Sound

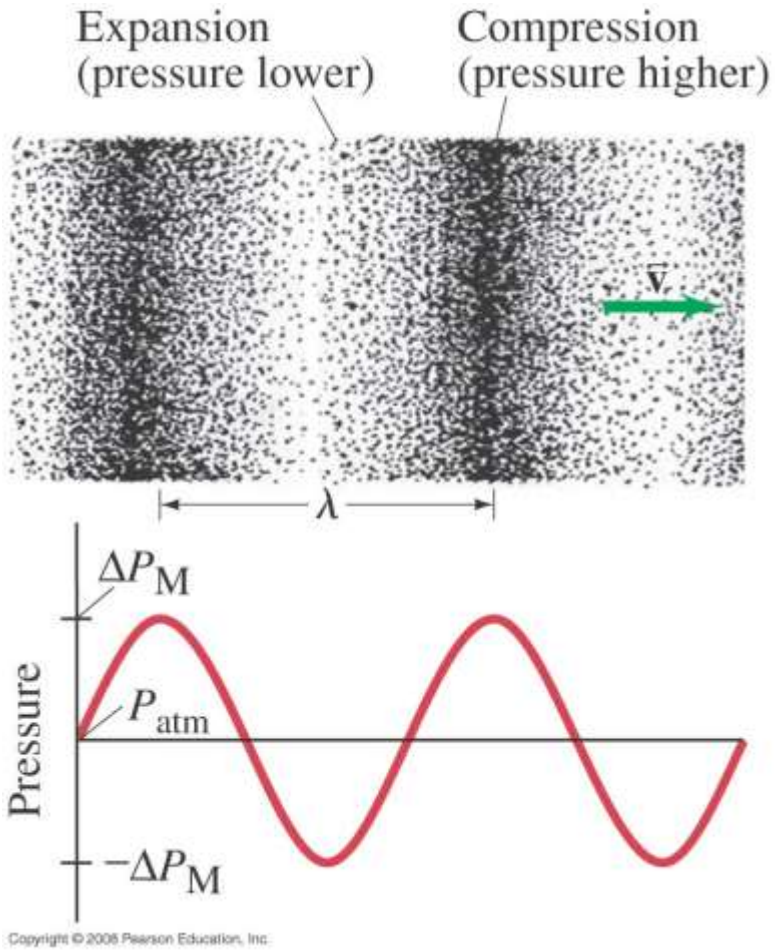
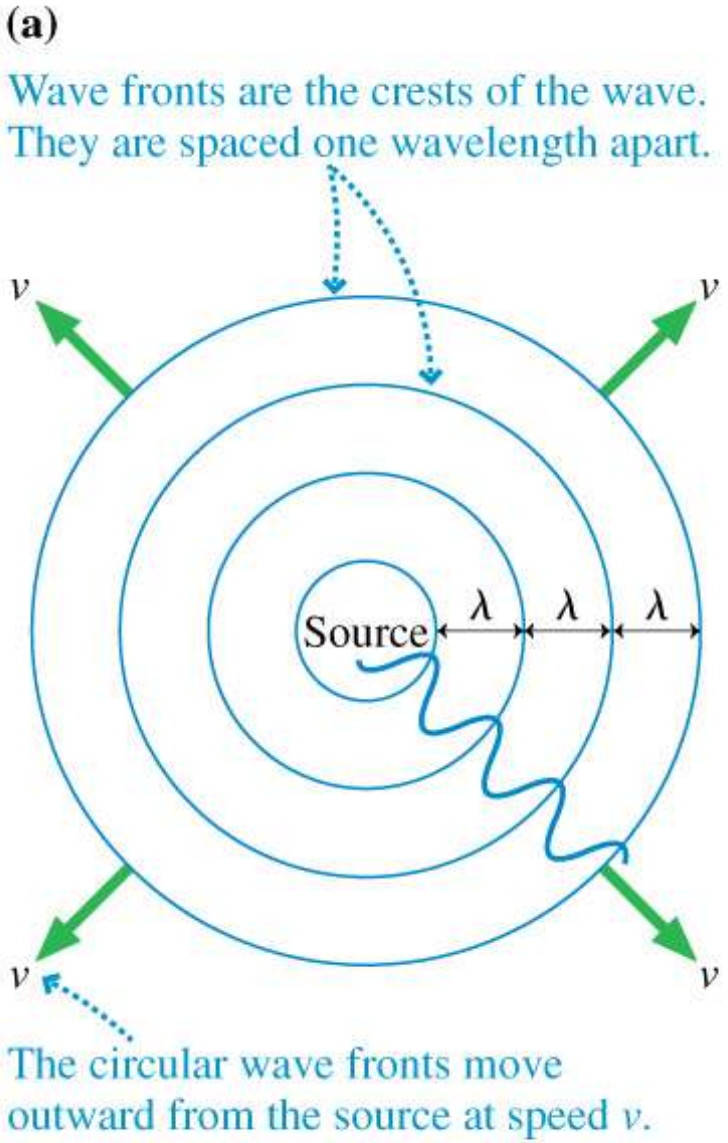


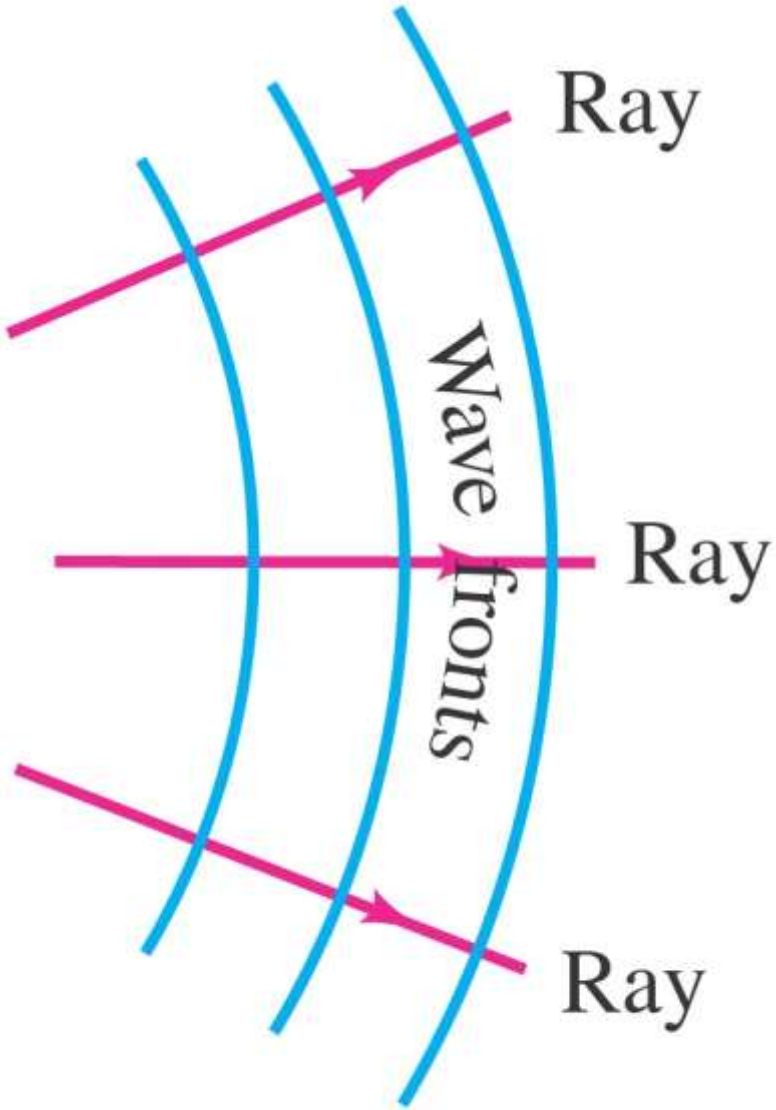
TABLE 16–1 Speed of Sound in Various Materials (20°C and 1 atm)

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

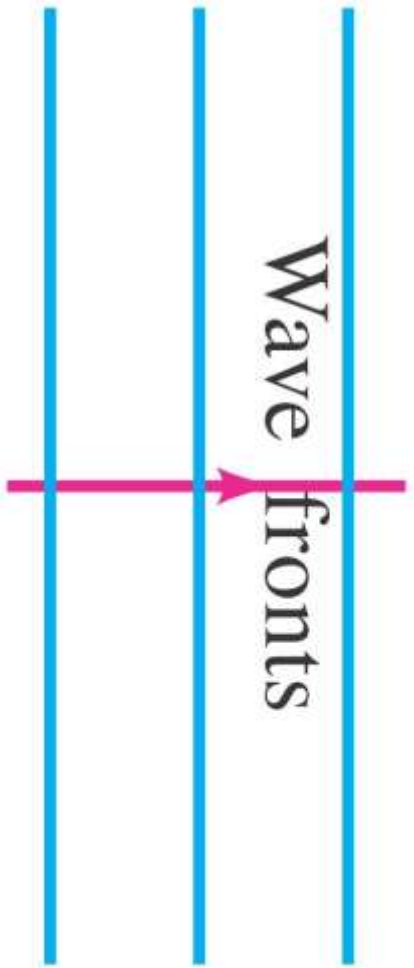
Waves in 2D and 3D



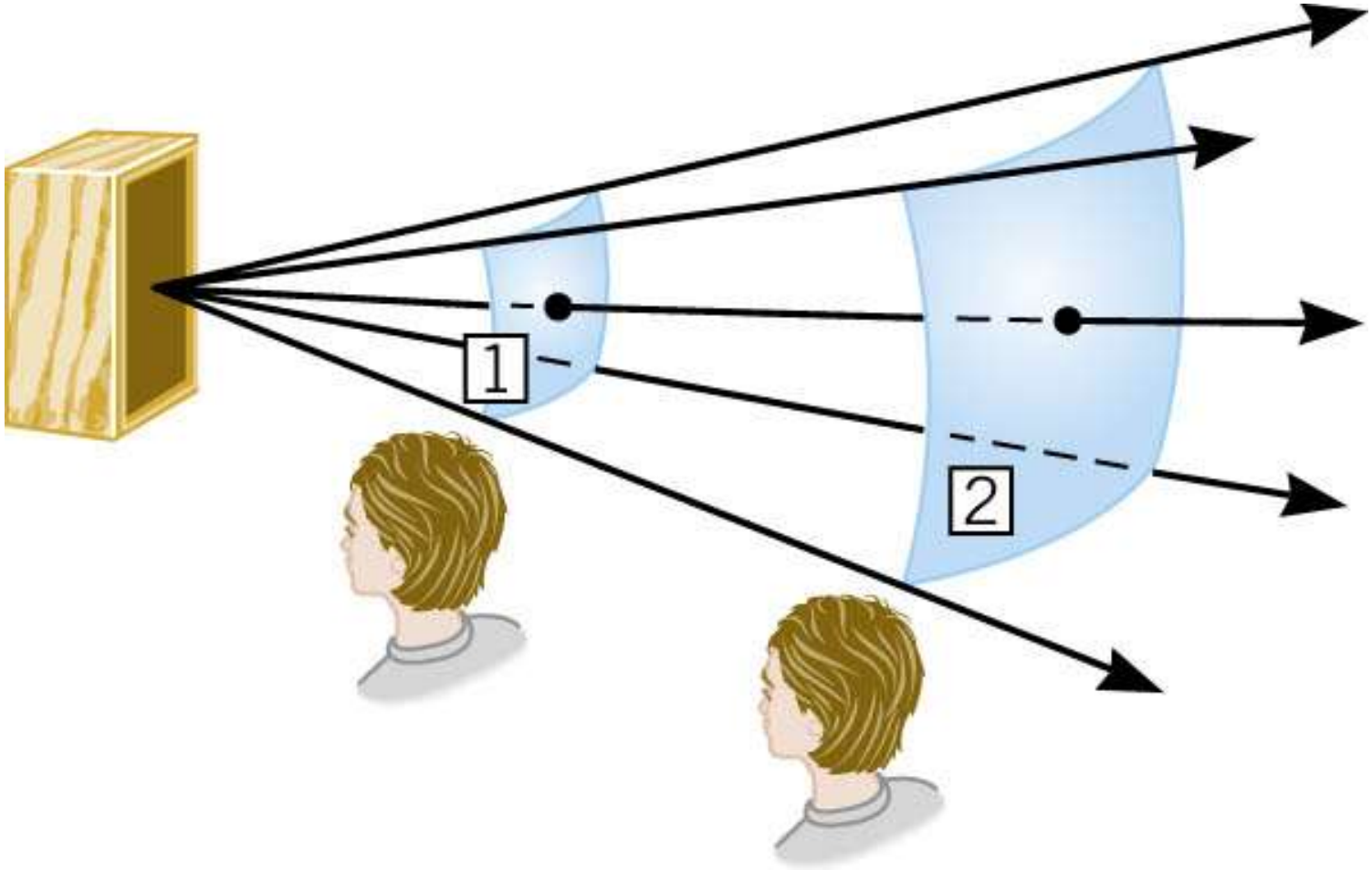
Waves in 2D and 3D



(a)



(b)



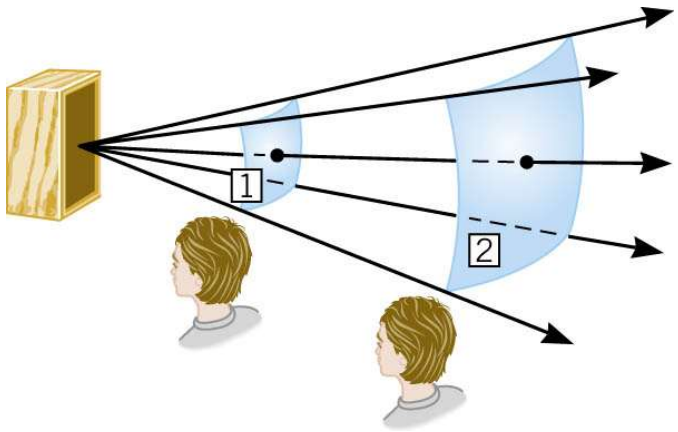
Questions

Sound Intensity

Intensity I = Power/Area (W/m^2)

Spherical sound source:

$A = 4\pi R^2$, $I = P / 4\pi R^2$



If $I = I_1$ at position 1,

$I_2 = I_1 / 2^2 = I_1 / 4$ since it is twice as far from source

TABLE 16–2
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}
Truck traffic	90	1×10^{-3}
Busy street traffic	80	1×10^{-4}
Noisy restaurant	70	1×10^{-5}
Talk, at 50 cm	65	3×10^{-6}
Quiet radio	40	1×10^{-8}
Whisper	30	1×10^{-9}
Rustle of leaves	10	1×10^{-11}
Threshold of hearing	0	1×10^{-12}

Sound Level

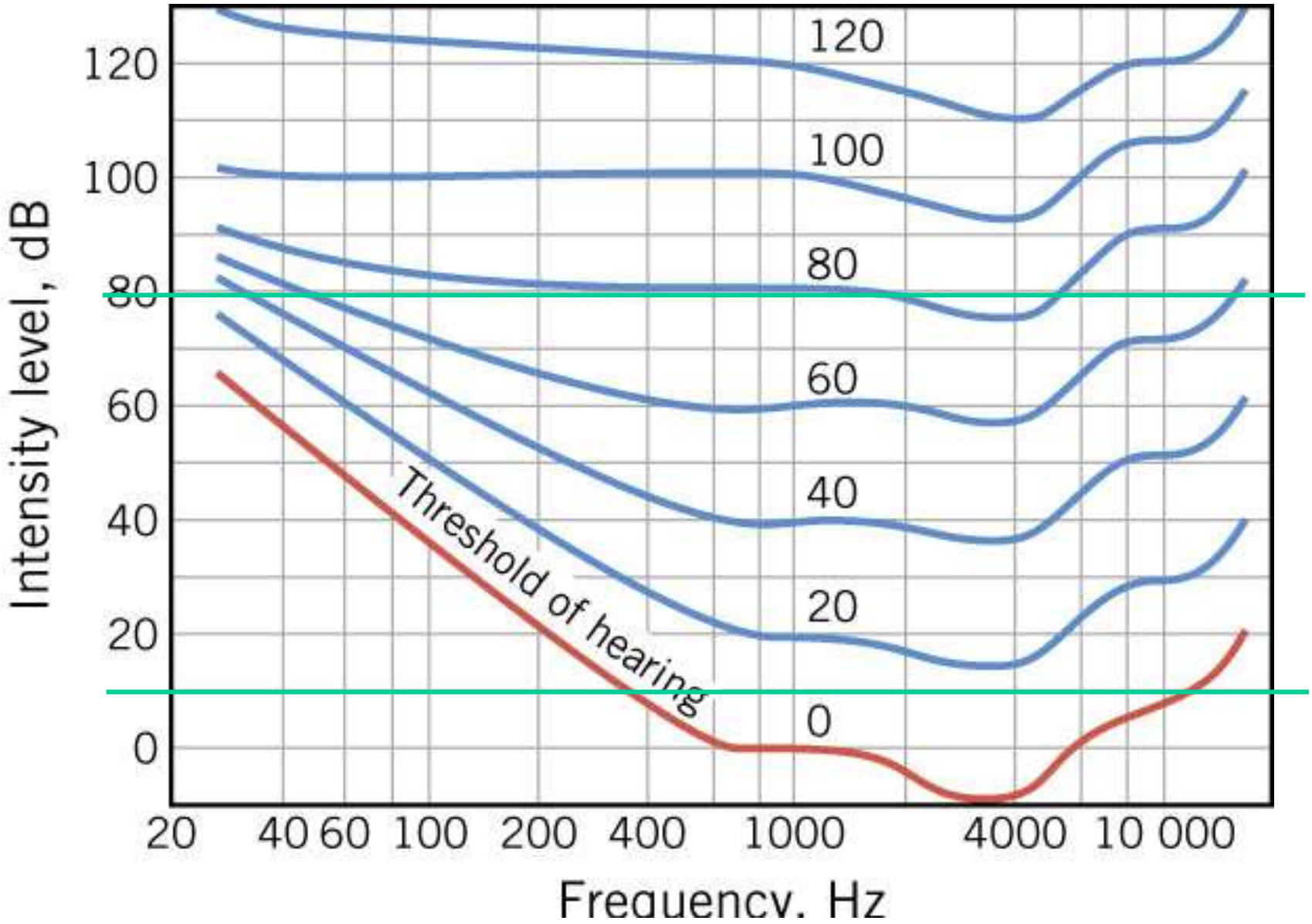
Describes perception of intensity

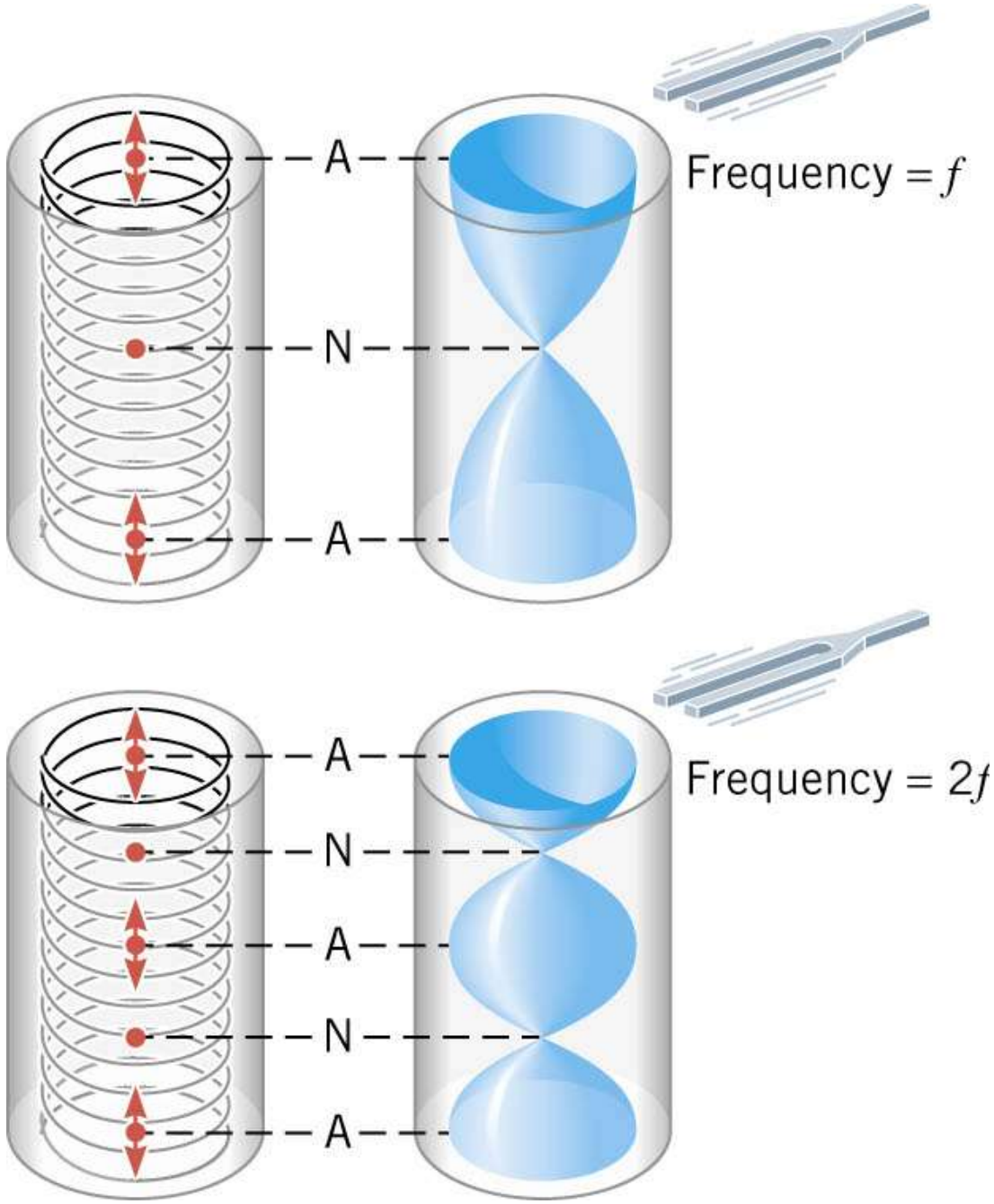
$$\beta = 10 log \frac{I}{I_0}, \quad I = I_0 \times 10^{\beta/10}$$

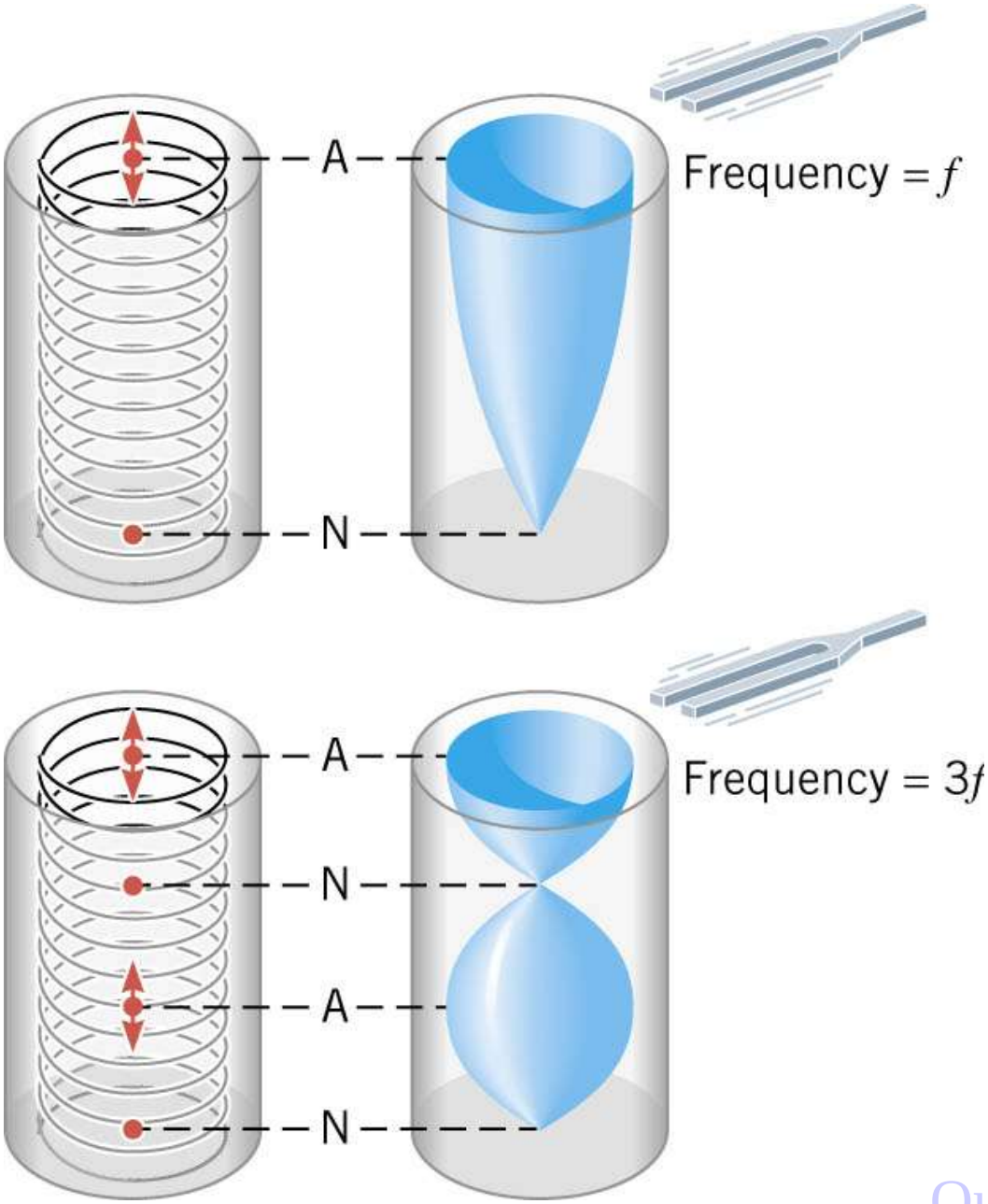
For multifrequency sound, intensity adds

$$I_{net} = I_1 + I_2 + \ldots$$

Note! $\beta_{net} \neq \beta_1 + \beta_2 + \ldots$

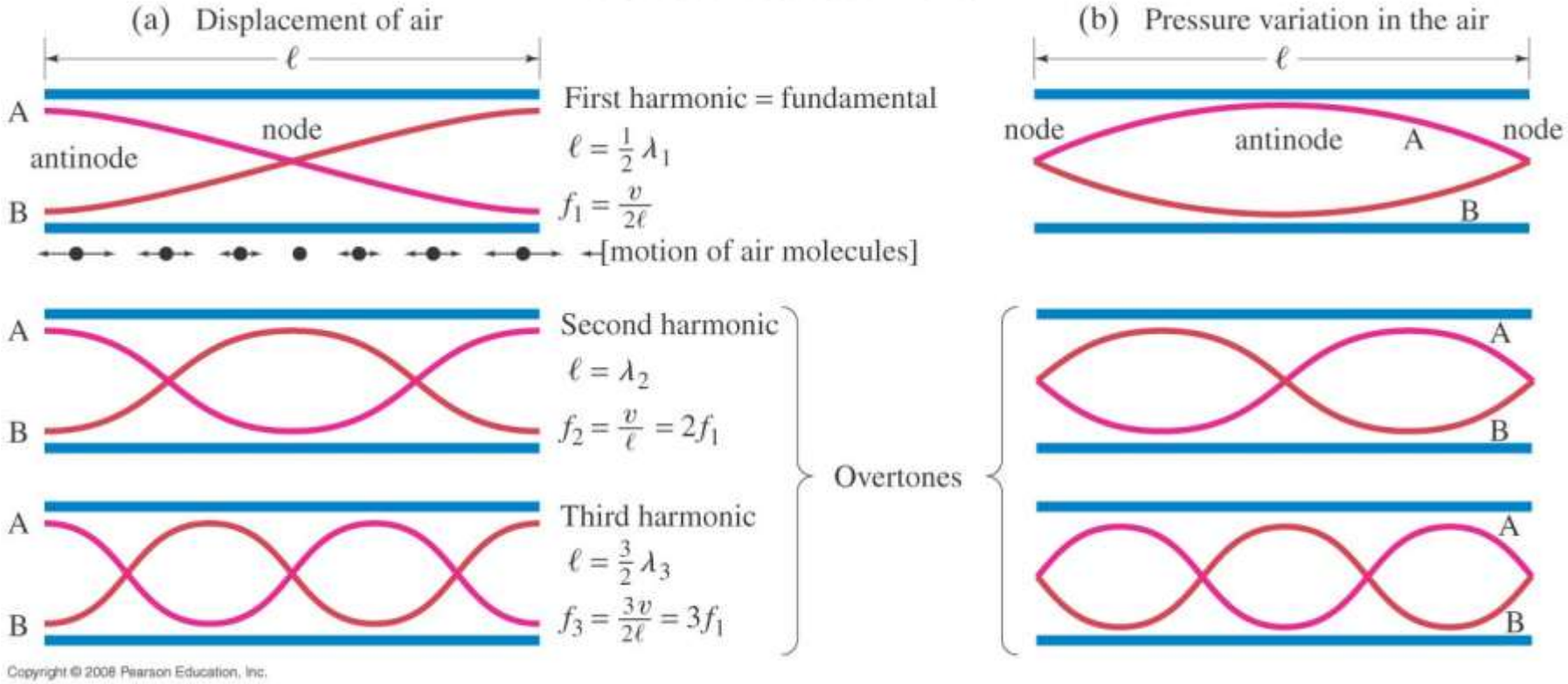

Intensity level, dB
120
100
80
60
40
20
0
120
100
80
60
40
20
0
Threshold of hearing
20
40
60
100
200
400
1000
4000
10 000
Frequency, Hz


