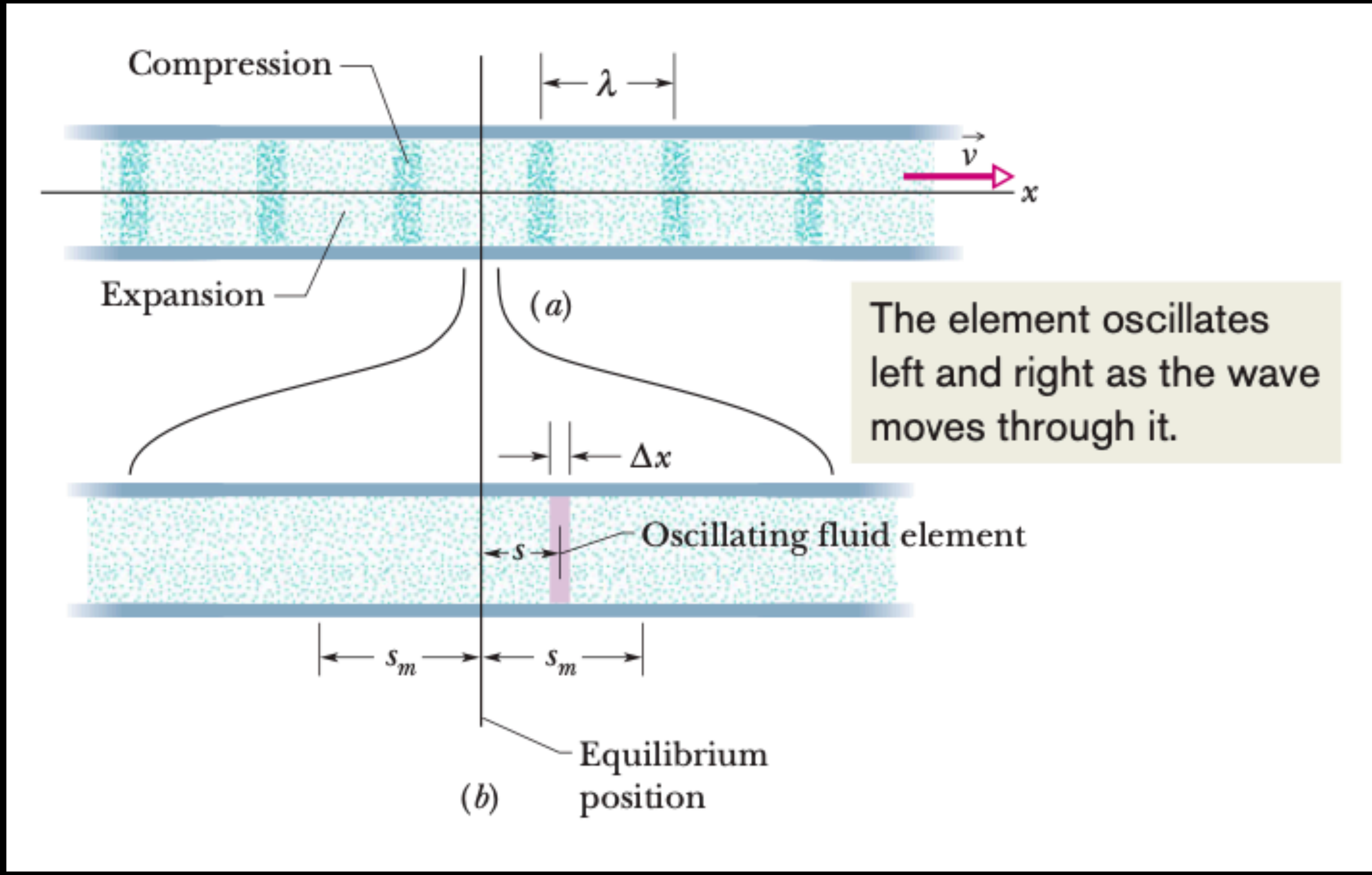
Power received ($P_{received}$) = Ia_d

Key concepts

Derivation of $I = \frac{1}{2}\rho v \omega^2 s_m^2$

- Consider a thin slice of air of thickness dx, area A, and mass dm oscillating back and forth as the sound wave passes through it:
  - The kinetic energy dK of the slice of air is:
    - $dK = \frac{1}{2}\ dm\ v_s^2$ ($v_s =$ speed of oscillating element of air *and not of the wave*)
    - $v_s = \frac{\partial s}{\partial t} = -\omega s_m \sin(kx - \omega t)$
  - Writing $dm = \rho A\ dx$
  - $dK = \frac{1}{2}\ \rho A\ dx\ (-\omega s_m)^2 \sin^2(kx - \omega t)$
  - $\frac{dK}{dt} = \frac{1}{2}\rho A v \omega^2 s_m^2 \sin^2(kx - \omega t)$
  - Average rate:

$$\left(\frac{dK}{dt}\right)_{avg} = \frac{1}{2}\rho A v \omega^2 s_m^2 \left[\sin^2(kx - \omega t)\right]_{avg}$$



