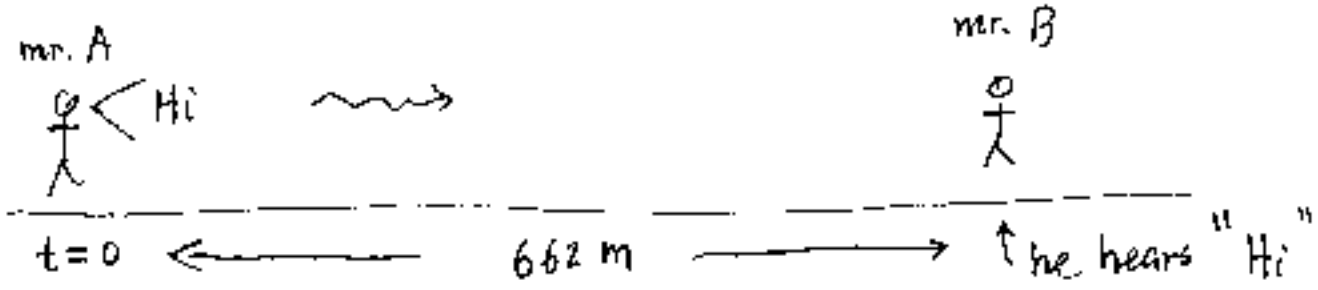
Chap. 11 sound and waves

How to describe sound? What are its properties?

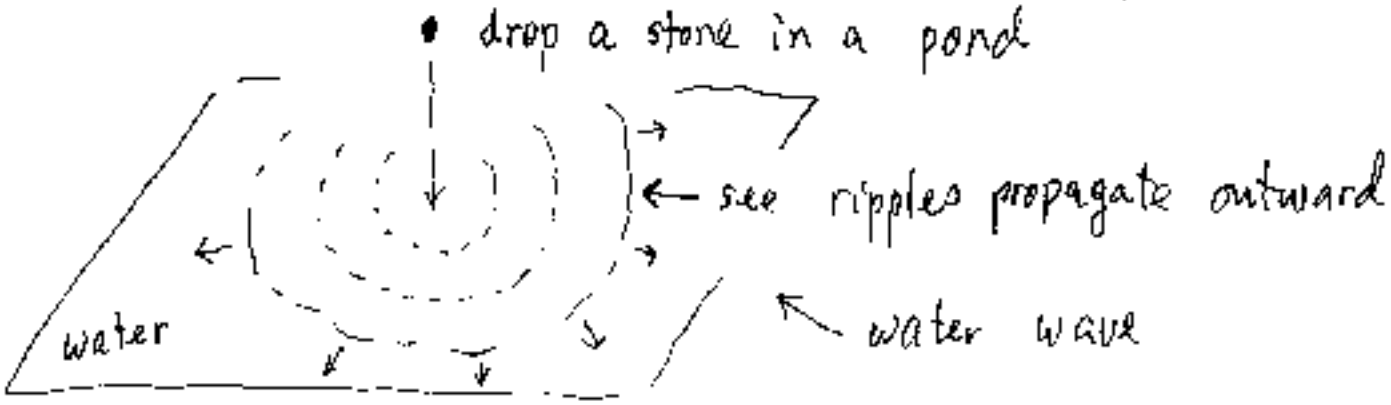
Suppose we compare

	"How are you" by Ms. Lily	"How are you" by Mr. K
frequency f	high (high pitch)	low (hoarse)
intensity I	low (gentle)	high (loud)
quality	sweet	no comment

