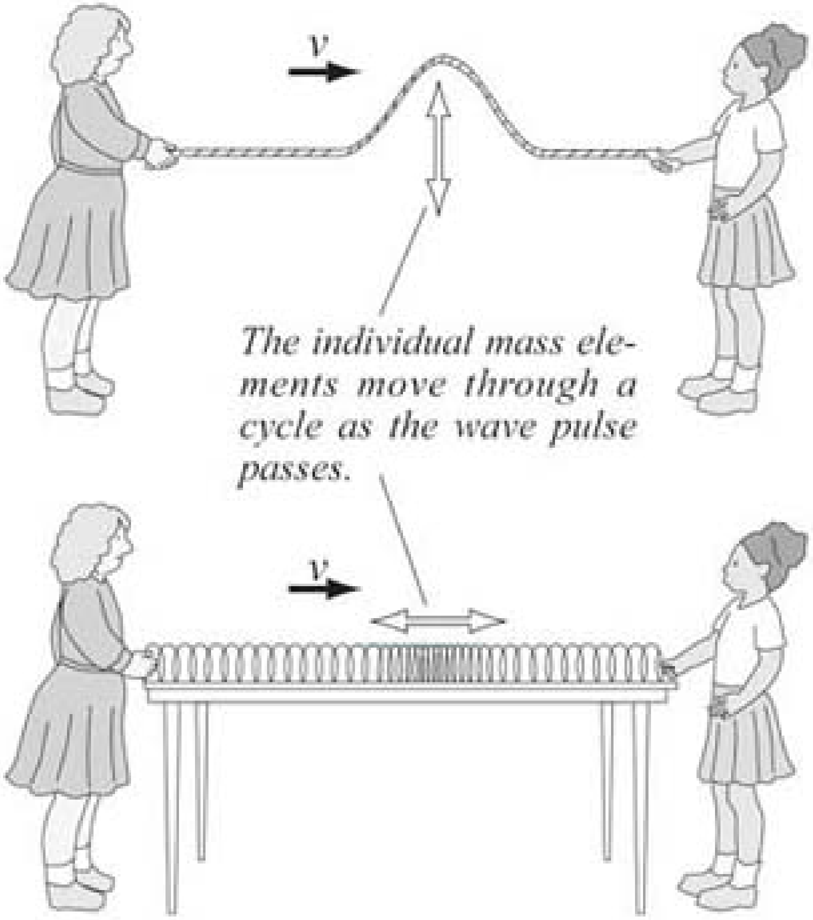
Module 5

Waves

Session Slides with Notes

Waves

Transverse and Longitudinal Waves



A transverse pulse. *If the displacements associated with wave disturbances move in a direction perpendicular to wave motion, the wave is transverse.*

electromagnetic waves

A longitudinal pulse. *If the displacements associated with wave disturbances move in a direction parallel to wave velocity, the wave is longitudinal.*