Key concepts

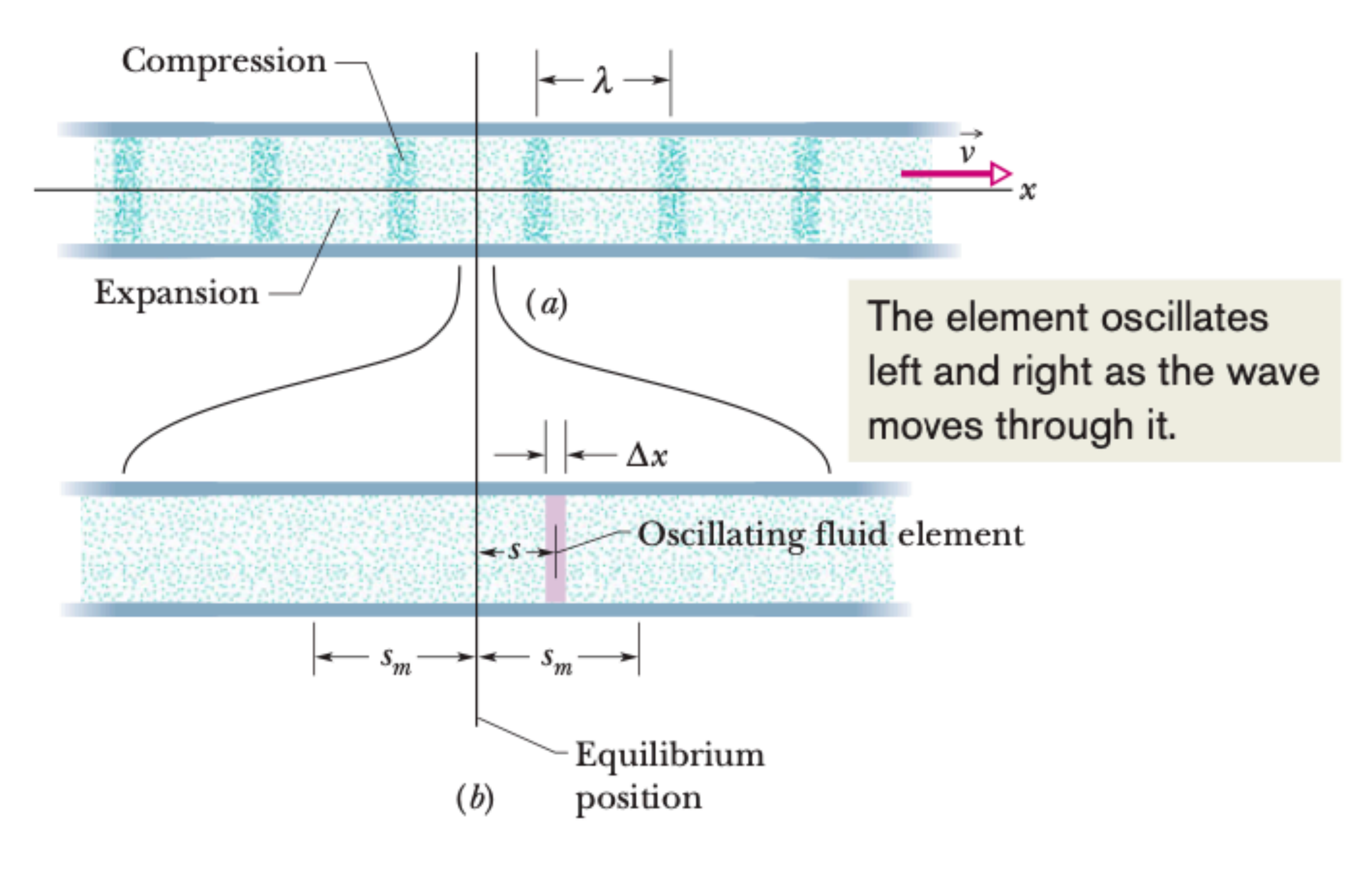
Derivation of $I = \frac{1}{2}\rho v \omega^2 s_m^2$

- Average rate:

$$\left(\frac{dK}{dt}\right)_{avg} = \frac{1}{2}\rho A v \omega^2 s_m^2 \left[\sin^2(kx - \omega t)\right]_{avg}$$

- $$\left(\frac{dK}{dt}\right)_{avg} = \frac{1}{2}\rho A v \omega^2 s_m^2 \left(\frac{1}{2}\right)$$
- $$\left(\frac{dK}{dt}\right)_{avg} = \frac{1}{4}\rho A v \omega^2 s_m^2$$

- Assuming *potential energy* is carried along with the wave at the same average rate:
  - $$I = \frac{2(dK/dt)_{avg}}{A} = \frac{1}{2}\rho v \omega^2 s_m^2$$



By how much does the intensity of a sound decrease when you move 10 times further away from the source of the sound?

a) 100 times
b) 10 times
c) There is no decrease
d) 1000 times
e) 10,000 times

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Key concepts: The Decibel scale

- We deal with an enormous variation in displacement amplitude:
  - 10^{-5} m (loudest tolerable sound) to 10^{-11} faintest sound
  - We need a logarithmic scale
  - $\beta = (10 \text{ dB})\log \dfrac{I}{I_0}$
  - Decibel scale: named after Alexander Graham Bell
  - I_0: standard reference ($10^{-12} W/m^2$)
  - As β increases by 10 dB, sound intensity increases by an order of magnitude

Table 17-2 Some Sound Levels (dB)

Hearing threshold	0
Rustle of leaves	10
Conversation	60
Rock concert	110
Pain threshold	120
Jet engine	130