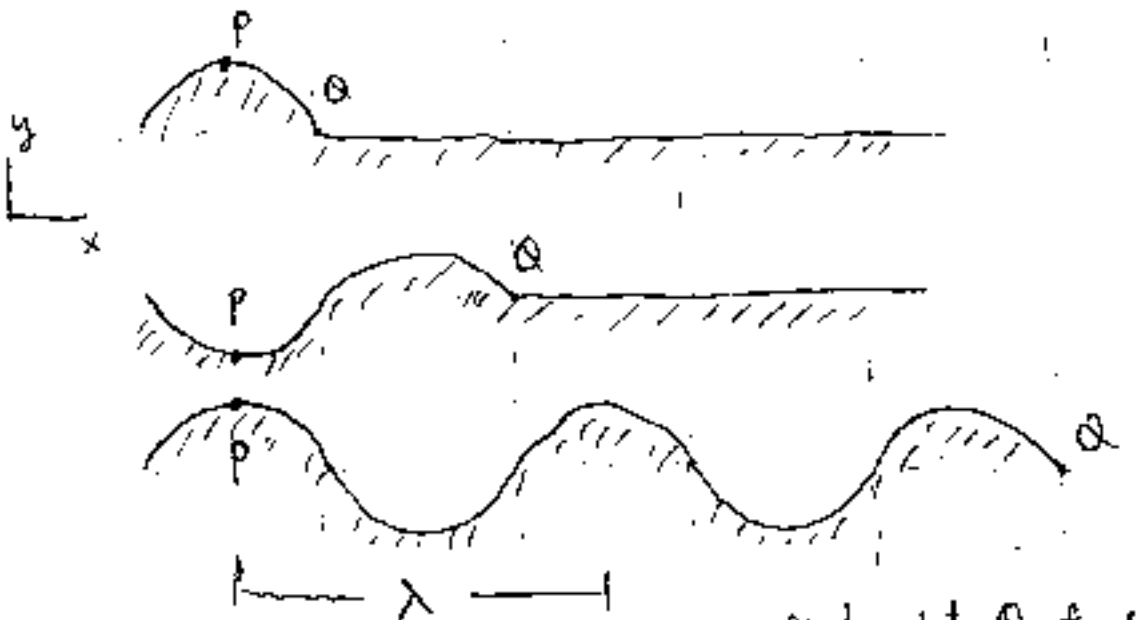


Speed of sound $v = \frac{\text{distance}}{\text{time}} = \frac{662}{2} = 331$ m/sec

sound is <u>wave</u>. Let us first study some simple cases:



"movie" of water wave



say

$t = 1$ sec

$t = 2$

$t = 5$

endpoint Q of wave shape is advancing (to right)

speed of Q = "speed of wave"

v

P = small chunk of water

P just moves up and down (no motion in x direction)

P ↕ oscillates with frequency f

λ = wave length (distance between peak and next-peak)

see figure above

important result

$$v = f\lambda$$

v: [m] wave velocity

f: Hertz $\left[\frac{1}{\text{sec}}\right]$ wave frequency

λ: [m]

11/9 monday exam 11/12/98

review { 11/12 Wed AM, PM lectures
6:30 meet in front of C137 my office

Review waves, simple:

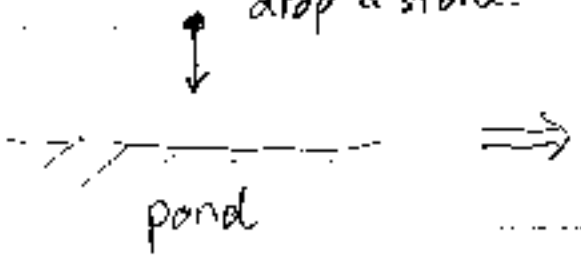
$v = f\lambda$

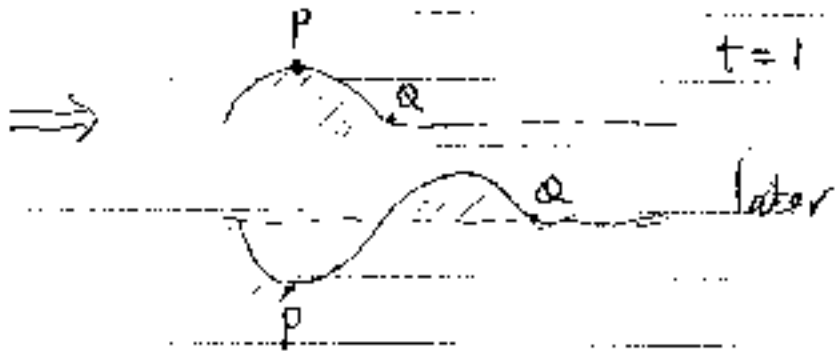
wave velocity — freq — wave length λ

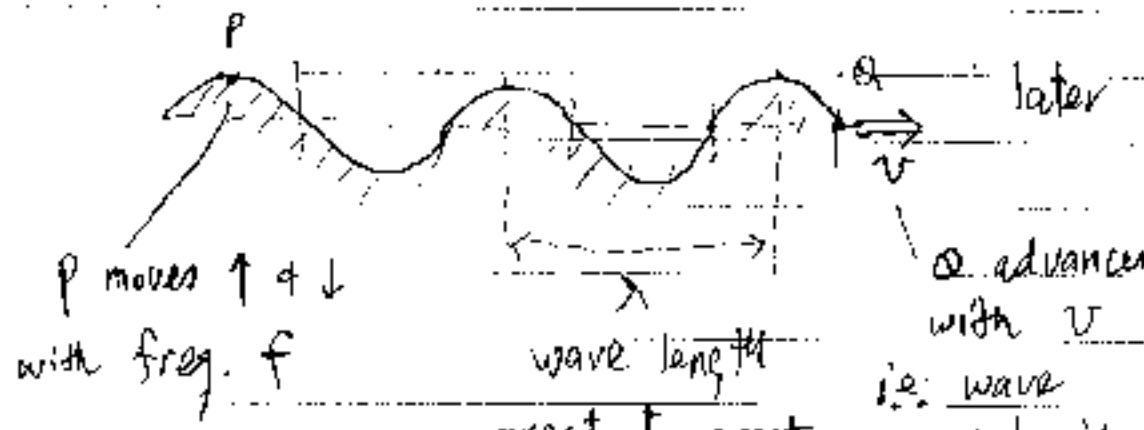
m/sec — Hz = 1/sec

Water wave

drop a stone.