sound waves

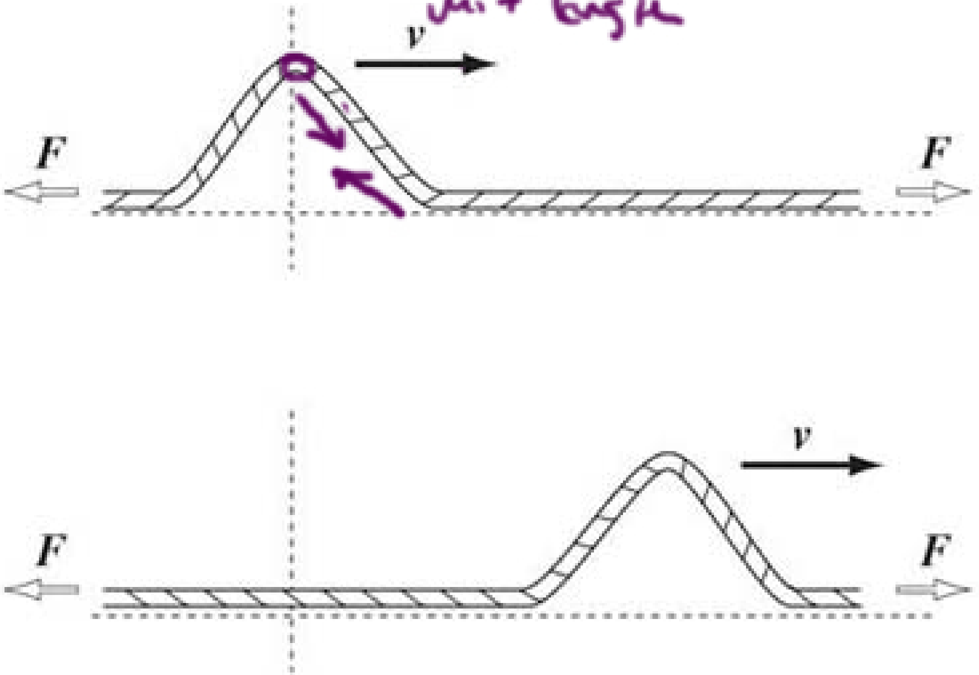
Speed of a Wave on a Stretched String

tension

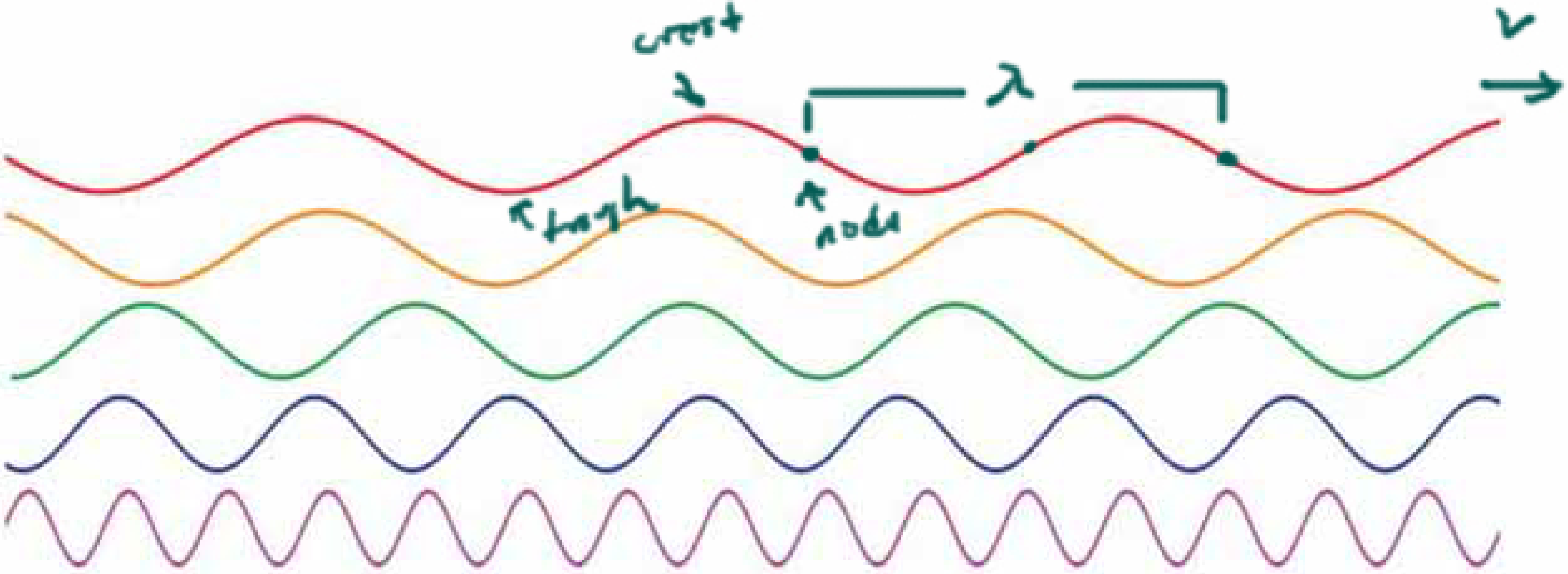
$$v = \sqrt{\frac{F}{\mu}}$$

mass/ unit length

v = wave speed
F = tension
μ = mass per unit length



Harmonic Waves Repeat Themselves



$\lambda : m, \frac{m}{cycle}$

$k = m^{-1}, \frac{cycle}{m}$

$T = s, s/cycle$

$f = s^{-1}, \frac{cycle}{s}, Hz$

Harmonic Waves

$$\left(\frac{m}{cycle}\right)\left(\frac{cycle}{s}\right) = m/s$$

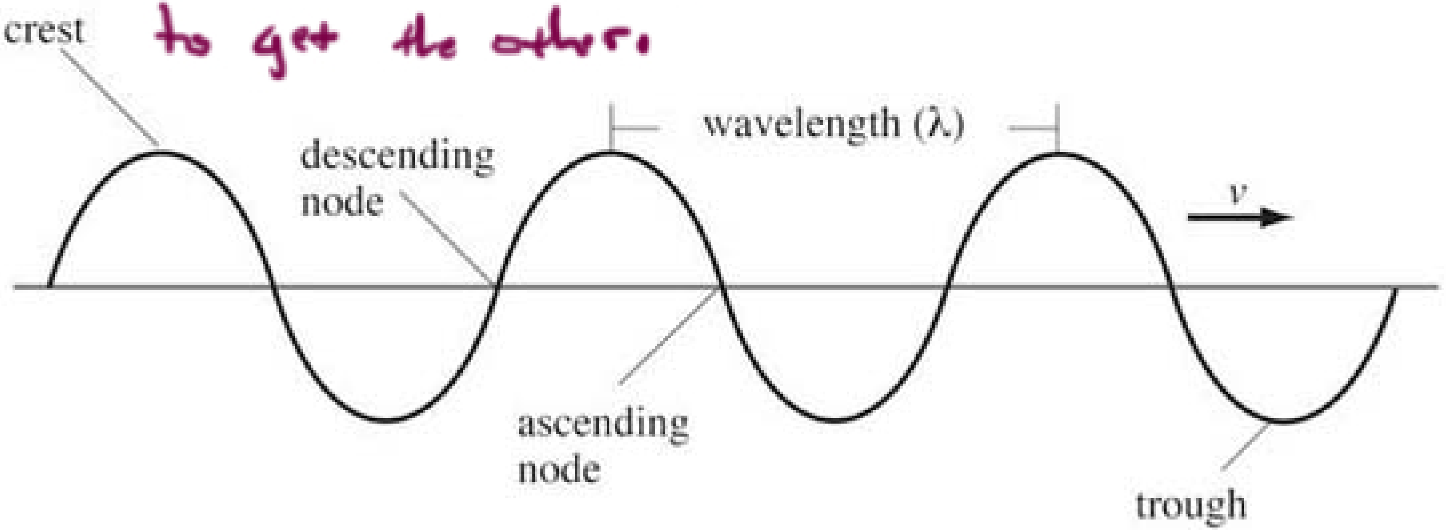
$$(\lambda)(f) = v$$

$$v = \lambda f$$

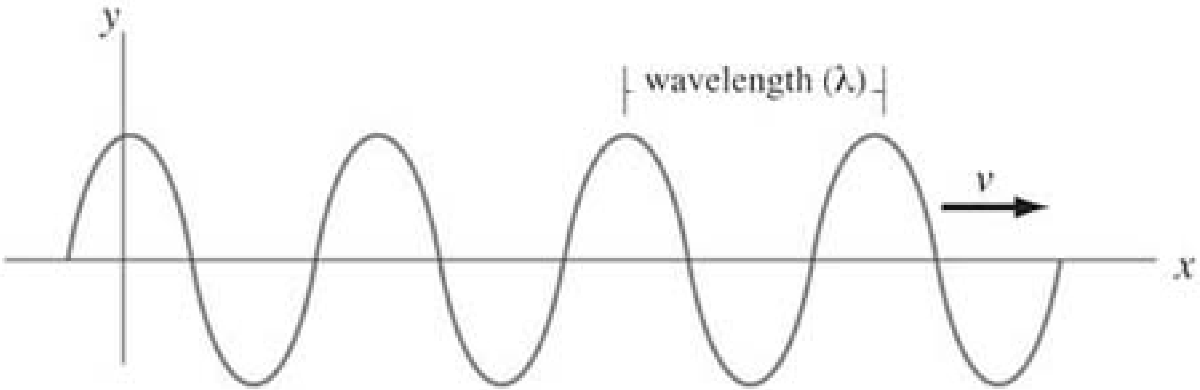