A
N
A
Frequency = f
A
N
A
N
A
Frequency = 2f

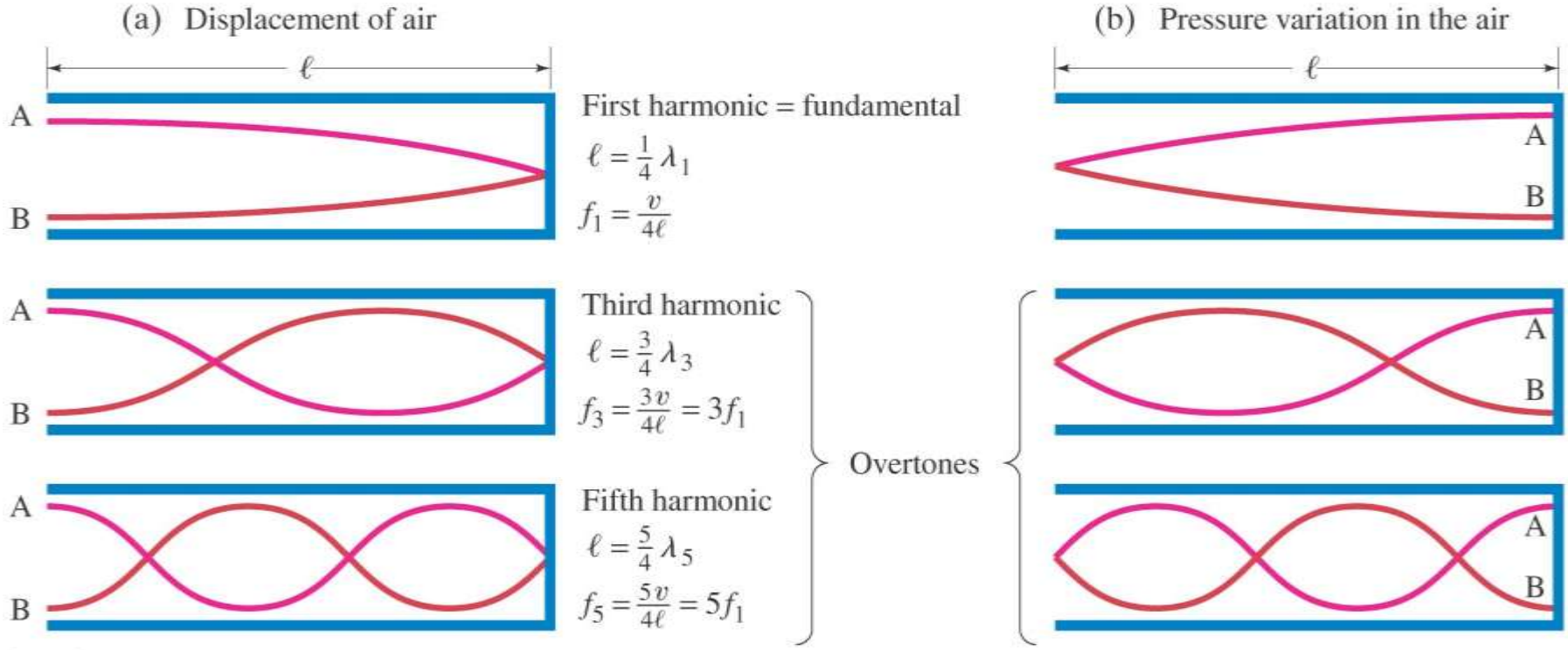


Questions

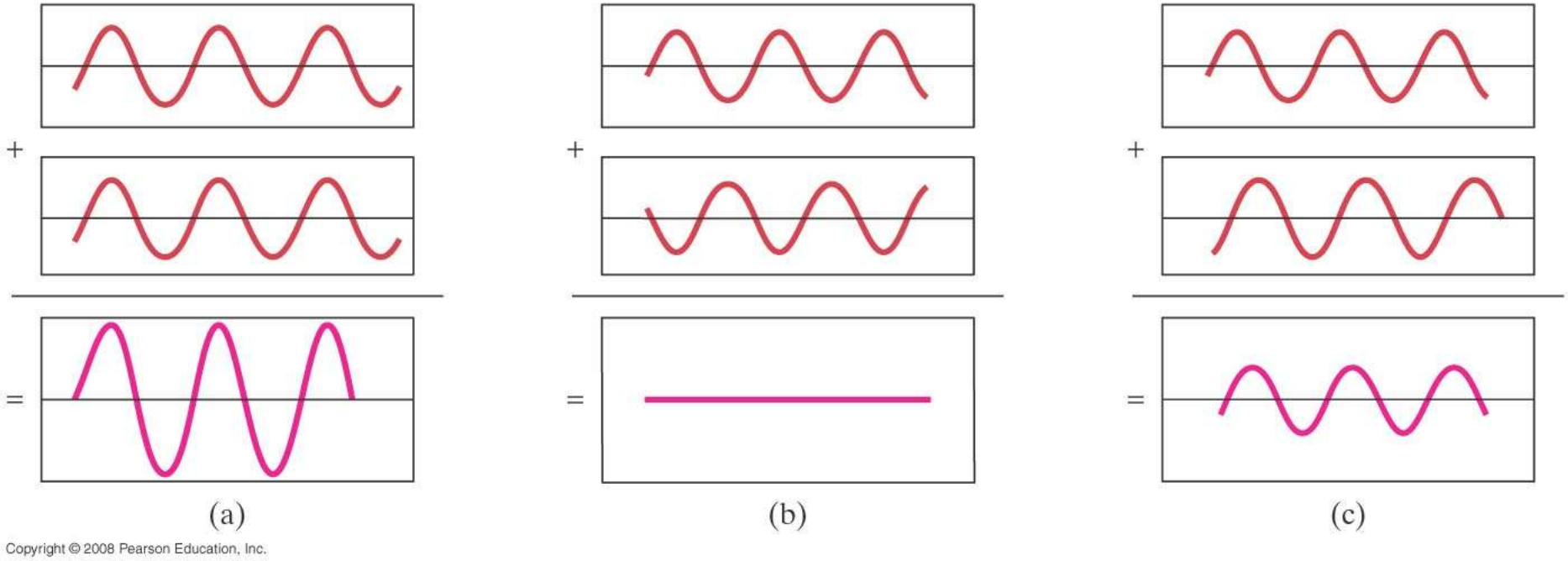
TUBE OPEN AT BOTH ENDS



TUBE CLOSED AT ONE END

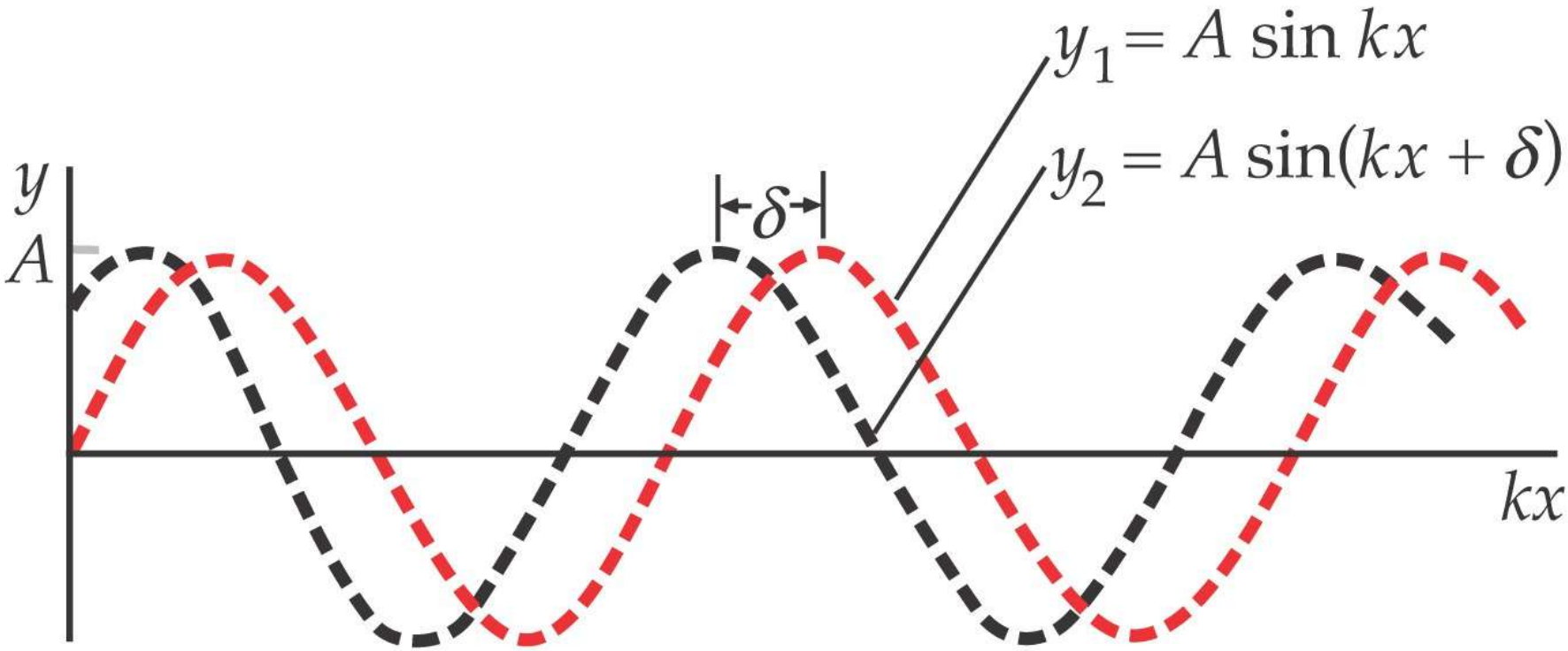


Recall Interference



Constructive Interference

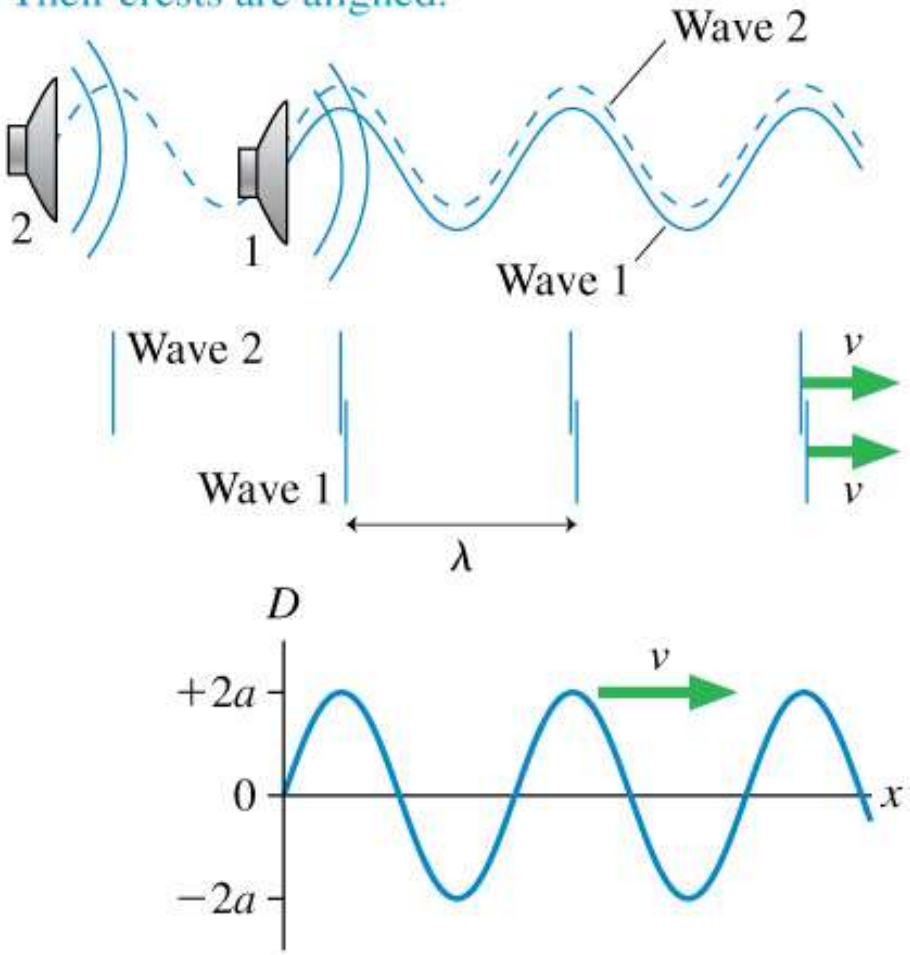
Destructive Interference



Questions

(a) Constructive interference

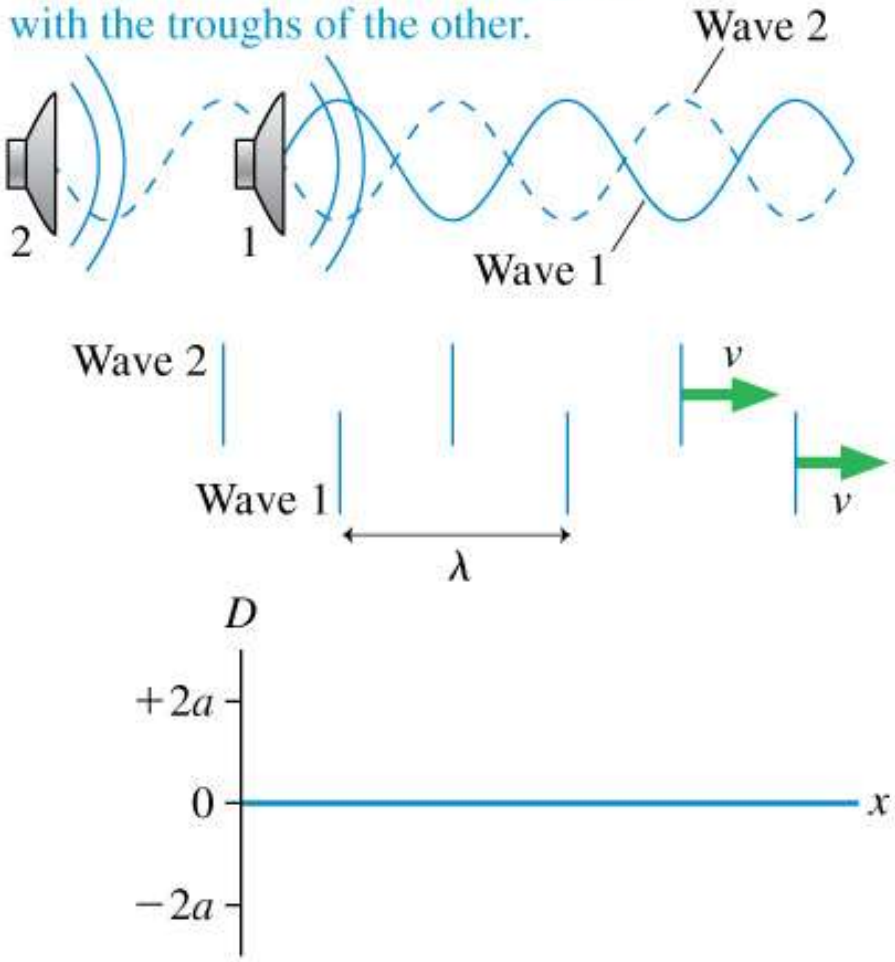
These two waves are in phase.
Their crests are aligned.



