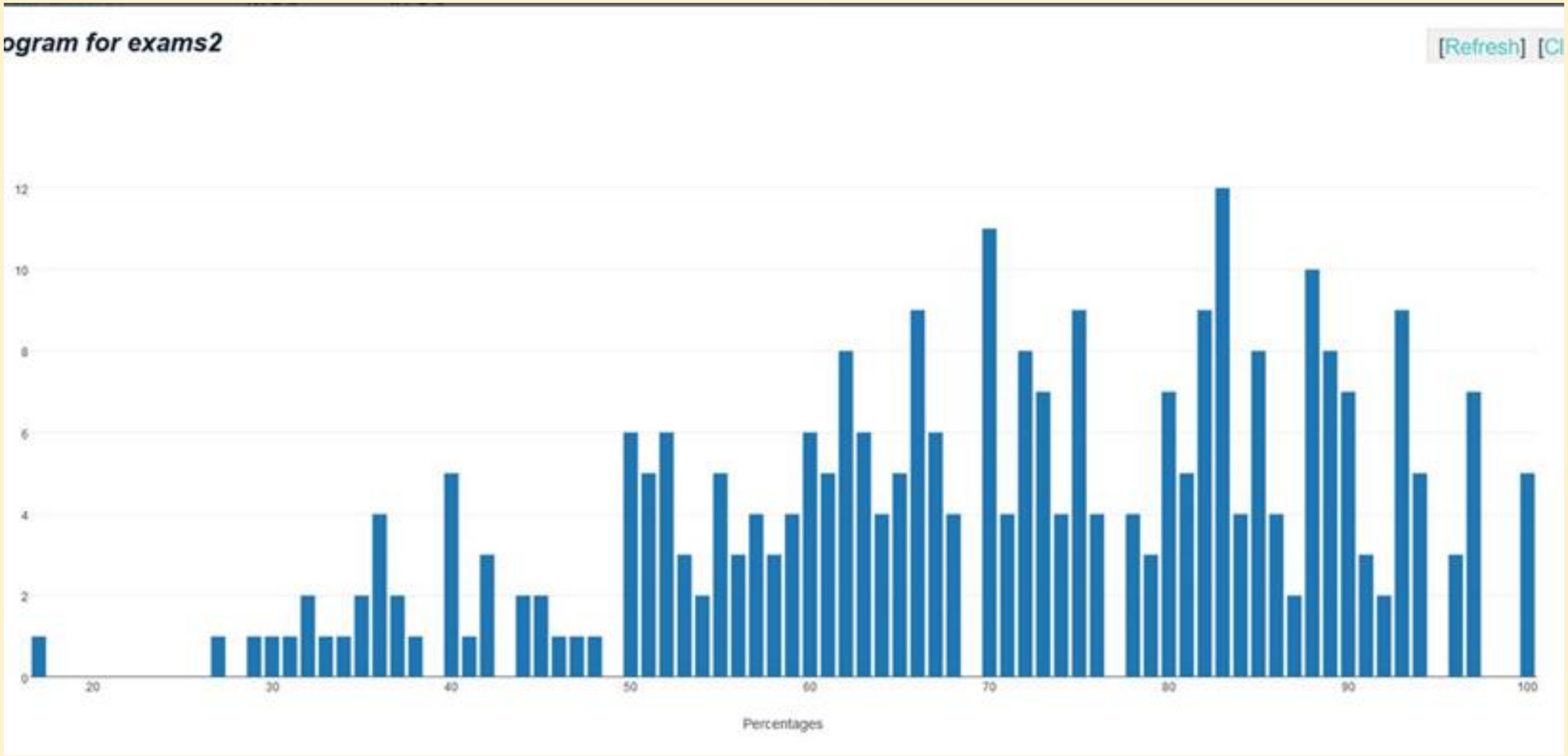
Physics 101: Lecture 23

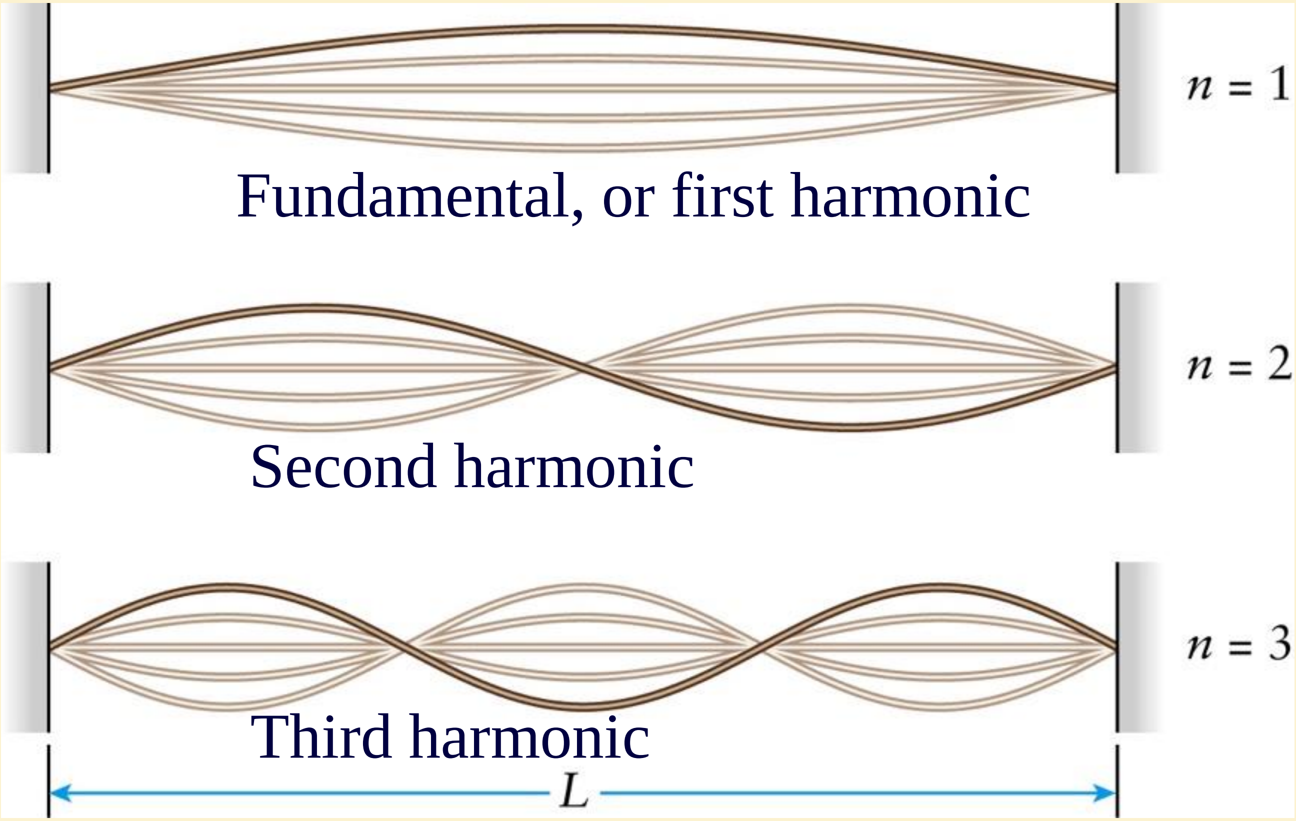
Sound

Exam Results

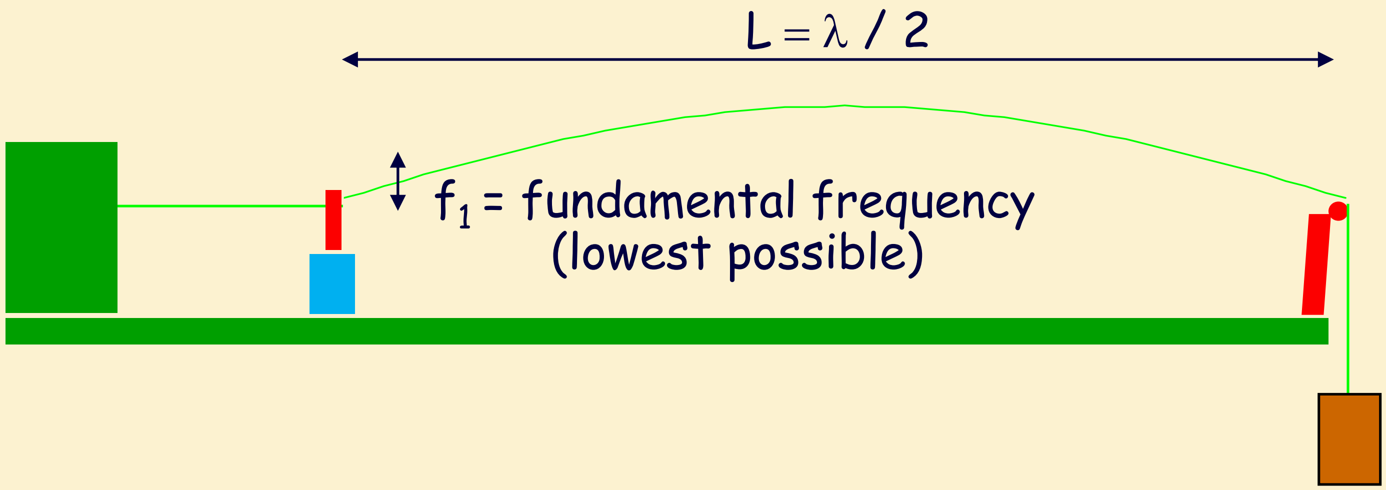


Standing Waves Fixed Endpoints

- Fundamental n=1 (2 nodes)
- $\lambda_n = 2L/n$
- $f_n = n\,v / (2L)$



Standing Waves Example



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)