$$\lambda = \frac{v}{f} \qquad f = \frac{v}{\lambda} \qquad T = \frac{1}{f}$$

v = wave speed
λ = wavelength
f = frequency
T = period

Divide either λ or f into v to get the other.



The wavelength of a harmonic wave divided by its speed of propagation is equal to:



$$\frac{m/cycle}{m/s} = s/cycle$$

a. the frequency

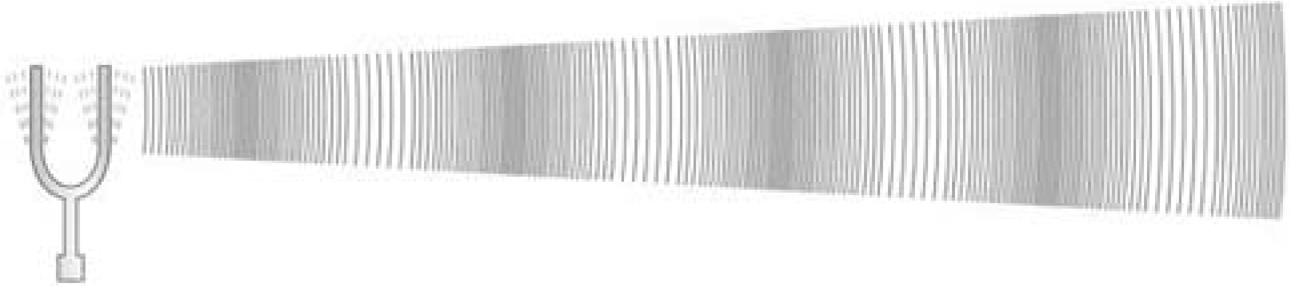
b. the angular frequency

c. the wave number

d. the period

A tuning fork produces an E note (frequency = 660 Hz). The wavelength is 0.5 m. At what speed do sound waves move through the air of this room?

