

Physics 101: Lecture 22

Sound

Sound Waves get your wash clean, claims Robert Bosch of Stuttgart, Germany. This seven-pound machine works on principle of auto horn. Hooter must sound for five minutes. Cost is \$32.



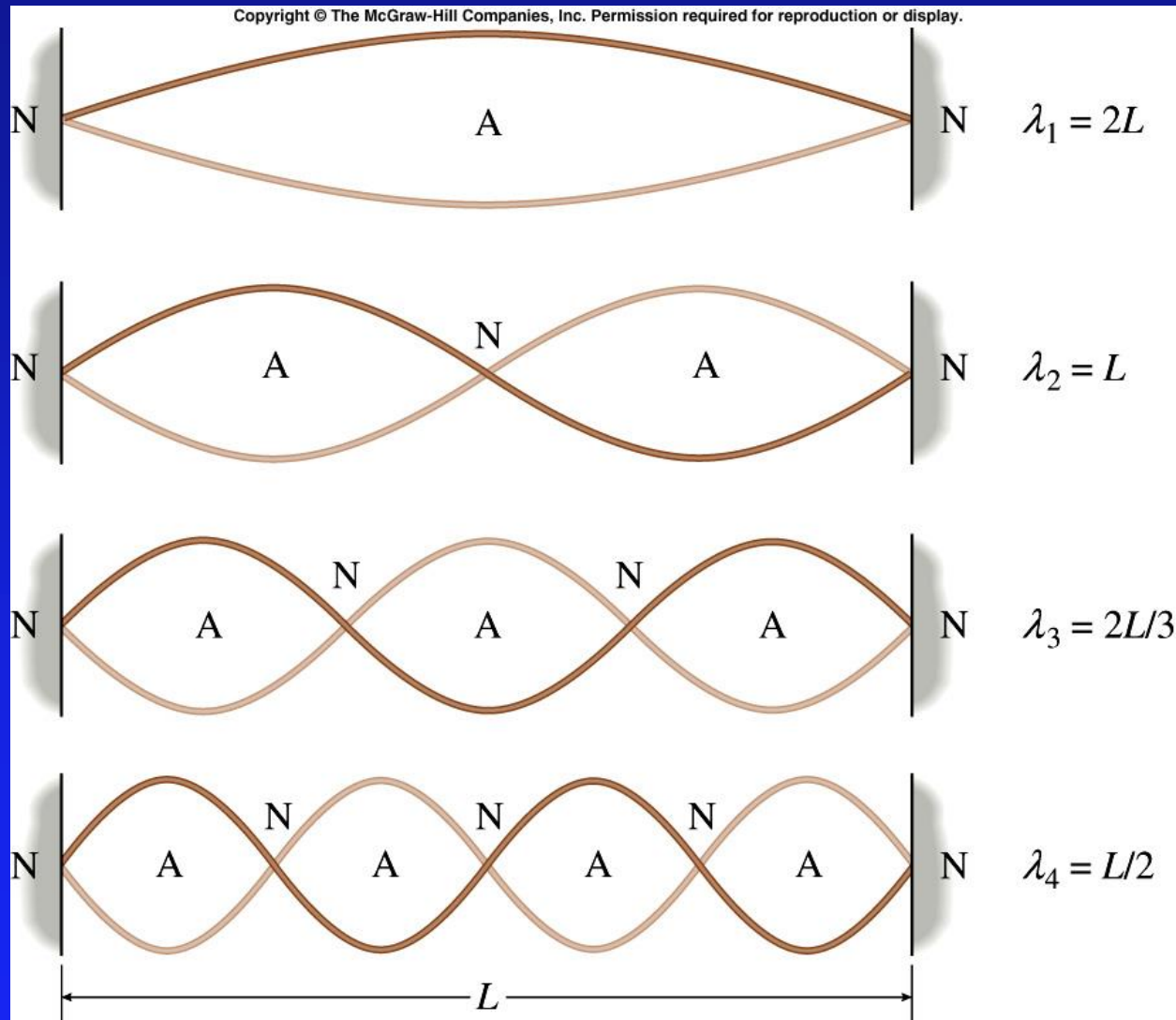
Today's lecture will cover
Textbook Chapter 12