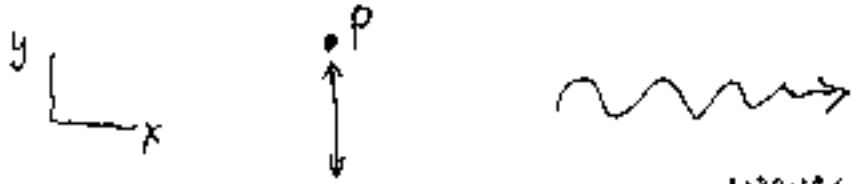




motion of P (medium) $\updownarrow \perp \vec{v}$ (propagation) $\Rightarrow$ transverse wave

to

note: For the water wave of previous page



waves propagates in x-direction

P oscillates in y-direction

$\therefore$ direction of medium oscillation $= y$ $\qquad y \perp x$

<u>transverse wave</u> defined as those with

direction of medium oscillation $\perp$ direction of wave propagation

above water wave is transverse

Ex

water wave:

wave speed = 5 m/sec

wave length = 30 cm

what is its frequency f ?

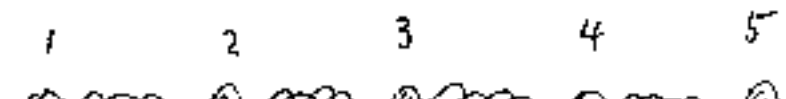
$v = f \lambda$ $\qquad \therefore f = 16.67$ Hertz

(5, 0.3)

model for sound wave

plastic balls linked by springs

give a tap ⇒



↔

↔ ↔ ← time t_1

↔ ↔ ↔ ← t_2

↔ ↔ ↔ ← t_3

ball-3 begins oscill

ball 4, 5 not yet oscill.

$$\text{wave speed} = \frac{x_3 - x_1}{t_3 - t_1}$$, i.e. the speed of signal propagation

↑ foremost ball which oscillates

above wave is call "longitudinal wave" ⟷ for which direction of medium oscill } ∥ { direction of wave propagation

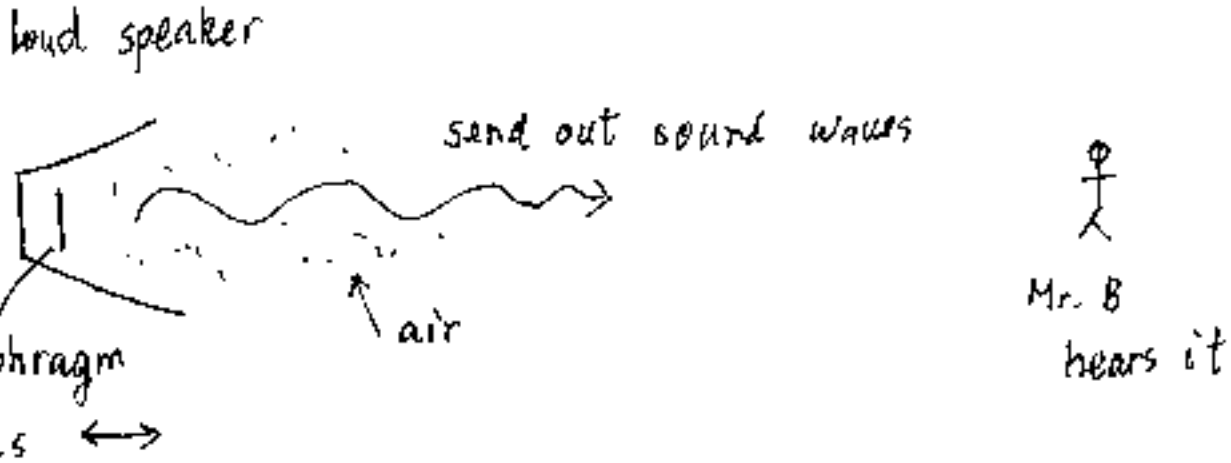
sound wave is <u>longitudinal</u>

it propagates in air, water, steel --- etc

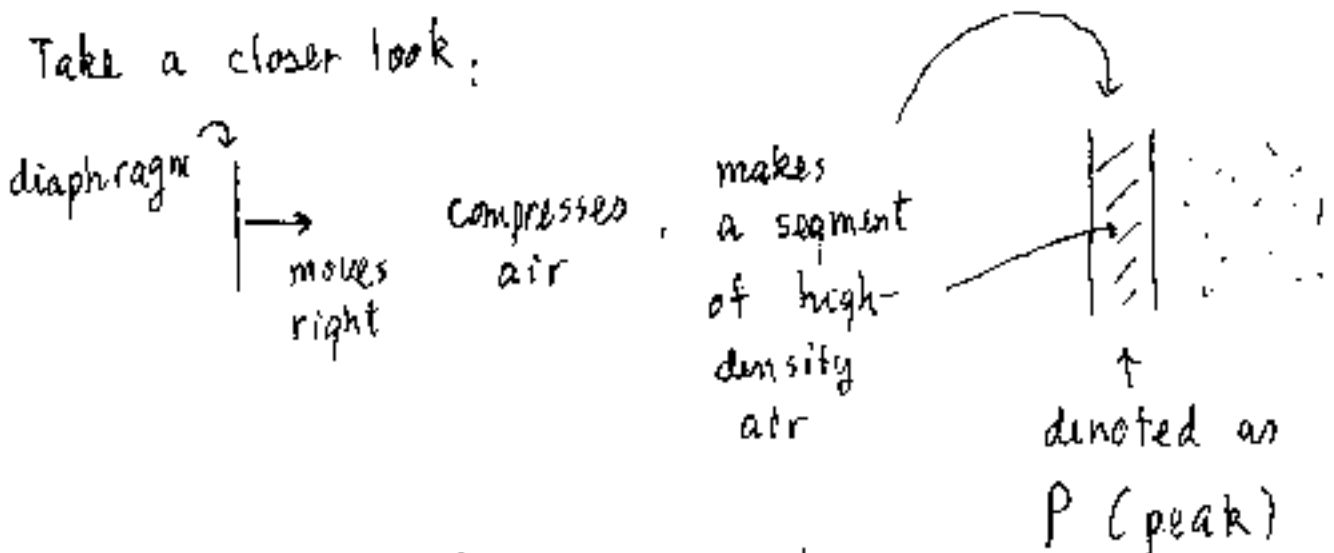
Consider sound in air.