$v = f\lambda$



a. 132 m/s

b. 165 m/s

c. 330 m/s

d. 1320 m/s

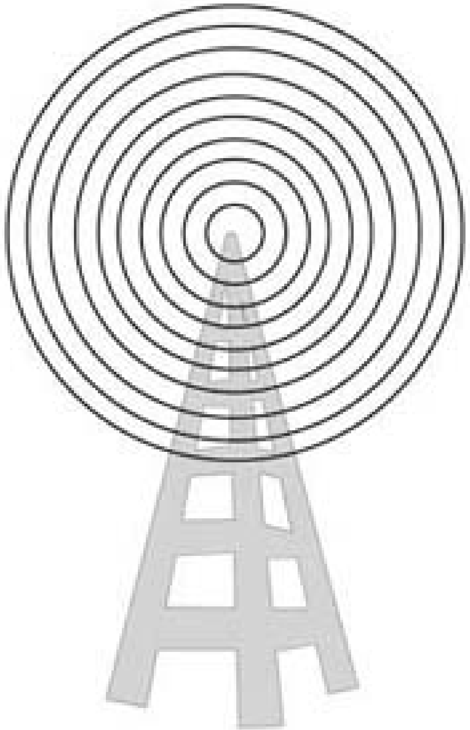
An FM radio station broadcasts at 100MHz on the dial. What is the wavelength of its signal?

a. 1.0×10^{-8} m

b. 0.33 m

c. 3 m

d. 100 m



$$\lambda = \frac{v}{f}$$

$$\lambda = \frac{3 \times 10^{8}\ m/s}{1 \times 10^{9}\ s^{-1}}$$

$$= 3m$$

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

analogous

Sound Waves

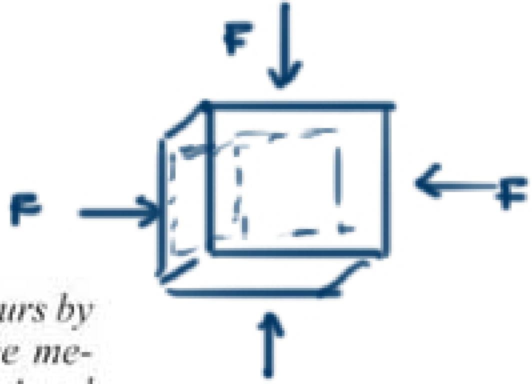
Bulk Modulus (stiffness)

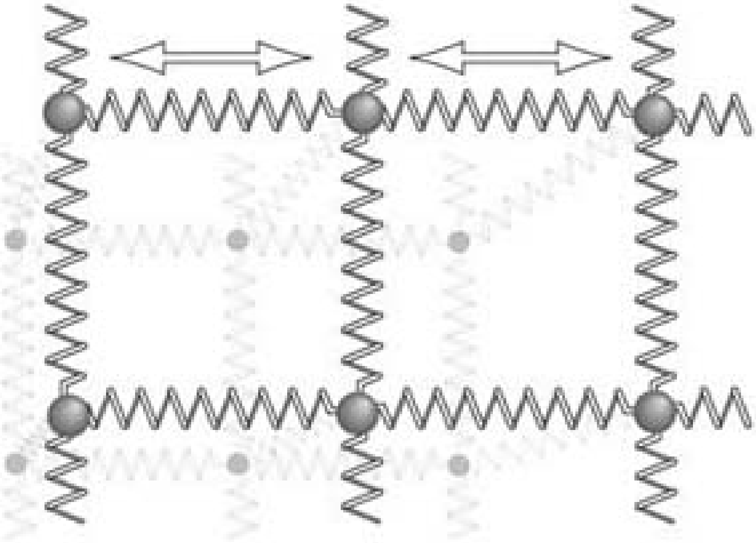
$$v = \sqrt{\frac{B}{\rho}}$$

inertia

v = speed of sound
B = bulk modulus
ρ = density

$$\beta = \frac{F/A}{-\Delta V/V_0}$$





Sound wave propagation occurs by means of the elasticity of the medium. Imagine a three dimensional matrix in which mass elements are connected by springs. Increasing the strength of the springs (bulk modulus) would increase the speed of waves through the medium. Increasing the mass of the elements (density) would slow the waves down.

elastic modulus $= \frac{\text{stress}}{\text{strain}}$

$$k = \frac{-F}{\Delta x}$$

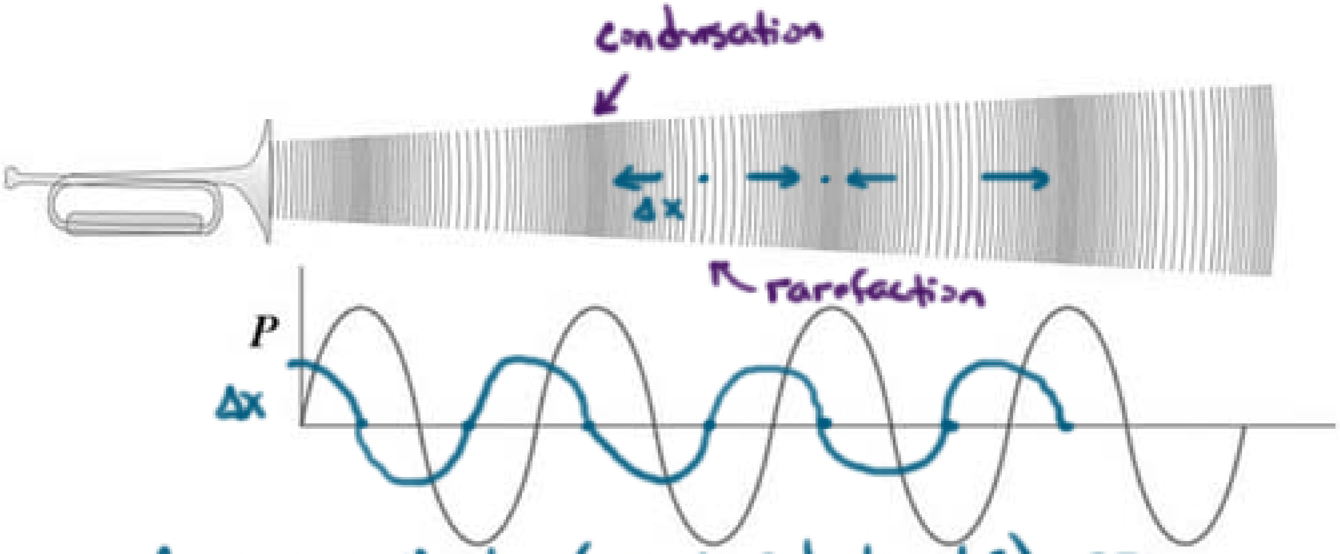
Which of the following is a true statement concerning sound waves?