Standing Waves Fixed Endpoints

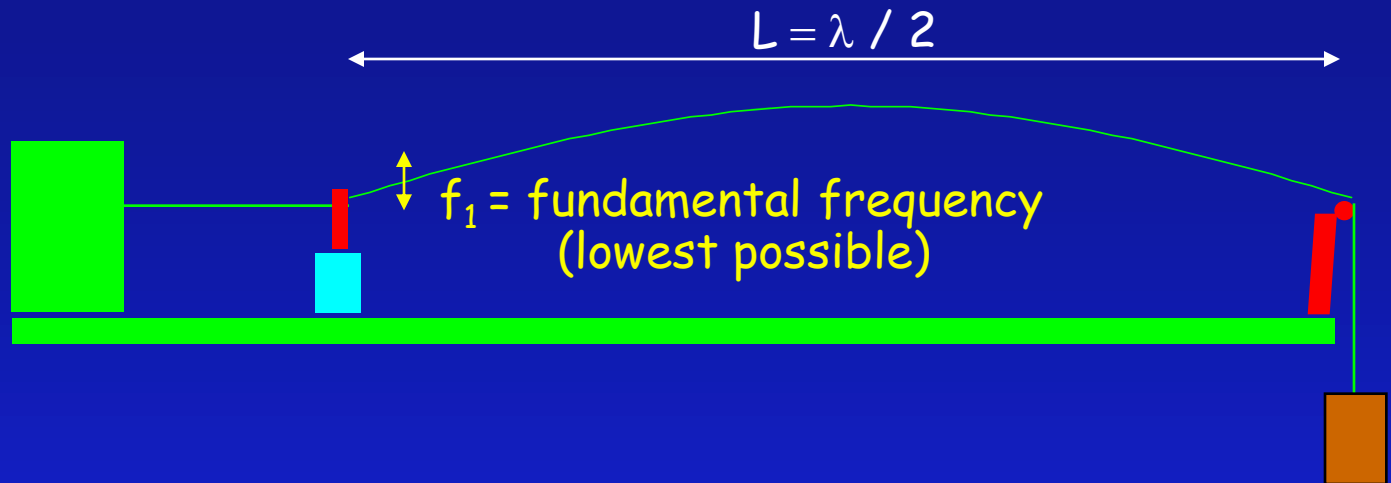
- Fundamental
 $n=1$ (2 nodes)

- $\lambda_n = 2L/n$

- $f_n = n v / (2L)$



Standing Waves:



A guitar's E-string has a length of 65 cm and is stretched to a tension of 82N. If it vibrates with a fundamental frequency of 329.63 Hz, what is the mass of the string?

$$v = \sqrt{\frac{T}{\mu}}$$

$f = v / \lambda$ tells us v if we know f (frequency) and λ (wavelength)

$$\begin{aligned} v &= \lambda f \\ &= 2 (0.65 \text{ m}) (329.63 \text{ s}^{-1}) \\ &= 428.5 \text{ m/s} \end{aligned}$$

$$\begin{aligned} v^2 &= T / \mu \\ \mu &= T / v^2 \\ m &= T L / v^2 \\ &= 82 (0.65) / (428.5)^2 \\ &= 2.9 \times 10^{-4} \text{ kg} \end{aligned}$$

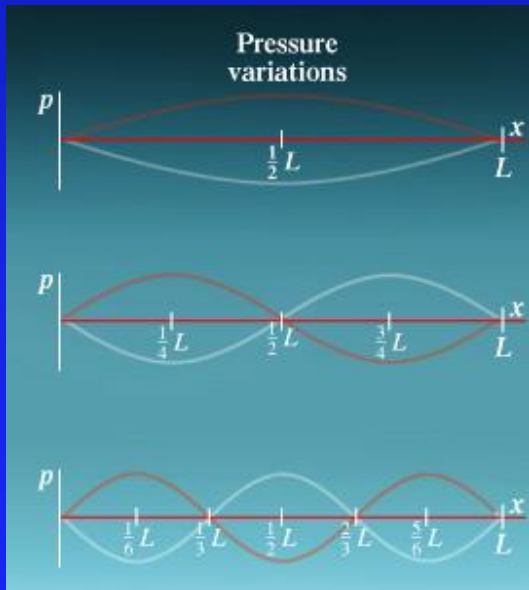
Standing Waves in Pipes

Nodes still! Nodes in pipes!

Open at both ends:

Pressure node at end

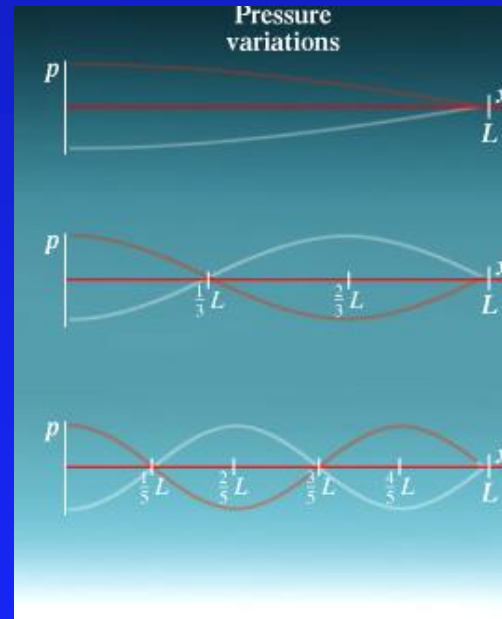
$$\lambda = 2L / n \quad n=1,2,3..$$



Open at one end:

Pressure antinode at closed end : $\lambda = 4L / n$

n odd



Resonance ACT

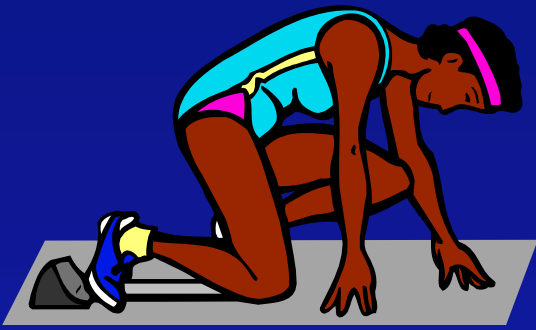
- What happens to the fundamental frequency of a pipe, if the air ($v=343$ m/s) is replaced by helium ($v=972$ m/s)?