Their superposition produces a wave with amplitude $2a$. This is constructive interference.

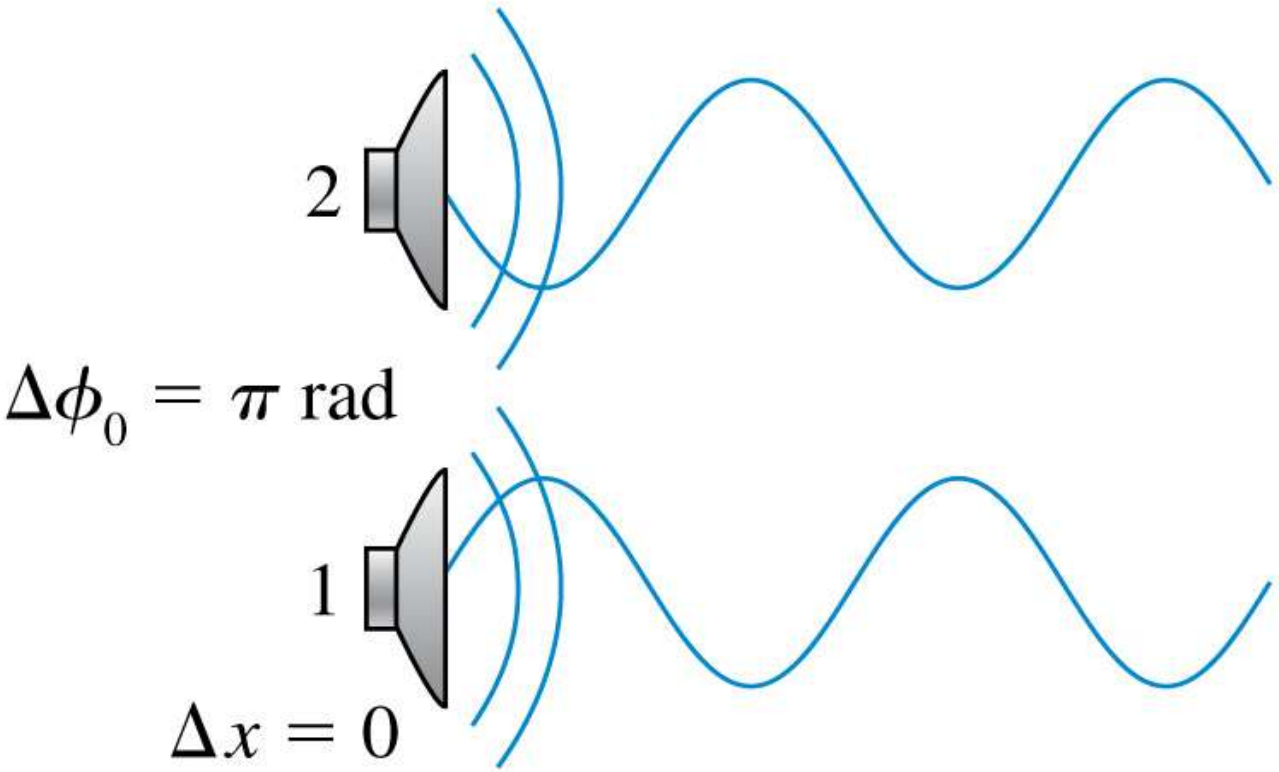
(b) Destructive interference

These two waves are out of phase. The crests of one wave are aligned with the troughs of the other.

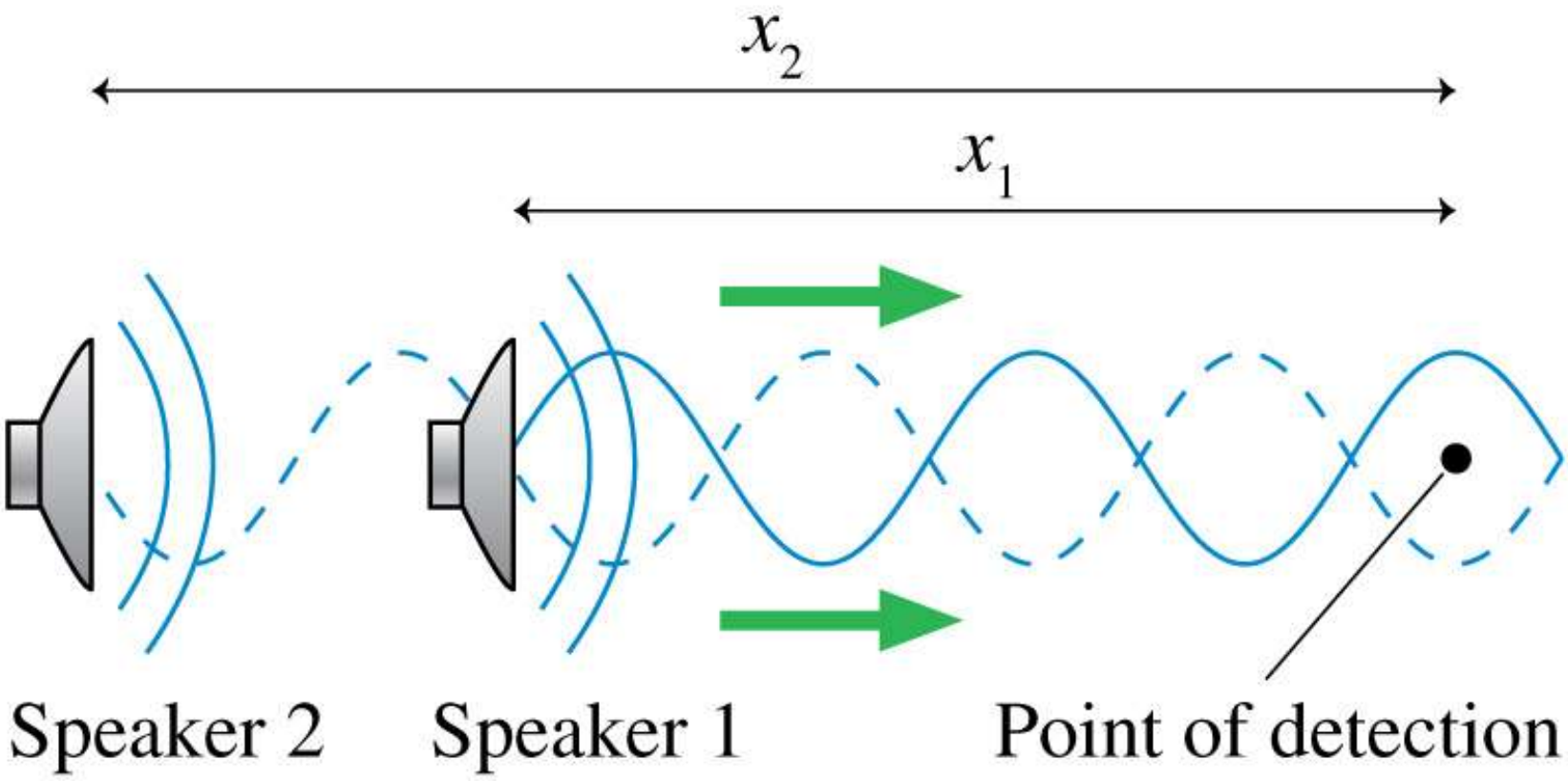


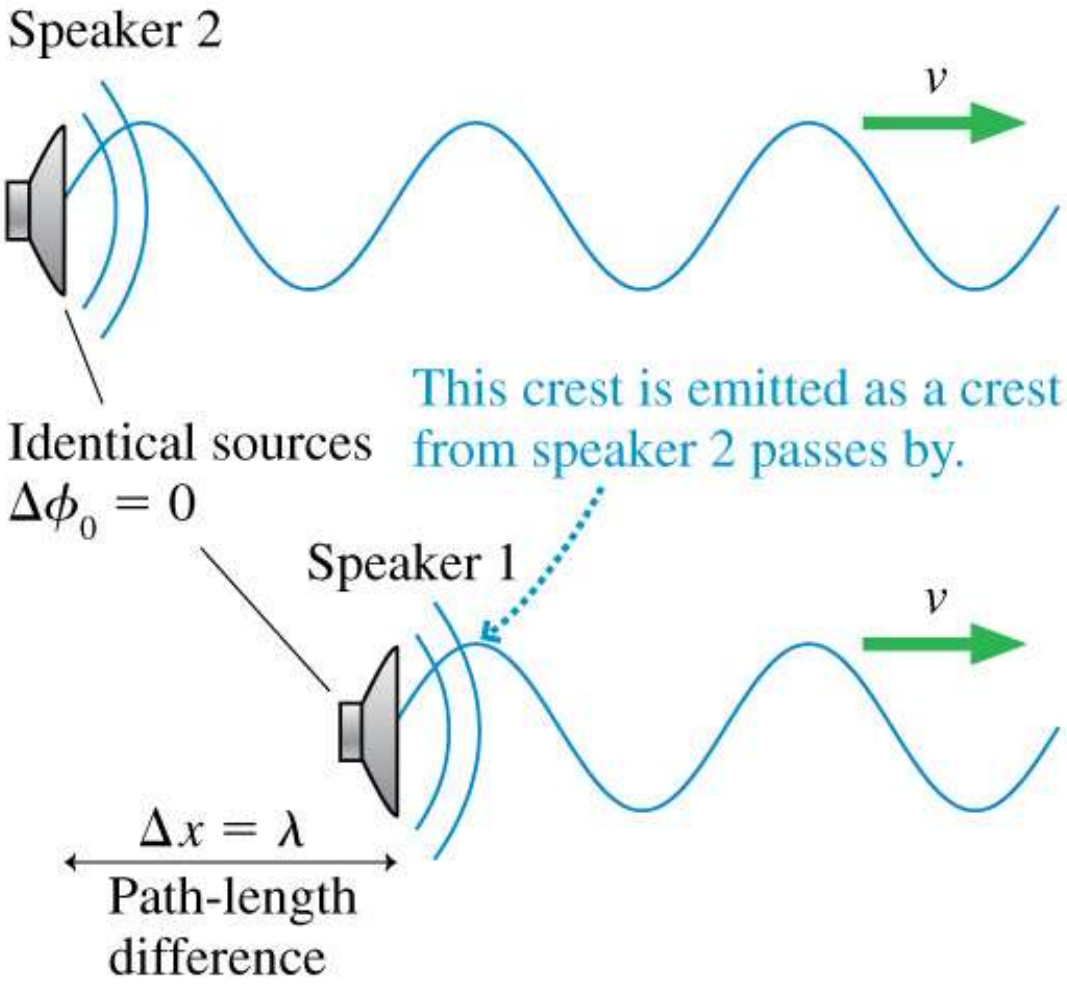
Their superposition produces a wave with zero amplitude. This is destructive interference.

(a) The sources are out of phase.