The sound level of sounds below the standard threshold of hearing at a frequency of 1 kHz is

a) zero

b) positive

c) negative

d) 1 kHz

The sound level of sounds below the standard threshold of hearing at a frequency of 1 kHz is

a) zero

b) positive

c) negative

d) 1 kHz

$$\beta = (10\ \text{dB})\log\frac{I}{I_0}, I < I_0, \beta < 0$$

If a sound increases in intensity by a factor 100 times, the sound level

a) increases by a factor of 100 times

b) decreases by a factor 100 times

c) increases by 100 dB

d) increases by 10 dB

e) increases by 20 dB

If a sound increases in intensity by a factor 100 times, the sound level

a) increases by a factor of 100 times

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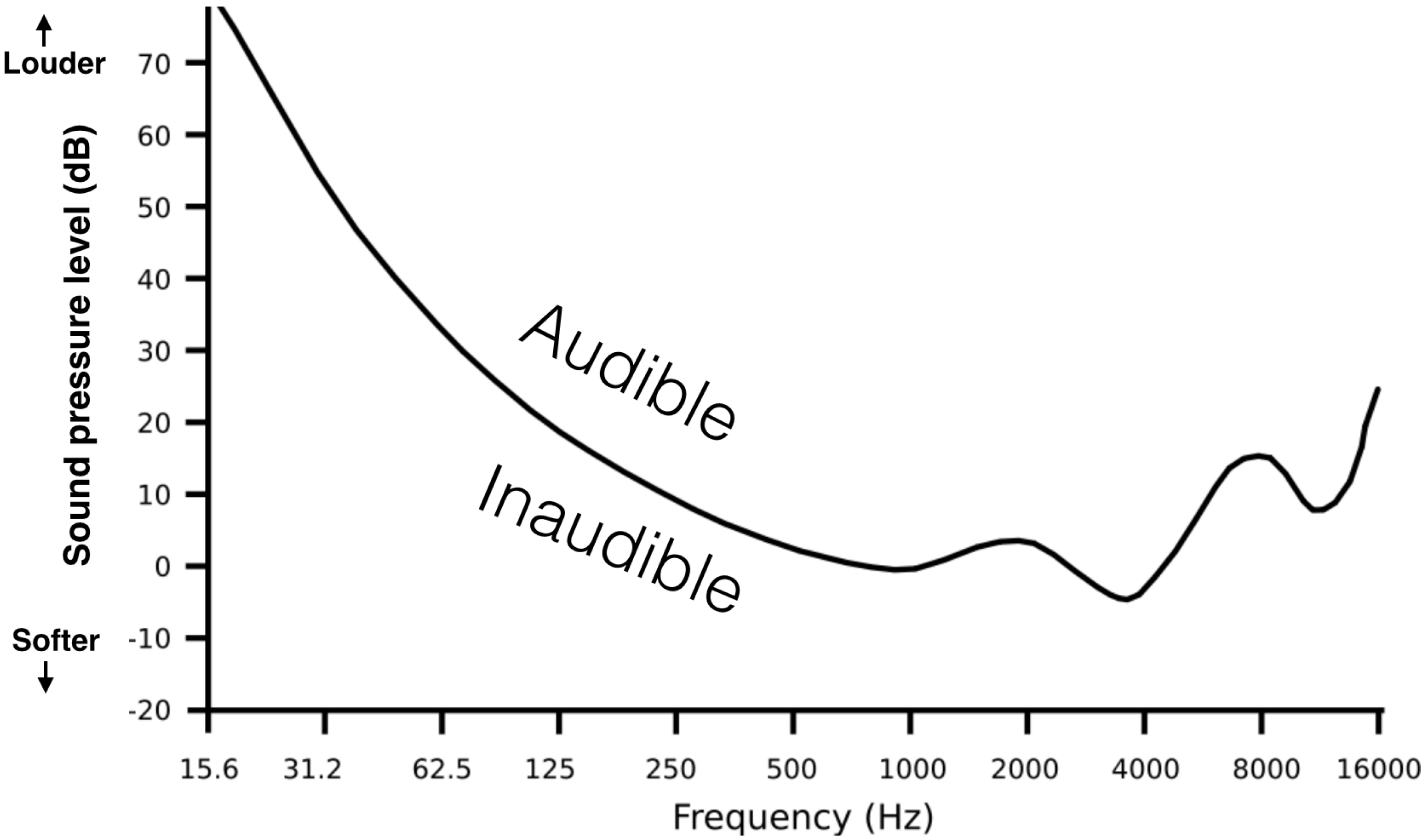
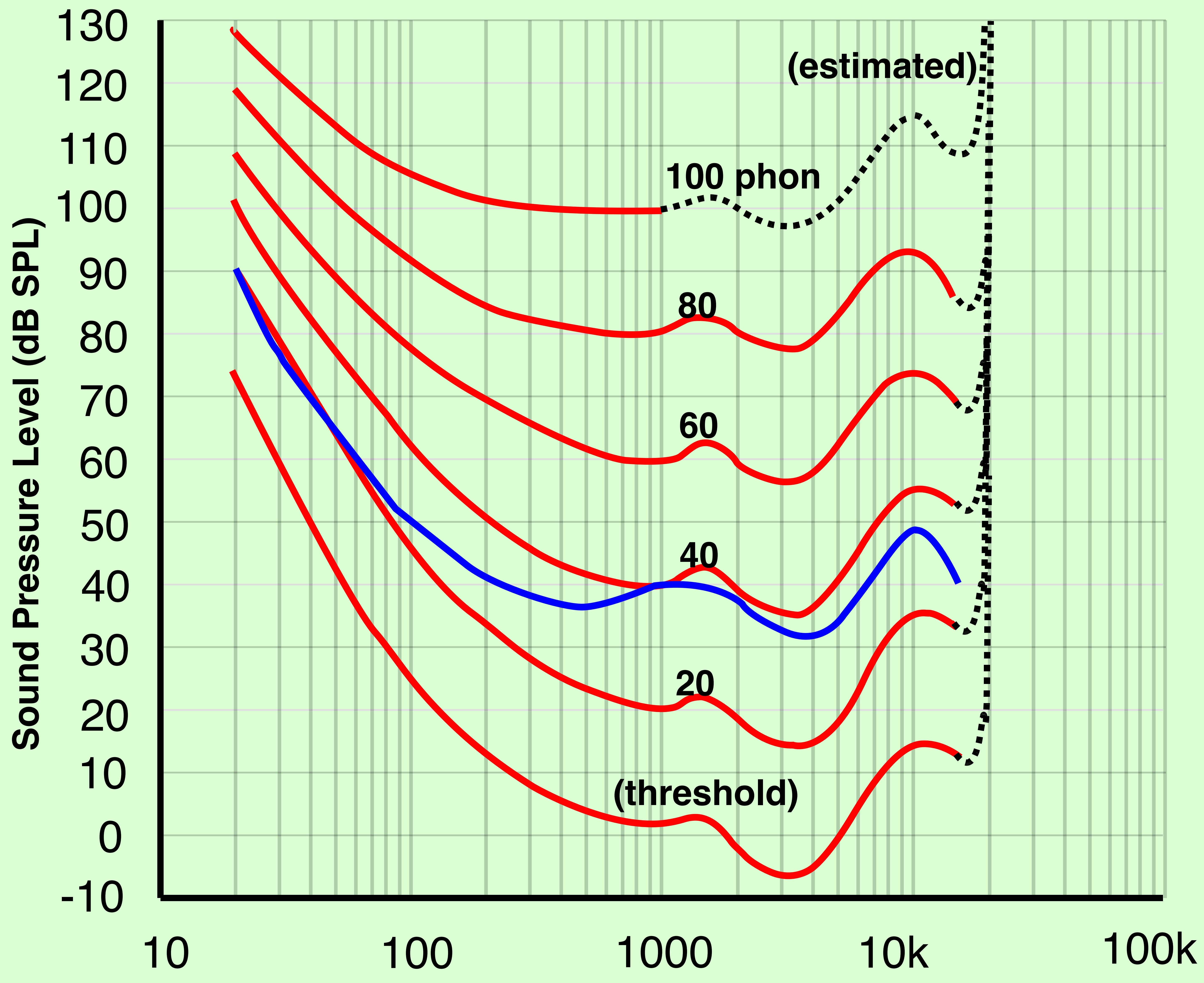