1) Increases

2) Same

3) Decreases

$$f = v/\lambda$$



Speed of Sound



- Recall for pulse on string: $v = \sqrt{T / \mu}$
- For fluids: $v = \sqrt{B/\rho}$

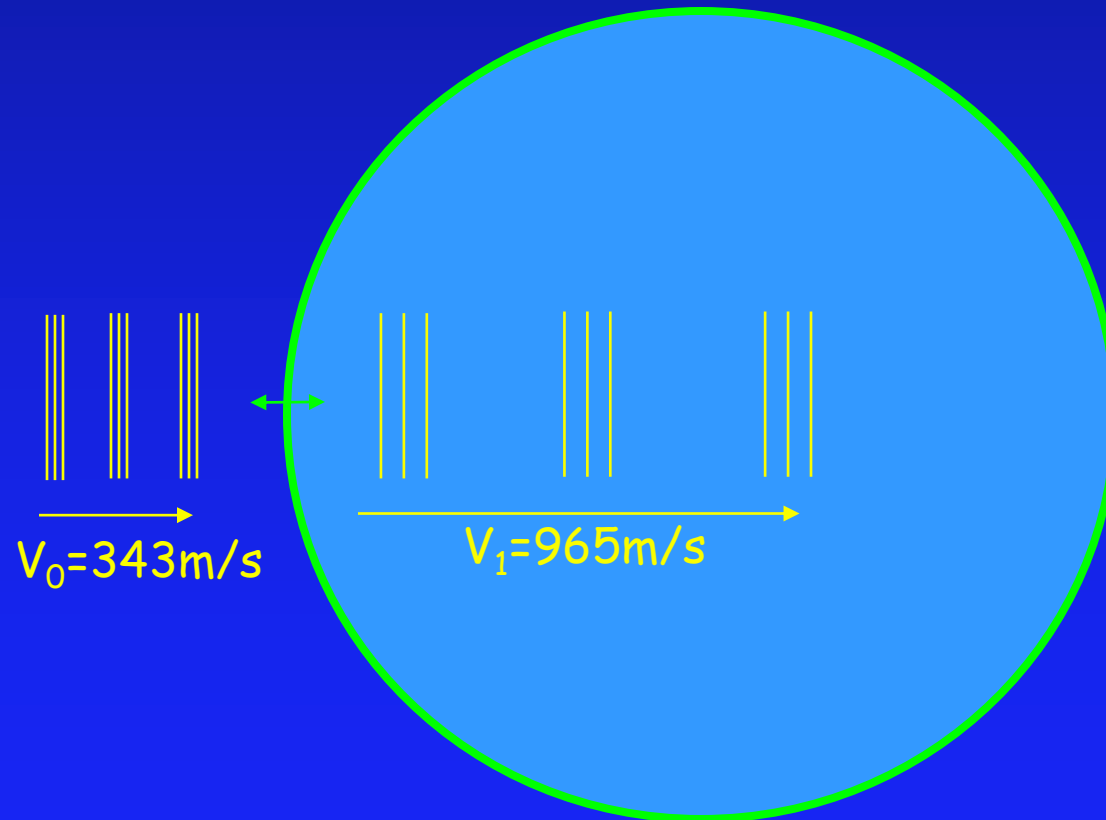
B = bulk modulus

| Medium | Speed (m/s) |
|--------|-------------|
| Air | 343 |
| Helium | 972 |
| Water | 1500 |
| Steel | 5600 |

Velocity ACT

A sound wave having frequency f_0 , speed v_0 and wavelength λ_0 , is traveling through air when it encounters a large helium-filled balloon. Inside the balloon the frequency of the wave is f_1 , its speed is v_1 , and its wavelength is λ_1 . Compare the speed of the sound wave inside and outside the balloon