$v = \lambda f$

$= 2\,(0.65\text{ m})\,(329.63\text{ s}^{-1})$

$= 428.5\text{ m/s}$

$v^2 = T / \mu$

$\mu = T / v^2$

$m = T L / v^2$

$= 82\,(0.65) / (428.5)^2$

$= 2.9 \times 10^{-4}\text{ kg}$

Standing Waves in Pipes

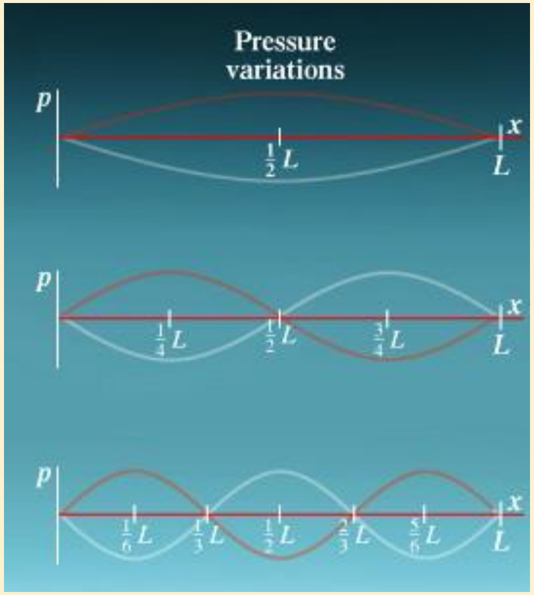
A pressure node is where pressure is normal (open to atmosphere)

NOTE: A pressure *node* corresponds to a displacement *antinode* and
A pressure *antinode* corresponds to a displacement *node*

Open at both ends:

Pressure Node at end

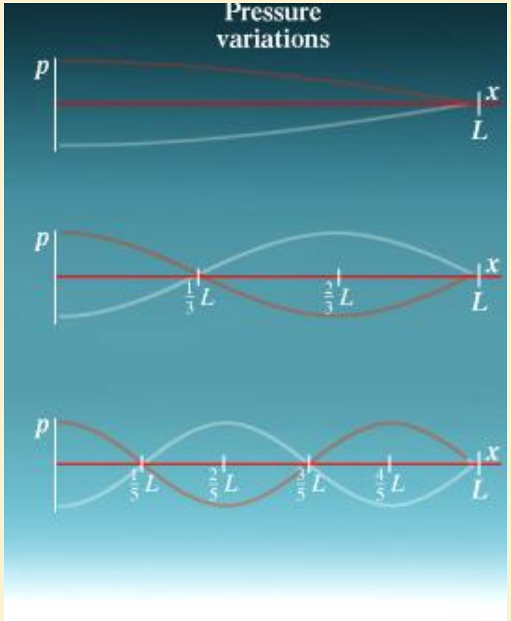
$\lambda = 2\,L\,/\,n$ n=1,2,3..



Open at one end:

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

n odd



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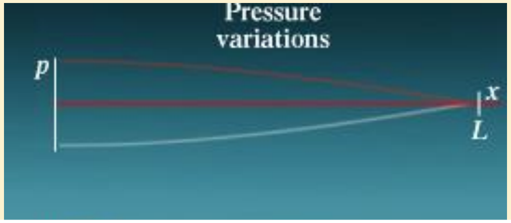
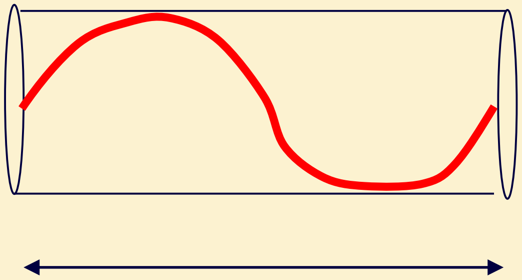


n odd

Organ Pipe Standing Wave Example

A 0.9 m organ pipe (**open at both ends**) is measured to have its second harmonic at a frequency of 382 Hz. What is the speed of sound in the pipe?



Pressure Node at each end.

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

$\lambda = L$ for second harmonic ($n=2$)