Louder
Softer
Sound pressure level (dB)
70
60
50
40
30
20
10
0
-10
-20
Audible
Inaudible
15.6
31.2
62.5
125
250
500
1000
2000
4000
8000
16000
Frequency (Hz)



Equal-loudness contours (red) (from ISO 226:2003 revision)
Original ISO standard shown (blue) for 40-phons

1. The Curves Slope Upward Equal-loudness contours (often referred to historically as Fletcher-Munson curves or by the modern ISO 226 standard) map the Sound Pressure Level (SPL) required for a tone to sound equally loud across the frequency spectrum.

Because our ears are less sensitive to high frequencies, the contour lines slope sharply upward as you move past **8,000 Hz**.

2. Higher Intensity is Required for the Same Loudness If you have a reference tone at **1 kHz** playing at a moderate volume (e.g., **40 dB**), it will sound fairly clear. To make a **15 kHz** tone sound like it has that exact same loudness, you have to pump significantly more acoustic power into it—often requiring an SPL of **60 dB** or higher, depending on the specific frequency and the listener's age.

3. The Threshold of Hearing Rises The absolute threshold of hearing (the lowest curve on the graph, representing the quietest sound a human can detect in a perfectly quiet room) rises rapidly in this regime. Eventually, the curve hits a "wall" around **20 kHz**, which is the upper limit of human hearing, where the required intensity to perceive the sound approaches infinity.

Why does this happen? This drop-off is primarily biological and mechanical. The ear canal acts as a resonator that naturally amplifies frequencies between **2 kHz** and **5 kHz** (which is why our hearing is most sensitive there). For higher frequencies, this resonance effect is lost. Additionally, the tiny hair cells in the cochlea that detect high frequencies are more rigid, require more energy to stimulate, and are the most susceptible to degradation over time (high-frequency hearing loss).