1. $v_1 < v_0$
2. $v_1 = v_0$
3. $v_1 > v_0$ ← correct



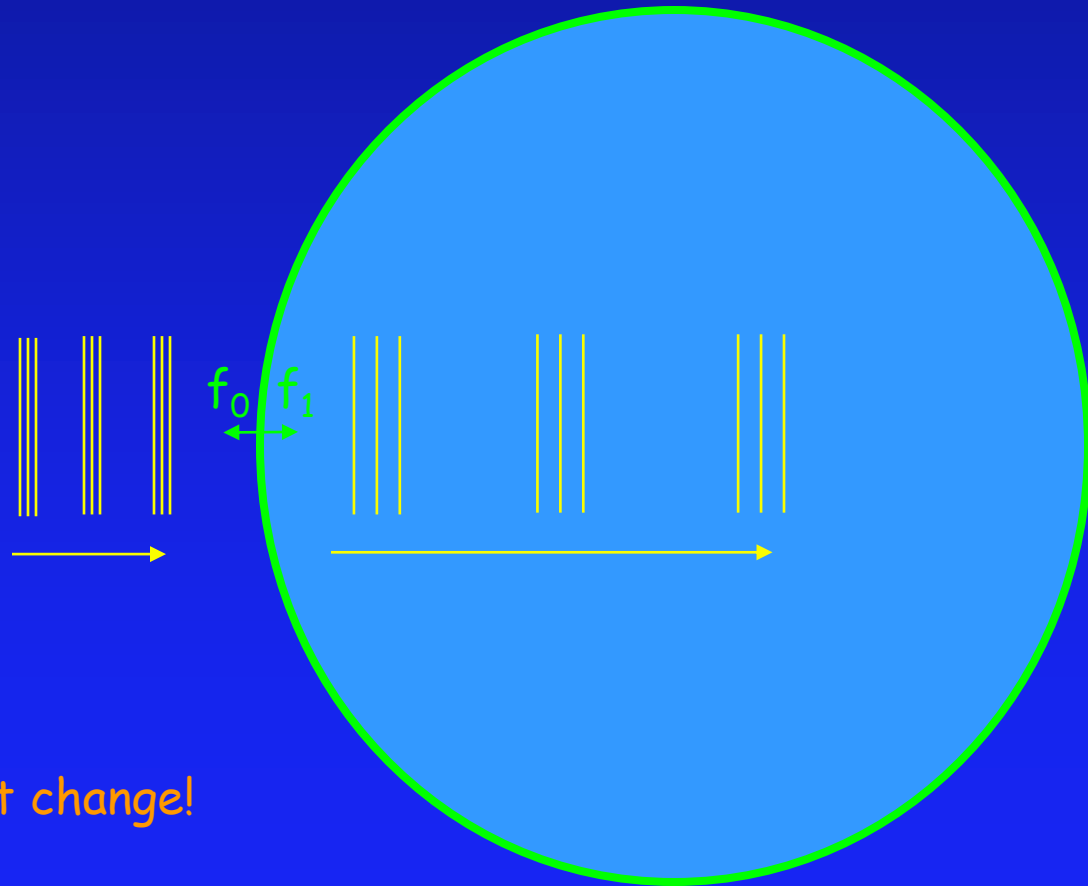
Frequency ACT

A sound wave having frequency f_0 , speed v_0 and wavelength λ_0 , is traveling through air when it encounters a large helium-filled balloon. Inside the balloon the frequency of the wave is f_1 , its speed is v_1 , and its wavelength is λ_1 . Compare the frequency of the sound wave inside and outside the balloon

1. $f_1 < f_0$

2. $f_1 = f_0$ ← correct

3. $f_1 > f_0$

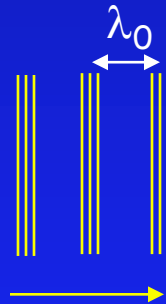


Time between wave peaks does not change!