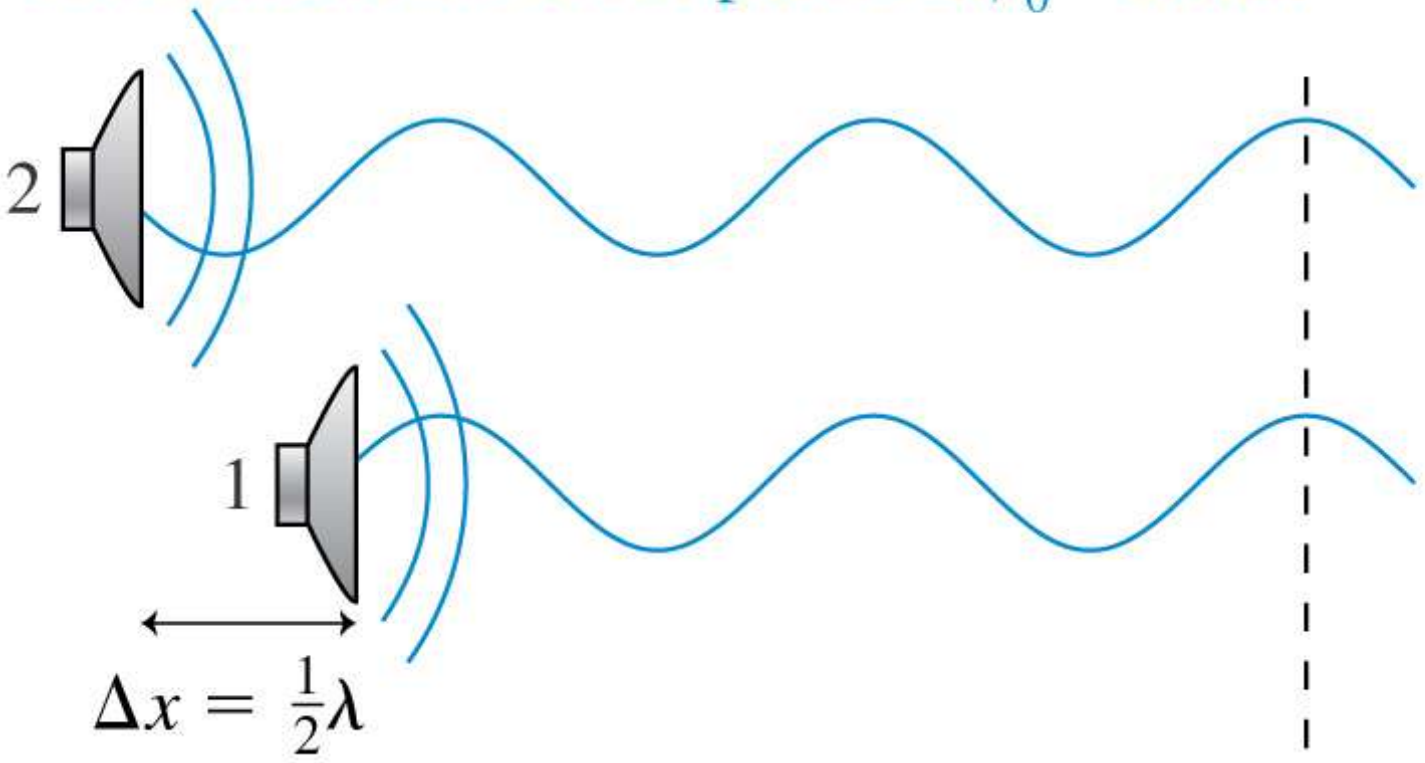
(b) Two overlapped sound waves





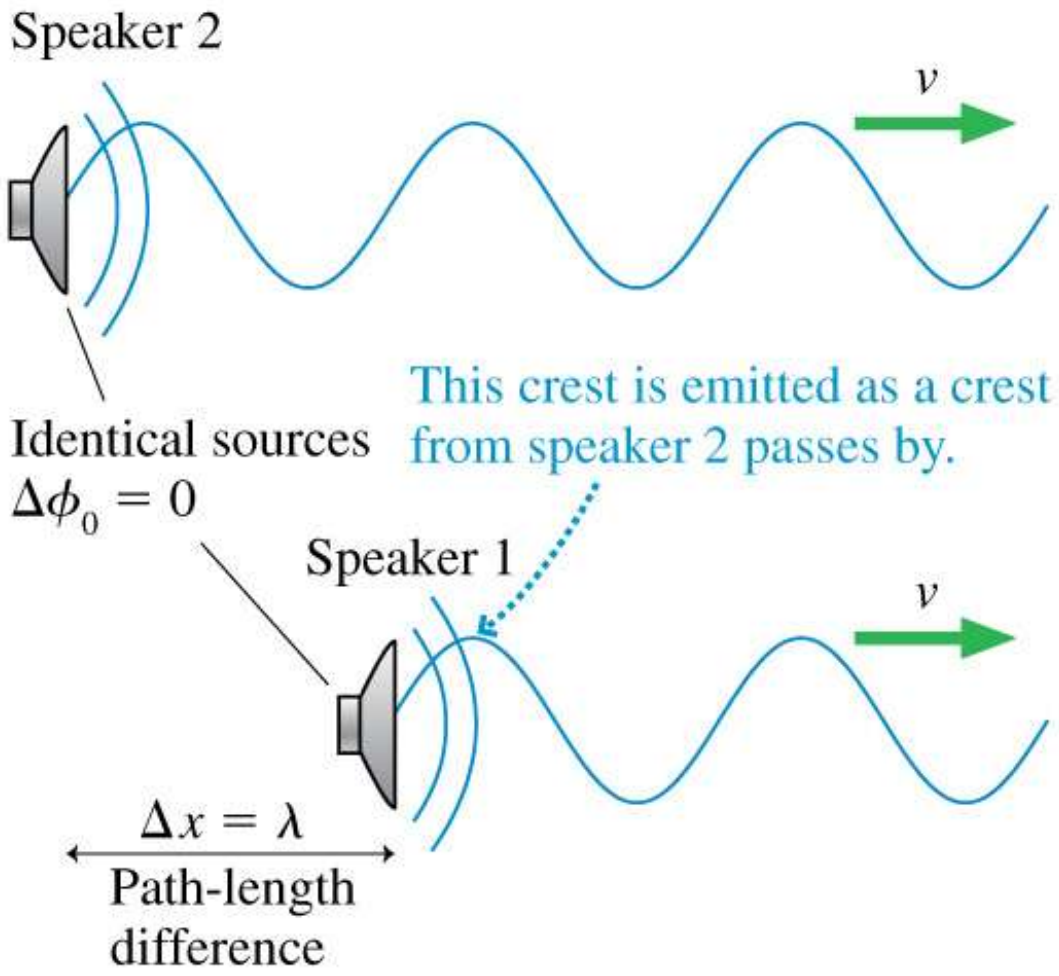
The two waves are in phase ($\Delta\phi = 2\pi$ rad) and interfere constructively.

The sources are out of phase, $\Delta\phi_0 = \pi$ rad.



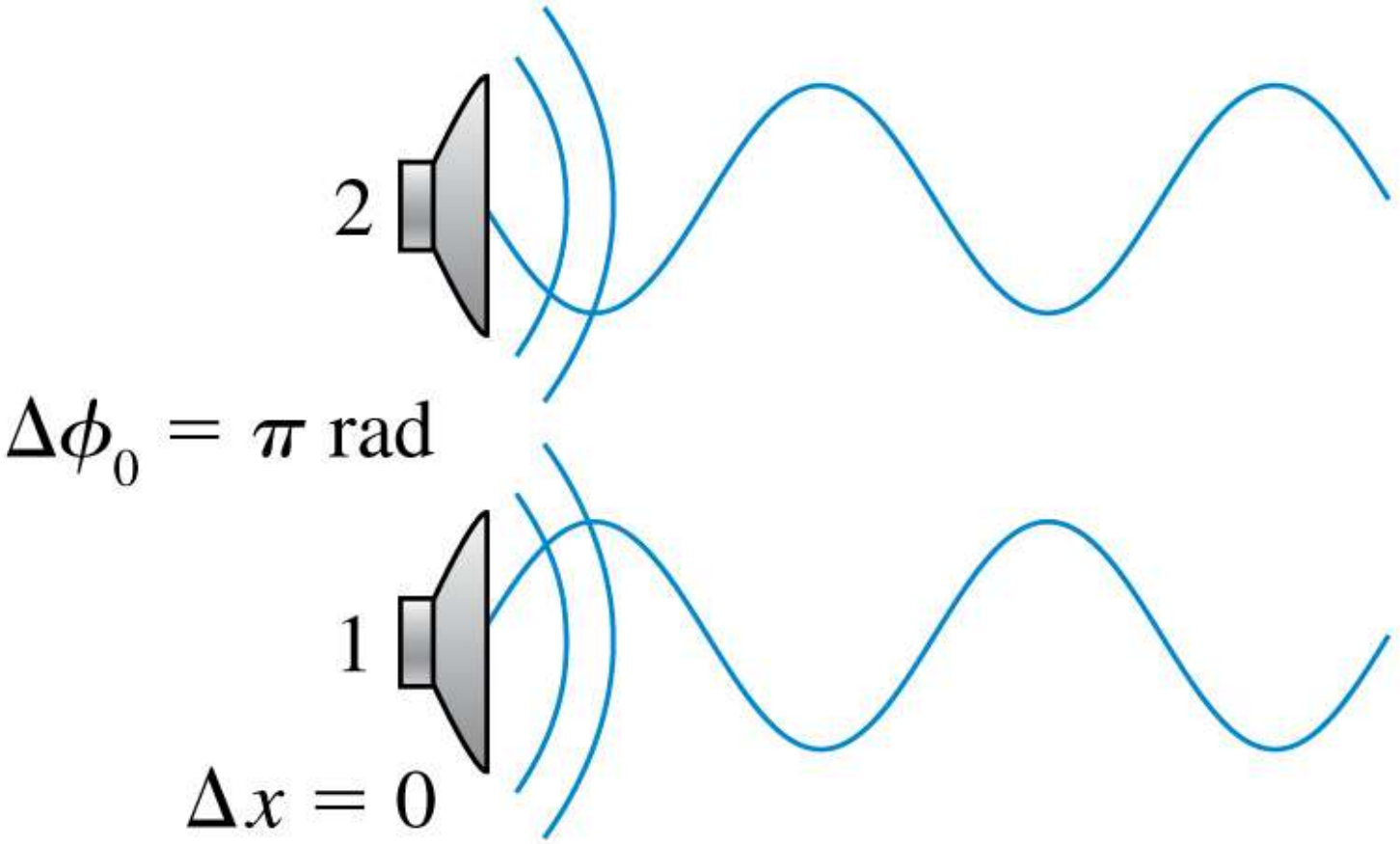
The sources are separated by half a wavelength.

As a result, the waves are in phase.

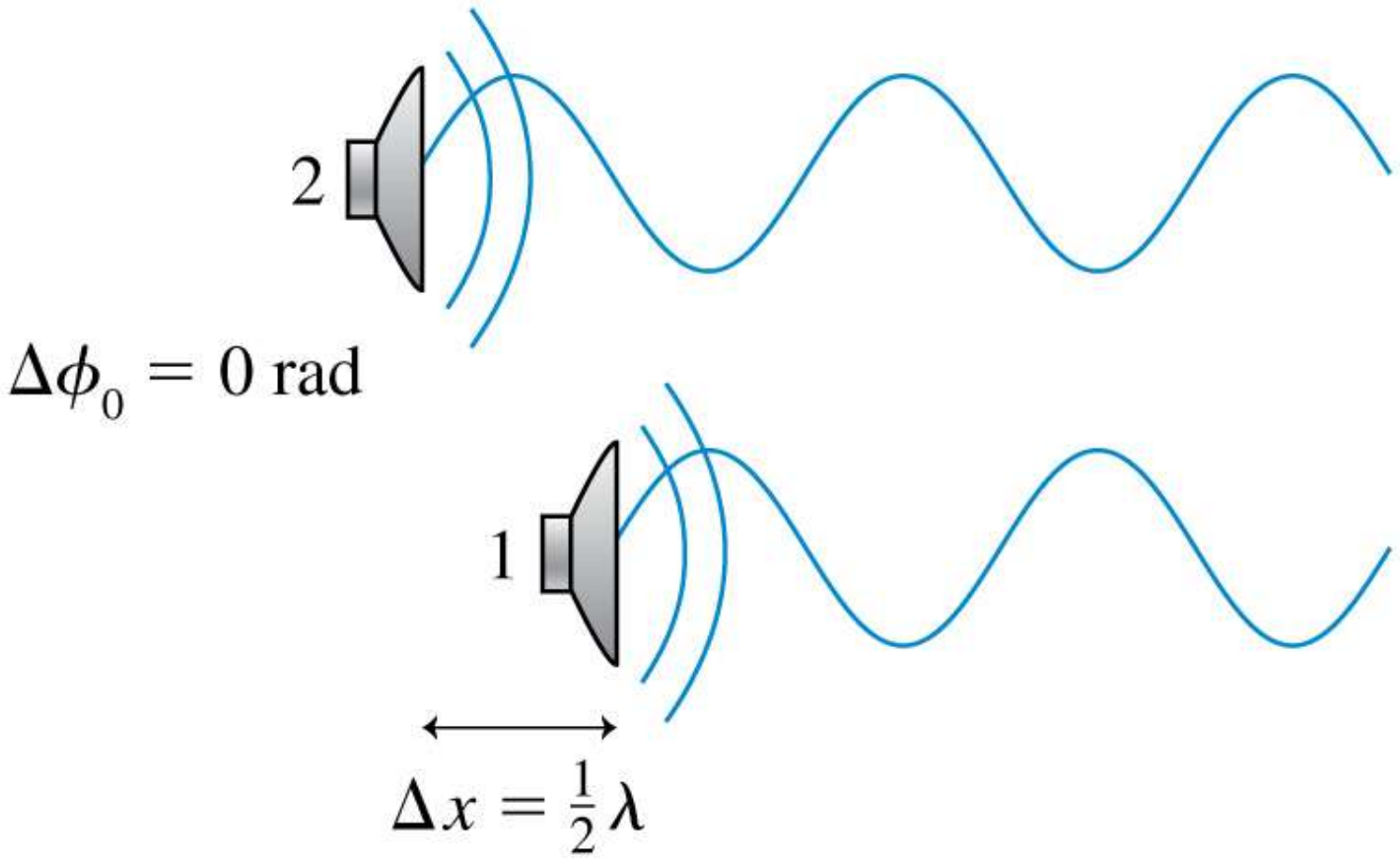


The two waves are in phase ($\Delta\phi = 2\pi$ rad) and interfere constructively.