a. Sound waves can pass through a vacuum.

b. The speed of sound does not depend on the medium of propagation.

c. Sound waves are longitudinal waves.

d. Sound waves cannot be reflected.



pressure antinodes (crests and troughs) are displacement nodes.

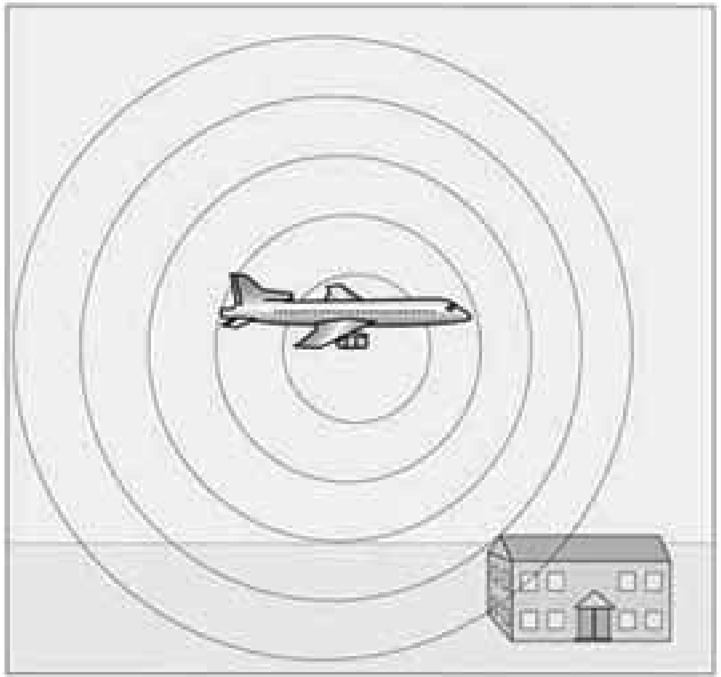
Loudness

original $10 \log (I/I_0)$

multiply intensity by A

new $= 10 \log A (I/I_0)$

$= 10 \log A + 10 \log I/I_0$



$$\beta = 10 \log \left(\frac{I}{I_0}\right)$$

Multiply I 10x
add 10dB

Multiply I 100x
add 20dB

Multiply I 1000x
add 30dB

β = loudness in decibels
I = intensity
I_0 = 10^{-12} W/m²

Intensity - W/m²

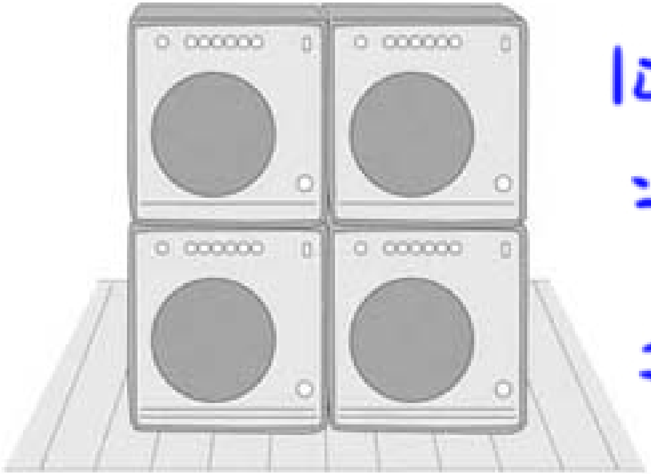
After judging a value of 120 dB a few meters in front of the stage to be insufficiently loud enough, a rock-and-roll band doubled the number of amplifiers in its stack. What was the loudness after the addition of the new amplifiers?