$v = f\,\lambda = (382\ s^{-1})\,(0.9\ m)$

$= 343\ m/s$

Note: fundamental, $n=1$, has a wavelength of $\lambda = 2\,L$

Clicker Q

- 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

Speed of Sound

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

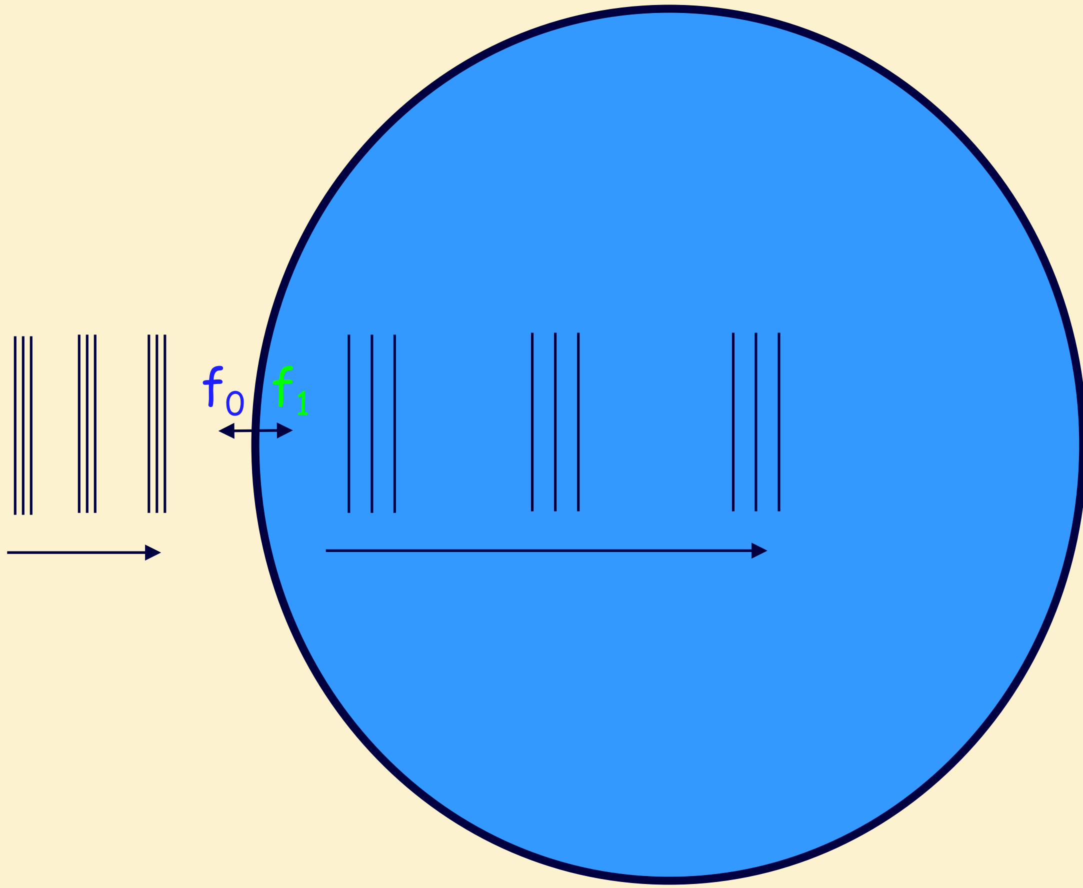
B = bulk modulus

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

Frequency Clicker Q

A sound wave having frequency f_0, speed v_0 and wavelength λ_0, is traveling through air when in 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. $f_1 = f_0$
3. $f_1 > f_0$



Velocity Clicker Q

A sound wave having frequency f_0, speed v_0 and wavelength λ_0, is traveling through air when in 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