air, of uniform density

production of sound waves:



Take a closer look:



Sound waves propagate as

$t=0$ P

$t=1$ B P

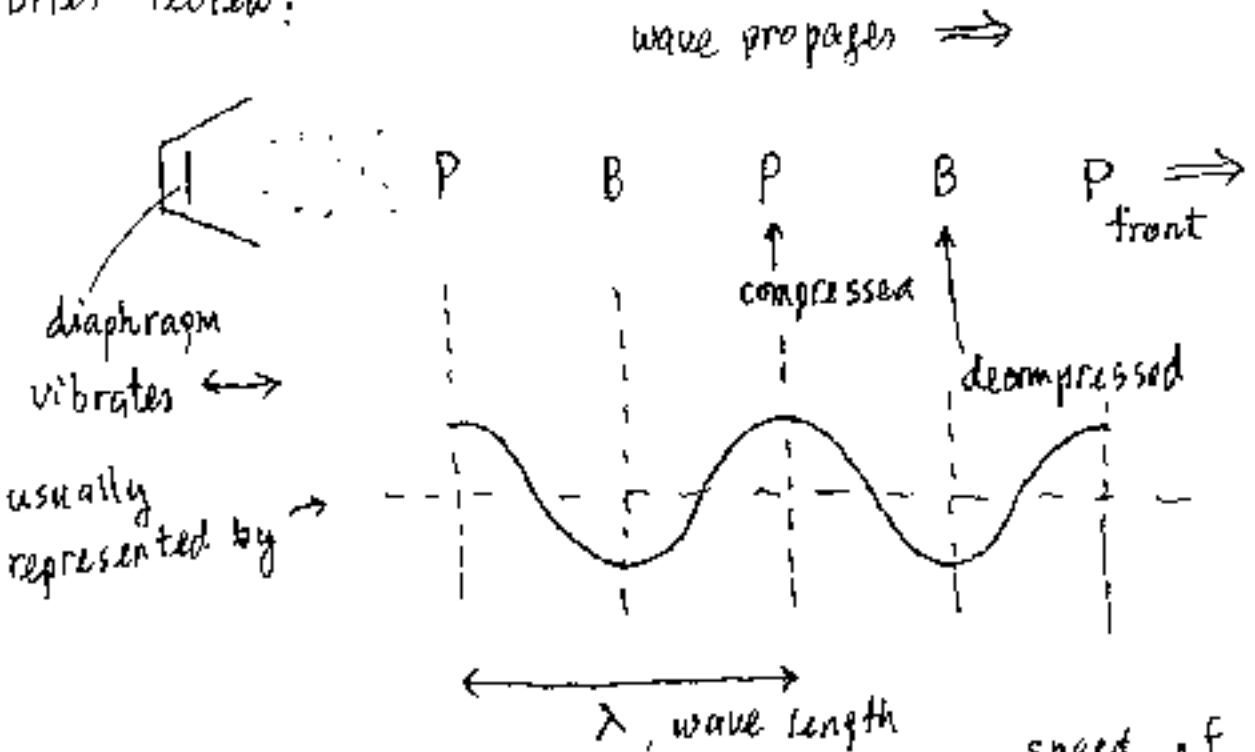
$t=2$ P B P

⋮

$t=9$ P B P B ⋯ P ⇒ direction of propagation

(t in arbitrary unit)

brief review:



speed of P_{front}

$= v$

$=$ wave velocity

f = frequency
of diaphragm
vibration

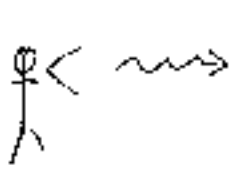
we can hear sound in range $40 \lesssim f \lesssim 10000$ Hz