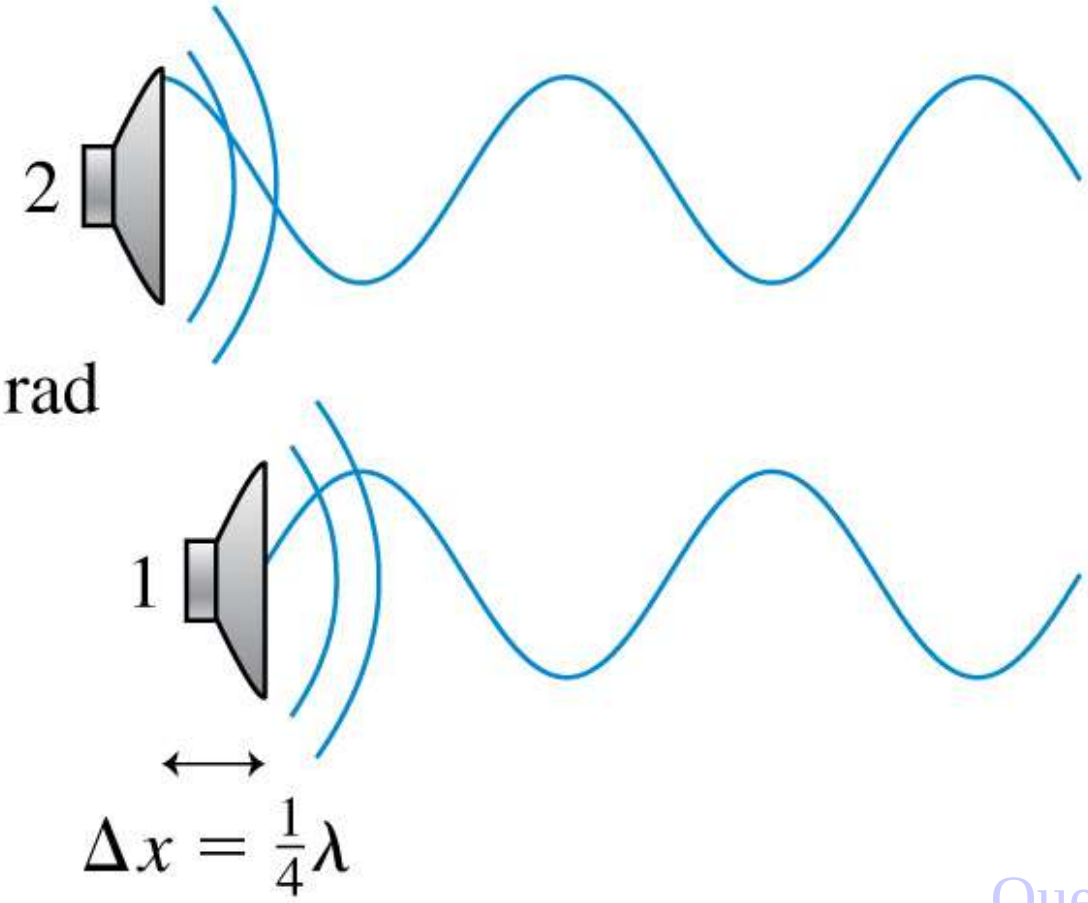
(a) The sources are out of phase.



(b) Identical sources are separated by half a wavelength.



(c) The sources are both separated and partially out of phase.



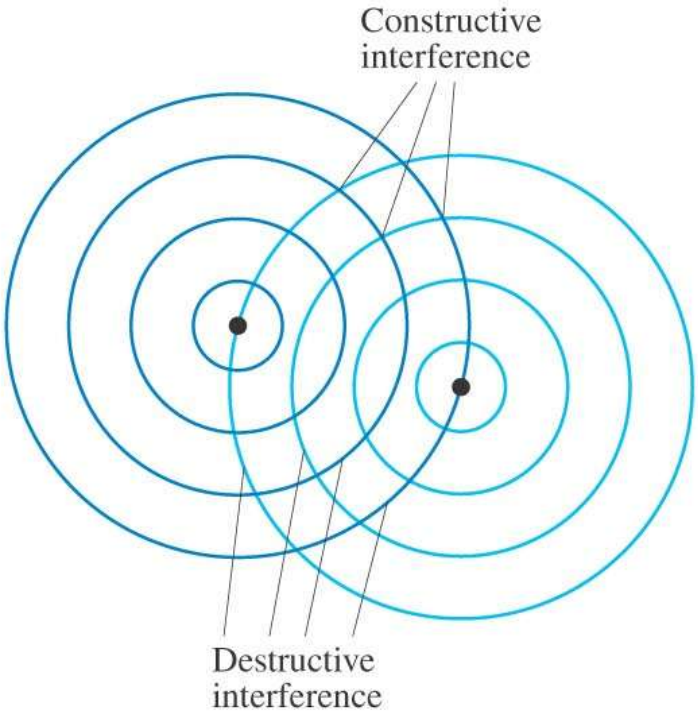
$\Delta\phi_0 = \frac{\pi}{2}\,\text{rad}$

$\Delta x = \frac{1}{4}\lambda$

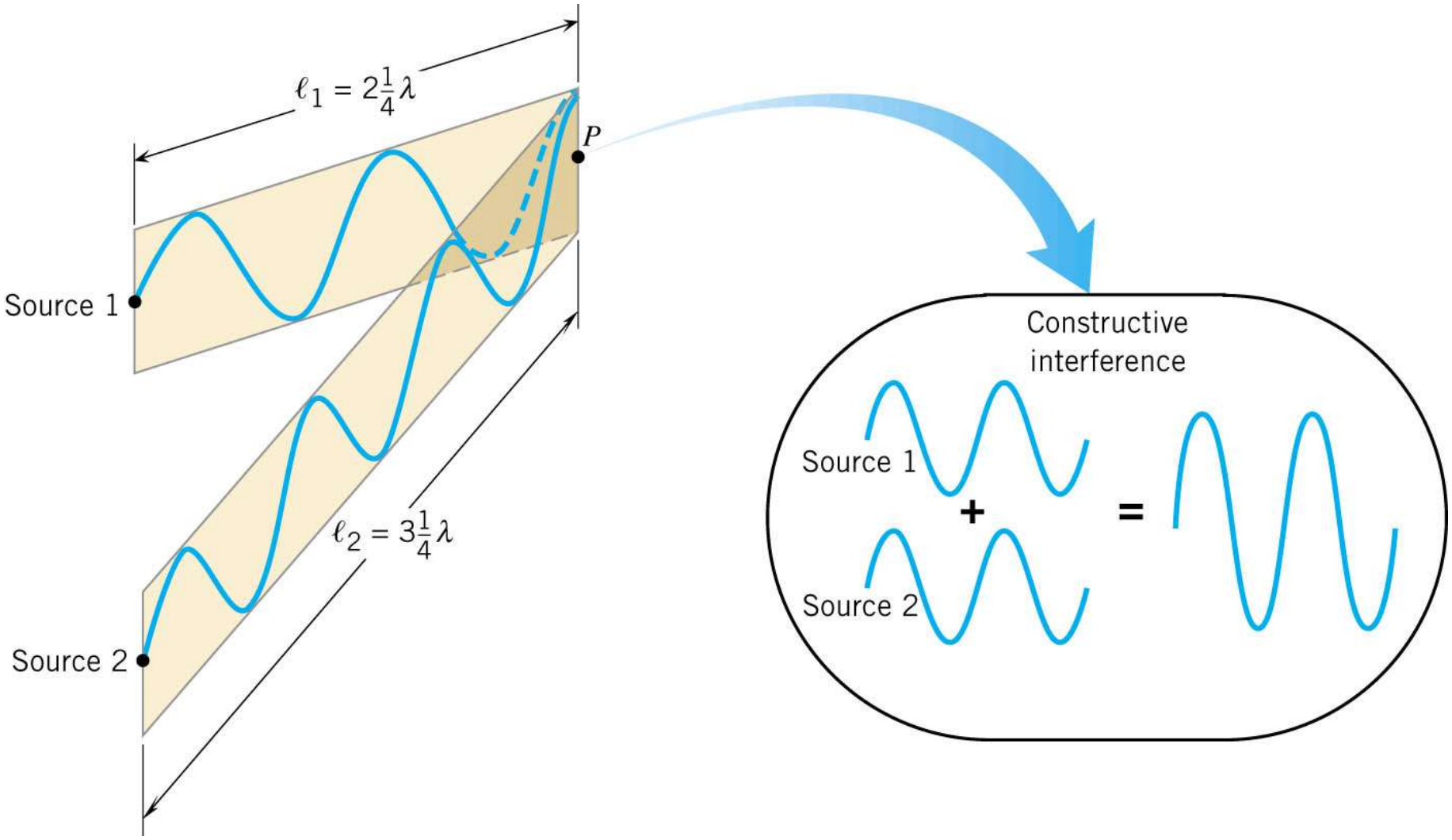
Questions

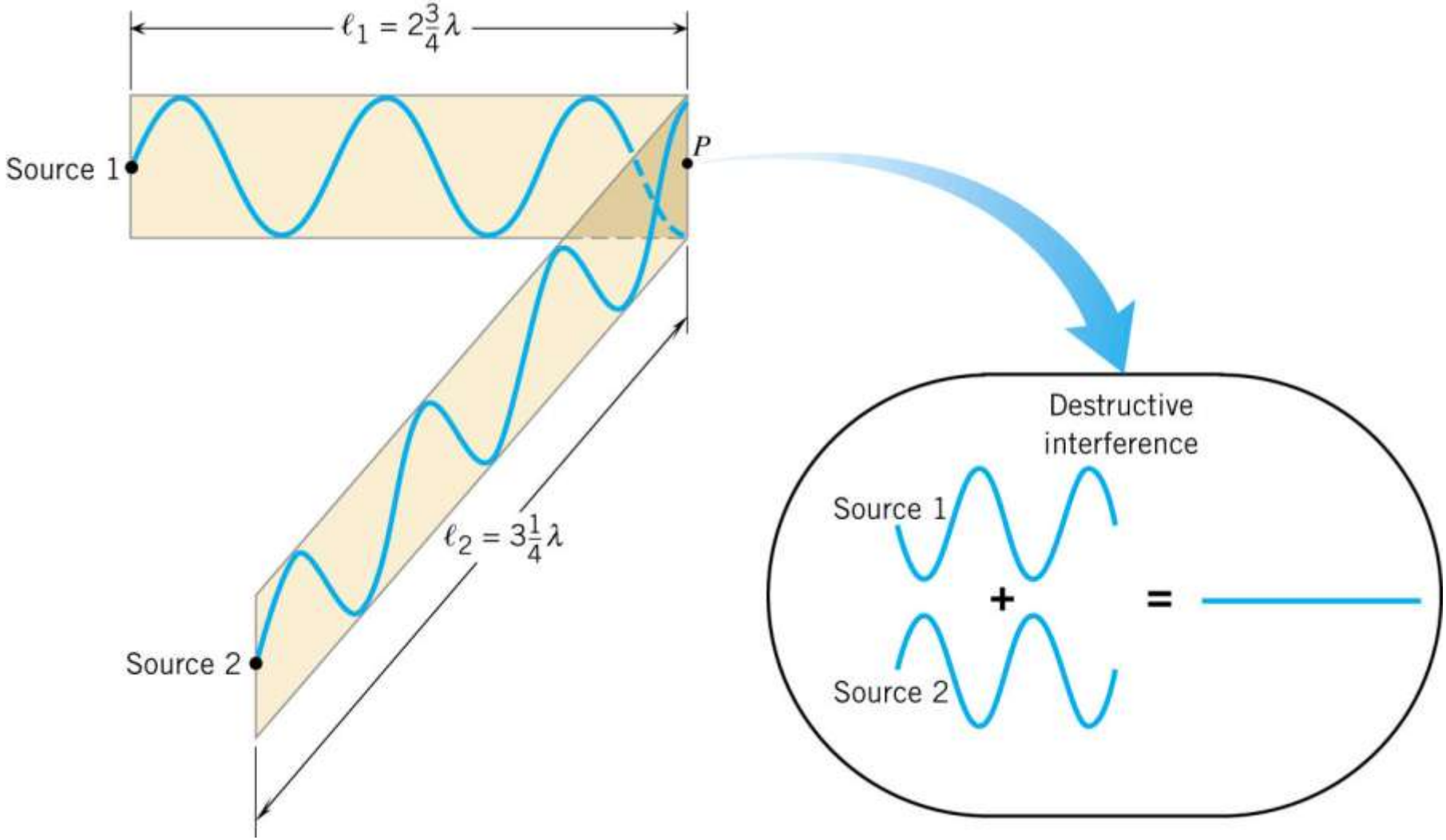
Superposition in 2D

(a)



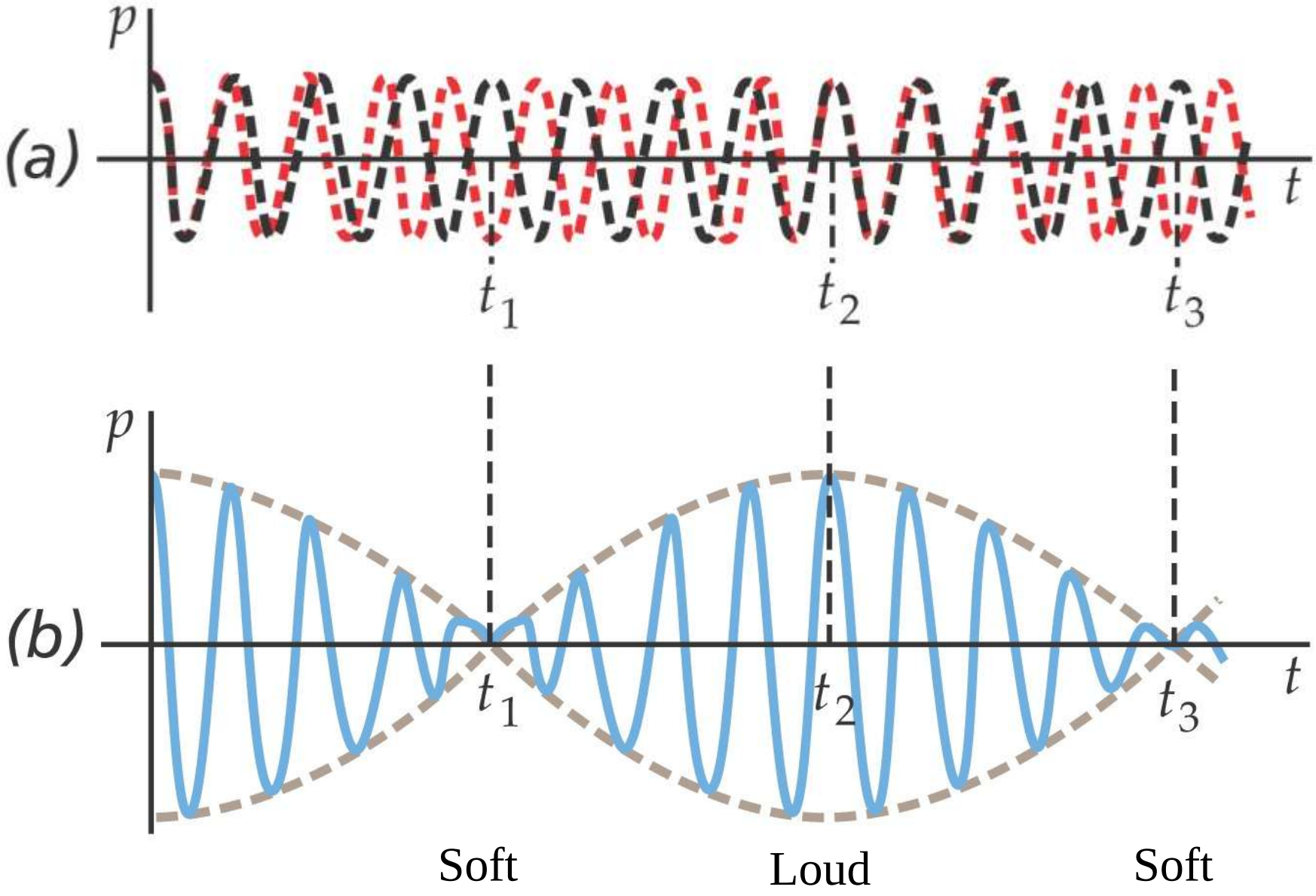
(b)