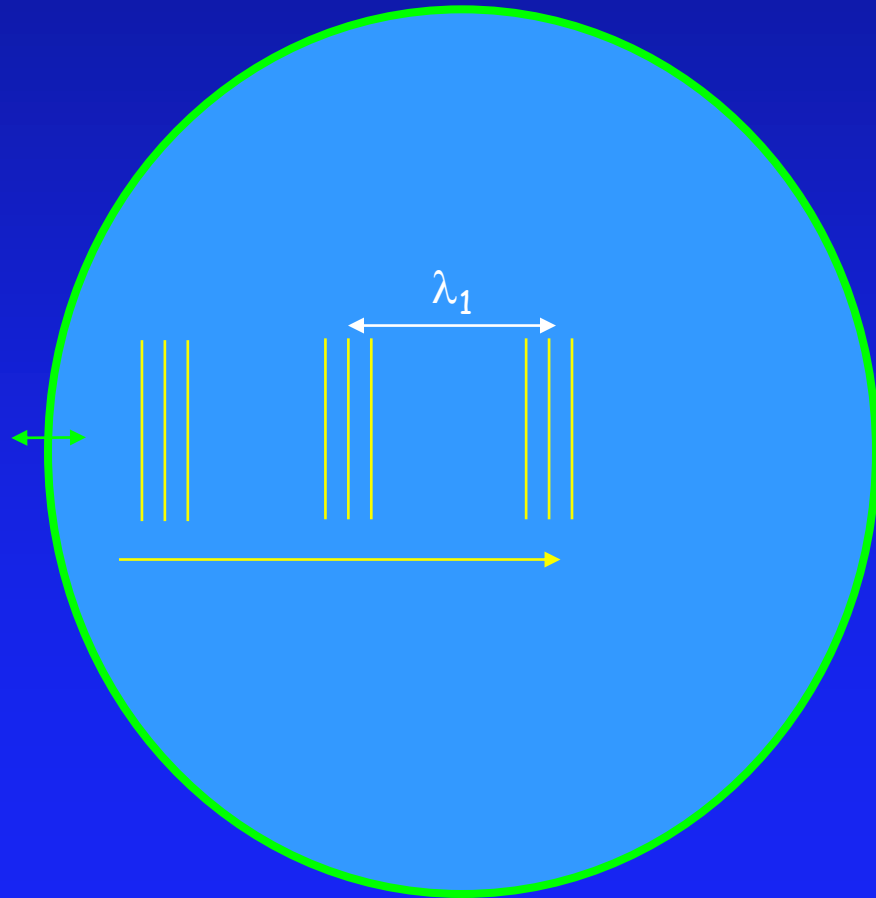
Wavelength ACT

A sound wave having frequency f_0 , speed v_0 and wavelength λ_0 , is traveling through air when it encounters a large helium-filled balloon. Inside the balloon the frequency of the wave is f_1 , its speed is v_1 , and its wavelength is λ_1 . Compare the wavelength of the sound wave inside and outside the balloon

1. $\lambda_1 < \lambda_0$
2. $\lambda_1 = \lambda_0$
3. $\lambda_1 > \lambda_0$ ← correct



$$\lambda = v / f$$



Intensity and Loudness

- **Intensity** is the power per unit area.

→ $I = P / A$

→ Units: Watts/m²



- **Loudness (Decibels)**

→ Loudness perception is logarithmic

→ Threshold for hearing $I_0 = 10^{-12} \text{ W/m}^2$

→ $\beta = 10 \log_{10} (I / I_0)$

→ $\beta_2 - \beta_1 = 10 \log_{10}(I_2/I_1)$



Log₁₀ Review

- $\log_{10}(1) = 0$
- $\log_{10}(10) = 1$
- $\log_{10}(100) = 2$
- $\log_{10}(1,000) = 3$
- $\log_{10}(10,000,000,000) = 10$

$$\beta = 10 \log_{10} (I / I_0)$$

$$\beta_2 - \beta_1 = 10 \log_{10}(I_2/I_1)$$

- $\log(ab) = \log(a) + \log(b)$
- $\log_{10}(100) = \log_{10}(10) + \log_{10}(10) = 2$

Decibels ACT

- If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout?

1) 52 dB

2) 70 dB

3) 150 dB

$$\beta_{100} - \beta_1 = (10 \text{ dB}) \log_{10}(I_{100}/I_1)$$

$$\beta_{100} = 50 + (10 \text{ dB}) \log_{10}(100)$$

$$\beta_{100} = 50 + 20$$

Intensity ACT

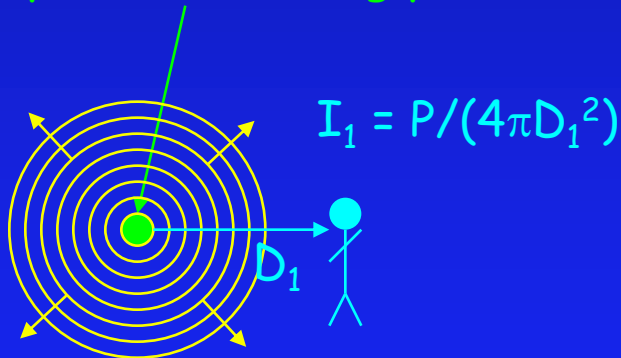
- Recall Intensity = P/A . If you are standing 6 meters from a speaker, and you walk towards it until you are 3 meters away, by what factor has the intensity of the sound increased?

1) 2

2) 4

3) 8

Speaker radiating power P



Area goes as d^2 so if you are $1/2$ the distance the intensity will increase by a factor of 4





Prelecture 1



- As a police car passes you with its siren on, the frequency of the sound you hear from its siren

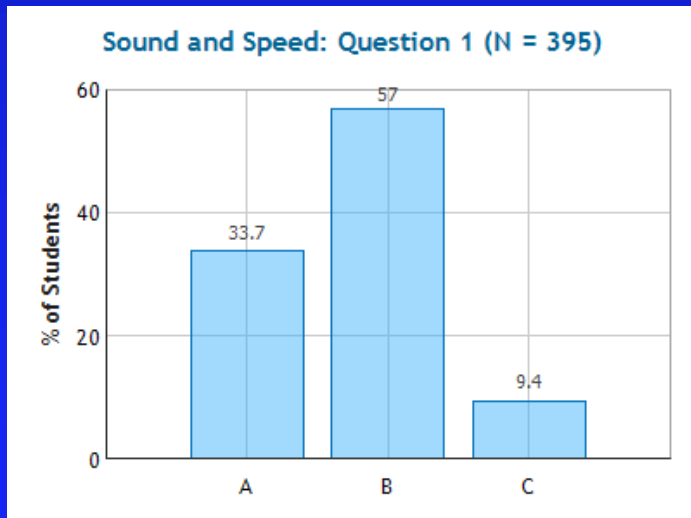
[Doppler Example Audio](#)

[Doppler Example Visual](#)

1) Increases

2) Decreases

3) Same



When a source is going away from you then the distance between waves increases which causes the frequency to increase.