Key concepts: Nodes and Antinodes

- Simplest standing wave pattern in a pipe with two open ends

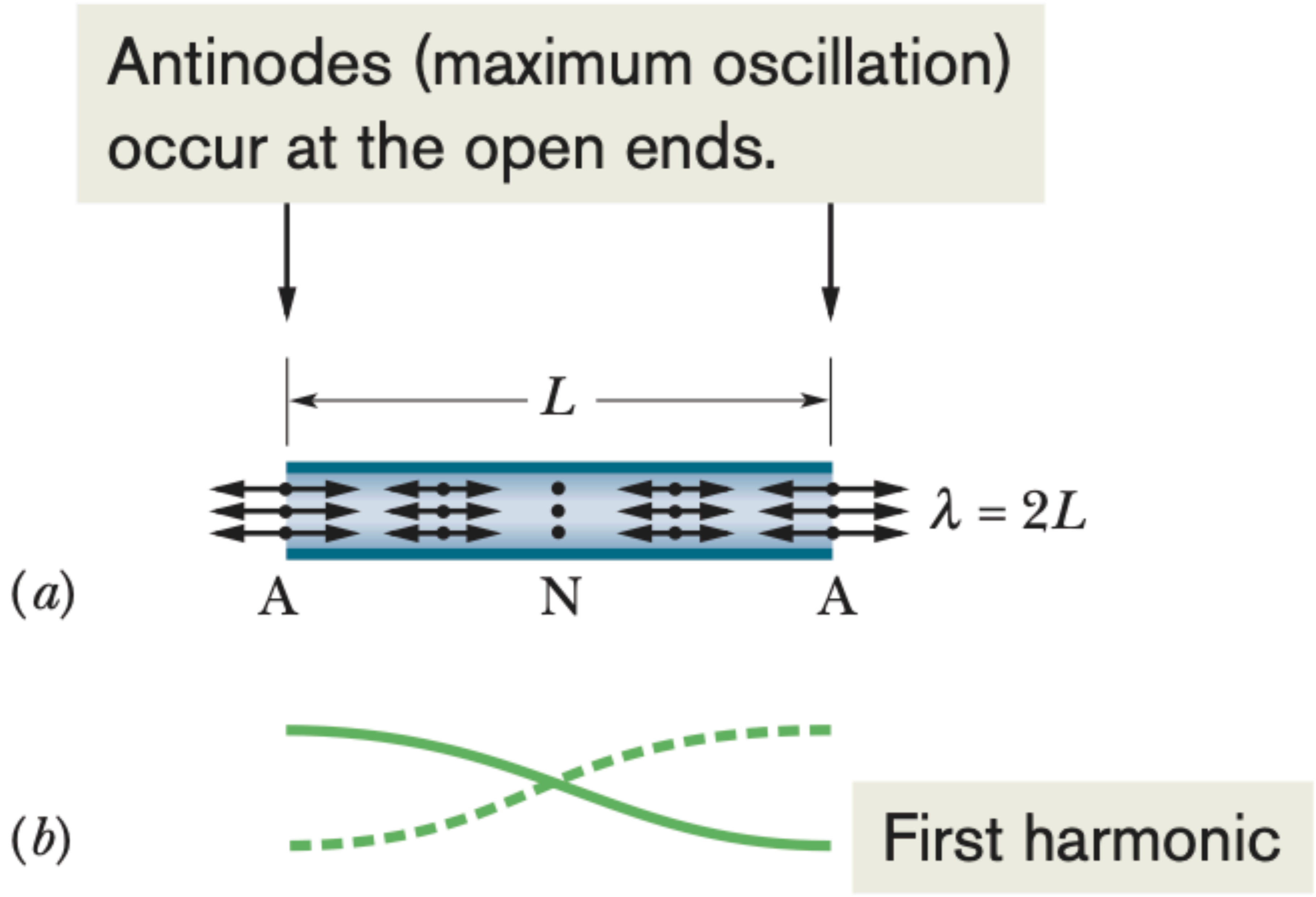
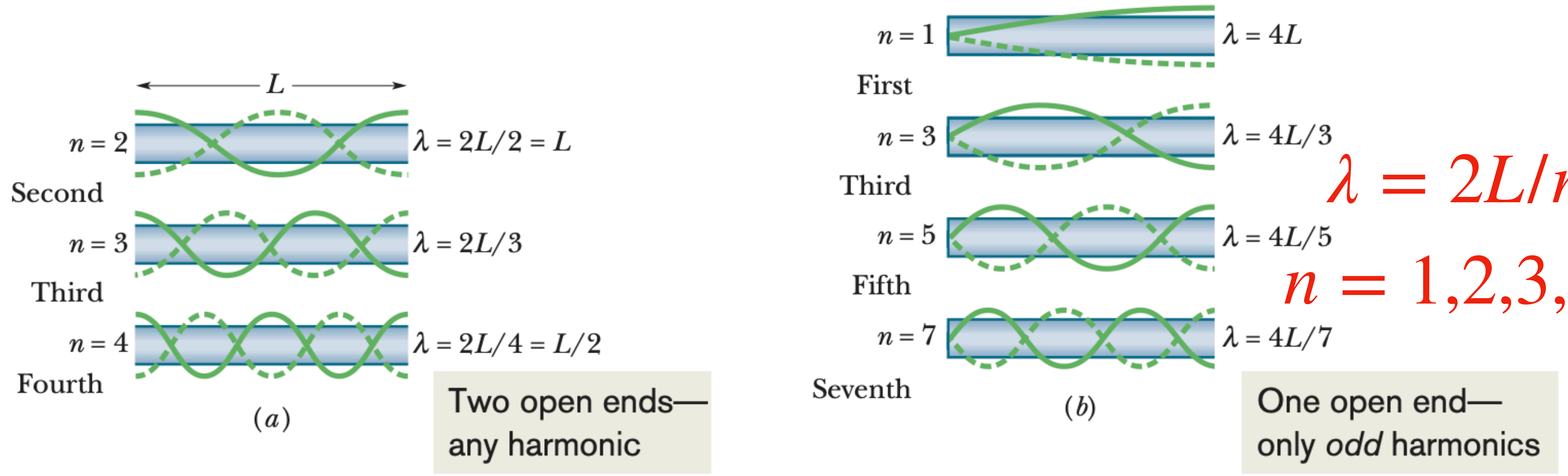


Figure 17-13 (*a*) The simplest standing wave pattern of displacement for (longitudinal) sound waves in a pipe with both ends open has an antinode (A) across each end and a node (N) across the middle. (The longitudinal displacements represented by the double arrows are greatly exaggerated.) (*b*) The corresponding standing wave pattern for (transverse) string waves.