a. 123 dB

b. 130 dB

c. 144 dB

d. 240 dB



$10 \log I/I_0$

new

$10 \log 2I/I_0$

$= 10 \log I/I_0 + 10 \log 2$

$= 120\text{ dB} + 3$

$= 123\text{ dB}$

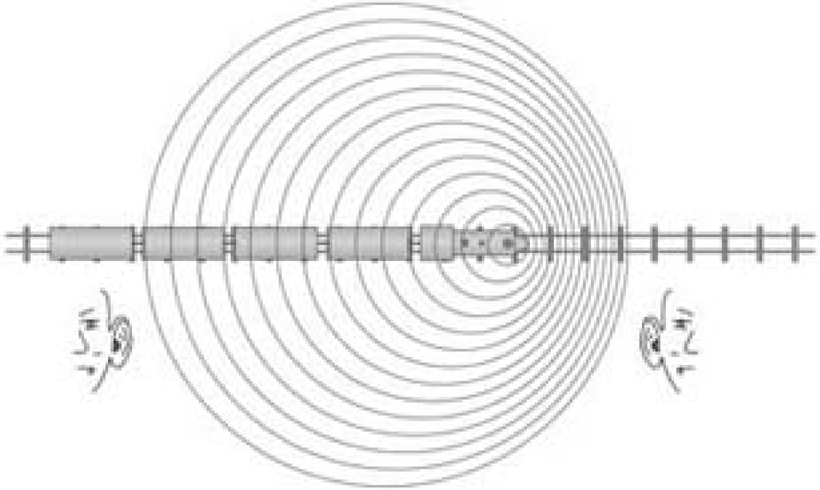
use the signs that make sense

Doppler Effect

$$f' = f\left(\frac{v \pm v_0}{v \mp v_s}\right)$$

f' = observed frequency
f = source frequency
v = wave speed
v_O = speed of observer
v_S = speed of source

Doppler sonography



v
blood flow

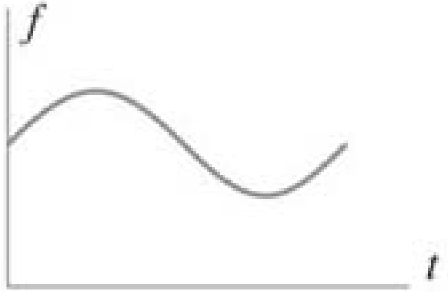
$$f' = f\left(\frac{v}{v \mp v_s}\right)$$

$$2t = v\,\Delta t$$

Because of the Doppler effect, the measured frequency of sound is greater for the observer the train is approaching than for the observer the train is leaving.

An astronomer discovers a planet orbitting a distant star, revolving once every 10 days. If her line of observation is within the orbital plane of the planet, which of the following curves best represents the observed frequency of the light from the planet as it undergoes one complete revolution around the star?

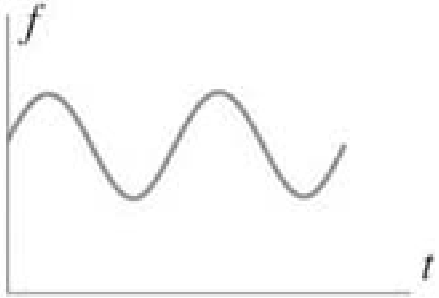
a.



b.

c.

d.



Standing Waves on a Stretched String

Standing waves which are possible have nodes at the pegs

$$\lambda_n = 2L,\ L,\ \frac{2L}{3},\ \ldots\ \frac{2L}{n}$$

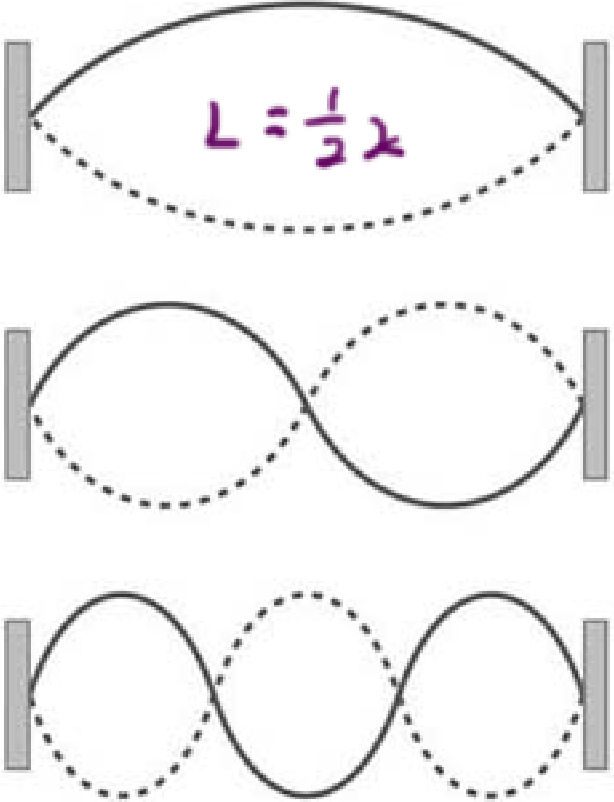
The wavelengths of the normal modes correspond to the possible waves with nodes at the fixed ends.