don't waste money to buy
hi-fi outside this range

from wave equation
... can prove

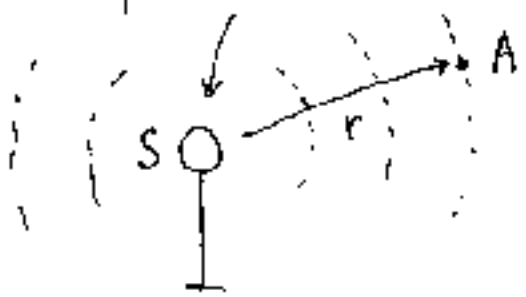
$$v = f\lambda$$ ← important eq

v: m/s, f: Hz, λ: m

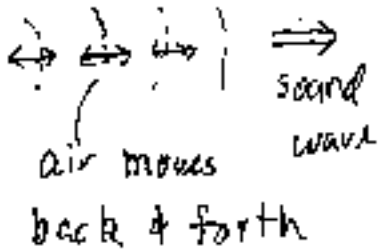
Ex.  $v = 331$ m/sec, $f = 700$ Hz

$\lambda = ? = \frac{331}{700} = .473$ m

sound source S
has power P watt



Sound wave carries power

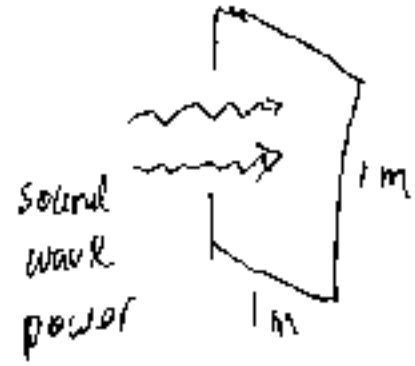


if sound wave is uniformly distributed in all directions,
then intensity at A is

$$I = \frac{P}{4\pi r^2}$$

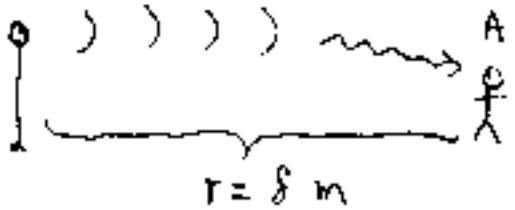
watt/m^2

$4\pi r^2$ = area of sphere with radius r



I is power transmitted per $meter^2$.

Ex. source P = 5 watt



$$I_A = ? = \frac{5}{4\pi r^2} = 0.62 \times 10^{-2} \ W/m^2$$

r^2 = 5^2

↑ this is very loud to his ear!

ear is very sensitive instrument

can hear sound as weak as 1.0×10^{-12} W/m^2

defined as I_0 ← threshold of hearing

false statement : my ear is made of log X

true statement : the response (feeling) of my ear is logarithmic ✓

review of log

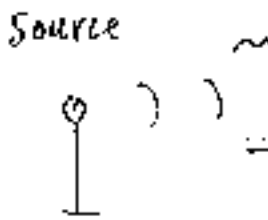
$\log_{10} X = y$ means $10^y = X$

e.g. $\log_{10} 100 = 2$, $\log_{10} 10000 = 4$, $\log_{10} 0.01 = -2$

$\log_{10} AB = \log_{10} A + \log_{10} B$

$\log_{10} \frac{A}{B} = \log_{10} A - \log_{10} B$

decibel [dB] } is a suitable unit for ear's hearing



at point A intensity is I $watt/m^2$

define → $\beta = 10 \log_{10} \frac{I}{I_0}$ ← [dB]

↖ $I_0 = 10^{-12}$ W/m^2 = hearing threshold

β has many names : intensity level, sound level, relative sound intensity, noise, noise level

Ex. Back seat in a lecture hall.

sound intensity $I = 10^{-6}\ W/m^2$ (10^{-6})

sound level $\beta = ? = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} 10^6$

($I_0 = 10^{-12}$)

$= 60\ dB$

Ex. 10 boys, each gives

noise = 70 dB

$noise_{total} = ?$

$\beta_{1\text{-boy}} = 10 \log_{10} \frac{I_{1\text{-boy}}}{I_0} = 70$

$\beta_{10\text{-boy}} = 10 \log_{10} \frac{10 \times I_1}{I_0} = \underbrace{10 \log_{10} 10}_{10} + \underbrace{10 \log \frac{I_1}{I_0}}_{70}$

$= 80 = noise_{total}$

See $\beta_{1\text{-boy}} = 70\ dB$, $\beta_{10\text{-boy}} \neq 700\ dB$!

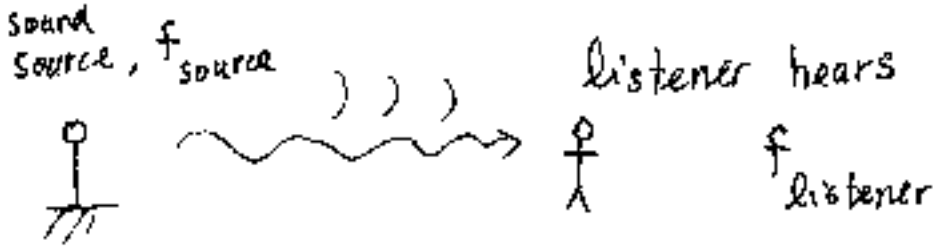
Doppler effect many many important applications

police used it to catch those who drive too fast

doctor ..... to measure how fast blood flows in artery

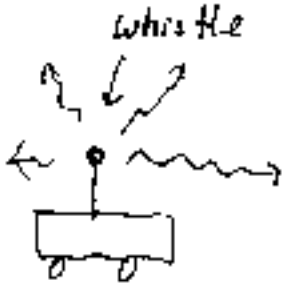
teachers use it to make good problems for exam !