Key concepts: Nodes and Antinodes

- The standing wave pattern on the previous slide is called the the fundamental mode or first harmonic
  - Sound waves in a pipe of length L must have a wavelength given by $L = \lambda/2, \lambda = 2L$
- Second harmonic requires sound waves of wavelength $\lambda = L$, third harmonic $\lambda = 2L/3$



$$\lambda = 2L/n$$

$$n = 1,2,3,\cdots$$

n = harmonic number

Figure 17-14 Standing wave patterns for string waves superimposed on pipes to represent standing sound wave patterns in the pipes. (*a*) With *both* ends of the pipe open, any harmonic can be set up in the pipe. (*b*) With only *one* end open, only odd harmonics can be set up.

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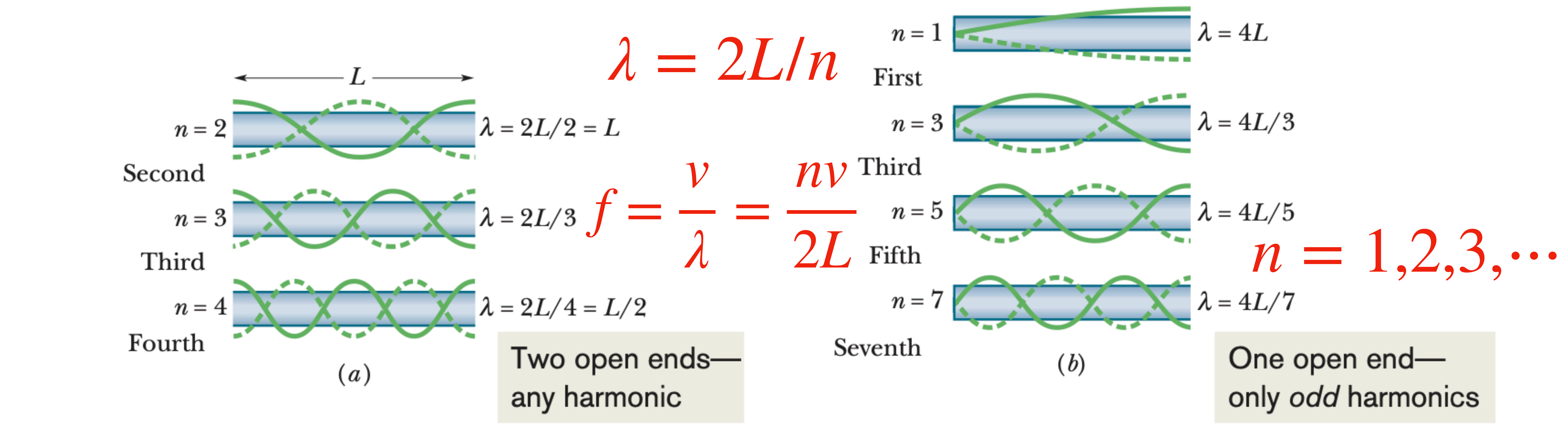

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Beats

Key concepts: Beats

- Beats arise when two waves having slightly different frequencies f_1 and f_2 are detected together:
  - $f_{\text{beat}} = f_1 - f_2$
- Time dependent variations of two sound waves of equal amplitude:
  - $s_1 = s_m \cos \omega_1 t$
  - $s_2 = s_m \cos \omega_2 t$
  - $s = s_1 + s_2$
  - $s = s_m(\cos \omega_1 t + \cos \omega_2 t)$
  - $s = 2s_m \cos \left[\frac{1}{2}(\omega_1 - \omega_2)t\right] \cos \left[\frac{1}{2}(\omega_1 + \omega_2)t\right]$
  - $s(t) = [2s_m \cos \omega' t \cos \omega t], \omega' = \frac{1}{2}(\omega_1 - \omega_2), \omega = \frac{1}{2}(\omega_1 + \omega_2)$