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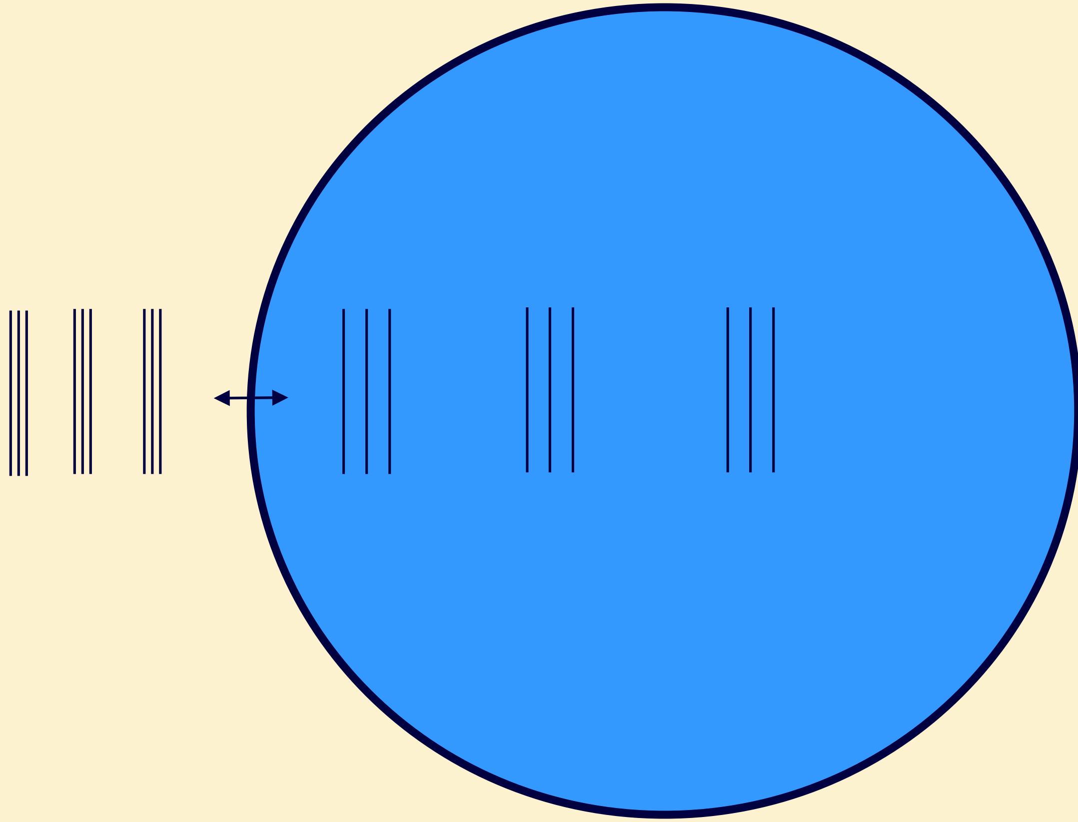
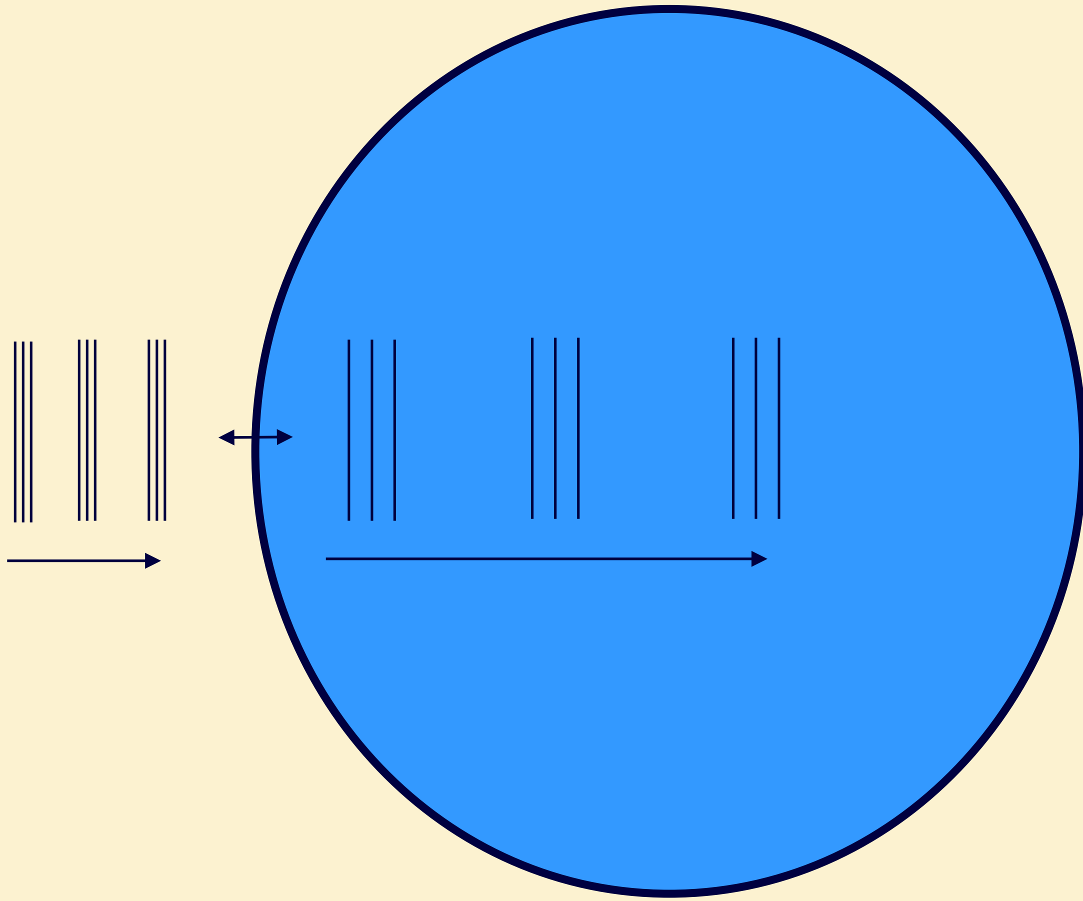


Wavelength Clicker Q

A sound wave having frequency f_0, speed v_0 and wavelength λ_0, is traveling through air when in 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. $\lambda_1 > \lambda_0$



Intensity and Loudness

- Intensity is the power per unit area of a sound.
  - ➔ $I = \text{Power} / A$
  - ➔ Units: $(J/s)/m^2$ (= Watts/m^2)

- Loudness (Decibels): We hear "loudness" not intensity, and loudness is a logarithmic scale.
  - ➔ Loudness perception is logarithmic
  - ➔ Threshold for hearing $I_0 = 10^{-12}\ W/m^2$ (defined as 0 dB)
  - ➔ Threshold for pain $I = 10^0\ W/m^2 = 1\ W/m^2$ (= 120 dB)

  This is a huge range:12 orders of magnitude (12 powers of 10)

  - ➔ $\beta = (10\ \text{dB}) \log_{10} (I / I_0)$
  - ➔ $\beta_2 - \beta_1 = (10\ \text{dB}) \log_{10}(I_2/I_1)$

Log_{10} Review

- $\log_{10}(1) = 0$
- $\log_{10}(10) = 1$
- $\log_{10}(100) = 2$
- $\log_{10}(1{,}000) = 3$
- $\log_{10}(10{,}000{,}000{,}000) = 10$
- $\log_{10}(2) = 0.3$

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

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

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

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Decibels Clicker Q

- If 1 person can shout with loudness 50 dB. How loud will it be when 100 people shout? Assume $I_{100} = 100I_1$