Briefly

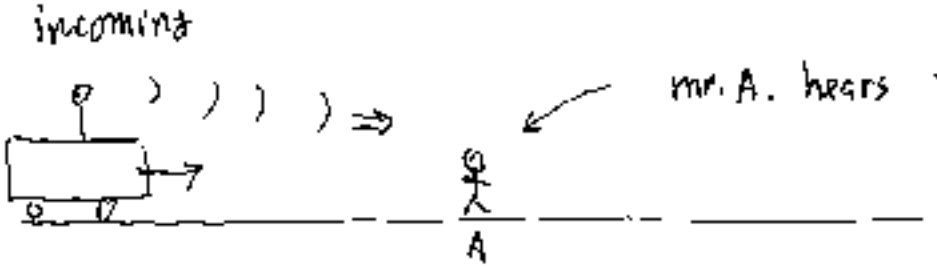


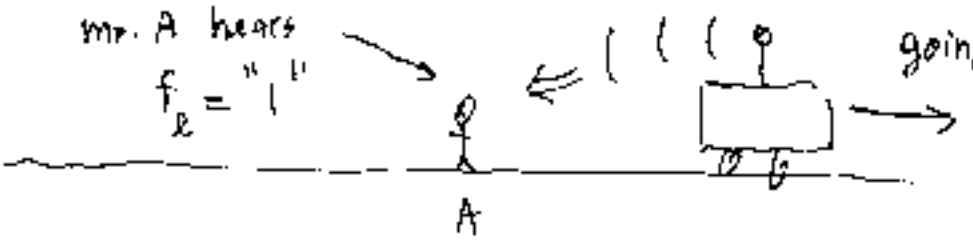
depending on motions of source and listener } f_ℓ can be different from f_s

Ex. train stationary, mr. A stationary



$f_{whistle} = "2" = f_{source}$





Let me give you the "formula" first (to derive it later)

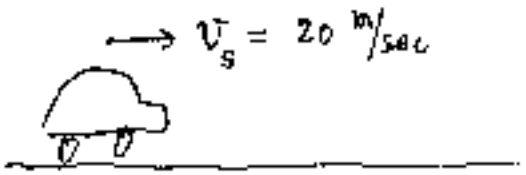
$$\frac{f_{listener}}{C + v_{listener}} = \frac{f_{source}}{C + v_{source}}$$

C = speed of sound in air = 331 m/sec or as given

"+" direction = that from listener to source

v = + if in l-to-s direction
= − if otherwise

Ex. car horn has $f_{source} = 350$ Hz



$$\frac{f_s}{C + v_s} = \frac{f_l}{C + v_l}$$

$f_s = 350$, $C = 340$ given, $v_s = -20$ opposite to l-to-s, $v_l = 0$

$$\therefore f_l = \frac{340}{340 - 20} \times 350$$

$$= 371.9 \text{ Hz}$$

$$\frac{f_s}{C + v_s} = \frac{f_l}{C + v_l}$$

$f_s = 350$, $f_l = 300$, $C = 340$, v_s in l-to-s, $v_l = 0$

$$v_s = \left(\frac{f_s}{f_l} - 1\right) C$$

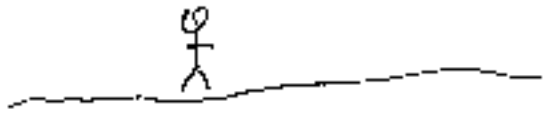
$v_s = 56.7$ m/s fast!

11/11/98 Let me first finish Doppler

Chap 11 Kuo finishes up to Doppler | Goldhaber from 11/13 do standing waves...

next semester 122 Kuo 1st 1/3 Goldhaber mid 1/3 Kuo last 1/3

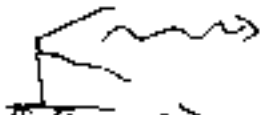
Doppler effect "what you hear" may differ from "what was said"



he hears however

f_ℓ = 480 Hz

↑ listener



sound wave is a series of

P B P B P B → 🧍

You count peaks P passing you per sec, that is f_ℓ

if source moving towards you, you count more P's

$\rightarrow f_\ell > f_s$

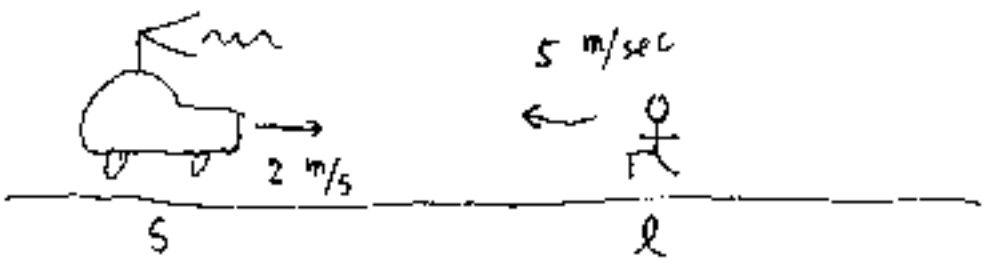
as done in the book. basic formula is simple:

$$\frac{f_\ell}{c + v_\ell} = \frac{f_s}{c + v_s}$$

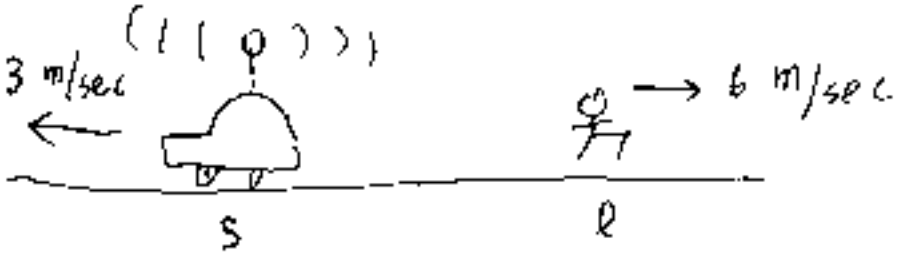
c = speed of sound in air
$= 331$ m/sec
ℓ = listener
s = source

Sign: [ℓ to s] = [+ direction]

Ex.



Here $v_s = -2$ m/sec $\quad v_\ell = +5$ m/s



Here $v_s = +3$ m/s $\quad v_\ell = -6$ m/s

Be sure to know the ± signs for v_ℓ and v_s.

You may check your calculations; should get:

- $f_\ell > f_s$ if ℓ and s approaching each other
- $f_\ell < f_s$ ..... moving away from each other

PHY 121/123 LECTURE NOTES -Week 11

Let us start with four problems, and then figure out the solutions.

1. A 0.2 m long pipe filled with air is closed at both ends. What is the lowest frequency? The period?

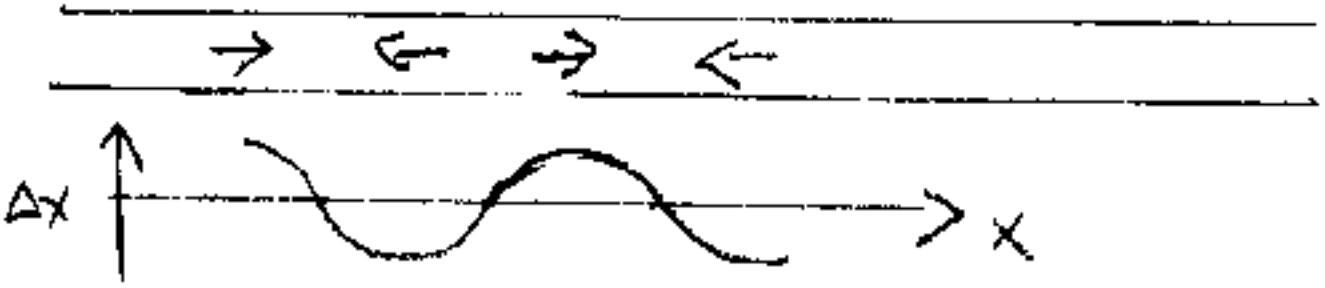
2. A 1.6 m horizontal string with one end fixed is attached at the other end to a very light slider, which can slide freely up and down in a track. With tension $T = 23$ N and mass per unit length $\mu = 0.03$ kg/m, what is the lowest vibration frequency?

3. What are the next two frequencies in the pipe? on the string?

4. If two tones have frequency 440 Hz and 445 Hz, what is the beat frequency?

Answers:

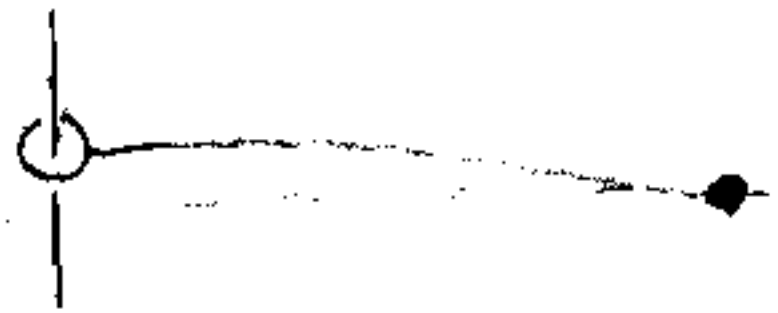
1. Inside the pipe if it were very long, waves could travel to left or right with speed $c = 340$ m/s. These are waves where the air moves along the direction of the pipe, forwards or backwards, making higher density in some spots and lower density in between.



If we look at the displacement Δx of an air molecule from its equilibrium position, then for a wave to the right (x increasing with time), we have $\Delta x = A\cos[2\pi(t/T - x/\lambda)]$, while a wave to the left would have a plus instead of a minus sign.

At either end of the pipe the air can't move because of the wall, so $\Delta x = 0$. This gives a wave made of equal-amplitude right and left moving waves with special wavelength:$\Delta x = A\cos(2\pi t/T)\sin(2\pi x/\lambda)$, such that $L/\lambda = (N+1)/2$, where N is the number of nodes or zero amplitude points in the middle of the pipe. Therefore the frequency is $f = c/\lambda = (N-1)c/2L = c/2L = (340\text{m/s})/(0.4\text{ m}) = 850$ Hz for the lowest-frequency, corresponding to no nodes in the middle.