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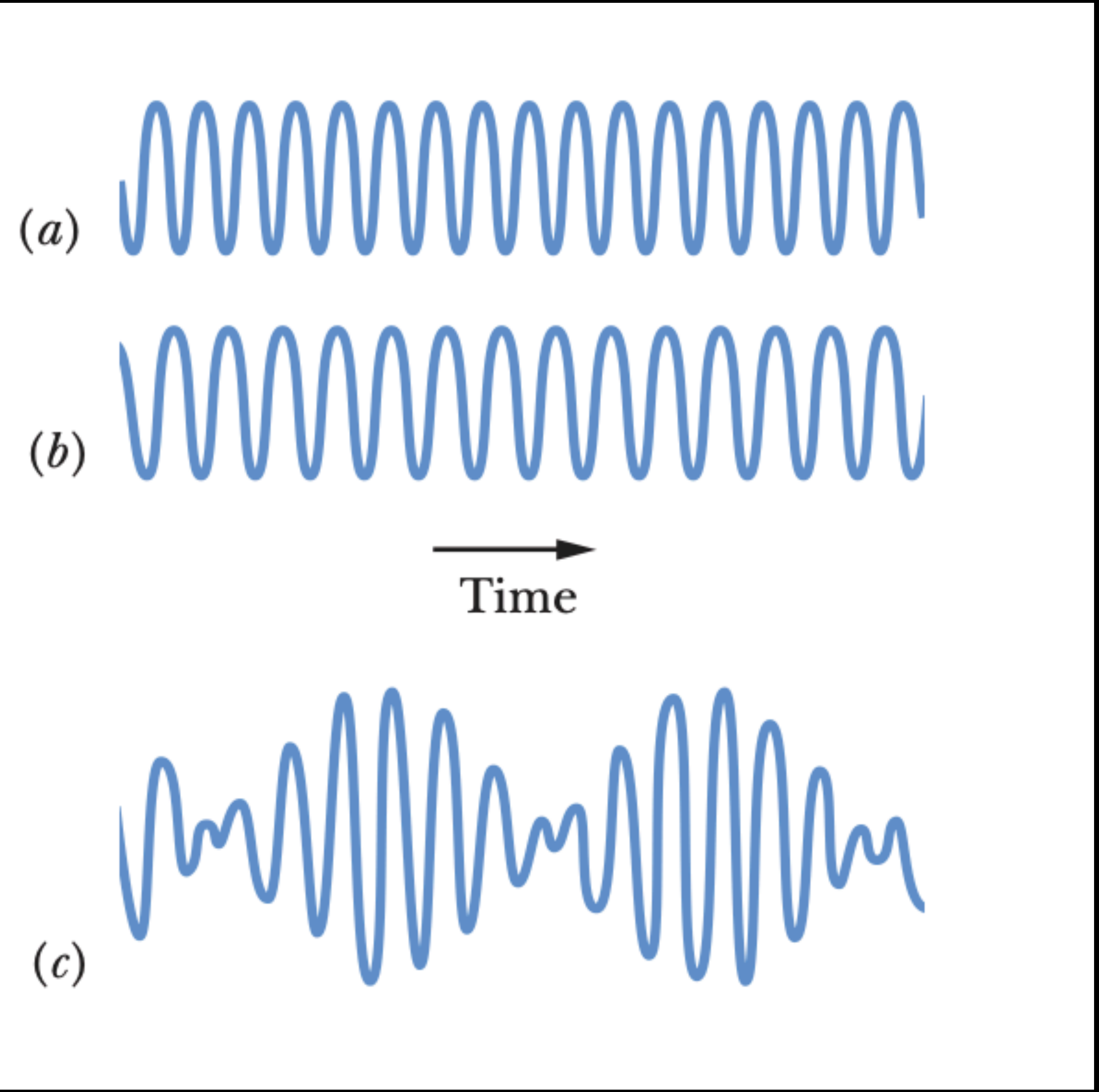


Key concepts: Doppler Effect

- The Doppler effect is a change in the observed frequency of a wave when the source or the detector moves relative to the transmitting medium (such as air)
- For sound the observed frequency f' is given in terms of the source frequency f by:
  - $f' = f \frac{v \pm v_D}{v \pm v_S}$
  - v_D: speed of the detector with respect to the medium
  - v_S: speed of the source with respect to the medium
  - v: speed of sound *in* to the medium
  - The signs are chosen such that f' tends to be *greater* for relative motion toward (one of the objects moves toward the other) and *less* for motion away

A child is swinging back and forth in front of a stationary horn.

At which position(s) will the child hear the lowest frequency for the sound from the horn?