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

It's a simple matter to move from wavelengths to frequency if you know the wave speed (deriving from the tension, F, and the mass per unit length, μ, *of the string):*

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

λ_n = wavelengths of normal modes
L = length of string
n = 1, 2, 3, …
f = frequencies of normal modes
v = wave speed



$\lambda = 2L$

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

$n = 1, 2, 3 \ldots$

Standing Waves in Air Columns

Pipe Open at Both Ends

$$\lambda_n = 2L, L, \frac{2L}{3}, \ldots \frac{2L}{n}$$

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

$(n = 1,2,3,\ldots)$

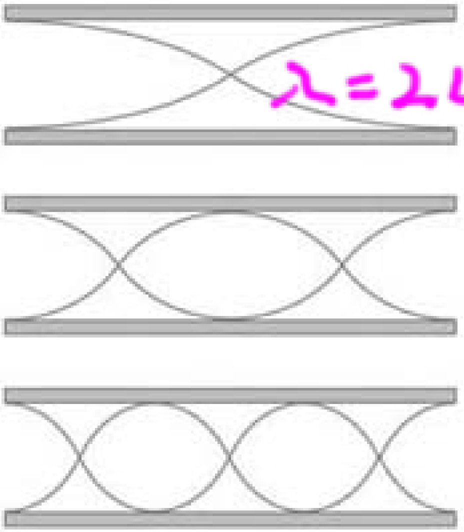
Pipe Closed at One End

$$\lambda_n = 4L, \frac{4L}{3}, \frac{4L}{5}, \ldots \frac{4L}{n}$$

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

$(n = 1,3,5,\ldots)$

just like stretched string

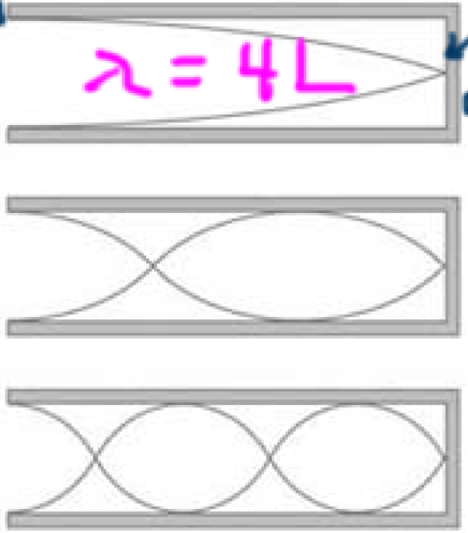


λ_n = wavelengths of normal modes

L = length of pipe

f = frequencies of normal modes

v = wave speed



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

$n = 1,3,5 \ldots$

Sound waves are represented as displacement waves

A flute is an example of a musical instrument that functions as a pipe closed at one end. What is the lowest musical note produced by a 0.75m long flute (the speed of sound in this particular air is 330 m/s).

a. A (110 Hz)

b. B (248 Hz)

c. A (220 Hz)

d. E (660 Hz)