2. This system has transverse vibrations of a string instead of longitudinal vibrations of air in a long tube, and in addition the slider can move freely up and down, so the string must come in straight (horizontal) where it attaches to the slider:

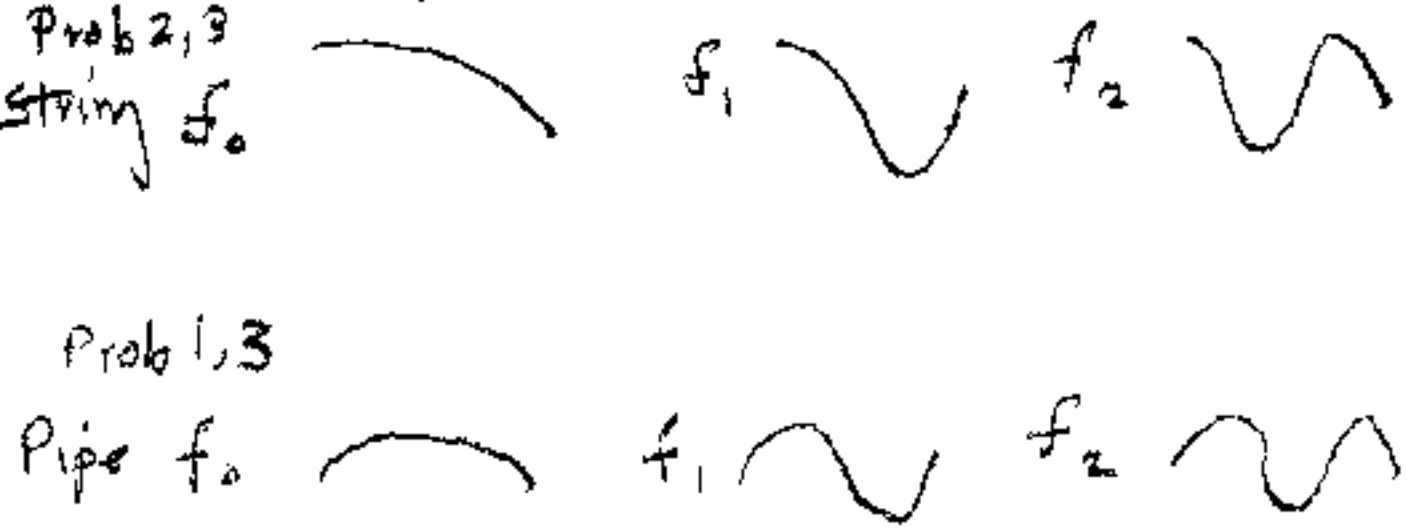


Otherwise, the vertical component of the tension in the string would quickly move the slider until the string was horizontal again. At the other end the string is fixed, and therefore we have $dy/dx = 0$ at $x = 0$ and $y = 0$ at $x = L$, giving $y = A\cos(2\pi t/T)\cos(2\pi x/\lambda)$, with $L = (2N+1)\lambda/4$. This gives for the lowest frequency $f = c/\lambda = c(2N+1)/4L = c/4L$, with $c = \sqrt{T/\mu} = 27.7$ m/s, so $f = (27.7\text{ m/s})/(6.4\text{ m}) = 4.33$ Hz.

3. For the pipe we use $f = (N+1)c/2L = (N+!)f_0$, giving $f_1 = 2f_0 = 1700$ Hz and $f_2 = 3f_0 = 2550$ Hz. The corresponding modes are pictured below. For the string we use $f = (2N+1)c/4L = (2N+1)f_0$, giving $f_1 = 3f_0 = 13.0$ Hz and $f_2 = 5f_0 = 21.6$ Hz. Again modes are below.

NOTE: In the CAPA problems there is a pipe open at one

end, and a string fixed at both ends, so the end conditions are interchanged compared to those for string and pipe in the above examples.



4. What is the meaning of beat frequency? Imagine two waves with amplitudes adding at a particular point in space, $A = A_1 \cos(2\pi f_1 t) - A_2 \cos(2\pi f_2 t)$. The amplitude will have its biggest magnitude at $t = 0$. When will this magnitude appear again? We need $(2\pi f_1 t) = N_1 =$ integer, and $(2\pi f_2 t) = N_2 =$ integer. The first time this happens is when $N_1 \quad N_2 = 1$, i.e., when the first oscillation has gotten one full period ahead of the second. Thus the first time T for a close repeat of the initial maximum amplitude is $f_1 - f_2 - 1/T = f_B$. In this example that gives $F_B = \cdot 5$ IIz! Something has gone wrong, because we can't have a negative frequency! The point is that if f_2 is bigger than f_1 then the second oscillation will be getting ahead of the first, implying $f_1 - f_2 = \quad 1/T = \cdot\cdot f_B$. The general statement becomes $f_B = |f_1 - f_2| = 5$ IIz for this example.