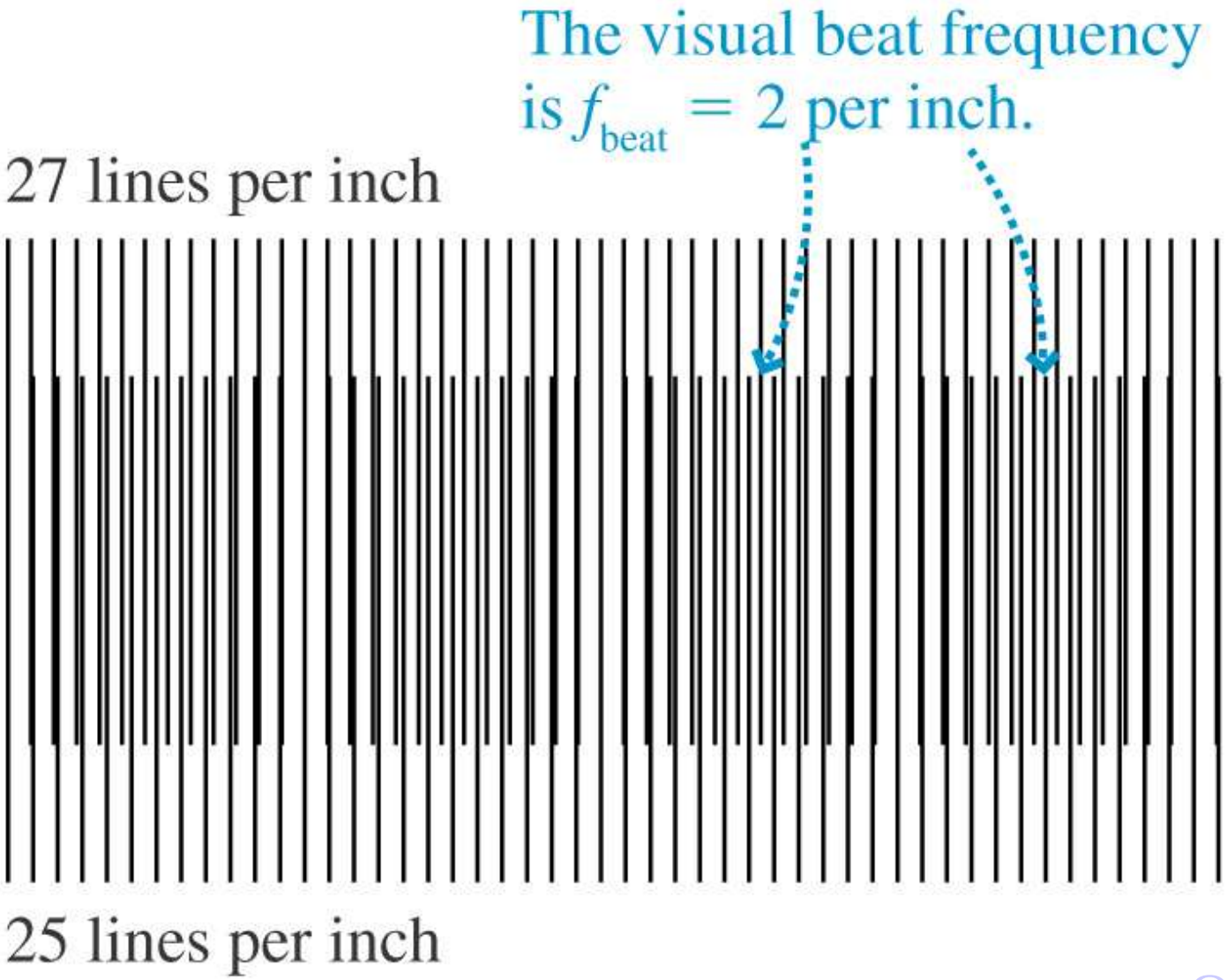

$\ell_1 = 2\frac{1}{4}\lambda$
P
Source 1
Source 2
$\ell_2 = 3\frac{1}{4}\lambda$
Constructive interference
Source 1
+
=
Source 2


$\ell_1 = 2\frac{3}{4}\lambda$
Source 1
P
$\ell_2 = 3\frac{1}{4}\lambda$
Source 2
Destructive interference
Source 1
+
=
Source 2

Questions

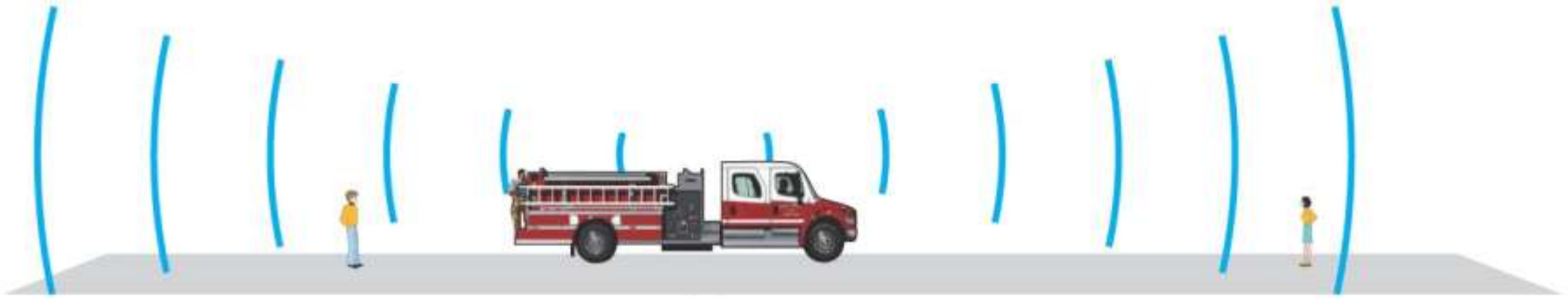
Beat Frequency



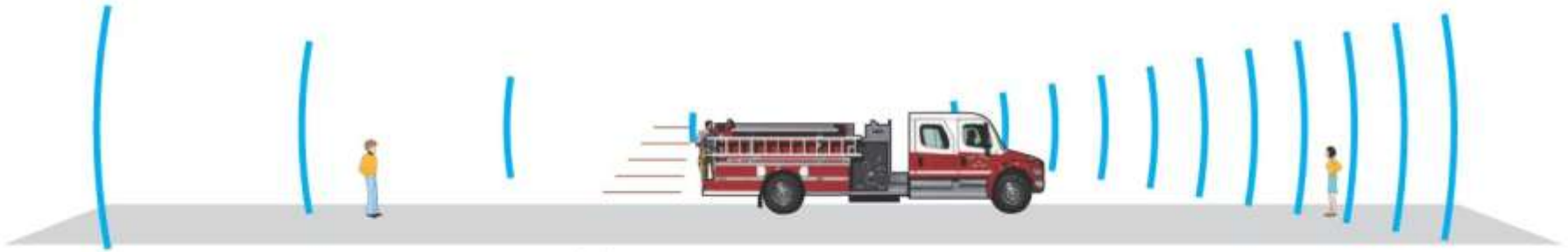


Questions

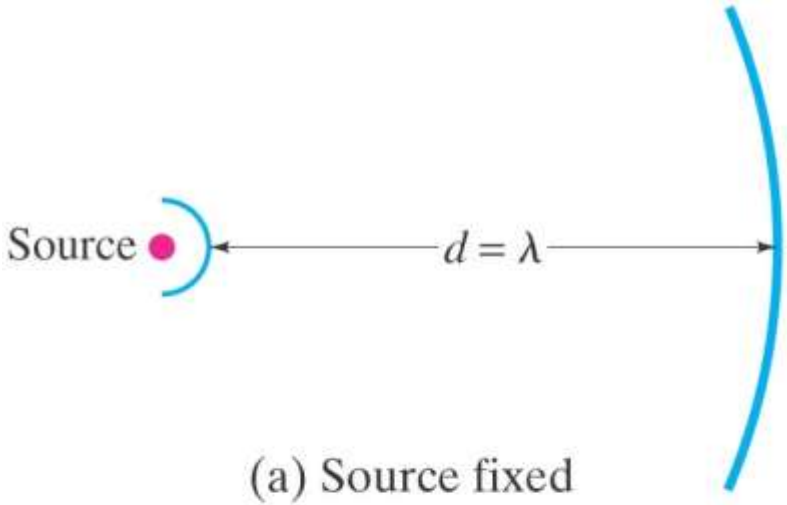
Doppler Effect



(a) At rest



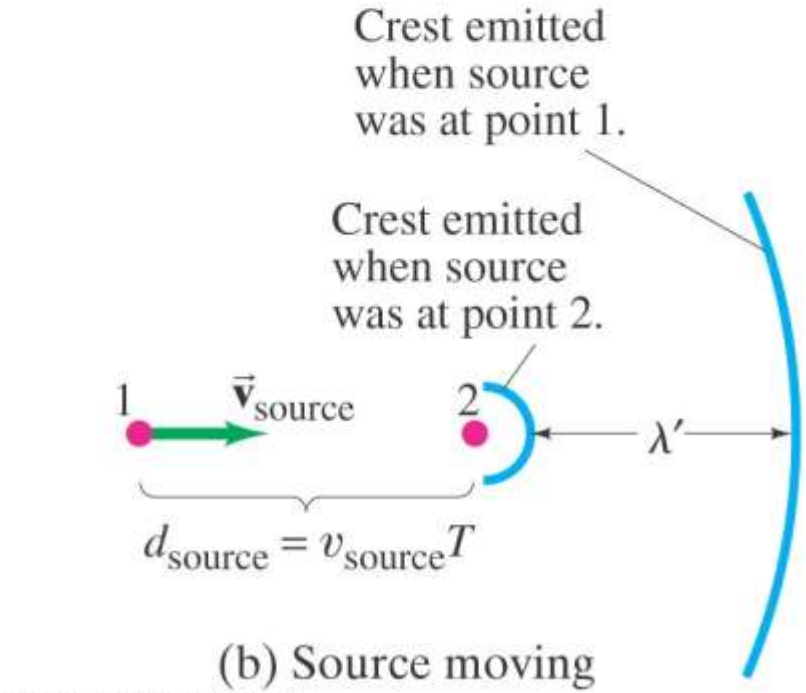
(b) Fire truck moving



$$\lambda_{source} = v_{sound}/f_{source}$$

$$\lambda' = \lambda_{source} - v_{source}/f_{source}$$
$$= (v_{sound} - v_{source})/f_{source}$$

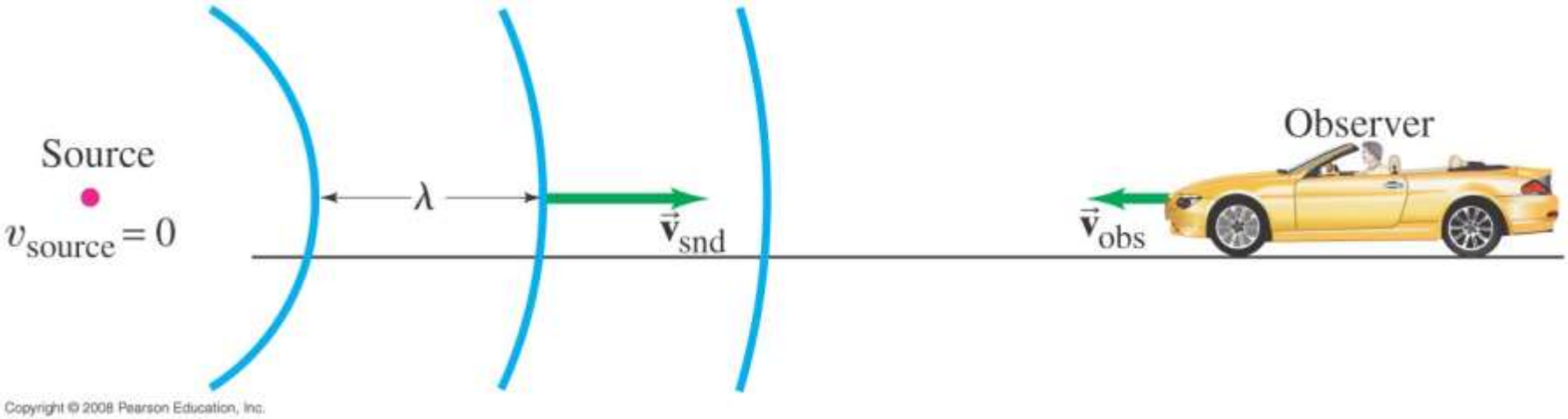
$$\lambda' = v_{sound}/f_{listener}$$



$$f_{listener} = f_{source}\frac{v_{sound}}{v_{sound} - v_{source}}$$

If source is moving away

$$f_{listener} = f_{source}\frac{v_{sound}}{v_{sound} + v_{source}}$$



To listener, λ unchanged but speed of wave is $v' = v_{sound} + v_{listener}$

$f_{listener} = (v_{sound} + v_{listener})/\lambda_{source}$ where $\lambda_{source} = v_{sound}/f_{source}$