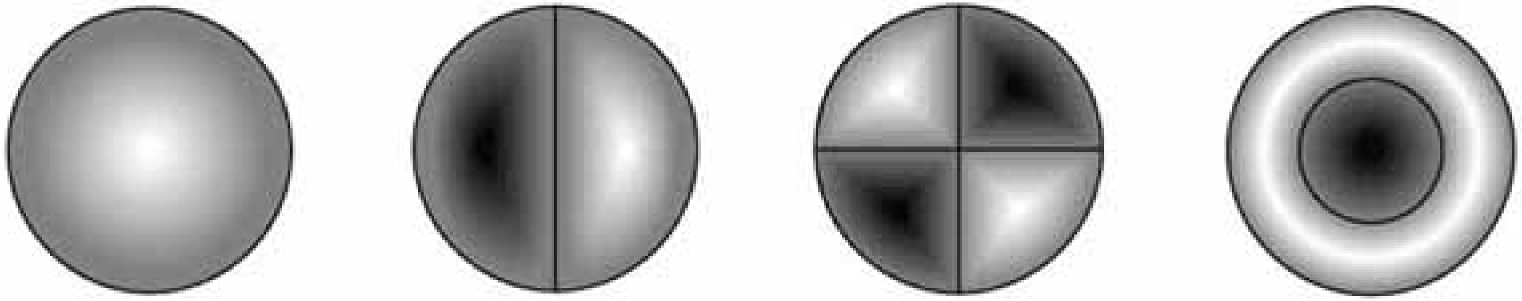
$\lambda = 4\,(0.75\,m)$

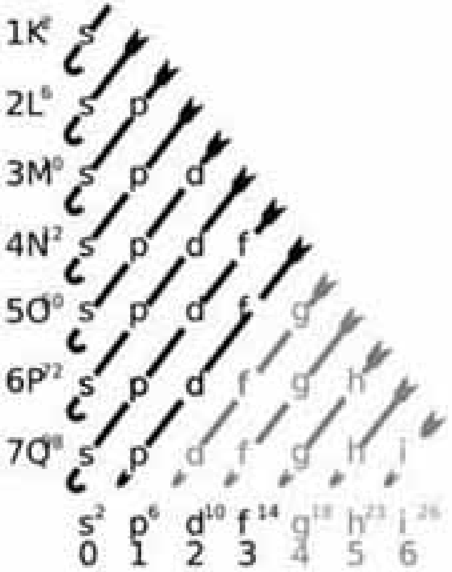
$= 3\,m$

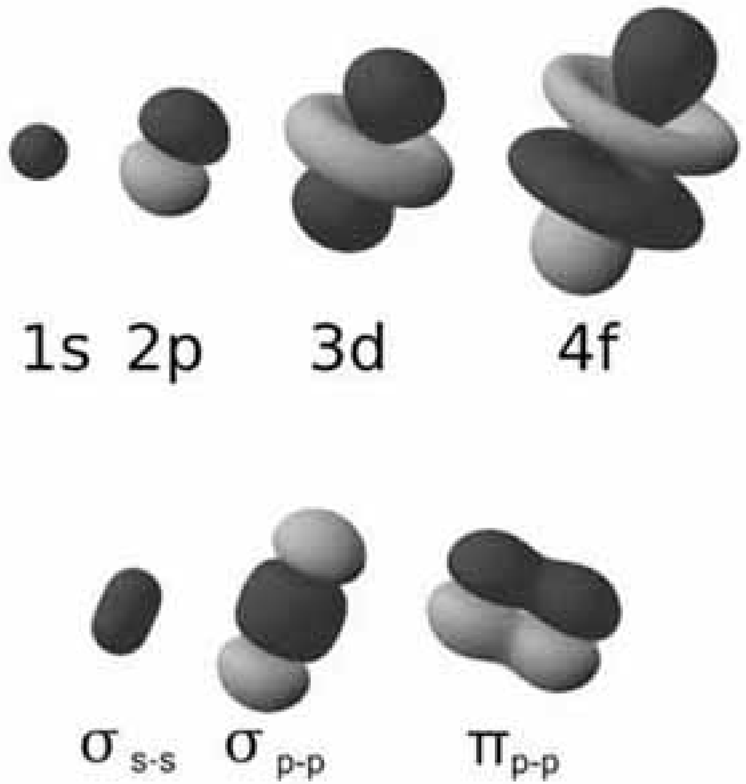
$v = 330\,m/s$

$f = \dfrac{330\,m/s}{3\,m}$

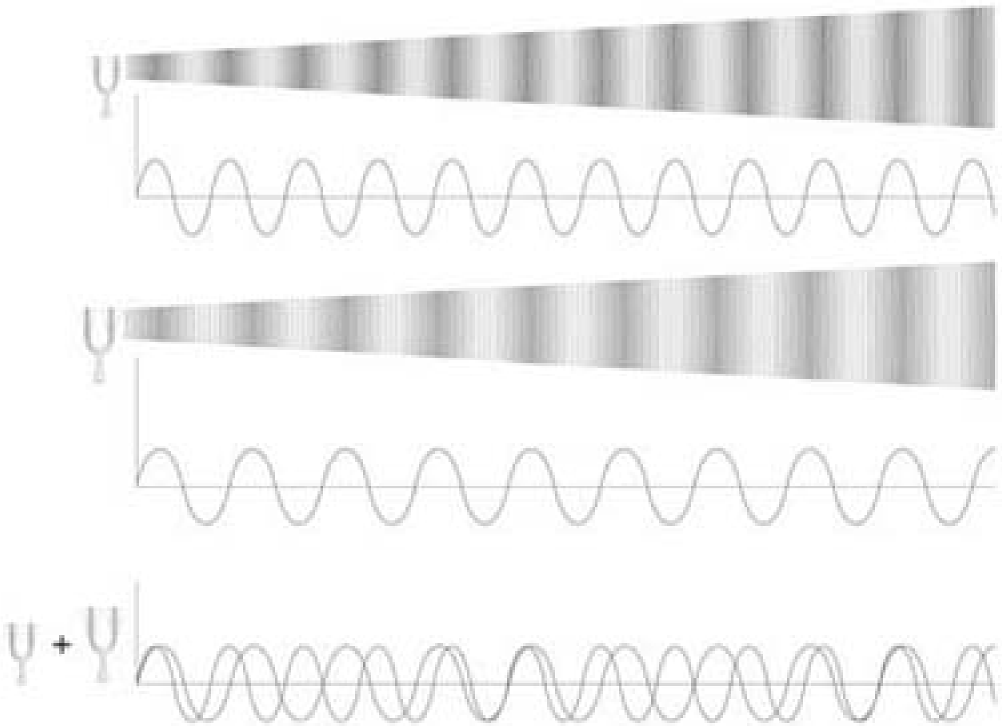
$= 110\,Hz$




1K s
2L s p
3M s p d
4N s p d f
5O s p d f g
6P s p d f g h
7Q s p d f g h i
s2 p6 d10 f14
0 1 2 3 4 5 6


1s 2p 3d 4f
σ s-s σ p-p π p-p

Beats



$$f_b = f_1 - f_2$$

f_b = beat frequency

Beats are fluctuations in sound intensity produced when two tones nearly equal in frequency are sounded simultaneously.