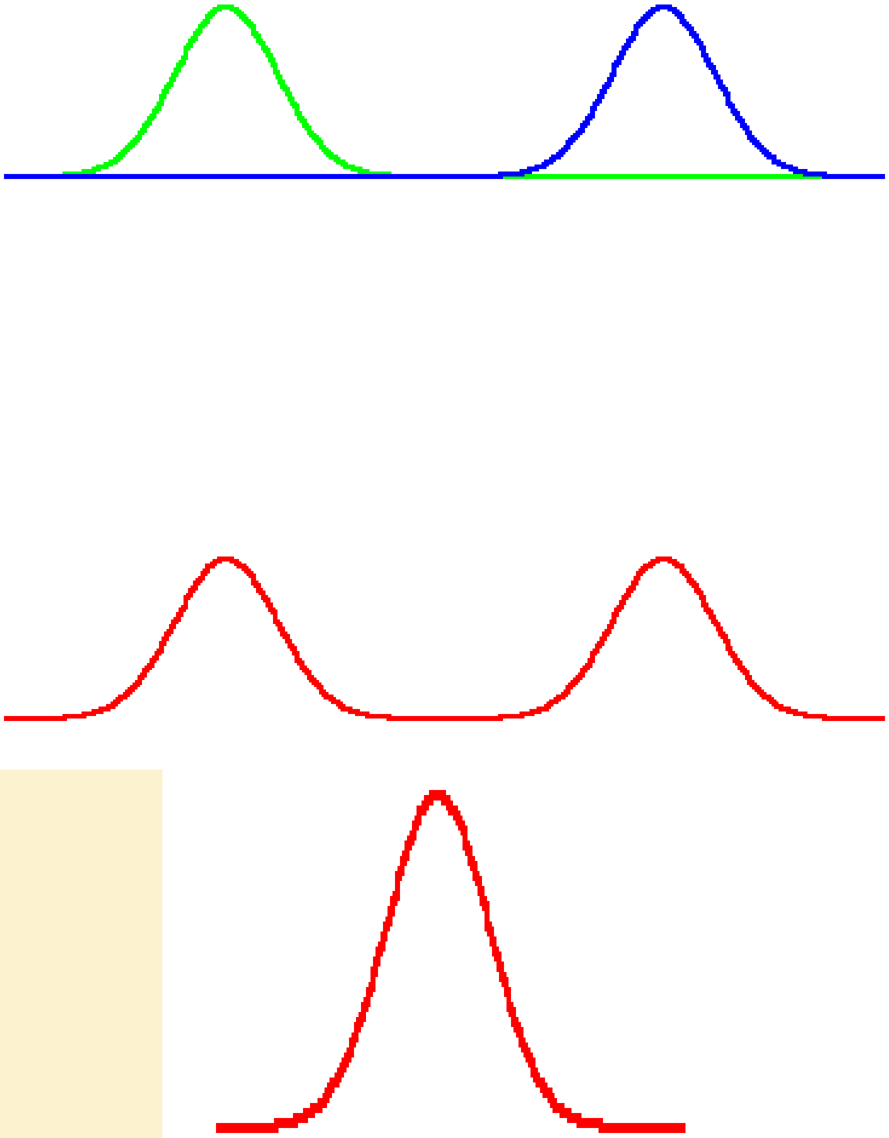
1) 52 dB 2) 70 dB 3) 150 dB

Intensity Clicker Q

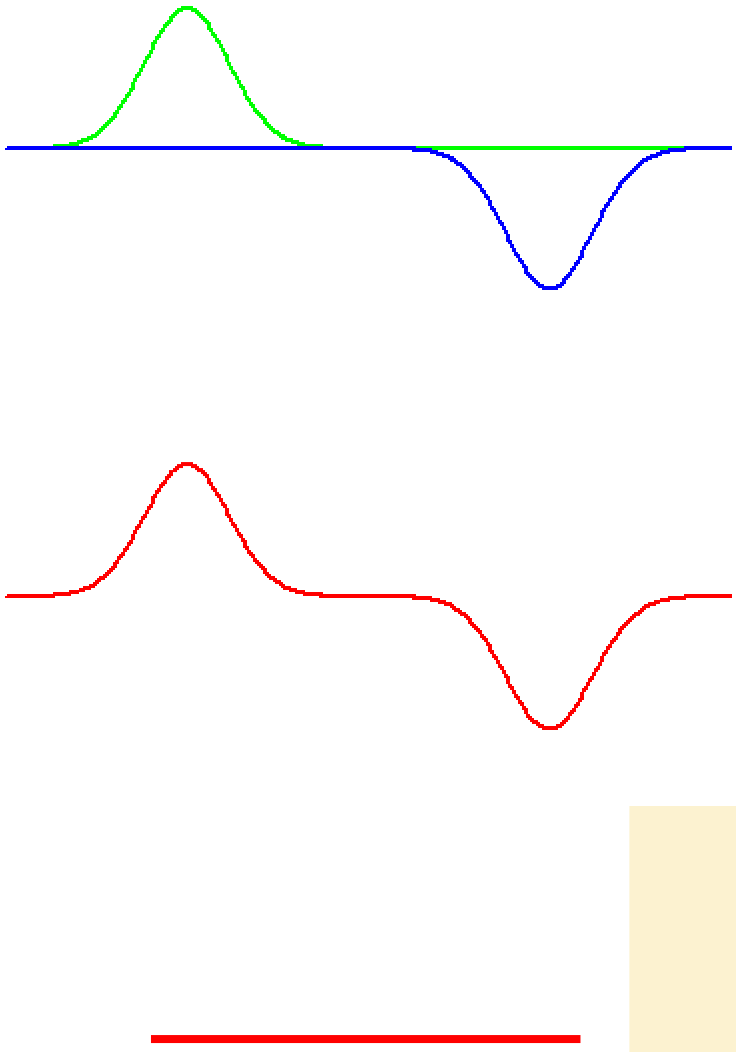
- Recall Intensity = Power/A. If you are standing 6 meters from a speaker, and you walk towards it until you are 3 meters away, by what factor has the intensity of the sound increased?