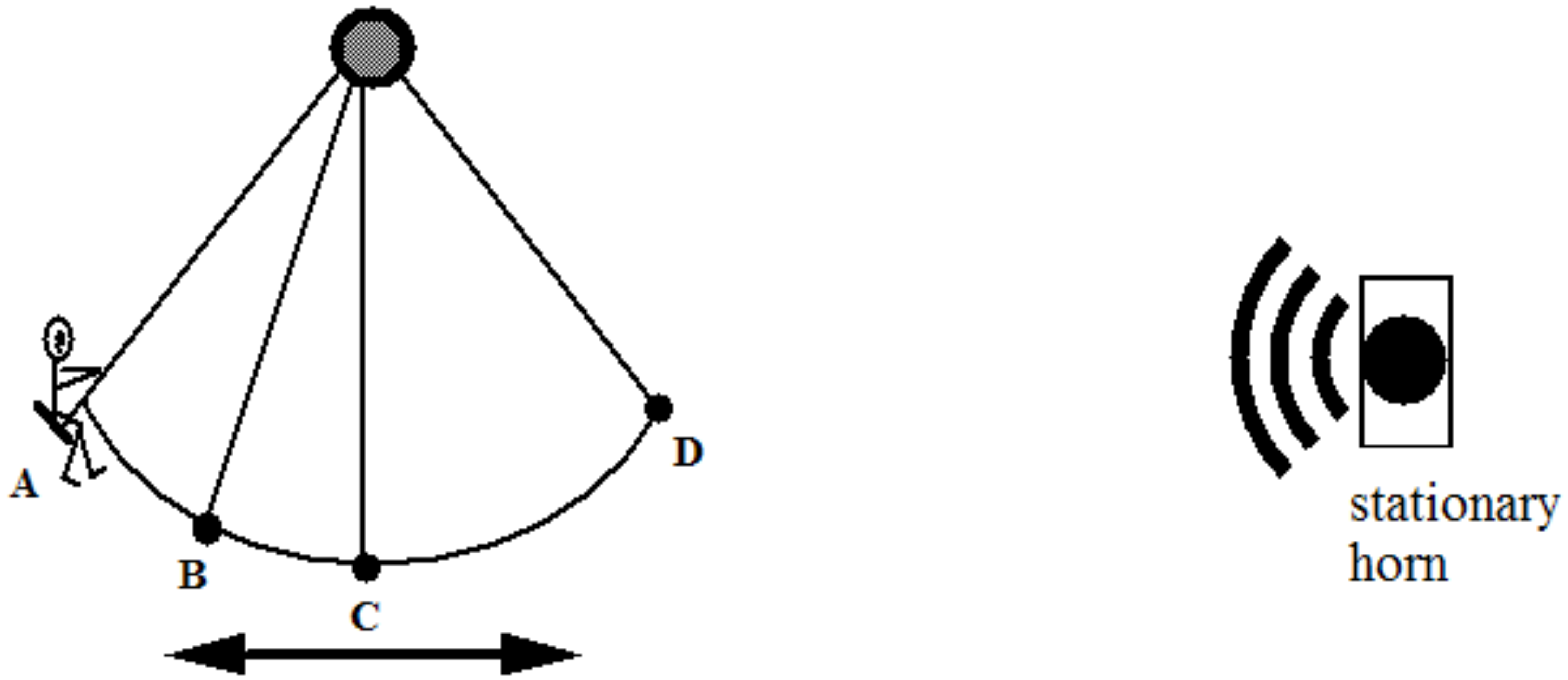
a) at **B** when moving toward **A**

b) at **B** when moving toward **C**

c) at **C** when moving toward **B**

d) at **C** when moving toward **D**

e) at both **A** and **D**



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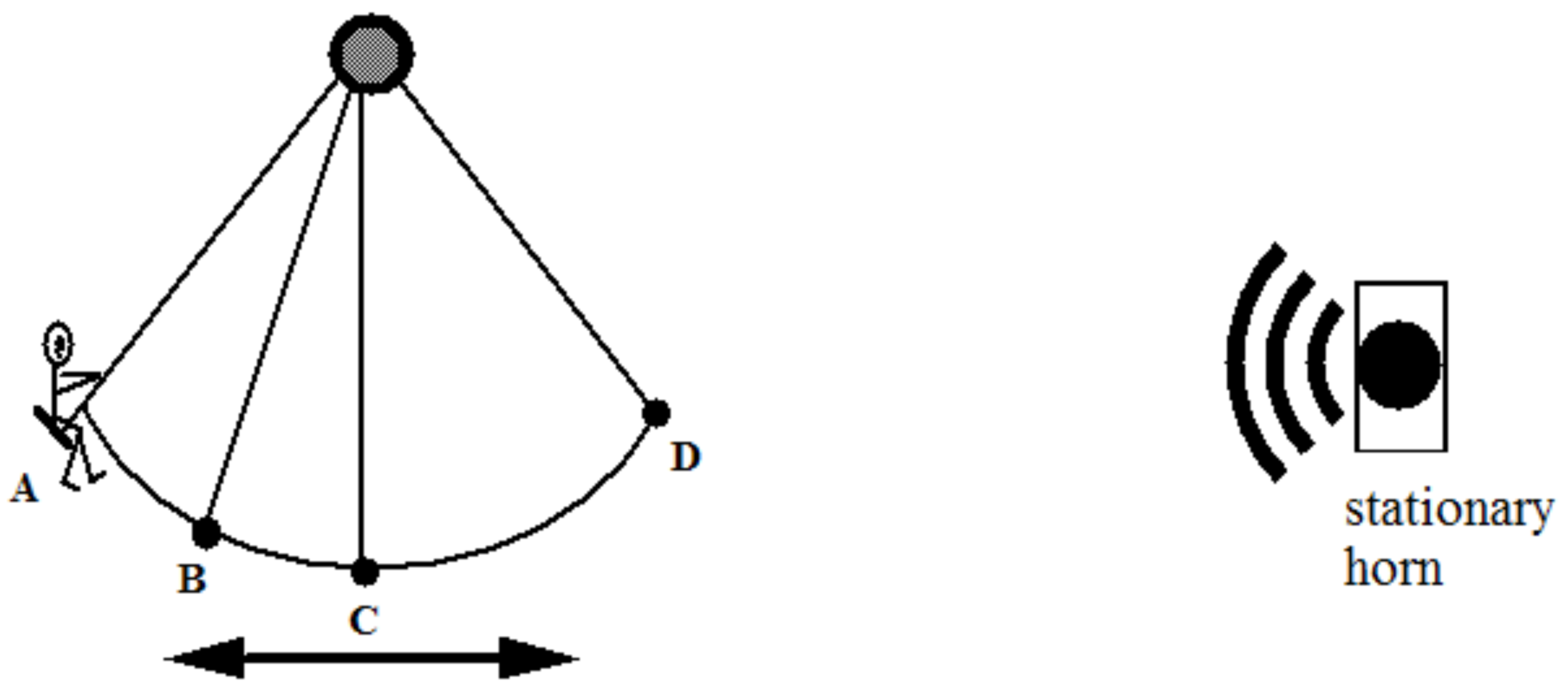

The Doppler Effect

The pitch (frequency) of a sound changes depending on the relative motion between the listener and the sound source.

- When moving **towards** a sound source, you encounter the sound waves more frequently, resulting in a **higher** perceived frequency.
- When moving **away from** a sound source, the sound waves are stretched relative to you, resulting in a **lowe** perceived frequency.

To hear the *lowest* possible frequency, the child must be moving **away** from the horn at the **highest possible speed**.

A swing acts like a simple pendulum, meaning the child's speed changes constantly throughout the arc:
Points A and D (the peaks): The child momentarily stops before changing direction (v=0). Because there is no relative motion at these exact instants, the perceived frequency is exactly the same as the horn's actual emitted frequency.
Point C (the lowest point): This is where gravity has accelerated the child the most. All potential energy has converted into kinetic energy, meaning the child is moving at their **maximum speed**.
Direction: The stationary horn is located to the right. To move *away* from it, the child must be traveling to the left.
Speed: The child must be at their fastest point, which is position **C**.