Doppler Effect

moving source v_s

Knowing if V_o and V_s are negative or positive.

- When source is coming toward you ($v_s > 0$)
 - Distance between waves decreases
 - Frequency is higher
- When source is going away from you ($v_s < 0$)
 - Distance between waves increases
 - Frequency is lower
- $f_o = f_s / (1 - v_s/v)$

Doppler Effect

moving observer (v_o)

- When moving toward source ($v_o < 0$)
 - ➔ Time between waves peaks decreases
 - ➔ Frequency is higher
- When away from source ($v_o > 0$)
 - ➔ Time between waves peaks increases
 - ➔ Frequency is lower
- $f_o = f_s (1 - v_o/v)$

Combine: $f_o = f_s (1 - v_o/v) / (1 - v_s/v)$

Doppler ACT

A: You are driving along the highway at 65 mph, and behind you a police car, also traveling at 65 mph, has its siren turned on.

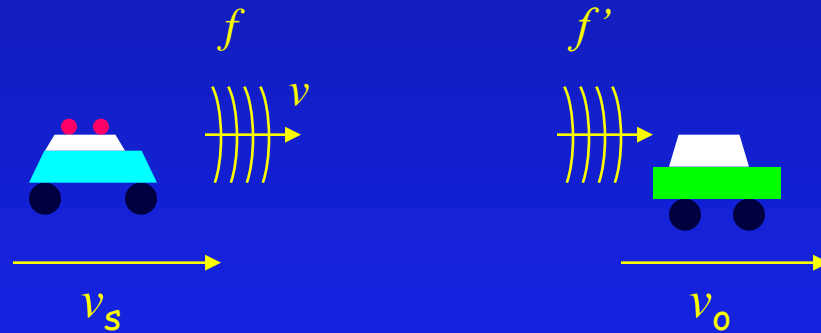
B: You and the police car have both pulled over to the side of the road, but the siren is still turned on.

In which case does the frequency of the siren seem higher to you?