$$f_{listener} = f_{source}\frac{v_{sound} + v_{listener}}{v_{sound}}$$

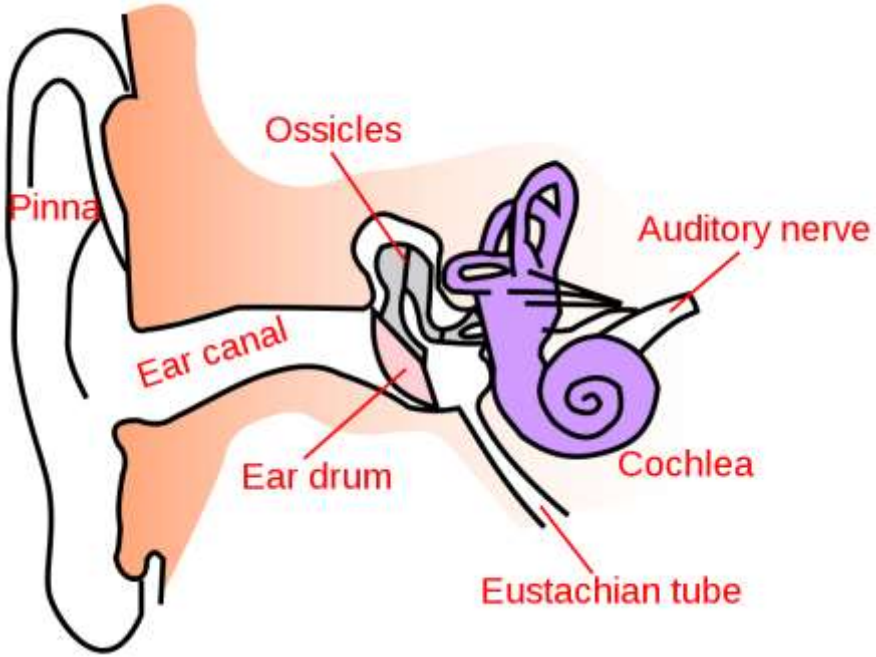
If listener is receding

$$f_{listener} = f_{source}\frac{v_{sound} - v_{listener}}{v_{sound}}$$

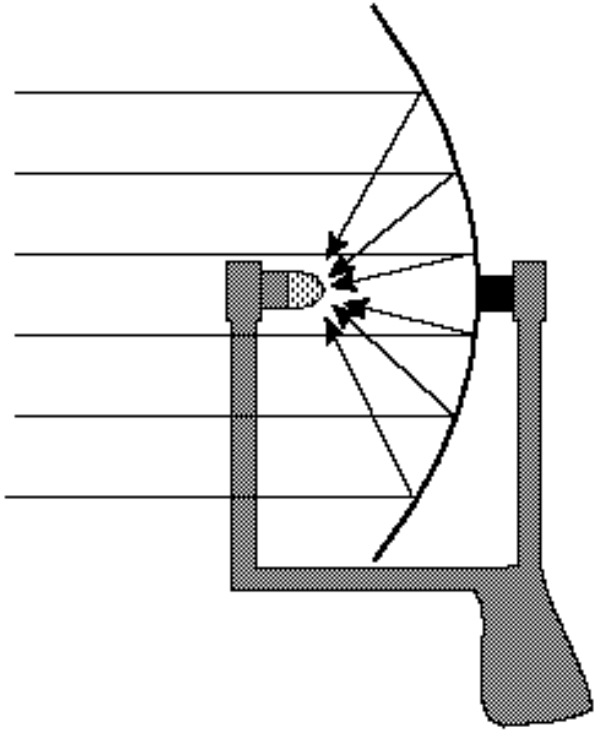
$$f_{\text{listener}} = f_{\text{source}} \frac{v_{sound} \pm v_{listener}}{v_{sound} \mp v_{source}}$$

- These are speeds! No signs!
- Remember if source approaches listener or vice versa, listener hears a higher frequency.

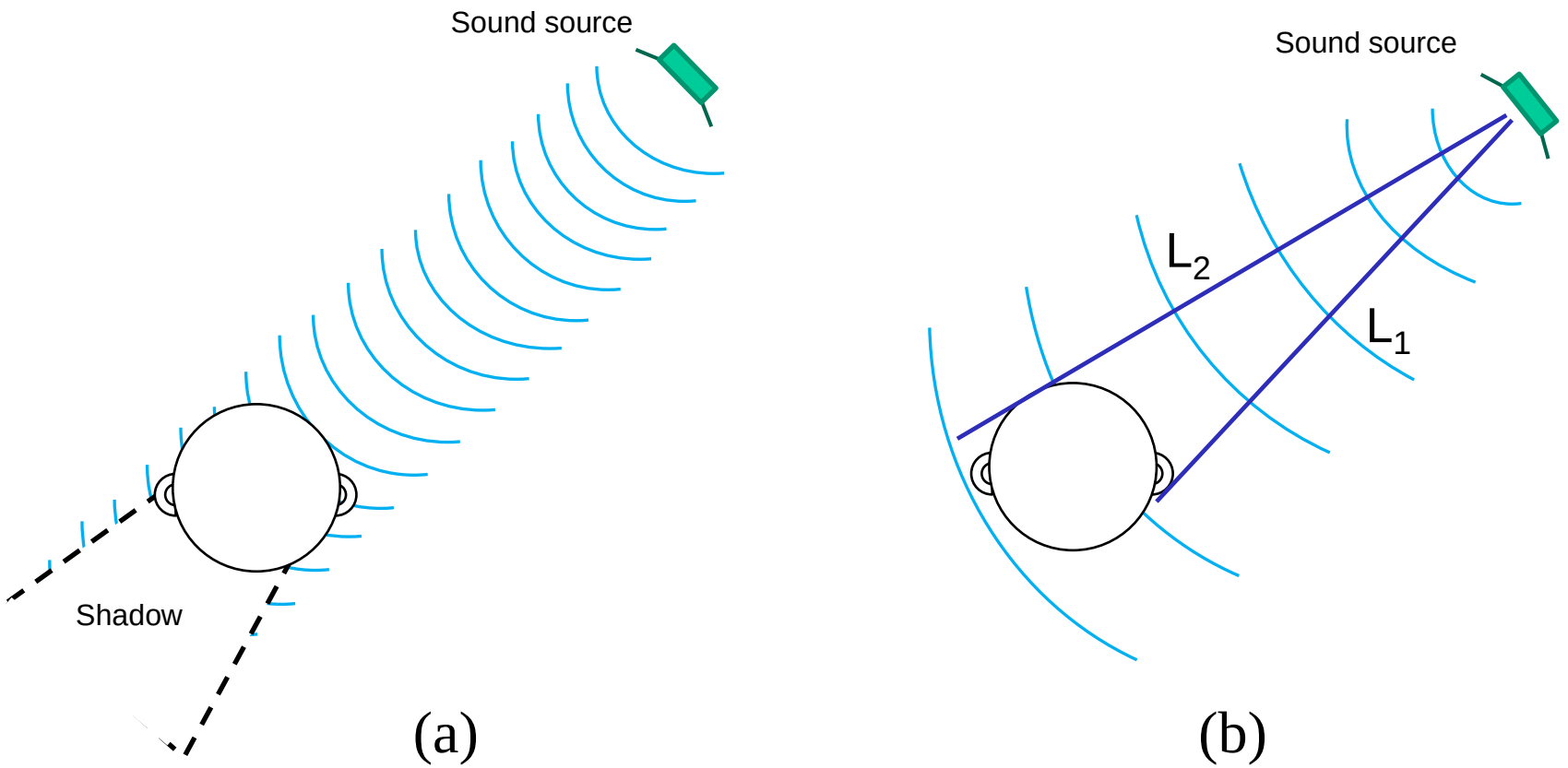
The Human Ear



- Outer ear collects sound energy acting as an amplifier.
- Hearing trumpet used as a hearing aid.

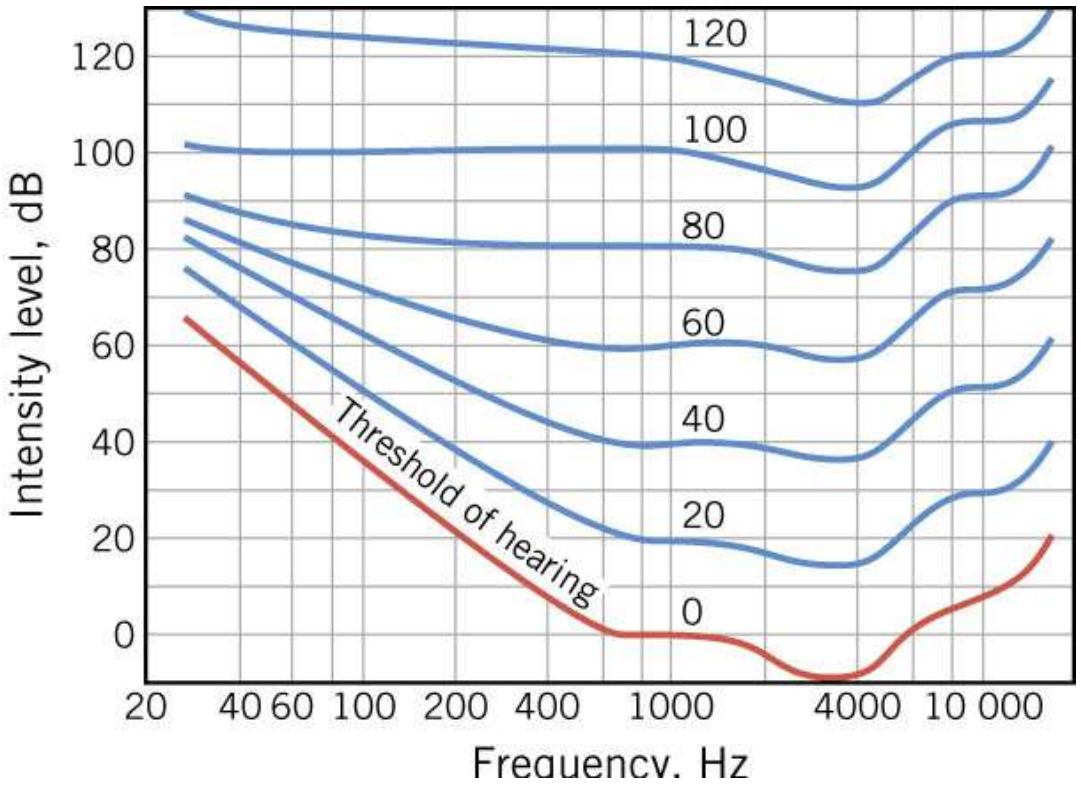


- Two ears gives us directional to sounds. Turn ear in direction of sound to pin down direction.
- Swivelling ears also work well for some animals.

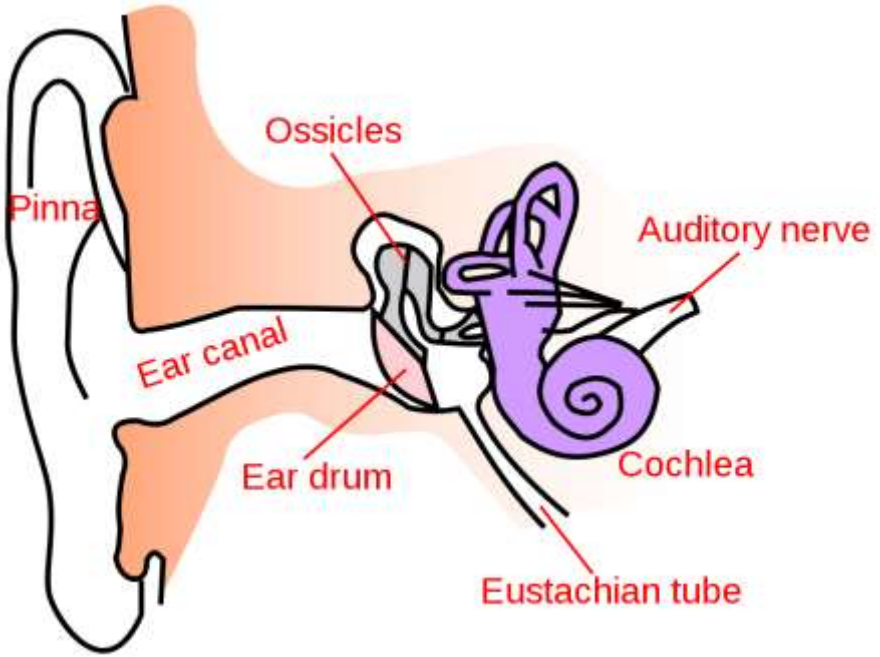


- At f > 4000 Hz, brain uses intensity difference (one ear is in sound shadow).
- At f < 1000 Hz, no shadow b/c diffraction waves bend around head, brain uses time difference between paths
- Between 1000 & 4000 Hz, accuracy declines. Methods don’t appreciably overlap.

- Ear canal is a tube open at one end.
- Has a resonant frequency.
- Systems with resonance are more sensitive at those frequencies than at others.
- Any sign of this in human hearing?



- Eardrum separates outer and middle ear
- Middle air contains fluid.
- Exterior pressure can change quickly (planes, swimming). Eustachian tube leads to mouth. Allows you to equalize pressure.
- May be slow to open – popping in ears.
- Ossicles are 3 small bones acting as a mechanical amplifier connecting eardrum to inner ear.



- Inner air – semicircular canals are horizontal-vertical detectors for balance
- Cochlea had little hairs sensitive to different vibrational frequency.
- Hairs convert auditory to electrical signal sent along auditory nerve.
- Vibrations also come to cochlea from conduction through bones of skull.
- Your recorded voice sounds different to you because it lacks the conducted sound.

Echolocation

- Speed of sound is constant
- It you send out a sound pulse at speed v, and the echo returns in time t, distance is
- $d = v \times \frac{1}{2}t$
- Bats, dolphins, whales, humans
  (using sonar & ultrasound imaging)
- Doppler shift let's you know if object is approaching/receding