1) 2 2) 4 3) 8

Interference and Superposition



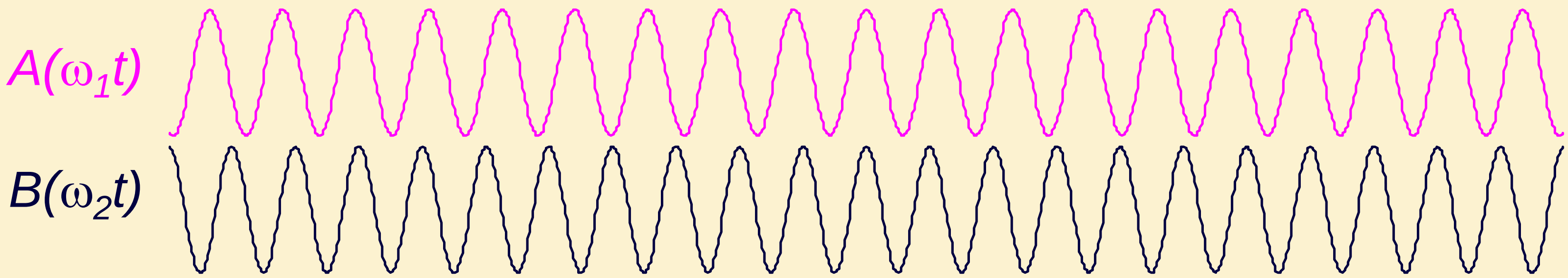
Constructive interference



Destructive interference

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??