A. Case A

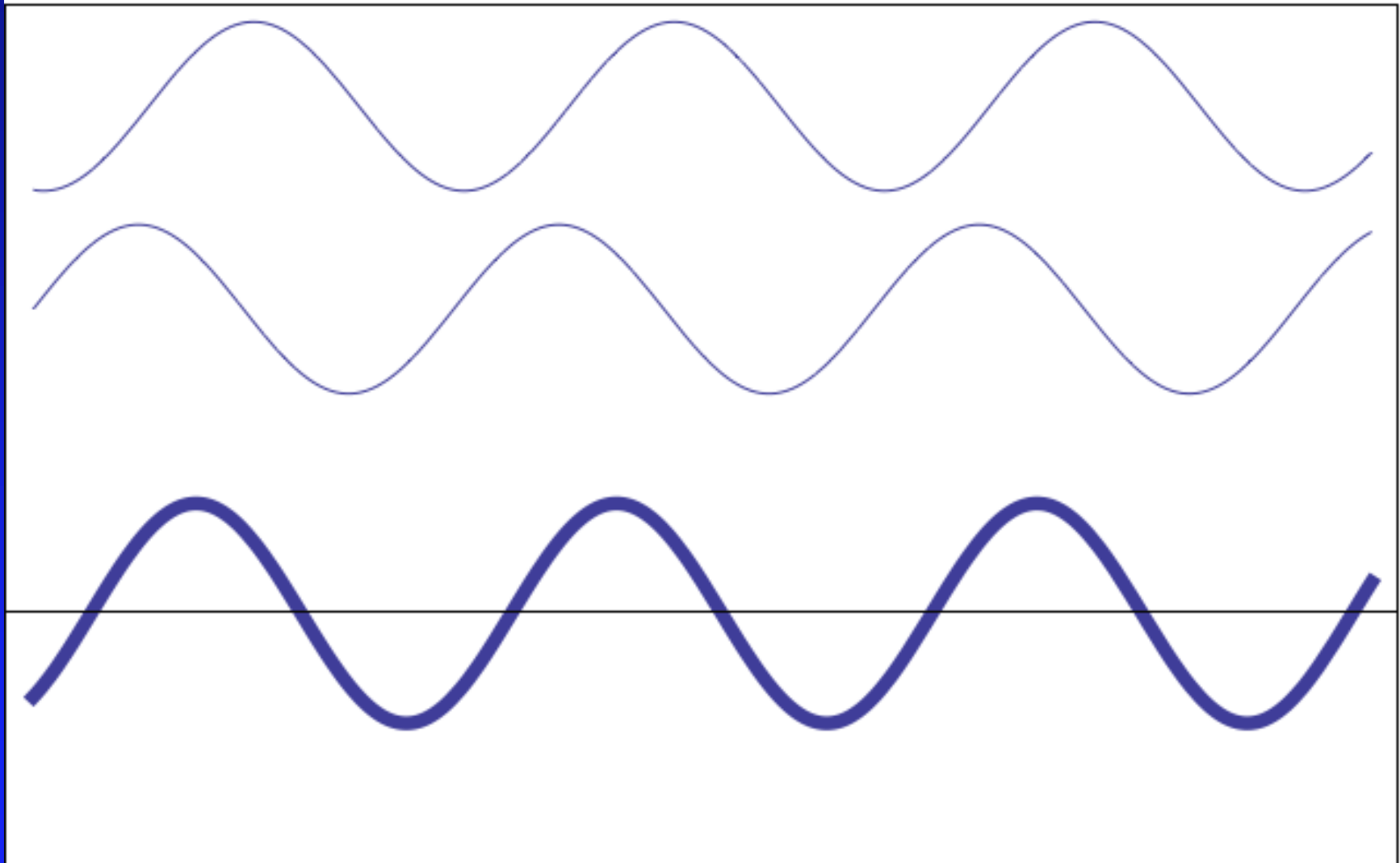
B. Case B

C. same ← correct



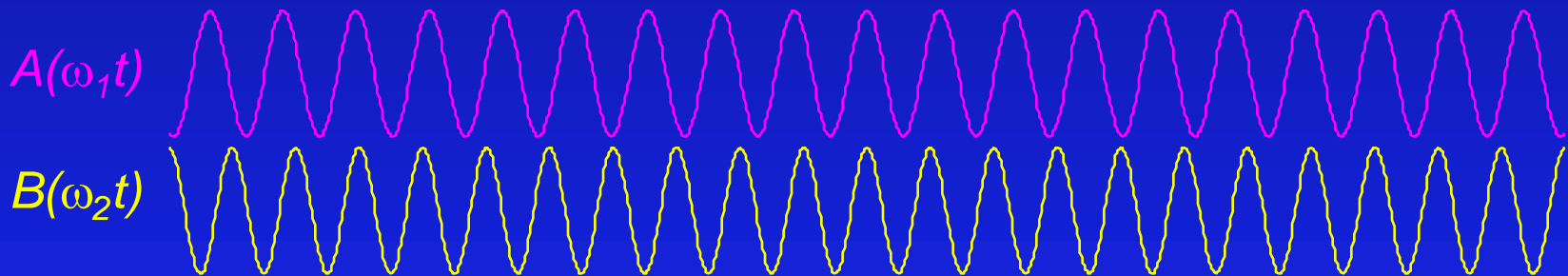
$$\frac{f'}{f} = \frac{1 - \frac{v_o}{v}}{1 - \frac{v_s}{v}} = \frac{1 - \frac{65 \text{ mph}}{v}}{1 - \frac{65 \text{ mph}}{v}} = 1$$

Interference and Superposition



Superposition & Interference

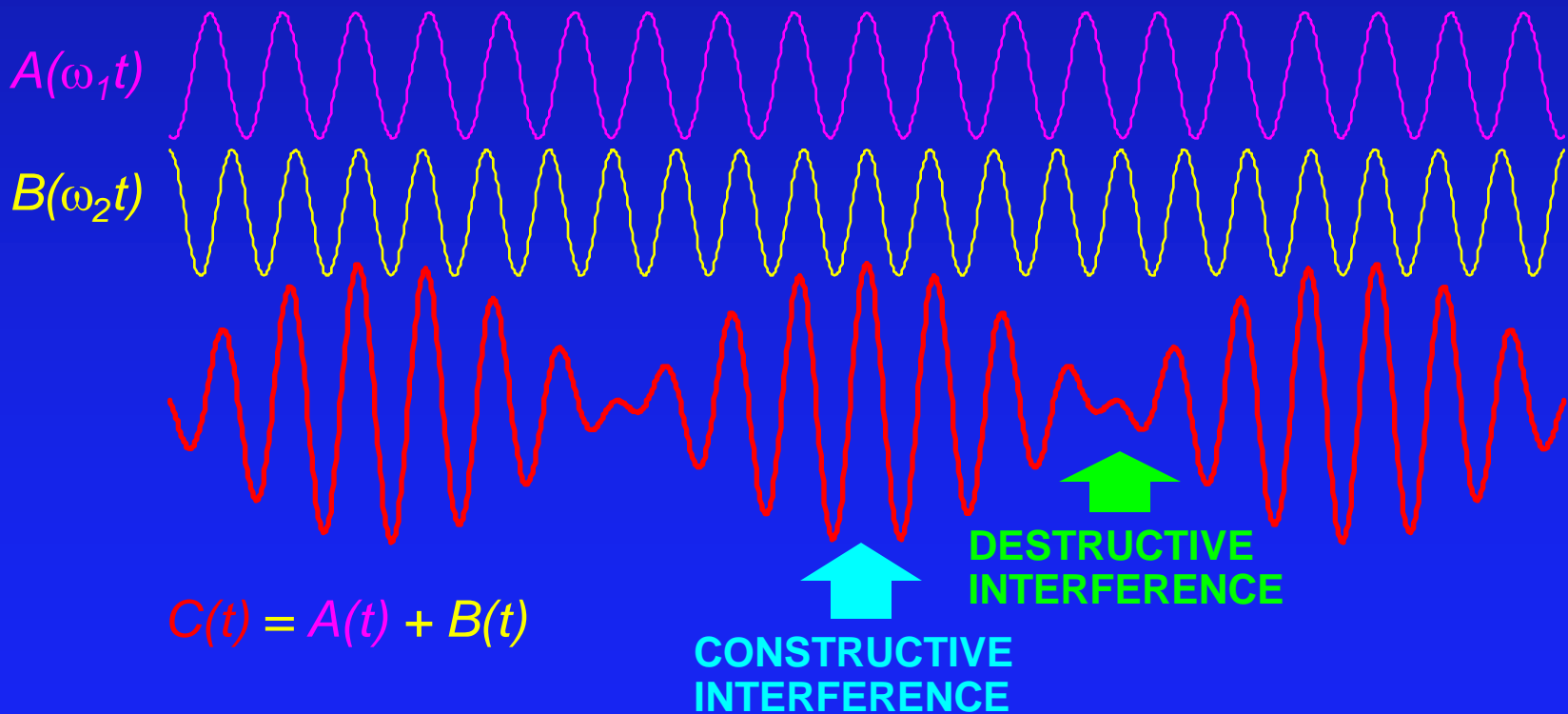
- Consider two harmonic waves A and B meeting at $x=0$.
 - Same amplitudes, but $\omega_2 = 1.15 \times \omega_1$.
- The displacement versus time for each is shown below:



What does $C(t) = A(t) + B(t)$ look like??

Superposition & Interference

- Consider two harmonic waves A and B meeting at $x=0$.
 - Same amplitudes, but $\omega_2 = 1.15 \times \omega_1$.
- The displacement versus time for each is shown below:

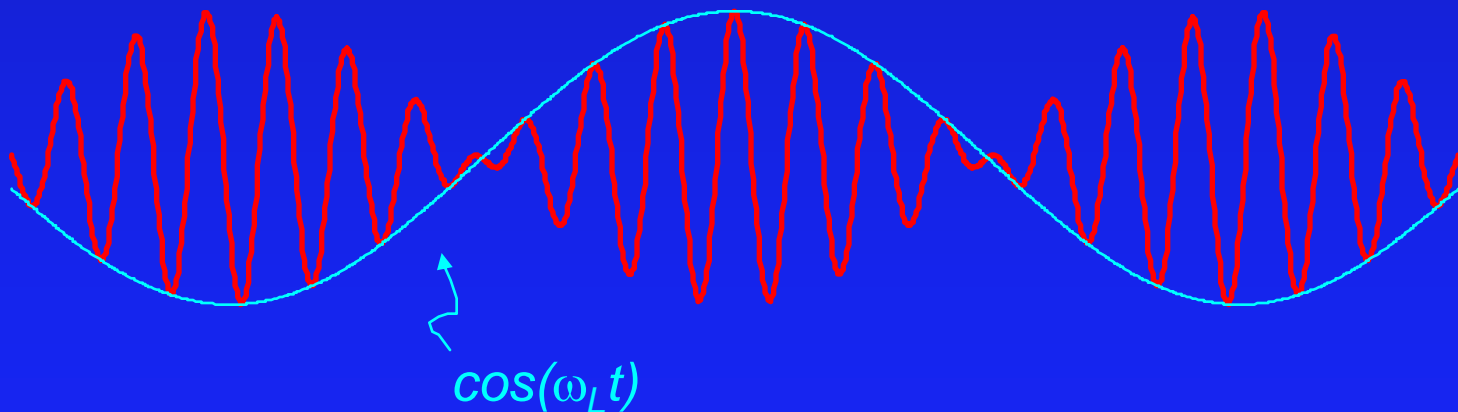


Beats

- Can we predict this pattern mathematically?
→ Of course!
- Just add two cosines and remember the identity:

$$A \cos(\omega_1 t) + A \cos(\omega_2 t) = 2A \cos(\omega_L t) \cos(\omega_H t)$$

where $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$ and $\omega_H = \frac{1}{2}(\omega_1 + \omega_2)$



Summary

- Speed of sound $v = \sqrt{B/\rho}$
- Intensity $\beta = (10 \text{ dB}) \log_{10} (I / I_0)$
- Standing Waves
 - $f_n = n v / (2L)$ Open at both ends $n=1,2,3\dots$
 - $f_n = n v / (4L)$ Open at one end $n=1,3,5\dots$
- Doppler Effect $f_o = f_s (v - v_o) / (v - v_s)$
- Beats $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$

Doppler sign convention

Doppler shift: $f_o = f_s (1 - v_o/v) / (1 - v_s/v)$

$v_s = v(\text{source})$

+ If *same* direction as sound wave

$v_o = v(\text{observer})$

- If *opposite* direction to sound wave

$v = v(\text{wave})$