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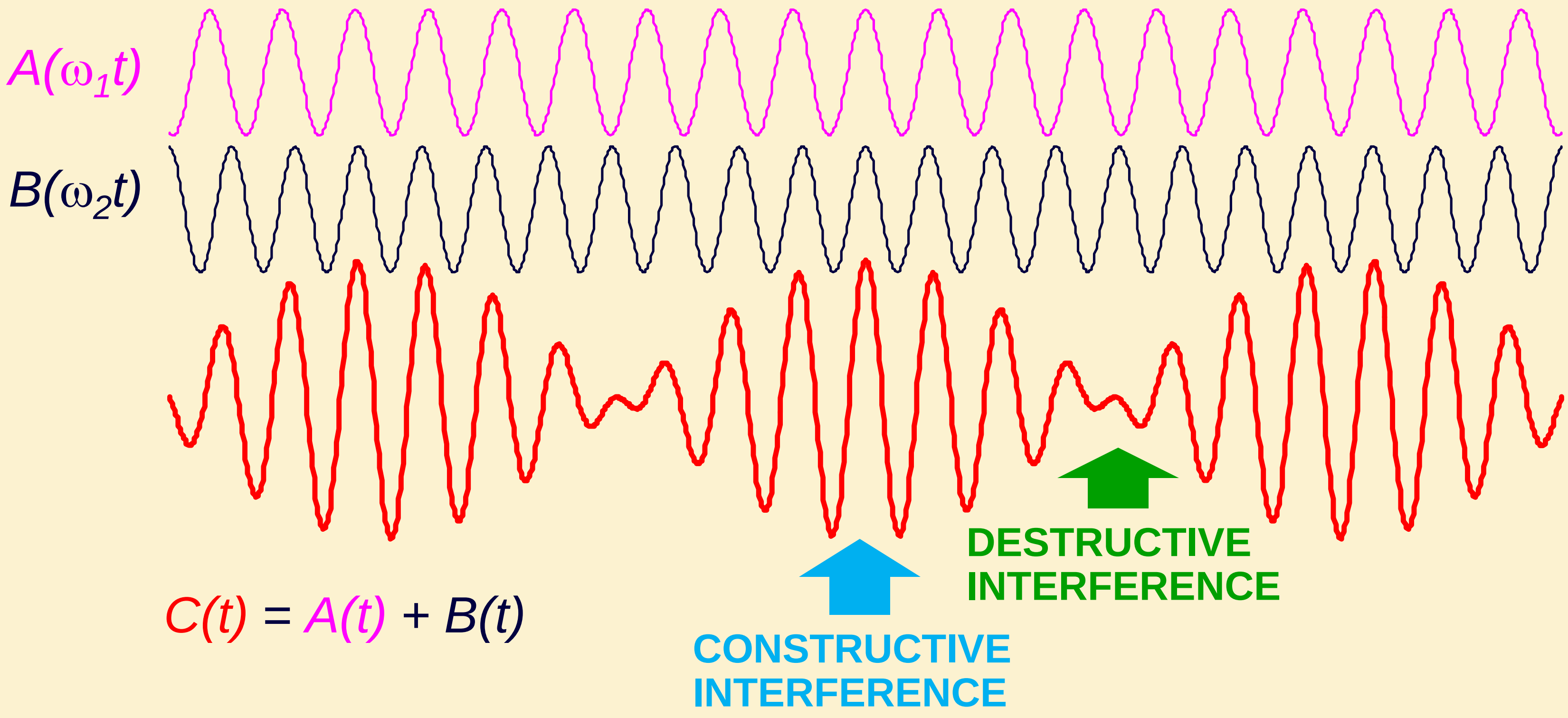
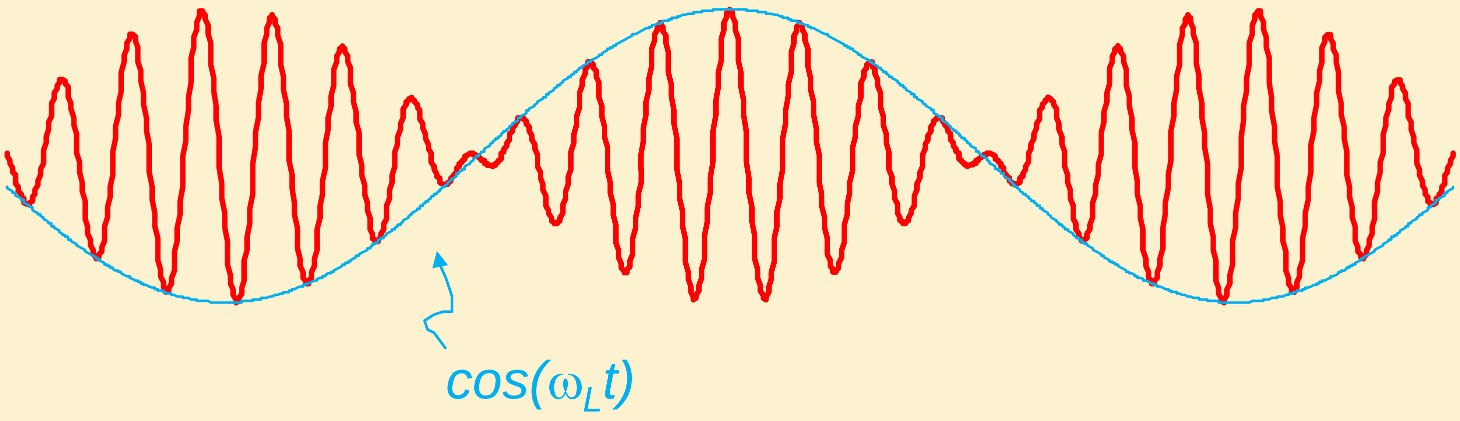


Beats

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

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

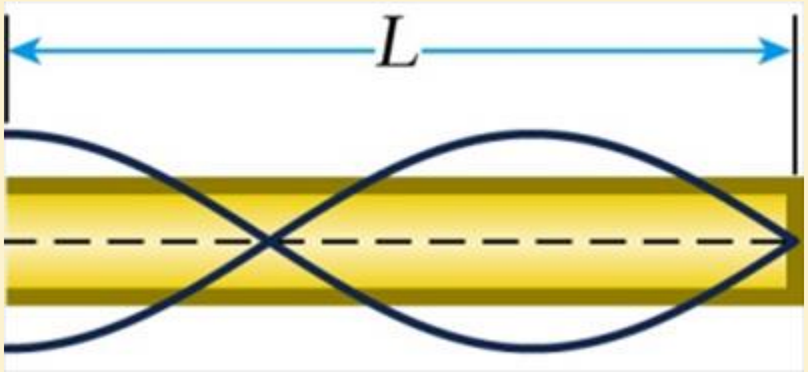
where $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$ and $\omega_H = \frac{1}{2}(\omega_1 + \omega_2)$



Checkpoint 2

A clarinet behaves like a pipe in which one end is closed and the other is open to the air. When a musician blows air into the mouthpiece and causes air in the tube of the clarinet to vibrate, the waves set up by the vibration create the **displacement** pattern of the third harmonic represented in the figure. Set x=0 at the open end of the tube. The antinodes (locations of maxima) of the **pressure** variation of the sound waves are located at:

A) x=0, x=L/3, x=2L/3, and x=L
B) x=0
C) x=0 and x=2L/3
D) x=L/3 and x=L
E) None of the above



Summary

- Speed of sound $v = \text{sqrt}(B/\rho)$
- Intensity $\beta = (10\text{ dB}) \log_{10} (I / I_0)$
- Standing Waves
- Beats $\omega_L = \frac{1}{2}(\omega_1 - \omega_2)$